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Bolting Applications

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Prepared for
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Commission

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ABSTRACT

An investigation of bolting practices specific to the nuclear industry was performed. The report covered a large spectrum of topics e.g. bolts embedded in concrete, specifications, inspection of bolting, both at receipt and inservice. Plots of preload versus yield strength for different bolting materials in different environments are presented as well as information relative to the stress corrosion cracking resistance of the more recent reactor internals bolting materials A286 and Inconel X-750. Part of the report contains input by Standard Pressed Steel Inc. (a bolting consultant) relative to bolting standards, cottering methods and potential areas for bolting improvement.

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1.0 INTRODUCTION

A great deal of concern has arisen (over the past several months) in the nuclear industry over the steadily increasing number of bolting failures reported at nuclear power plants.

Since the Materials Engineering Branch (MTEB) of the United States Nuclear Regulatory Commission (U.S. NRC) has the primary responsibility for evaluating performance of materials used on nuclear power plants, this regulatory concern was expressed in the form of a contract to Brookhaven National Laboratory to assist the NRC staff in developing acceptable criteria for bolting for nuclear applications.

The primary objective of the program was to obtain information leading to a regulatory position on material selection for bolting used in water reactors. This program was an extension of a previous U.S. NRC contract to Lawrence Livermore Laboratory, which produced NUREG/CR 2467 "Lower-Bound K_{ISCC} Values for Bolting Materials - A Literature Study," and encompassed the following tasks:

a. Convert the information presented in NUREG/CR 2467 to yield strength equivalent (hardness) vs. preload.

b. Perform a literature search for information on internals bolting (A286 and Inconel X-750) similar to that reported in NUREG/CR 2467 on low alloy and maraging steels.

c. Provide verification that information presented in NUREG/CR 2467 for chlorine is representative of environment of bolting embedded in concrete (i.e., high pH).

d. Review test sample requirements of frequently used fastener specifications and provide recommendations on statistical sampling of fasteners.

e. Provide recommendations for receiving and inservice inspection of bolting.

f. Provide written recommendations for acceptable methods of cottering that would not defeat the primary purpose of fasteners.

g. Provide recommendations for written improvements in bolting and bolting materials specification.

h. Provide a final technical report incorporating the above tasks into a technical position on bolting application requirements, to be issued as a NUREG report by the NRC.

Appendix A of this document is a report prepared for BNL by Standard Pressed Steels Inc. (SPS) under subcontract. The report encompasses tasks e, f and g.

2.0 CONVERSION OF NUREG/CR 2467 DATA [1] TO YIELD STRENGTH EQUIVALENT (HARDNESS) VS. PRELOAD

The data presented in NUREG/CR 2467 were in the form of K_{ISCC} vs. yield strength for various bolting materials.

In order to evaluate a given material's susceptibility to stress corrosion cracking (SCC) it is necessary to postulate a reference flaw size and then demonstrate that for a given environment at a certain applied stress level that the material's toughness is sufficient for preventing brittle fracture. The most common method of describing these conditions is through the use of Linear Elastic Fracture Mechanics (LEFM). LEFM is a correlation of three pertinent parameters: the reference flaw size and shape, applied stress, and the fracture toughness of the material. The stress intensity factor K is an integral part of LEFM in describing local crack tip response to surrounding conditions. This factor is calculated in terms of the crack length, applied stress and a geometry factor in accordance with the following relationship:

$$K_I = F \sigma \sqrt{a}$$

For a loading condition in which the load is applied perpendicular to the crack face (e.g. a bolt in tension) fracture would be predicted when the applied K_I value reached a critical point. A conservative estimate of this critical point would occur when plane strain conditions existed at the crack tip. The conservatism occurs due to the material's lowered resistance to fracture resulting from geometric restraint and the tri-axial stress state at the crack tip. For plane strain conditions, the critical point is referred to as K_{IC} (plane strain fracture toughness) with a boundary condition of;

$$K_I < K_{IC}$$

required in order to prevent fracture.

If a SCC mechanism were to be predicted, then the applied stress in a material would have to be high enough to raise the K_I level above a critical point called the threshold stress intensity factor for SCC (K_{ISCC}).

If the goal is the prevention of SCC of a bolt, then an allowable preload must be determined which would not propagate a stress corrosion crack from an assumed flaw of unlikely size and configuration. This condition occurs if:

$$K_I < K_{ISCC}$$

then, the allowable preload can be described by the following relationship:

$$\sigma = K_{ISCC}/F \sqrt{a}$$

σ = allowable preload based upon SCC

K_{ISCC} = threshold stress intensity factor

a = reference flaw size

In order to convert the data in NUREG/CR 2467 from K_{ISCC} vs. yield strength data to preload vs. yield strength, it was necessary to use the preceding formula. Initially, a major drawback in the conversions was the determination of both the reference flaw size and the geometry factor needed to provide conservative preload for field bolting applicability. By mutual consent between Brookhaven National Laboratory and the Materials Engineering Branch of the NRC, the references used for this purpose were generated by APTECH Engineering Services [2, 3]. Figure 1 is a graphical representation of stress intensity curves as a function of stud or bolt diameter with four and eight threads per inch originally developed for the Electric Power Research Institute (EPRI) under RP 1757-2. The following assumptions were used by APTECH in developing the curves:

The flow geometry was assumed to be a semi-elliptical surface crack of depth "a" and length "2c", with a = 0.02 inch and 2c = 0.08 inch providing an aspect ratio of (a/2c = 1/4). The flaw is considered to exist at the thread root with the load perpendicular to the crack face. A computer program was then used to calculate K_I at two locations along the crack front, 1) the point of maximum crack depth and 2) the point where the crack front intersects the free surface at the thread profile boundary. Peterson's book, Stress Concentration Factors, Wiley (1974) was the source used for approximating the stress at the thread root surface, which was treated as a single notched bar in tension. All bolt and thread dimensions taken from ANSI Standard B.1-1974, "Stress Gradients in Grooved Bars and Shafts". SESA Proceedings Vol. XII, No. 1, November 1955, was used to determine the thread attenuation along the thread root plane moving inward toward the center of the bolt. This was done by using the results from a circular shaft with an infinitely deep hyperbolic groove under tension. Thread radius values between 0.08 and 0.036 inch were used dependent upon thread pitch and APTECH's engineering judgement. The K values on the graph are the root mean square average values computed at the two different locations.

$$K = K_{RMS}/ \quad = [(K_A^2 + 2K_B^2)/3]^{1/2} \Big/ \sigma$$

K_A = stress intensity factor at the maximum depth point

K_B = surface stress intensity factor

σ = uniformly applied stress based upon the thread's <u>net</u> section

For purposes of this report, the nominal diameter was taken to be four inches and plots are made for both 4 and 8 threads per inch (TPI). An example of the approximate preload range exhibited by different diameters is given below for a bolt with a yield strength of 120 Ksi and a K_{ISCC} of 75 Ksi in$^{1/2}$:

Diameter	4TPI	8TPI
2 1/2"	133.0 Ksi	150.0 Ksi
3"	129.3 Ksi	147.0 Ksi
3 1/2"	127.0 Ksi	144.0 Ksi
4"	125.0 Ksi	141.5 Ksi
4 1/2"	123.0 Ksi	139.5 Ksi
5"	121.5 Ksi	138.4 Ksi

The next 36 figures are the result of these data conversions. All of the graphs have a linear regression line (average) plotted and data are presented for both 4 and 8 threads per inch for 4 inch nominal diameter bolts.

The conversions of yield strength to R_c hardness values were done using the graphs provided in SAE Information Report SAE J4136 (Mechanical Properties of Heat Treated Wrought Steels) and the ASM Handbook, Vol. 11, eighth edition.

Figures 2 and 2a are graphs of combined aqueous data for SAE 4340 steels. Although the data are reasonably consistent at the high yield strength end of the scale, the data below 130 Ksi yield strength include those in which preload levels were equivalent or in excess of the yield strength. This situation could give rise to fast fracture of the material.

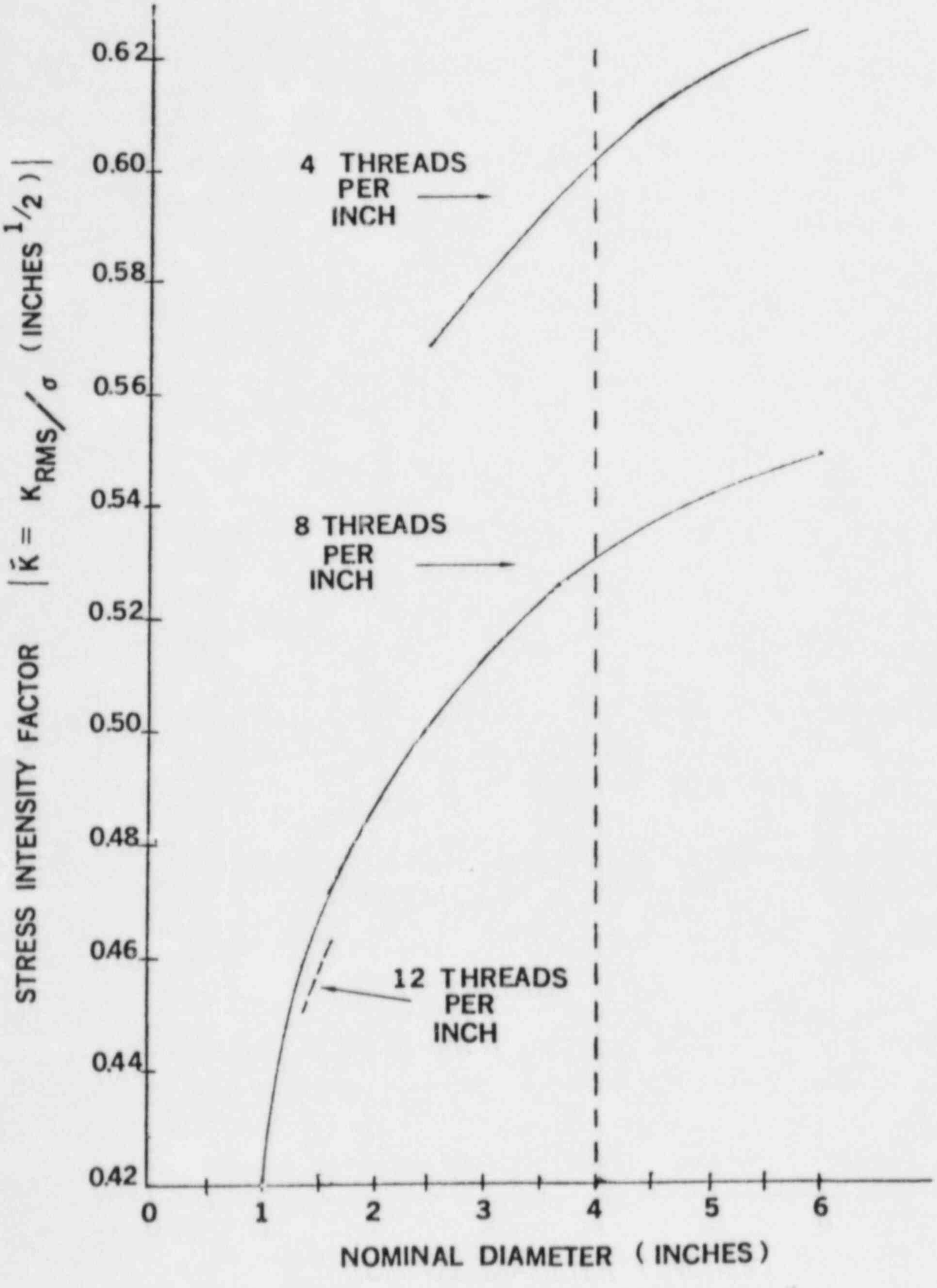


FIGURE 1 STRESS INTENSITY FACTOR FOR 0.020" REFERENCE FLAW IN THE THREAD REGION

Figures 3 and 3a are representations of SAE 4340 steels in environments of distilled water, humid air, aqueous solutions of NaCl, natural and sea coast sea water and synthetic sea waters. It is again seen on these graphs that the data will produce preload values that will exceed yield strength at the 120 Ksi preload and higher values.

Figures 4 and 4a are graphical representations of data in dry gas H_2S, wet gas H_2S, aqueous solutions of H_2S and some data points in 6% H_3BO_3 solutions. Some of the aqueous solutions of H_2S contained chloride and/or acetic acid. Goldberg [1] noted that the chloride additions did not have a significant effect on the K_{ISCC} but that the acidified solutions did appear to accelerate the cracking process. Again, considerable scatter is evident in both of the graphs.

Figures 5 and 5a contain data for several 43XX steels heat treated to ultra-high tensile strength and subjected to combined aqueous, moist air, aqueous NaCl, H_2O or industrial environments. For these two curves, all of the preloads fall below the yield strengths of the material with no point falling below about 185 Ksi yield strength.

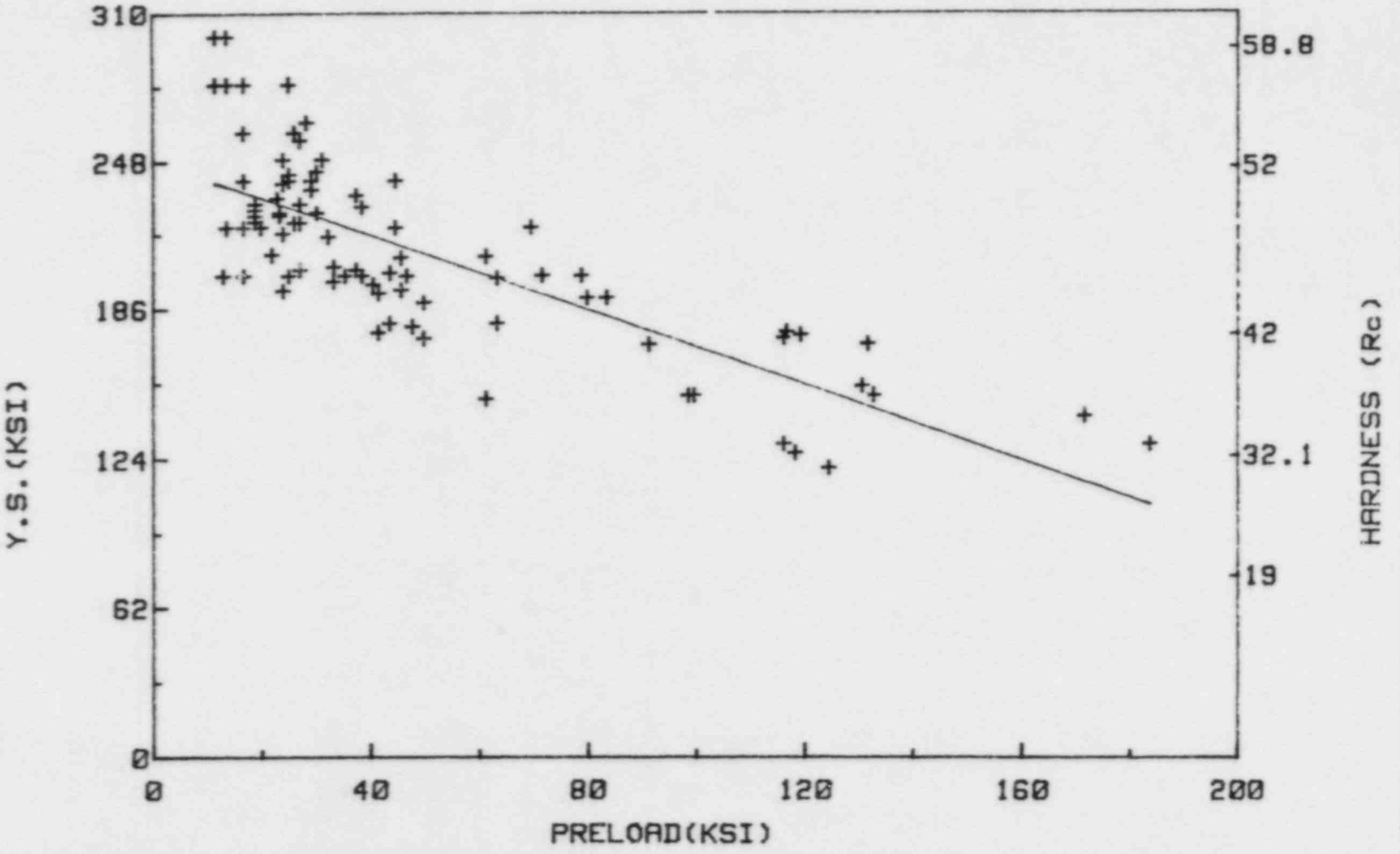
Figures 6 and 6a contain data for 4335 V, 4340 and 300M steels in H_2 gas. The large variations for a given yield strength were related to the variations in H_2 partial pressures.

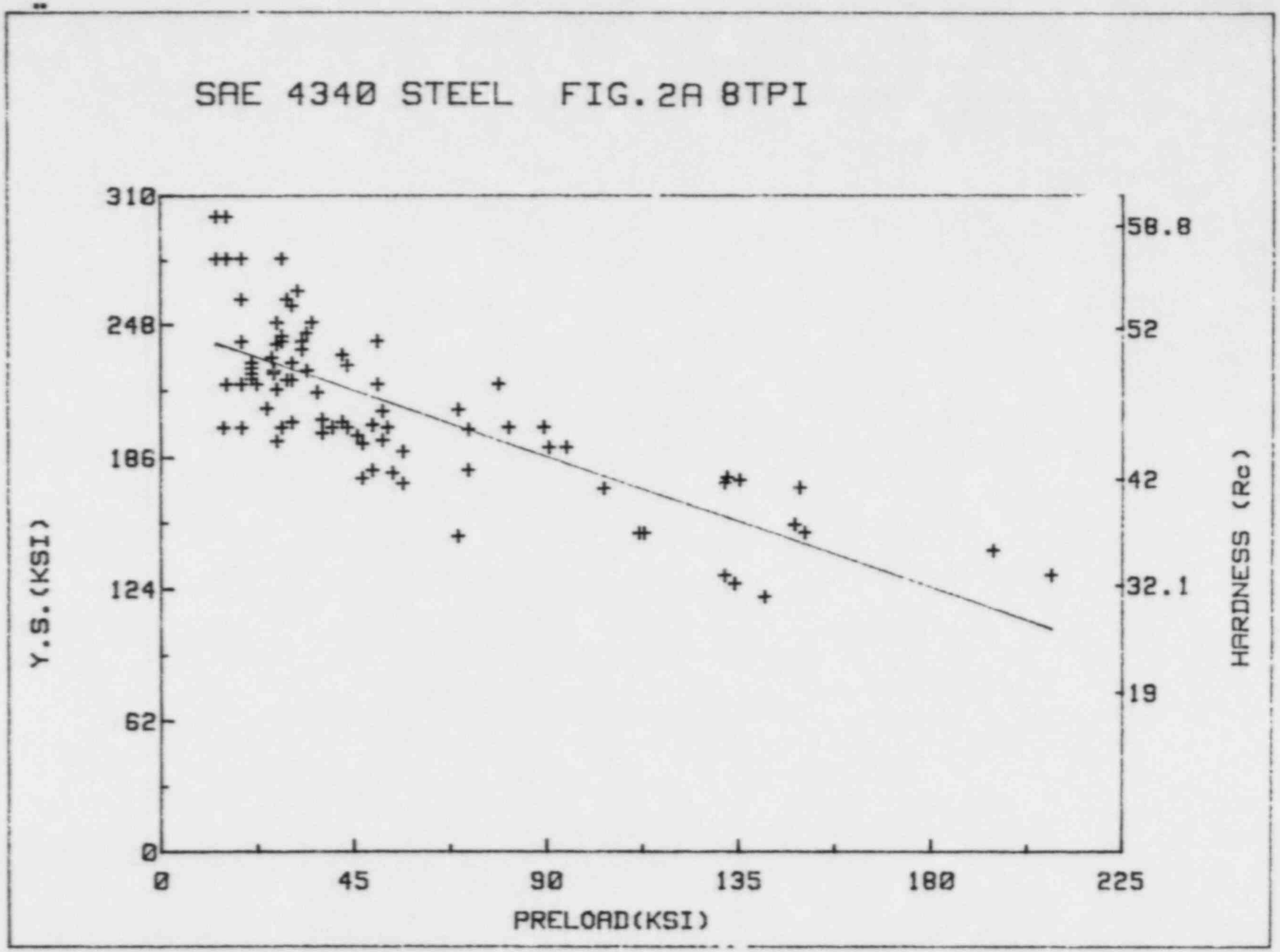
Figures 7 and 7a contain data generated for 4130 and 4140 steels tested in combined aqeous, H_2O and aqueous chlorides.

Figures 8 and 8a reflect data generated on 4130, 4130 modified, 4135 modified and 4140 in H_2S aqueous environments. There is scatter on the low end of the yield strength similar to that observed on prior graphs.

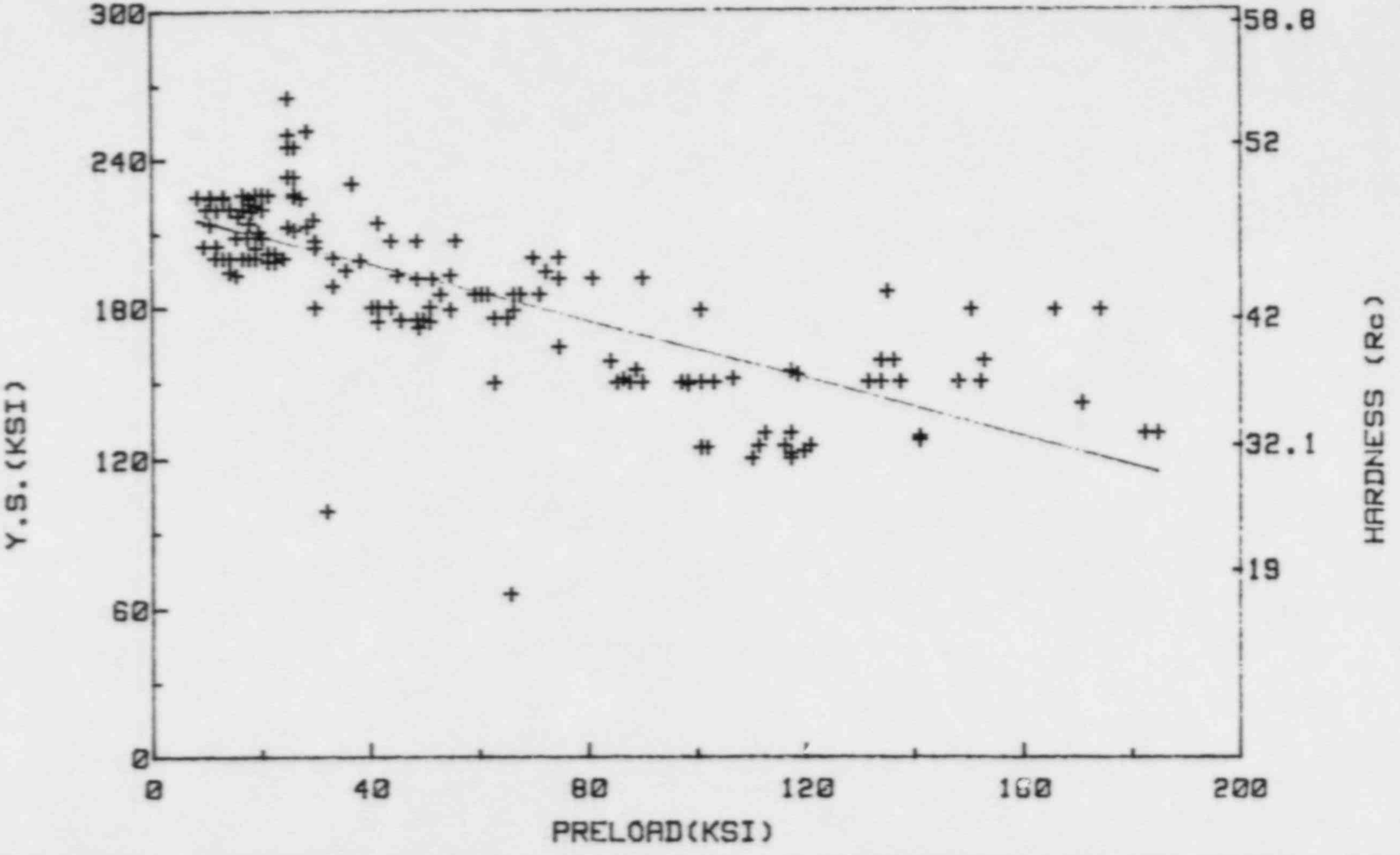
Figures 9 and 9a are a plot of hydrogen effects on SAE 4130, 4135, 4140, 4145 and 4147 steels. As in Figures 6 and 6a, considerable scatter is again attributable to the varying partial pressure of H_2.

SAE 4340 STEEL FIG. 2 4TPI

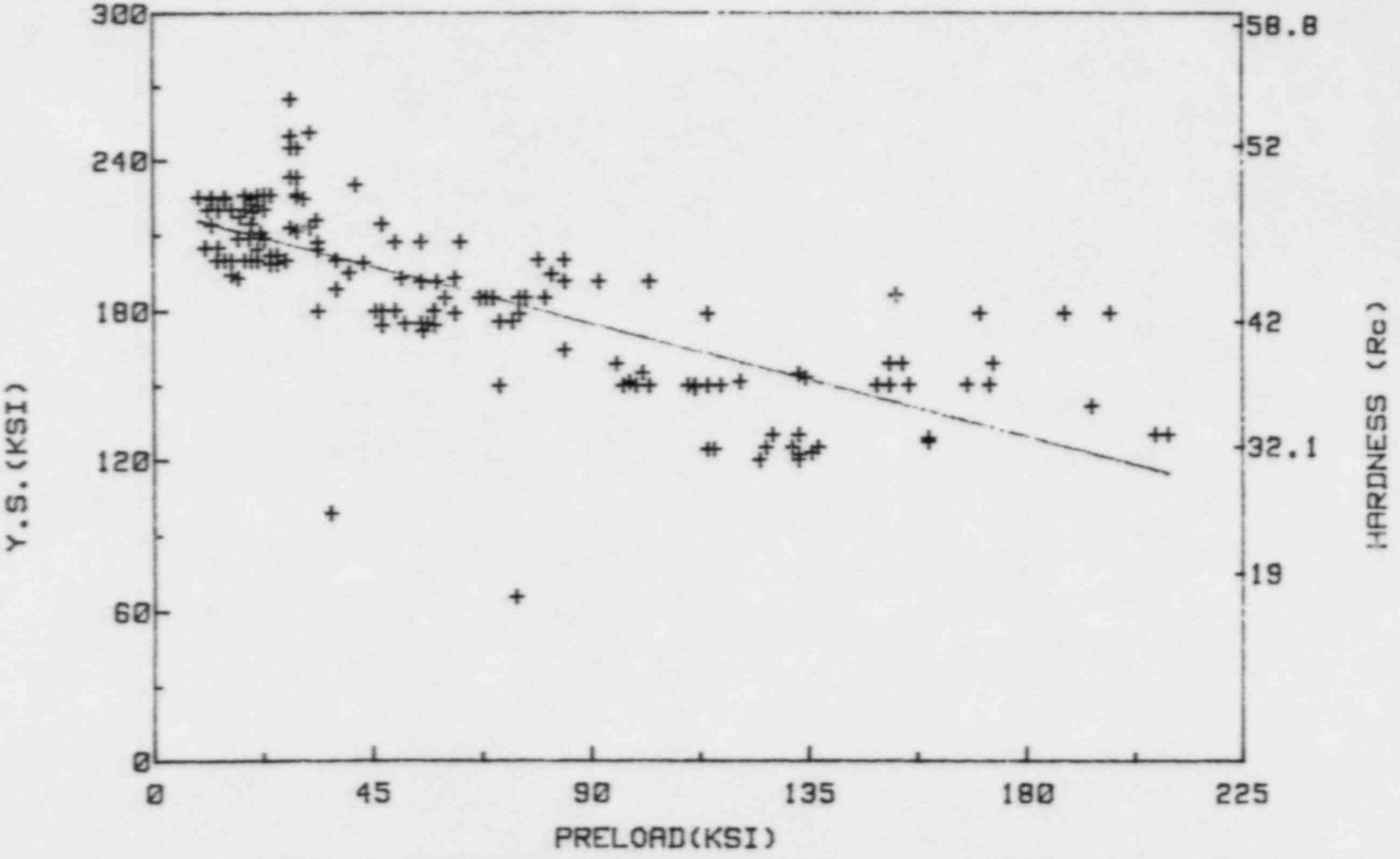



SAE 4340 STEEL FIG. 2A 8TPI
Y.S. (KSI)
310
248
186
124
62
0
HARDNESS (Rc)
58.8
52
42
32.1
19
0
45
90
135
180
225
PRELOAD(KSI)

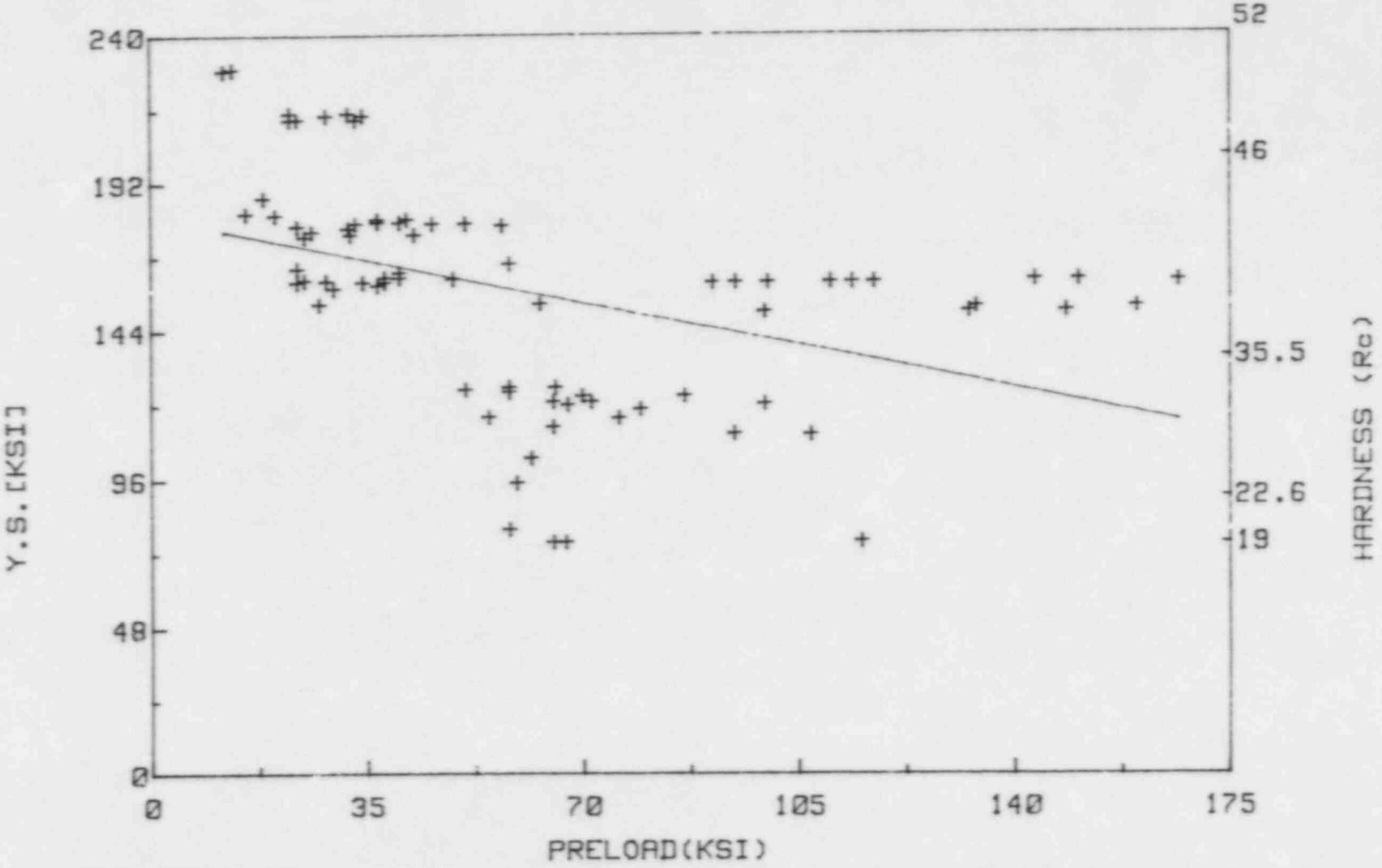
SAE 4340 STEEL FIG.3 4TPI

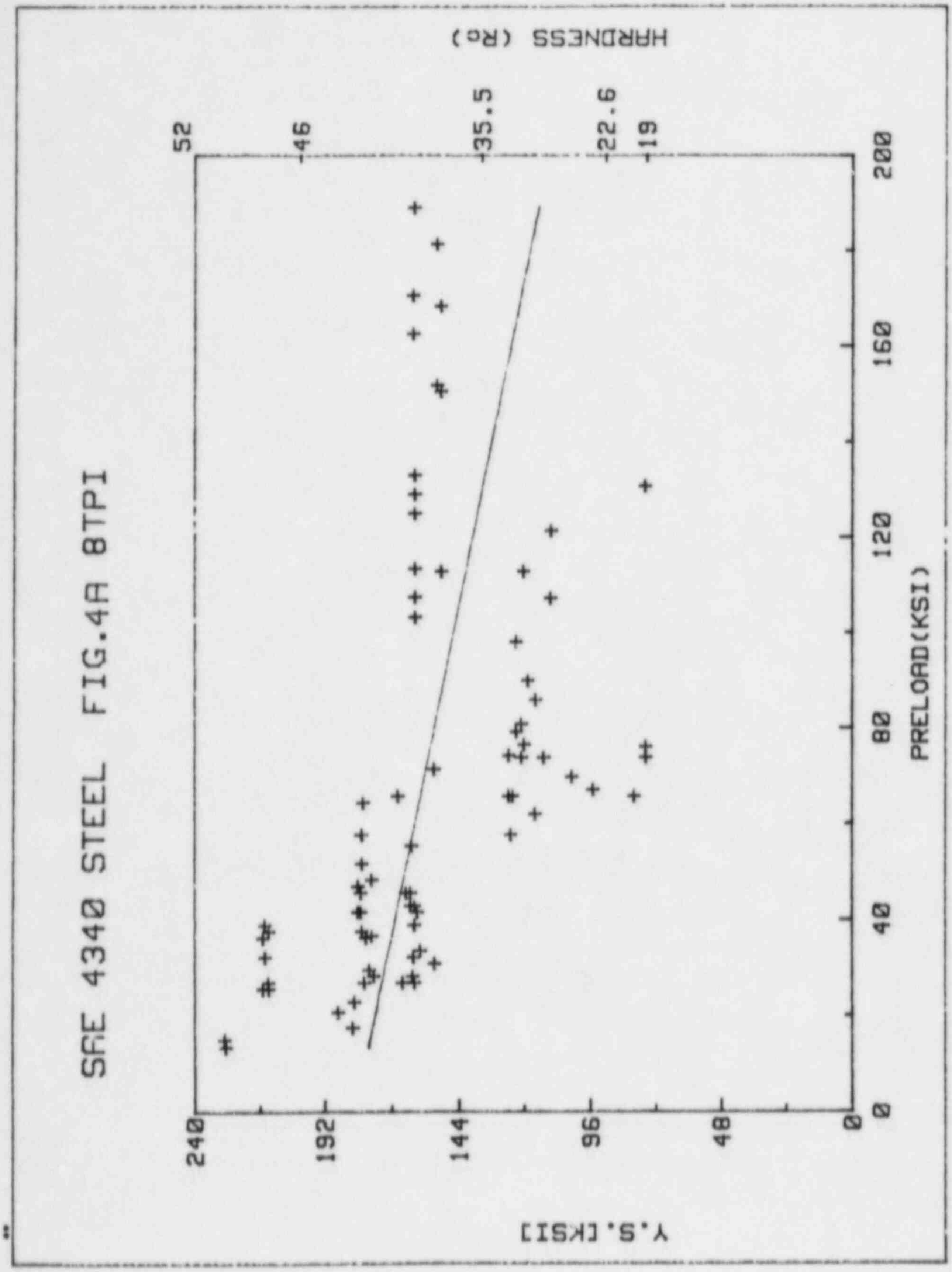


SAE 4340 STEEL FIG.3A 8TPI



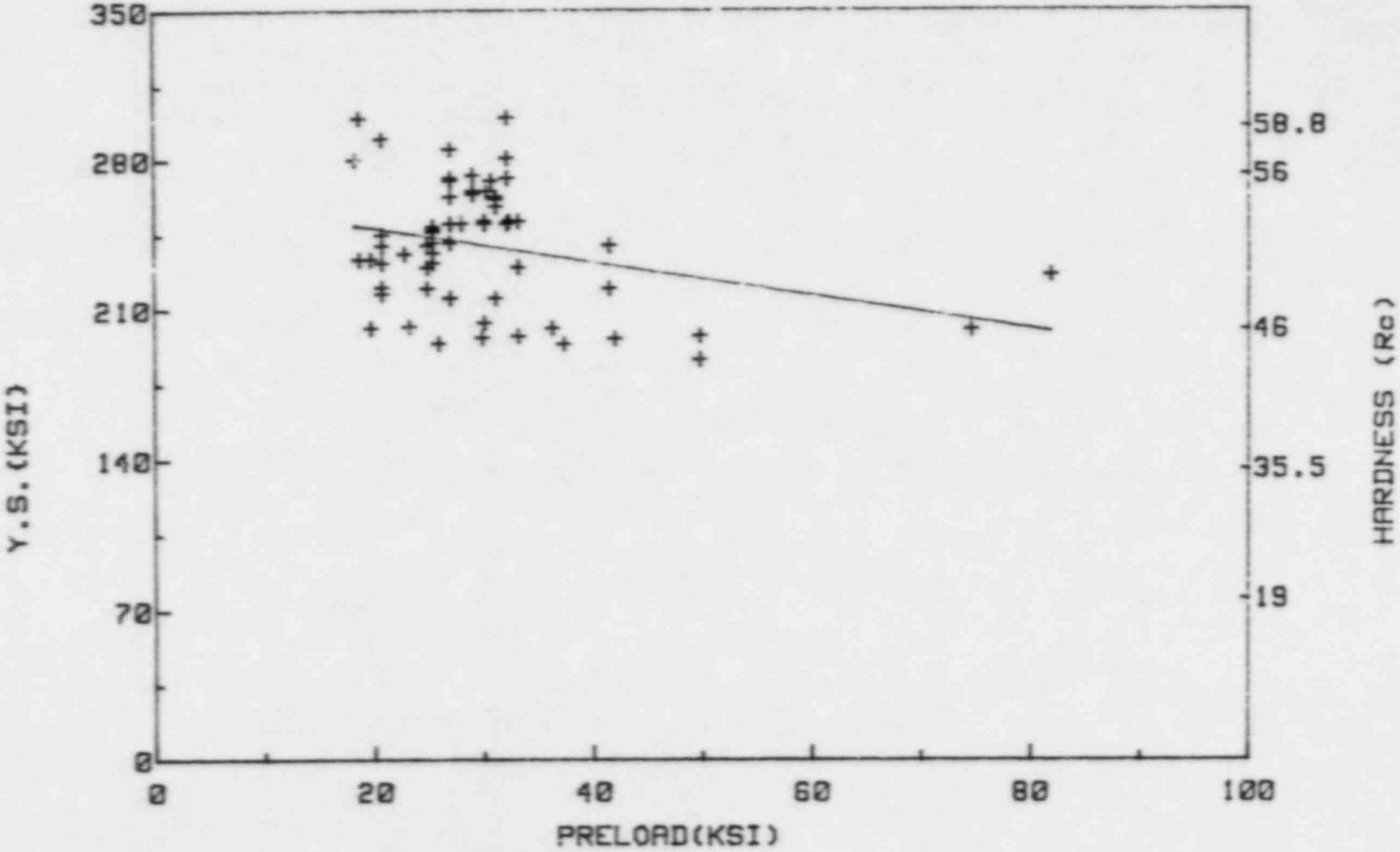
SAE 4340 STEEL FIG.4 4TPI



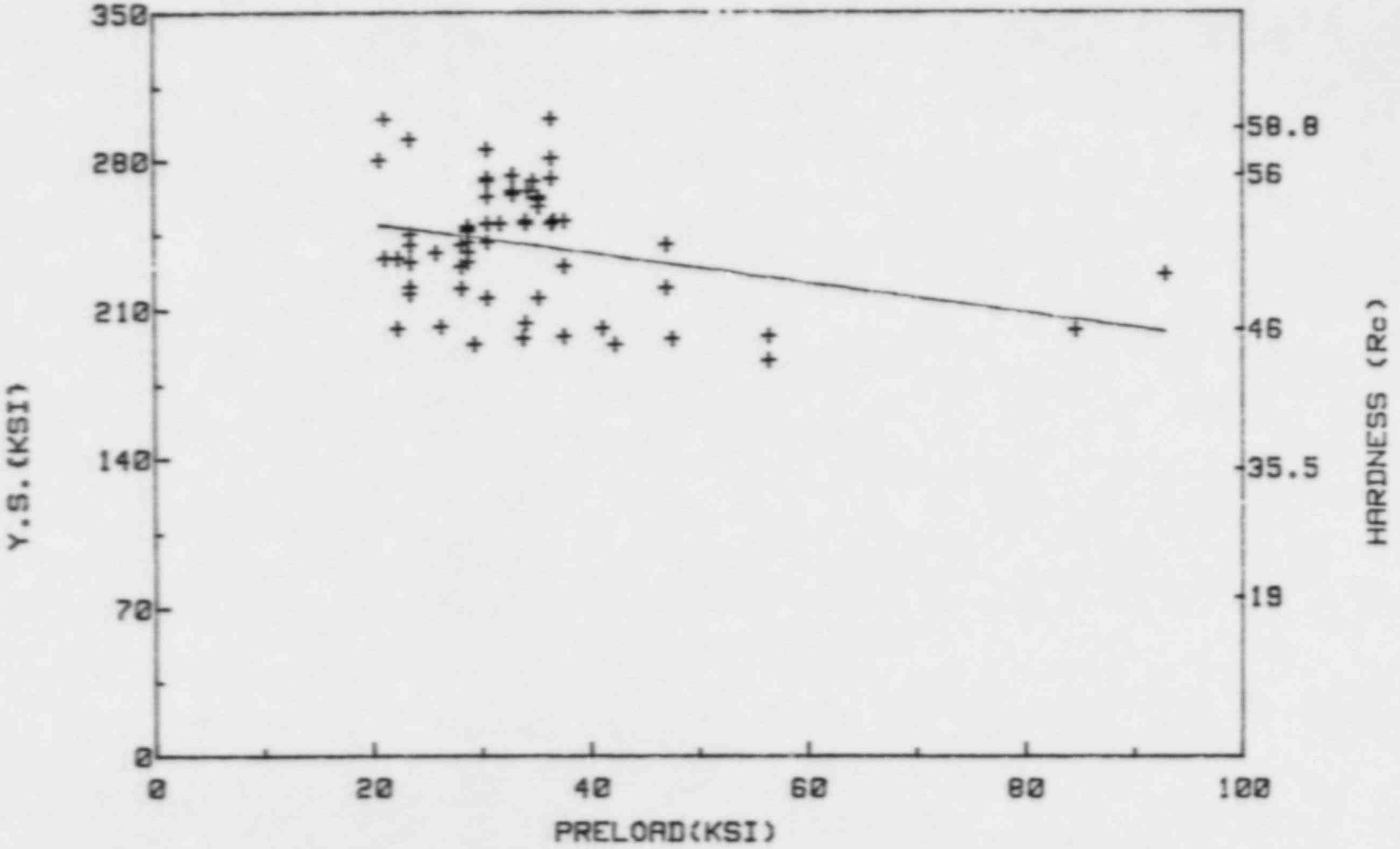


SAE 4340 STEEL FIG.4A 8TPI

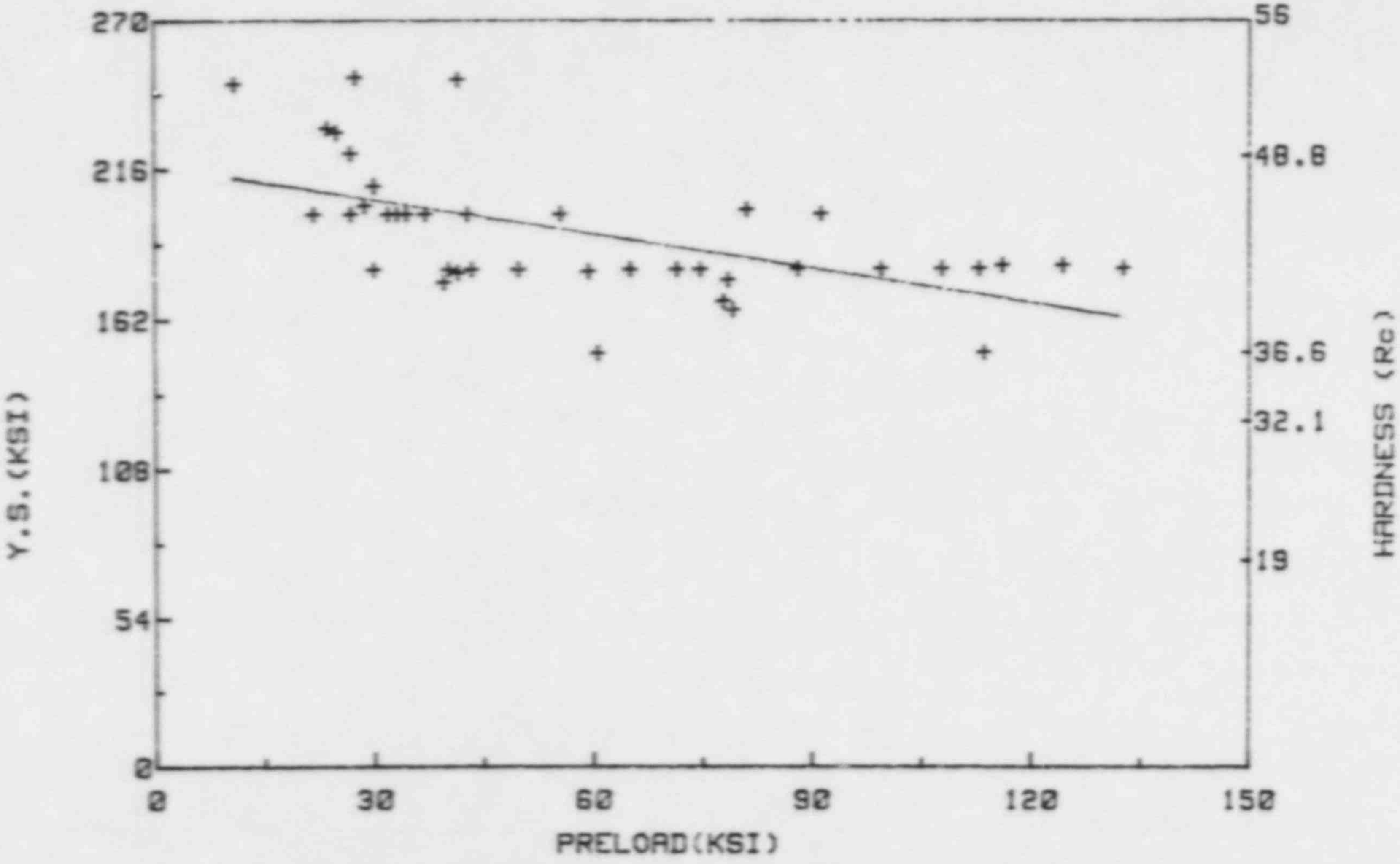
43XX TYPE STEELS FIG.5 4TPI

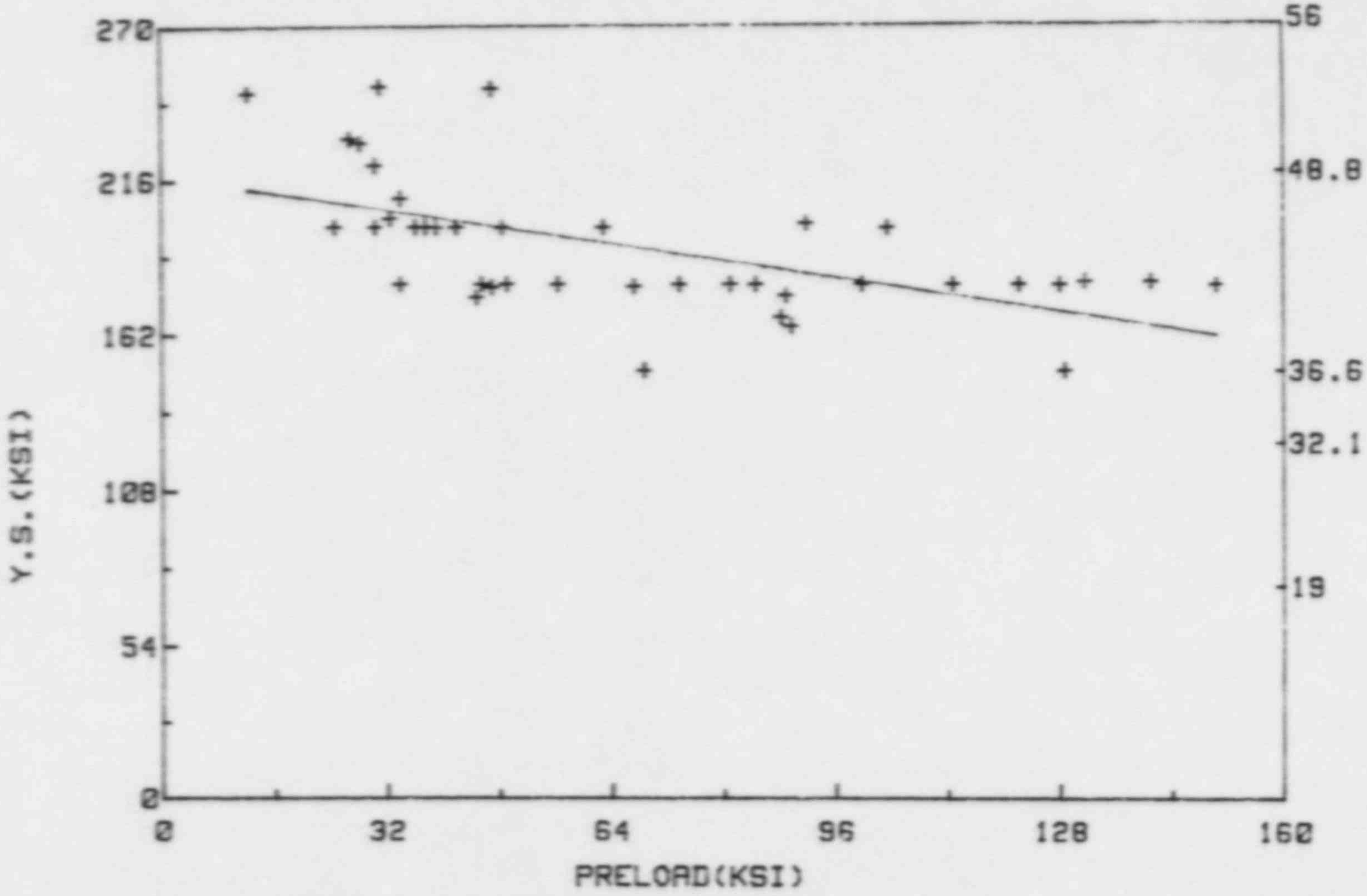


43XX TYPE STEELS FIG.5A 8TPI



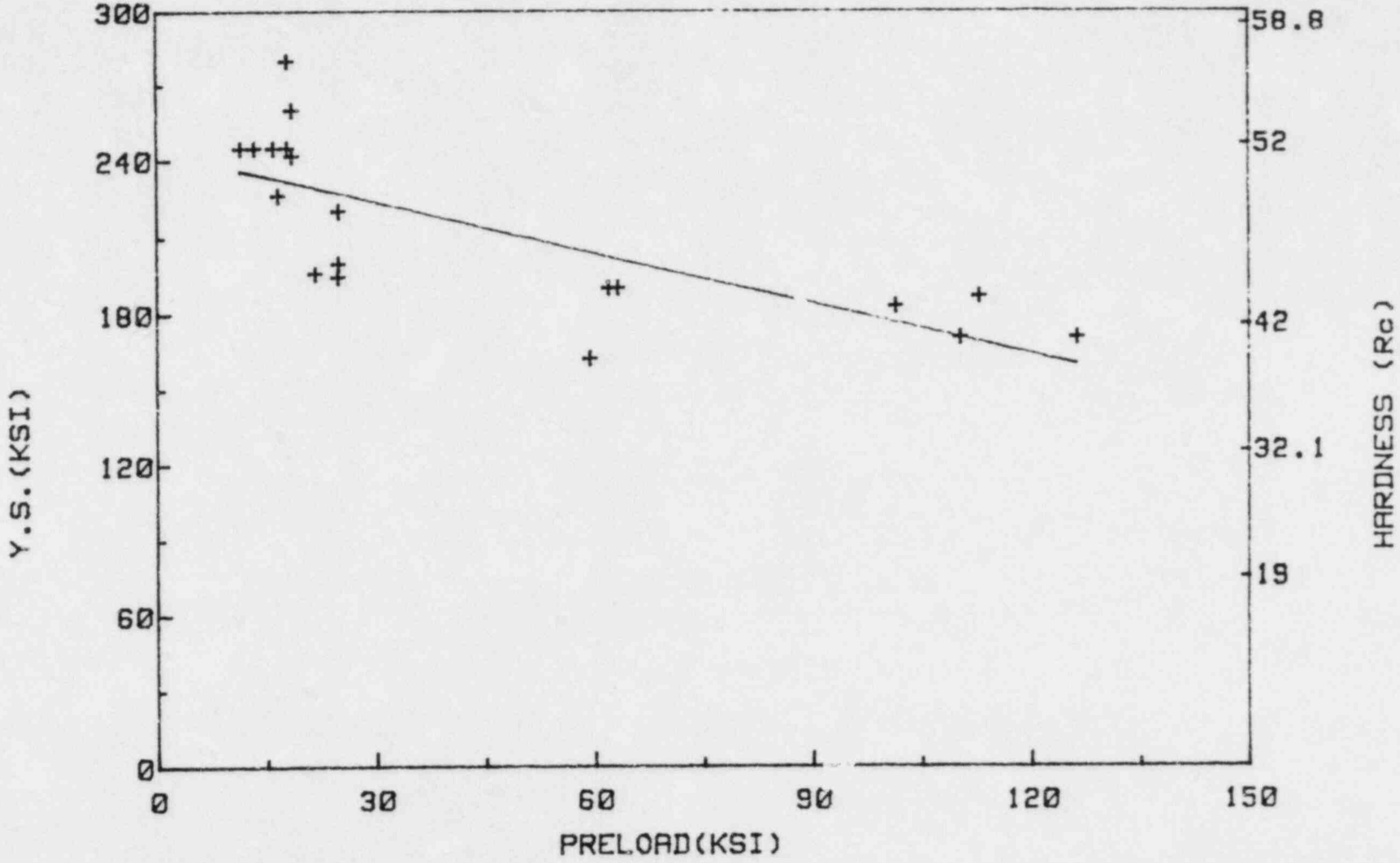
43XX TYPE STEELS IN H2 FIG.6 4TPI

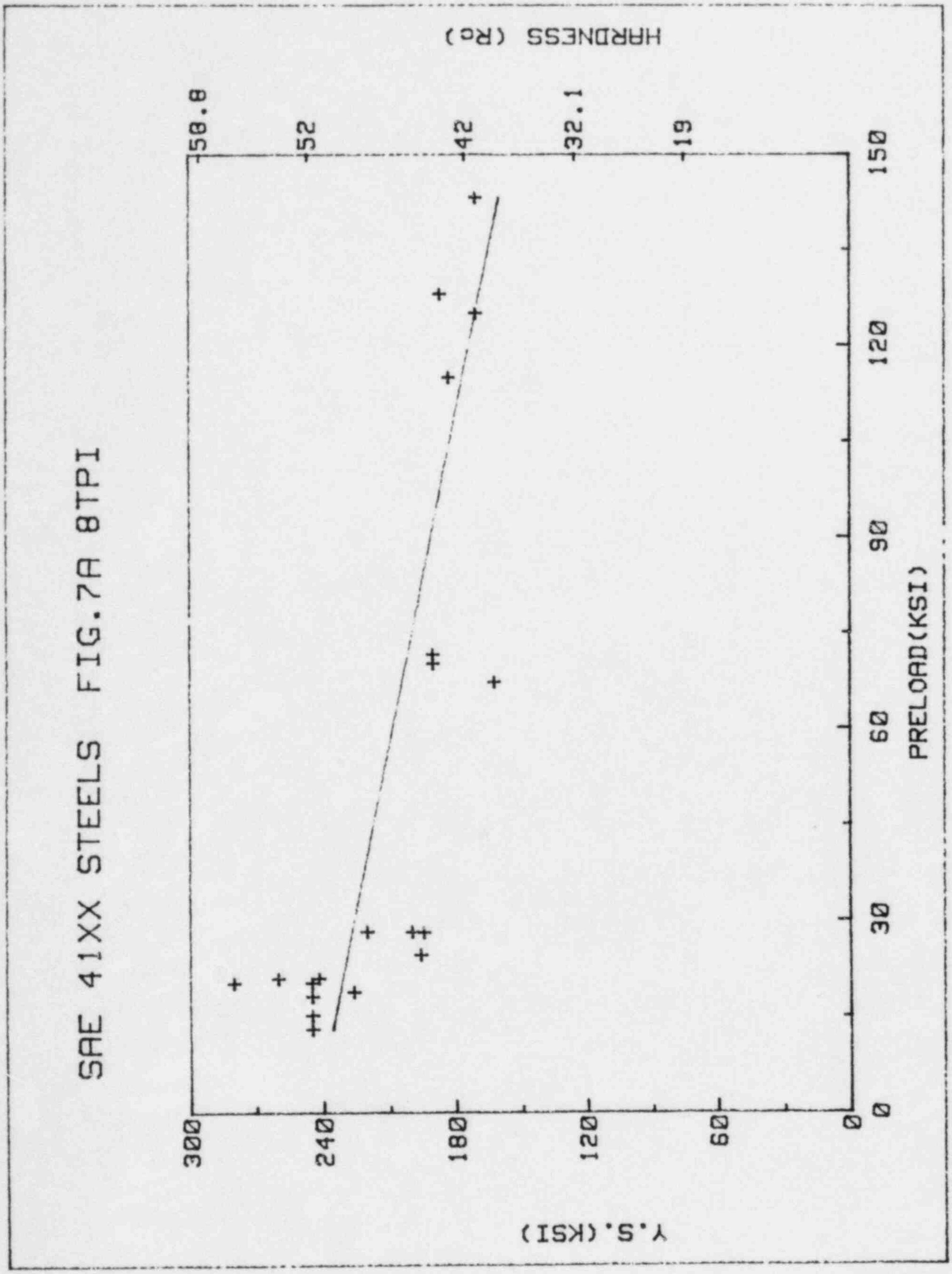




43XX TYPE STEELS IN H2 FIG.6A 8TPI

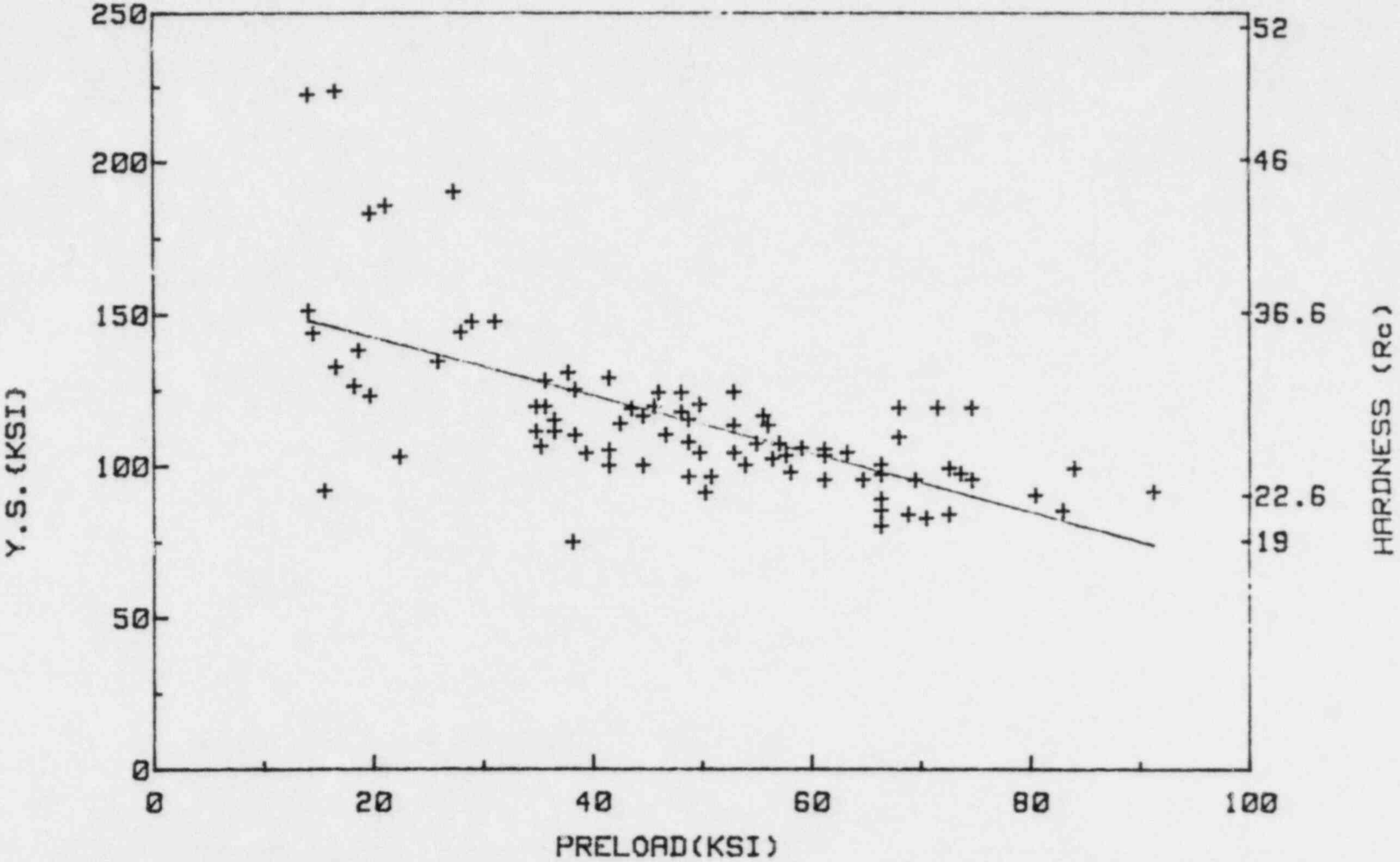
SAE 41XX STEELS FIG.7 4TPI



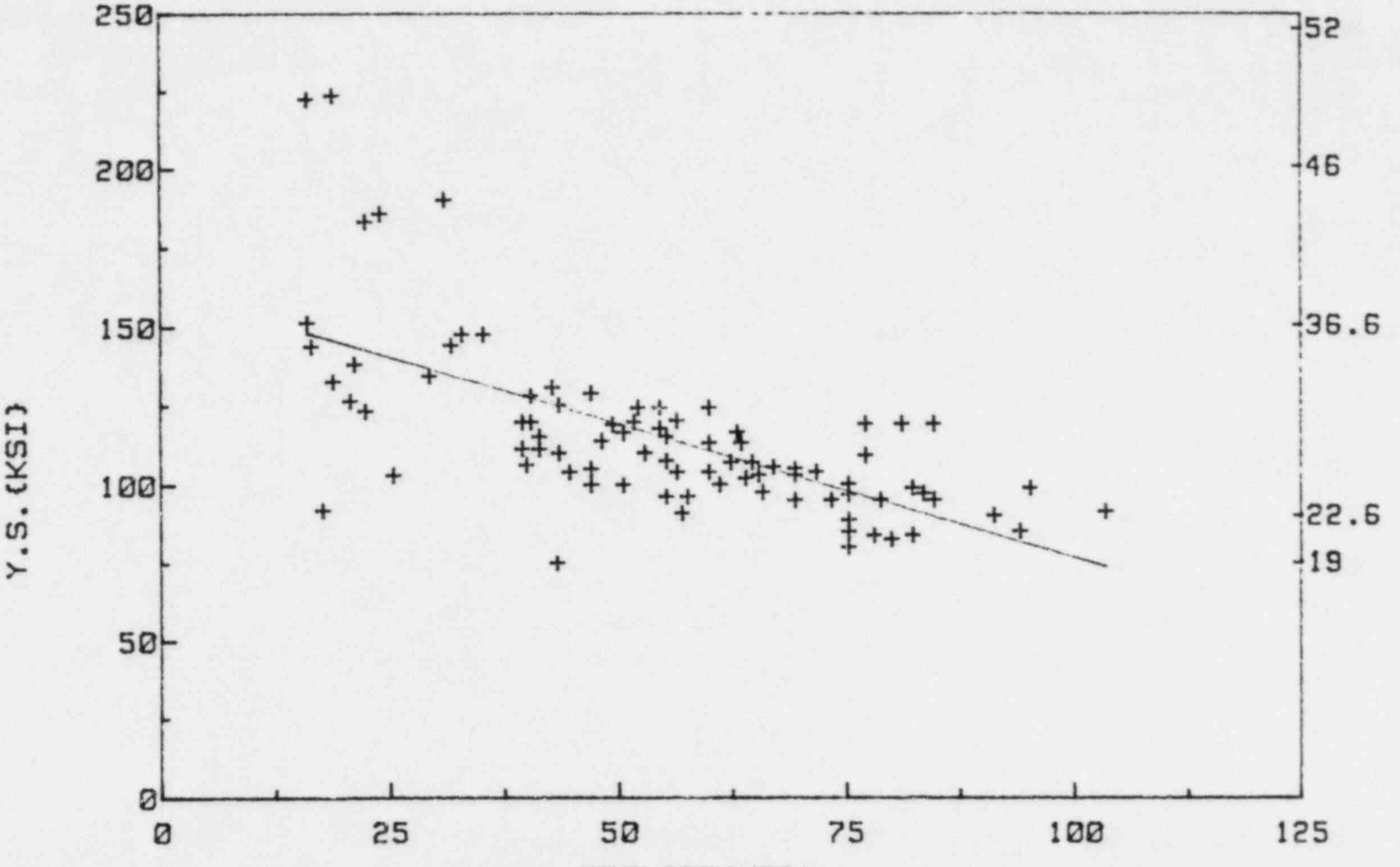


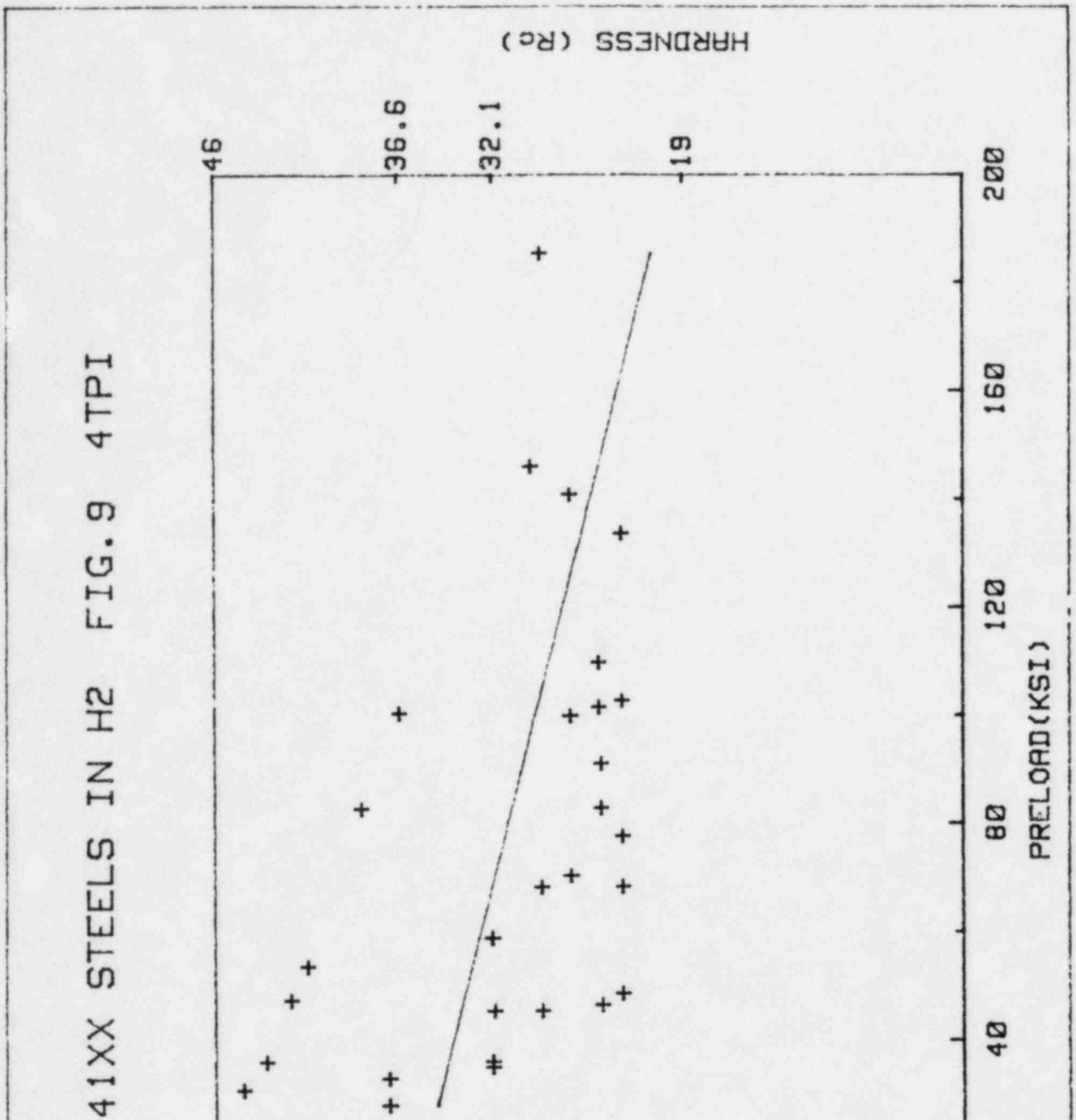
SAE 41XX STEELS FIG.7A 8TPI

41XX TYPE STEELS FIG.8 4TPI



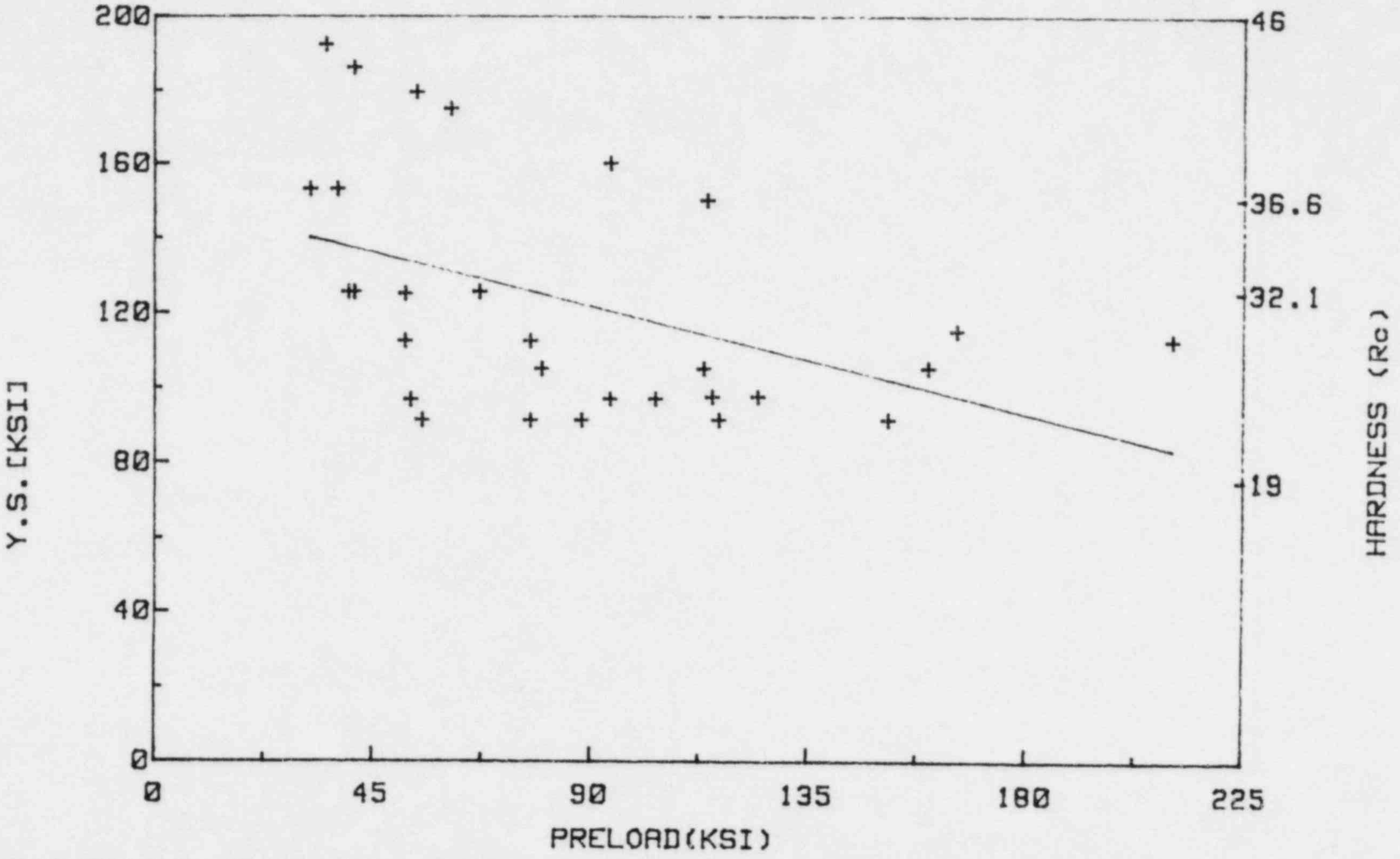
41XX TYPE STEELS FIG. 8A 8TPI





SAE 41XX STEELS IN H2 FIG.9 4TPI

SAE 41XX STEELS IN H2 FIG.9A 8TPI



Figures 10 and 10a reflect the environmental effects of combined aqueous, distilled H_2O and aqueous NaCl on D6AC steels. This series of data had reasonably good correlation when converted to preload data.

Data of H-11 die steel is presented in humid air, sea water/sea coast, aqueous NaCl, H_2O and humid air (0.1 - 100% relative humidity) environments in graphs 11 and 11a. Reasonably good correlations between preload and yield strength are also evident on these graphs.

Figures 12 and 12a are plots for HY 80 to HY 150 steels in aqueous NaCl, sea water, synthetic sea water, polarized Zn anode, combined aqueous, dry H_2S gas and aqueous H_2S. It is quite evident that these steels exhibit quite a large amount of scatter in these environments. In the case of these steels, the preload versus yield strength relationship would be extremely limiting in order to prevent SCC in these materials.

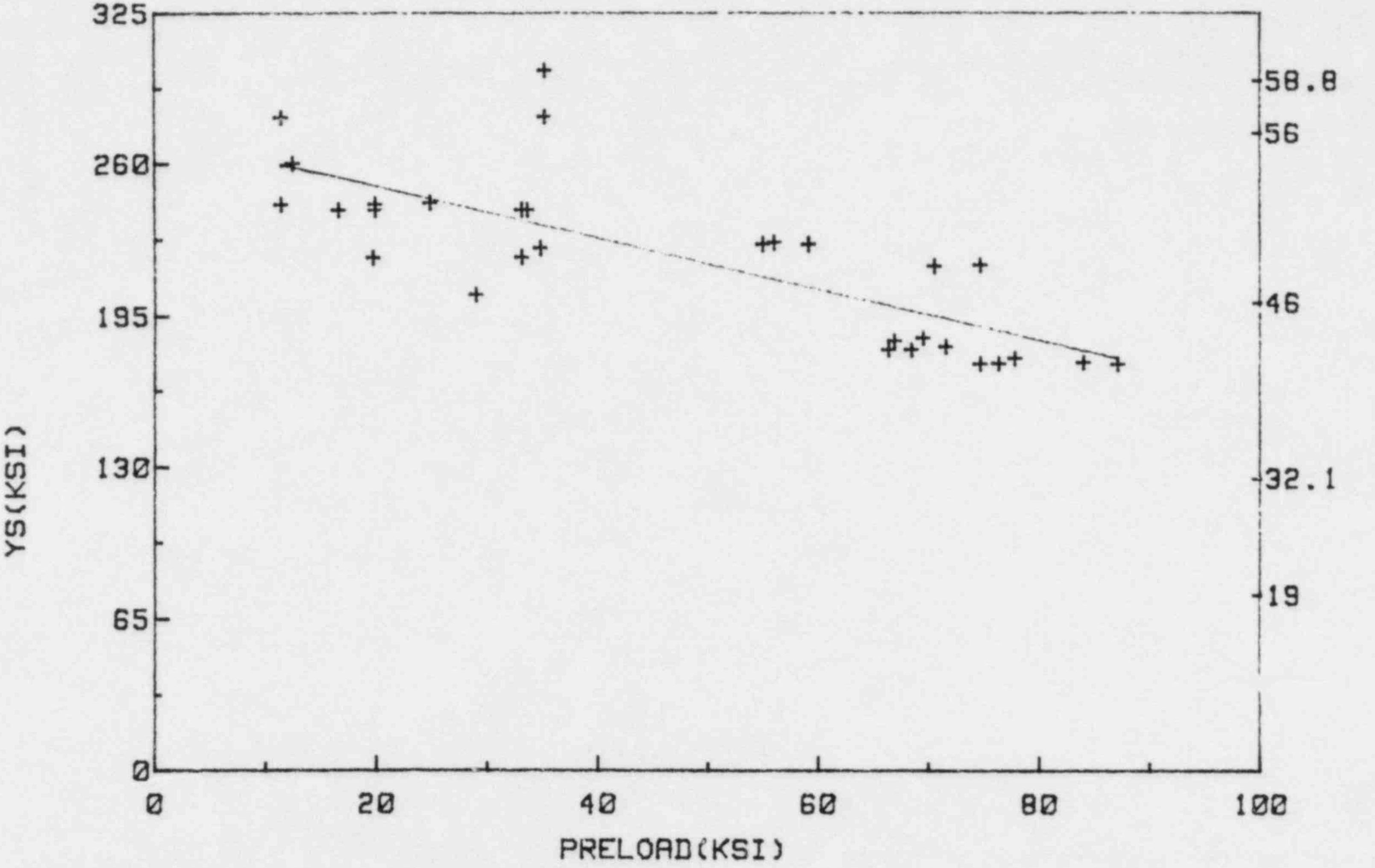
Foreign steel data (low alloy) in various aqueous chloride environments is plotted on graphs 13 and 13a. Above approximately 75 Ksi preload, there is scatter of the data with a few points allowing preloads up to or exceeding the materials yield strength.

Figures 14 and 14a are graphs of the effect of both aqueous H_2S and H_2S gas on miscellaneous low alloy steels. The aqueous H_2S solutions were normally saturated, 3.5% NaCl - 0.5% acetic acid NACE solution. It is evident that use of these steels is extremely limited in these types of environments.

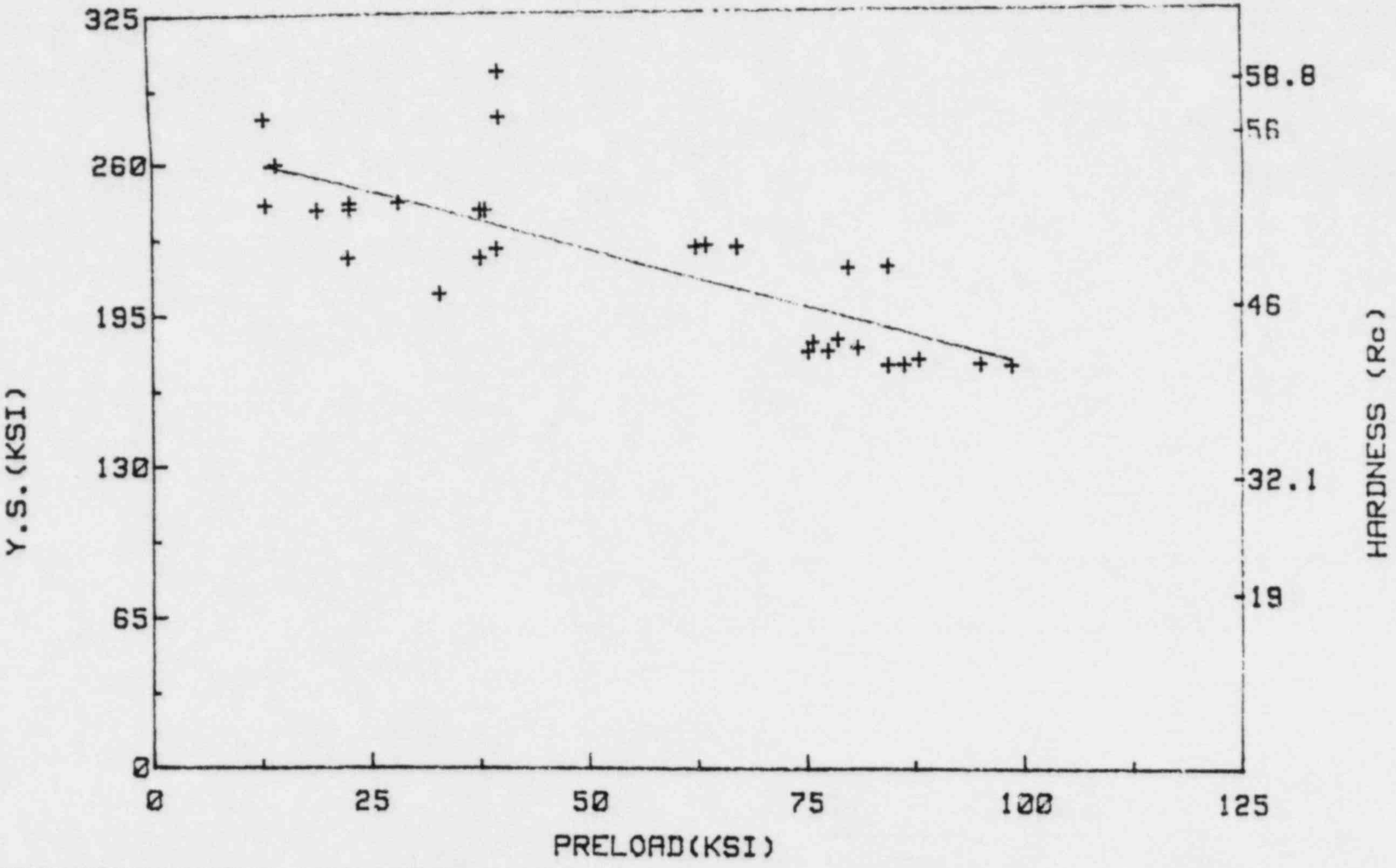
Miscellaneous low alloy steels, as well as, HY 80, 100, 130 and H-11 die steel in gaseous H_2 are shown in Figures 15 and 15a. These data again have scatter, related to the partial pressure of the hydrogen gas.

Custom 455 stainless steel data are presented in aqueous NaCl, synthetic sea water, laboratory air, distilled H_2O, H_2S gas - 50 psig and 6% H_3BO_3 solutions in Figures 16 and 16a. The linear regression curve is almost a horizontal line at a yield strength of approximately 220 Ksi.

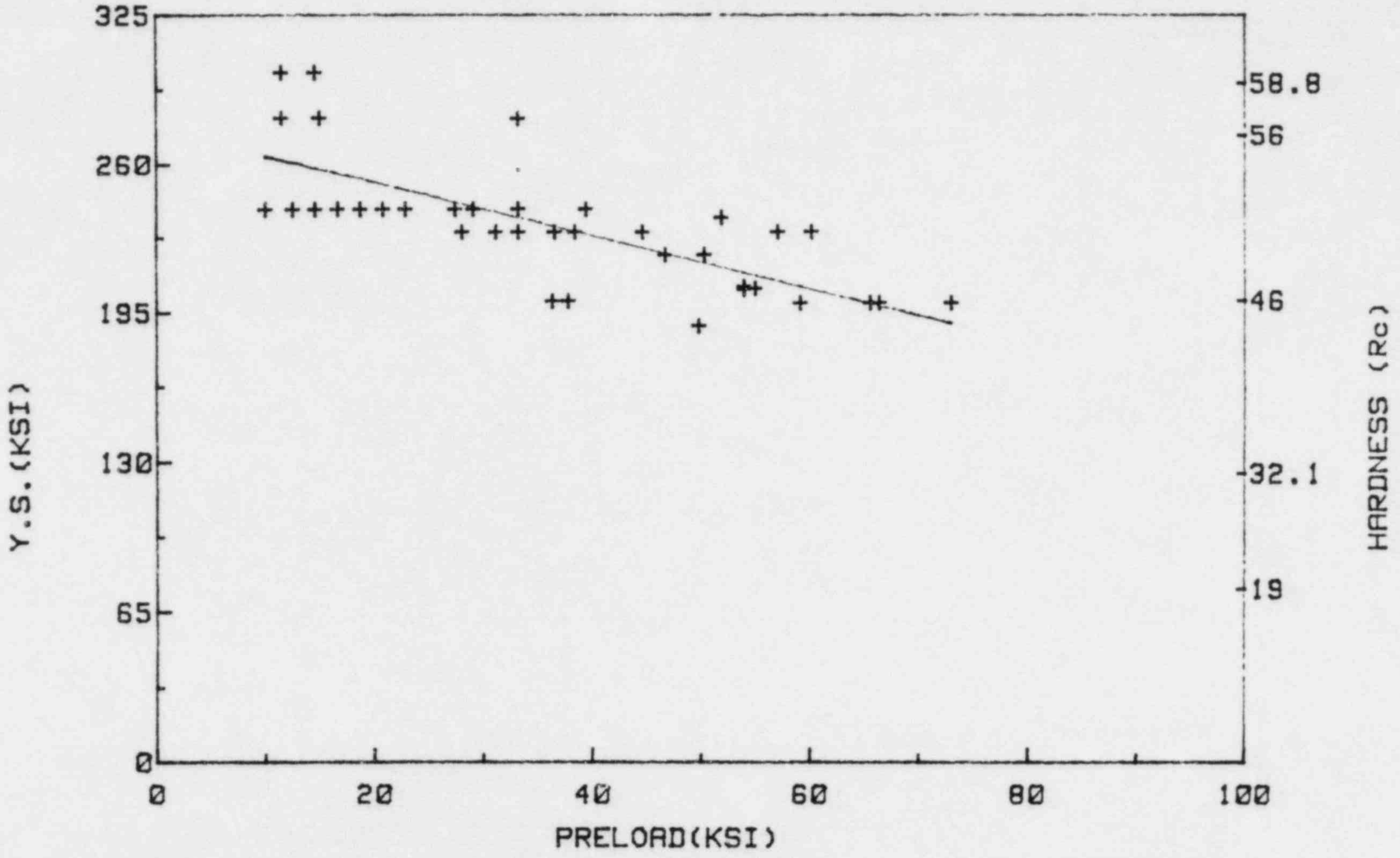
D6AC STEEL FIG.10 4TPI



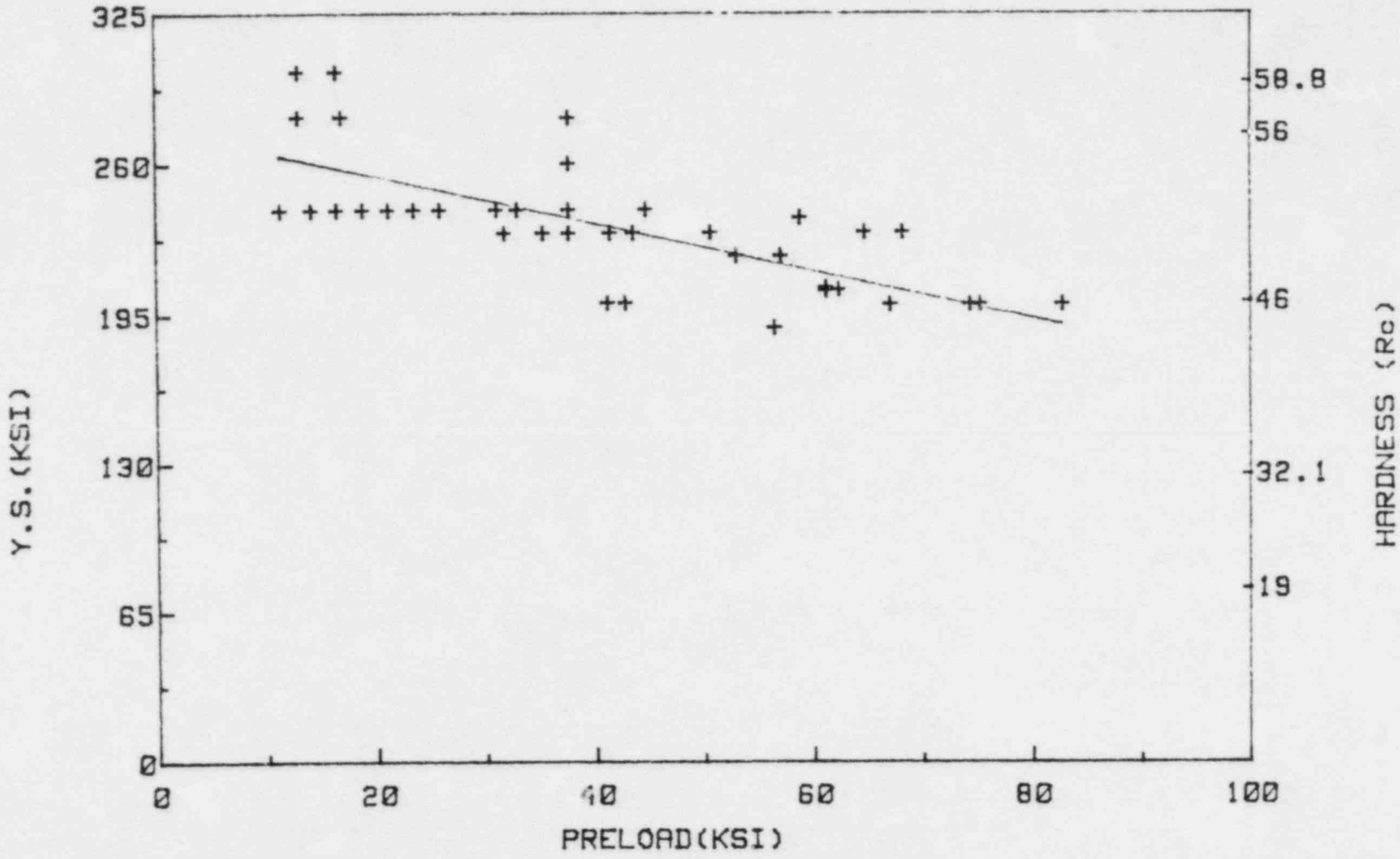
D6AC STEEL FIG.10A 8TPI



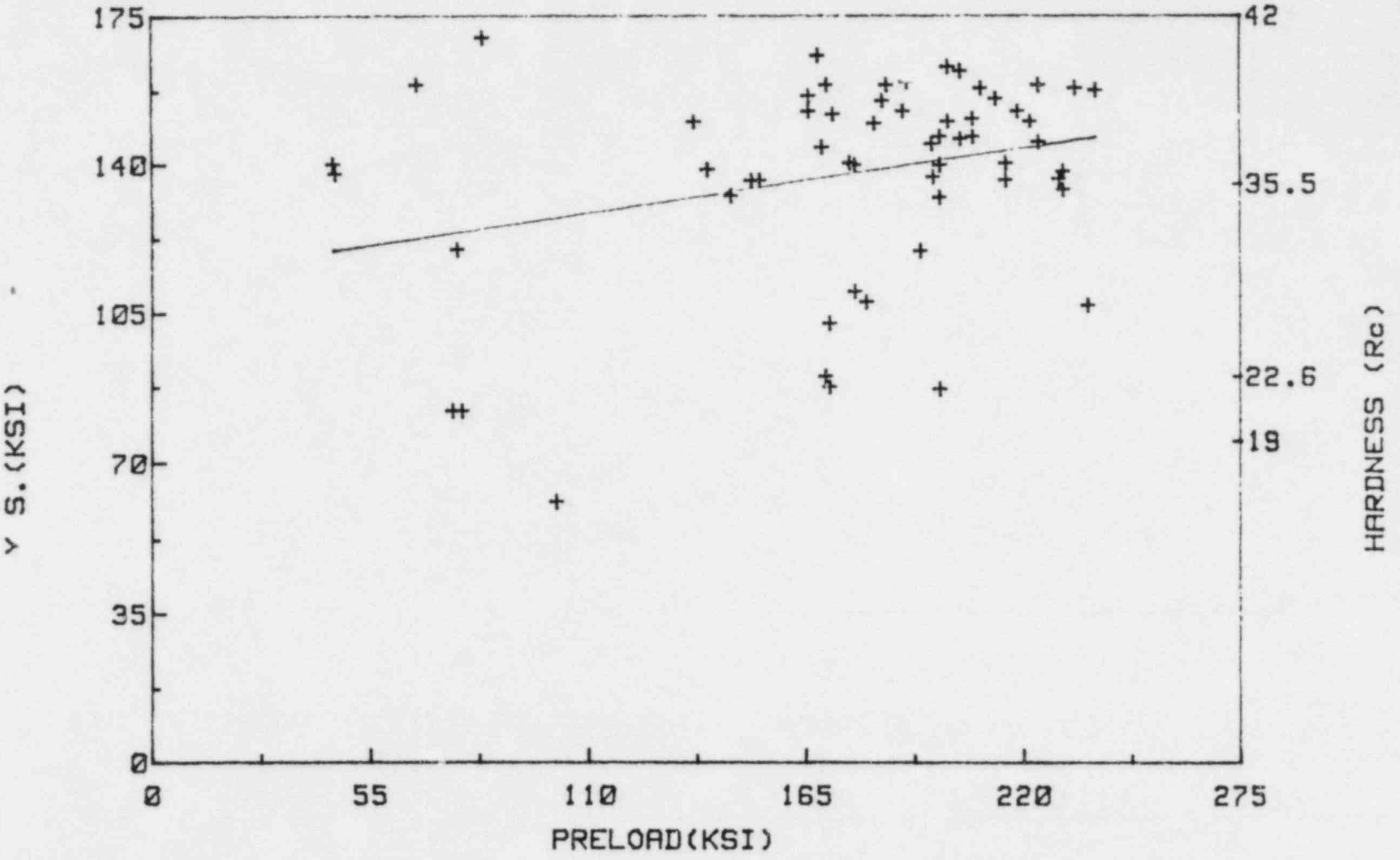
H-11 DIE STEEL FIG.11 4TPI



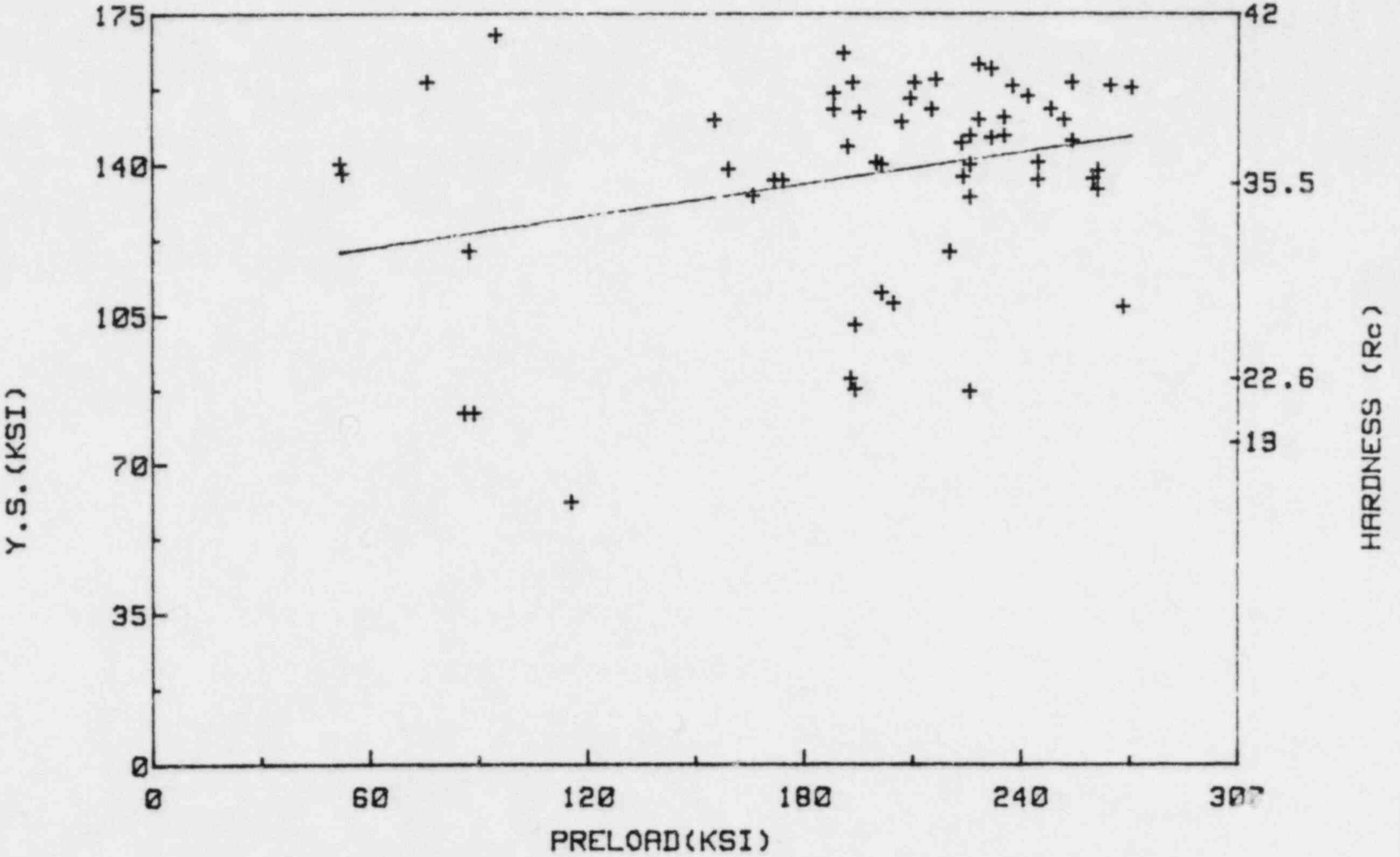
H-11 DIE STEEL FIG.11A 8TPI



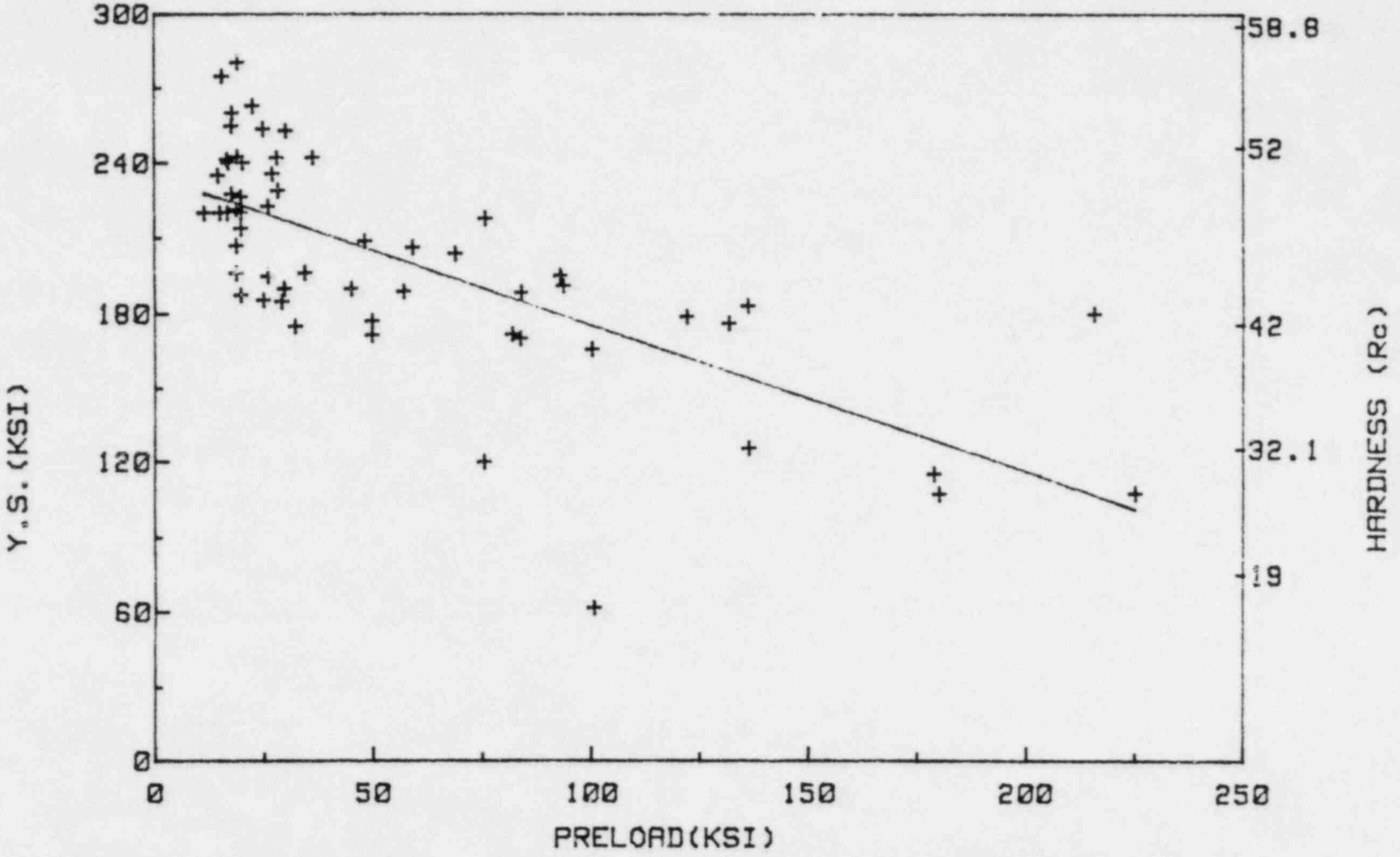
HY80 TO HY150 STEELS FIG. 12 4TPI



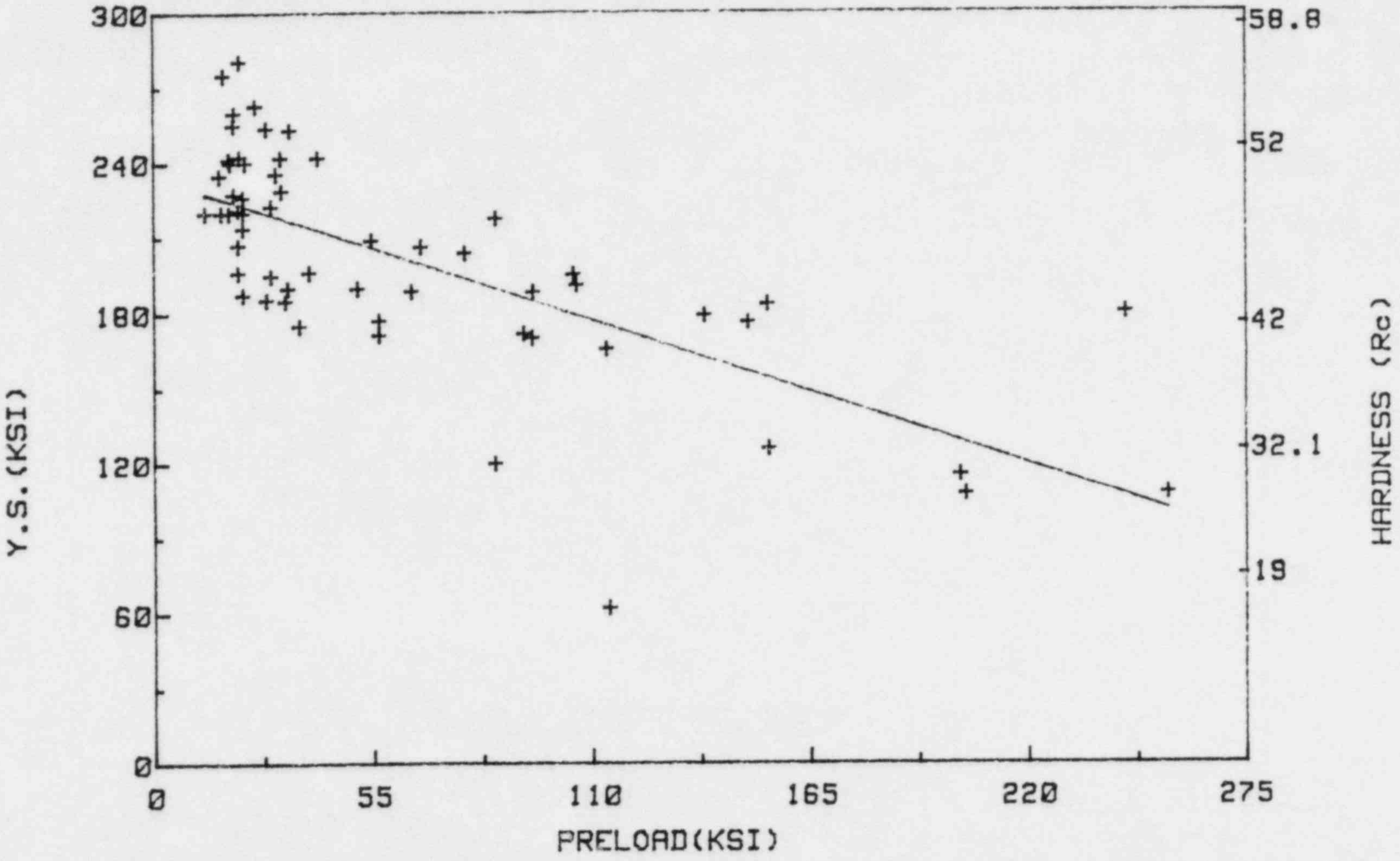
HY80 TO HY150 STEELS FIG.12A 8TPI



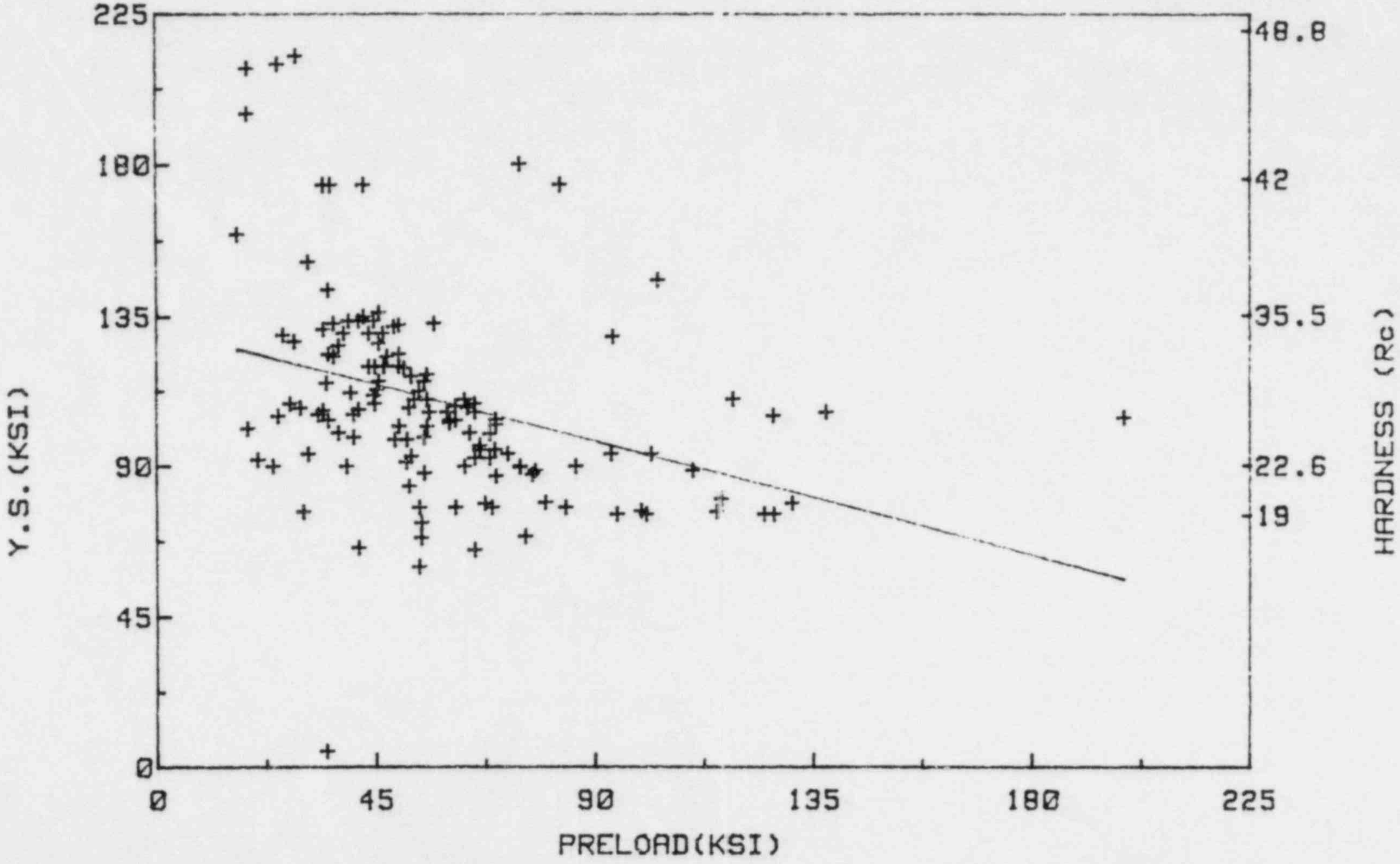
MISC. LOW-ALLOY STEELS FIG.13 4TPI



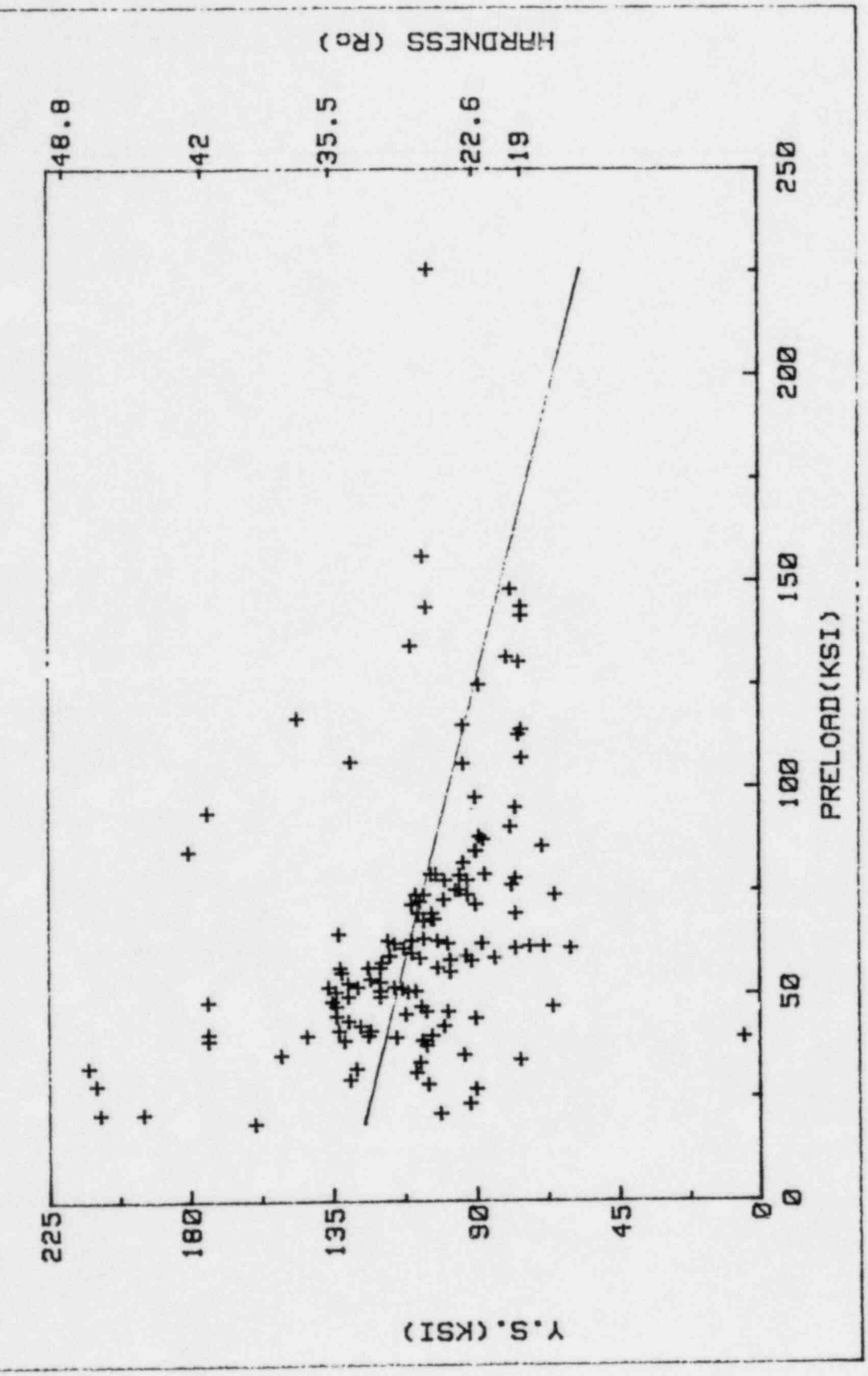
MISC. LOW-ALLOY STEELS FIG.13A 8TPI



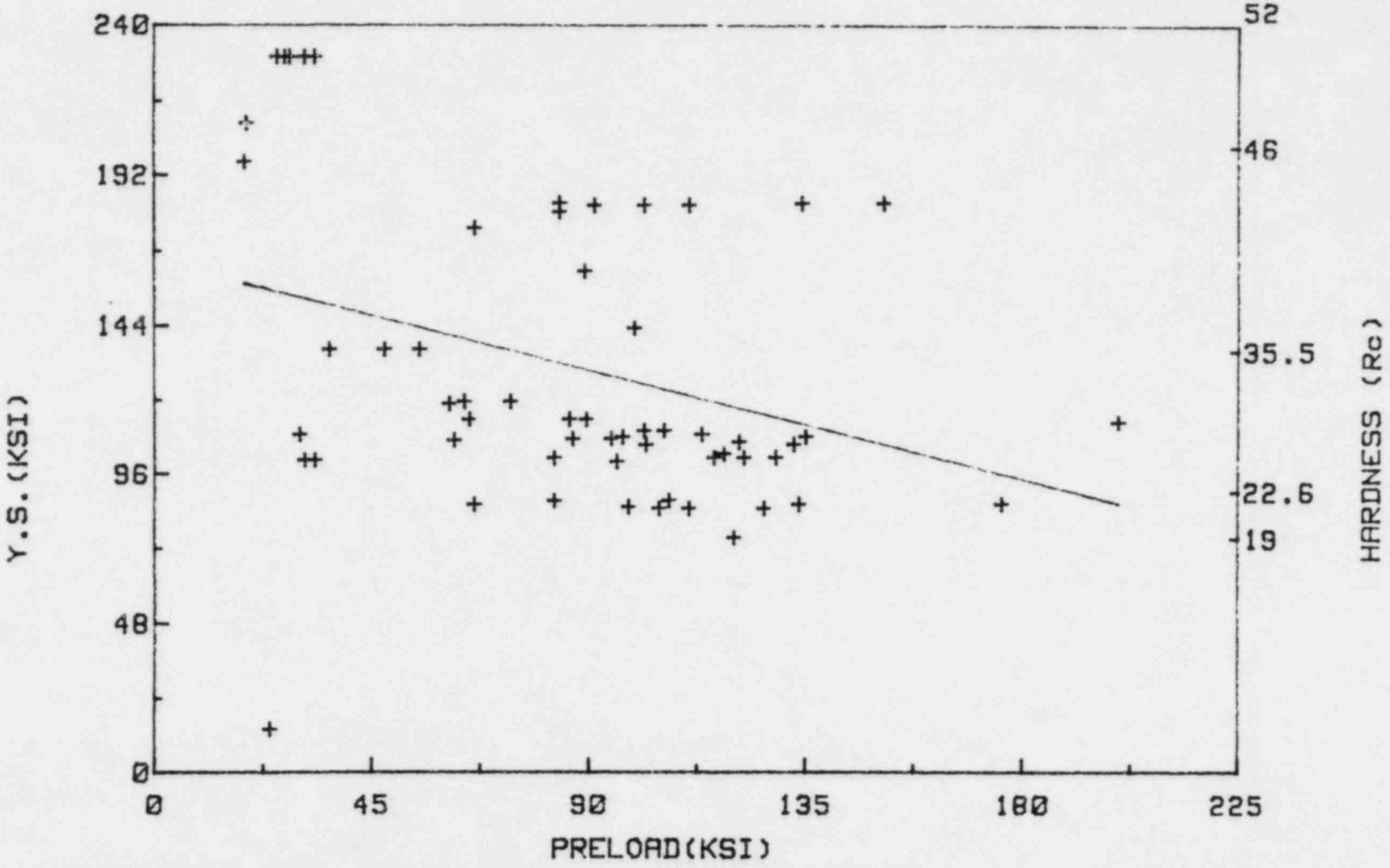
MISC. LOW-ALLOY STEELS FIG. 14 4TPI



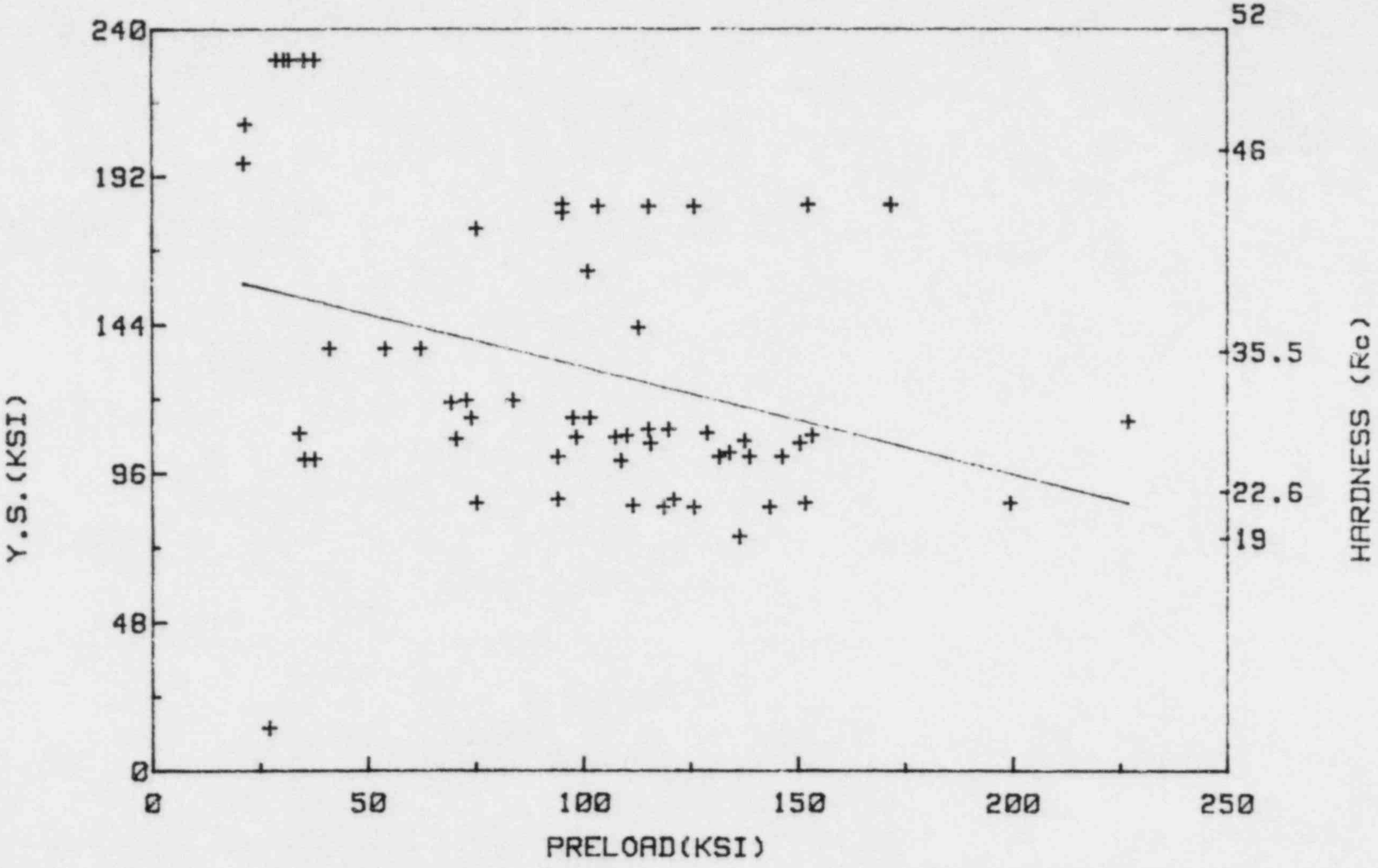
MISC. LOW-ALLOY STEELS FIG. 14A 8TPI



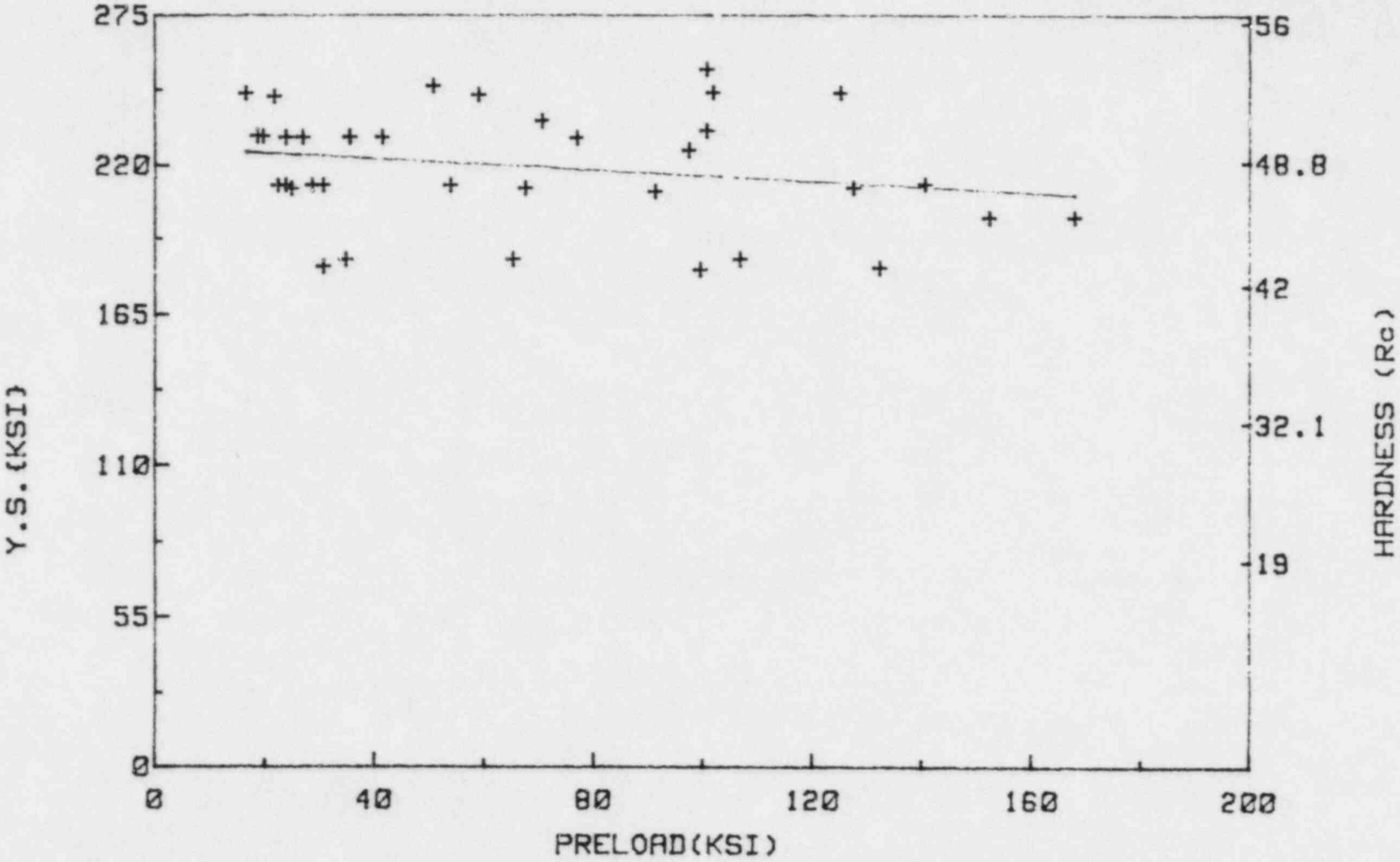
MISC. STEELS IN H2 (GAS) FIG.15 4TPI

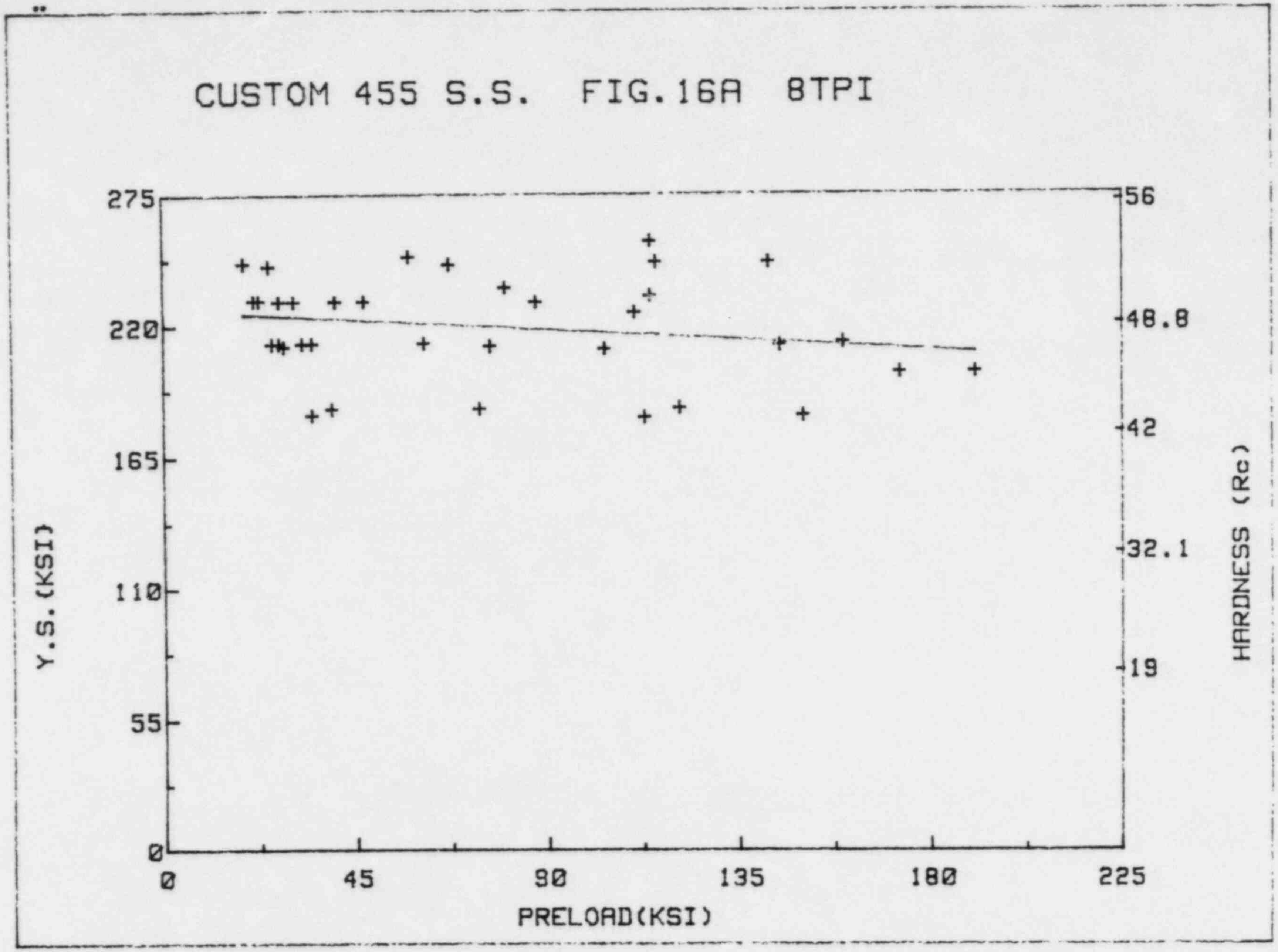


MISC. STEELS IN H2 (GAS) FIG.15A 8TPI



CUSTOM 455 S.S. FIG.16 4TPI




CUSTOM 455 S.S. FIG.16A 8TPI
275
220
165
110
55
0
56
48.8
42
32.1
19
Y.S.(KSI)
HARDNESS (Rc)
0
45
90
135
180
225
PRELOAD(KSI)

Figures 17 and 17a depict the effect of combined aqueous, aqueous NaCl, coastal and sea water and synthetic sea water environments on 17-4 PH stainless steels. Good correlation of data is evident up to a preload of approximately 160 Ksi, above which allowable preloads by this correlation would exceed the yield strength of the material.

18 Ni - maraging steel data in combined aqueous environments are presented in Figures 18 and 18a while Figures 19 and 19a display the 18 Ni-maraging steels in aqueous NaCl, distilled H_2O, air, synthetic sea water, and coastal/sea water environments. It is evident from all four graphs that considerable scatter occurs in the data.

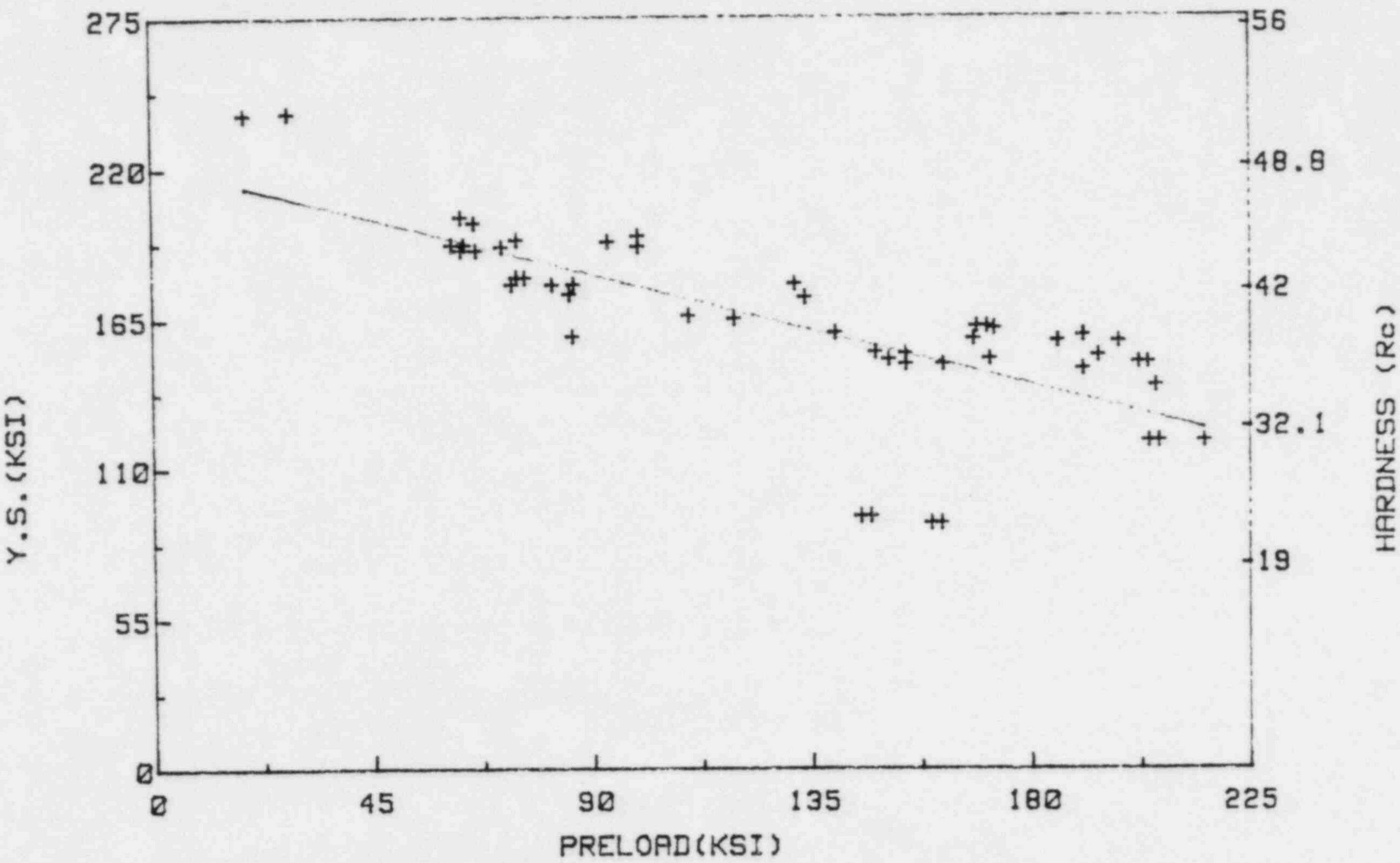
Since virtually all of the graphs exhibited a large degree of scatter in the data, two suggestions are made for obtaining a higher degree of confidence for specifying allowable preloads for a given material used in a particular environment. The first suggestion is that the data in NUREG/CR 2467 be refined in order to remove points considered questionable due to facility test results, experimental question, etc. The second suggestion is that any particular material proposed for use in the reactor environment be subjected to stress corrosion testing in the anticipated environment prior to its general use.

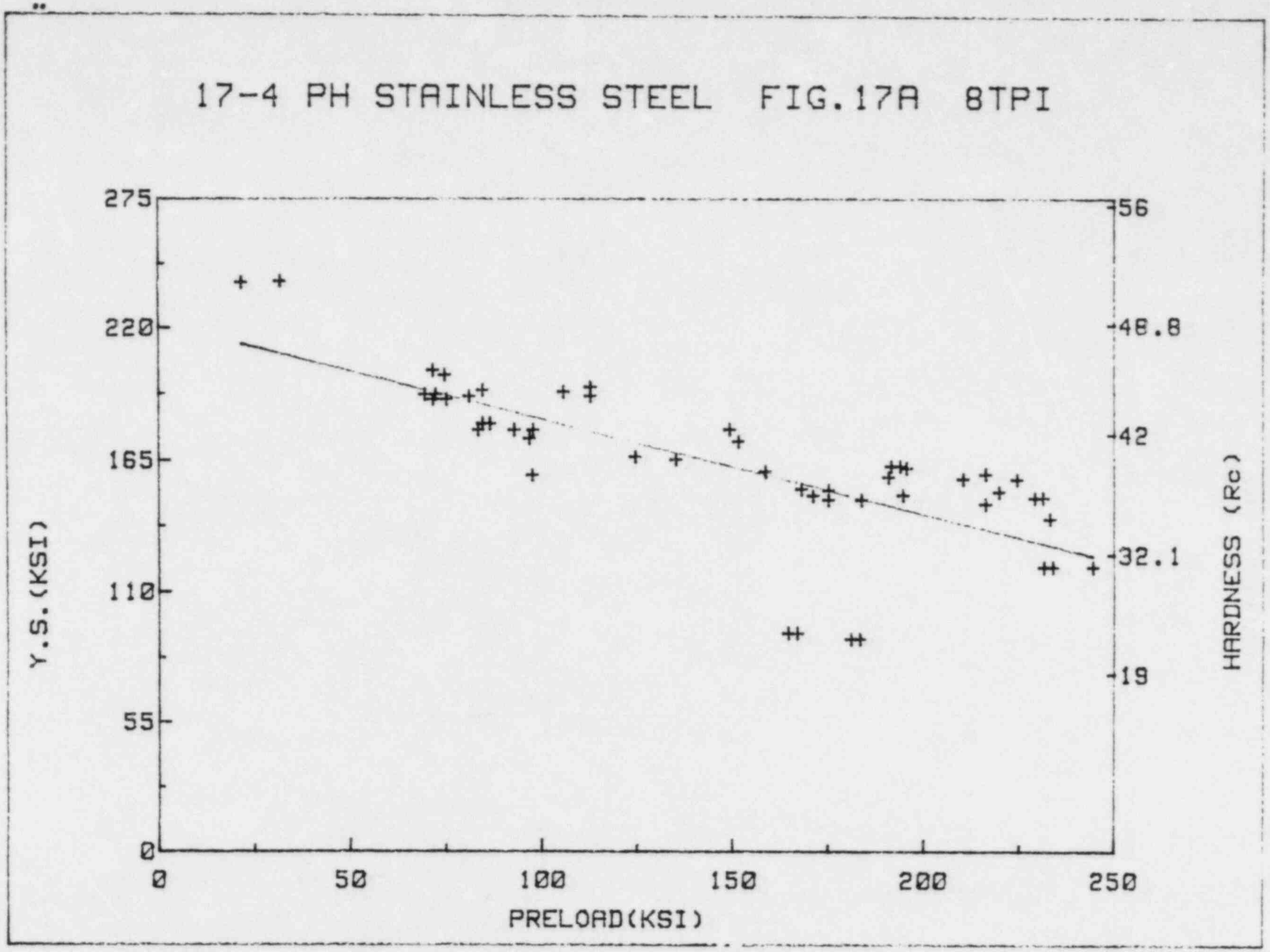
3.0 LITERATURE SEARCH FOR INFORMATION ON INTERNALS BOLTING (INCONEL X-750 AND A286)

3.1 Inconel X-750

Inconel X-750 is an age hardened nickel-based superalloy. It has been used extensively in LWR's for reactor internals in the form of bolts, guide pins, springs etc. Since reactor internals are extremely diifficult to inspect, it is necessary that materials used for this purpose be as SCC resistant as possible. Due to the recent stress corrosion failures observed on components of this material in both BWR's and PWR's, it was felt that this material should be included in this report.

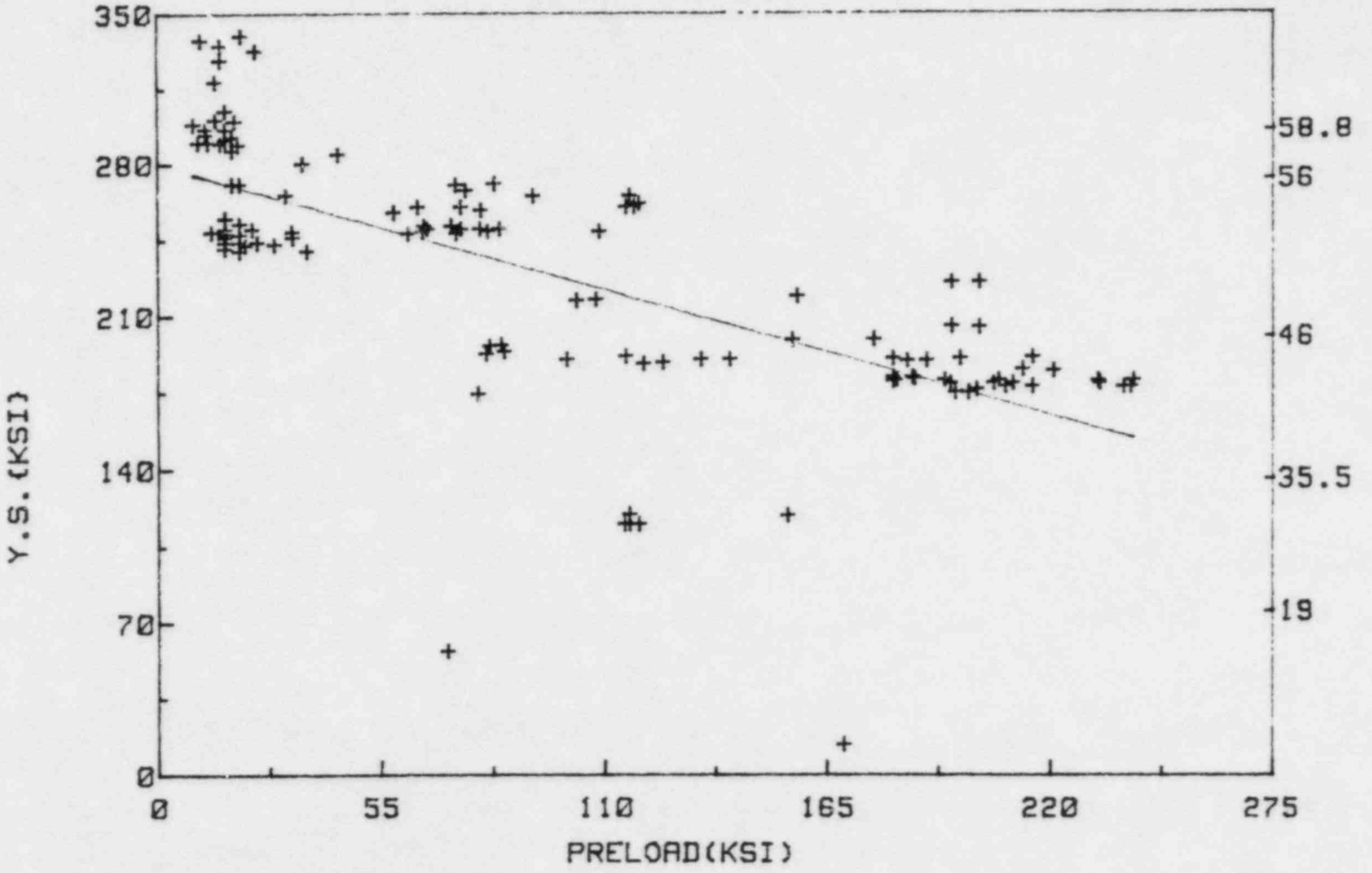
17-4 PH STAINLESS STEEL FIG. 17 4TPI



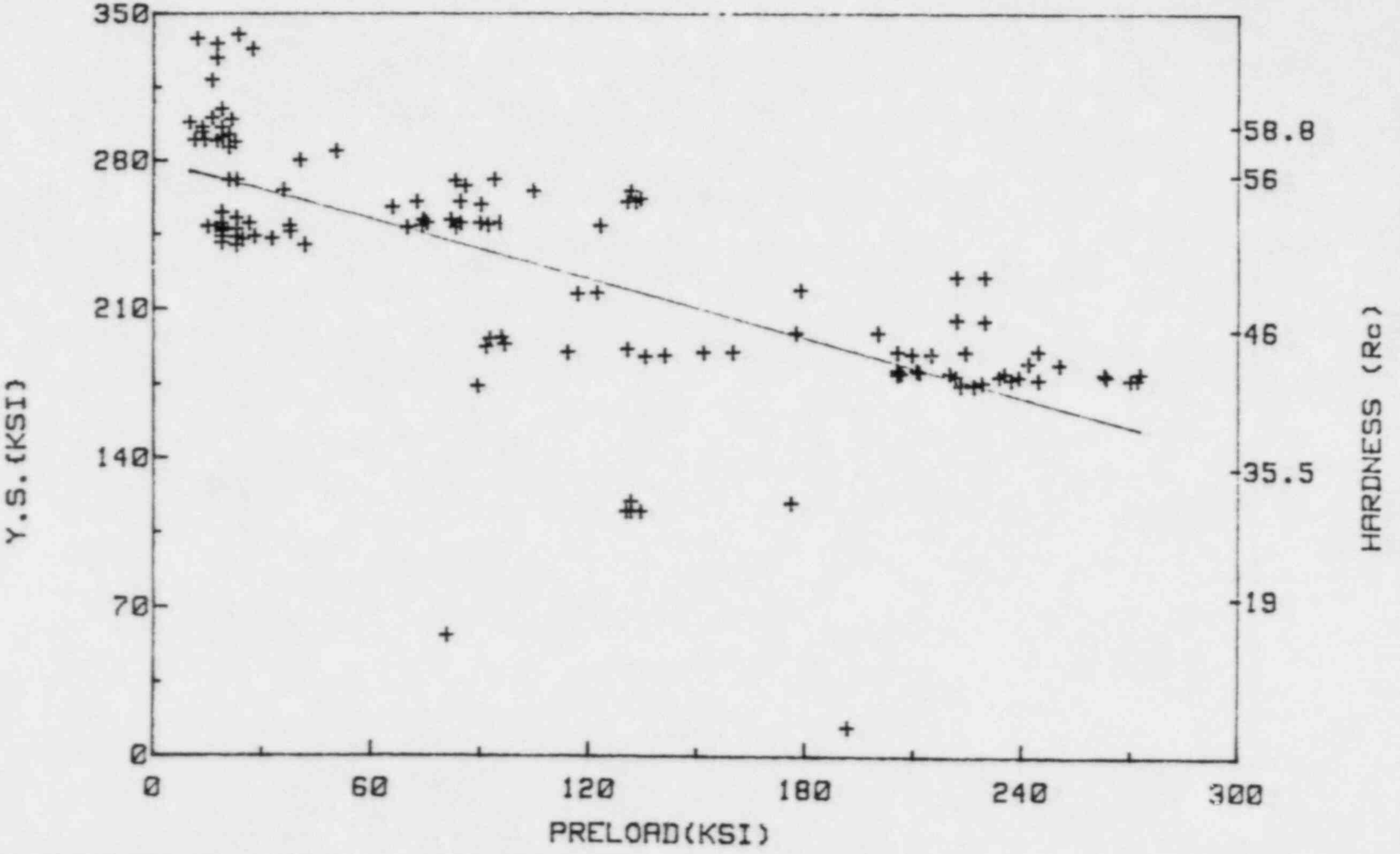


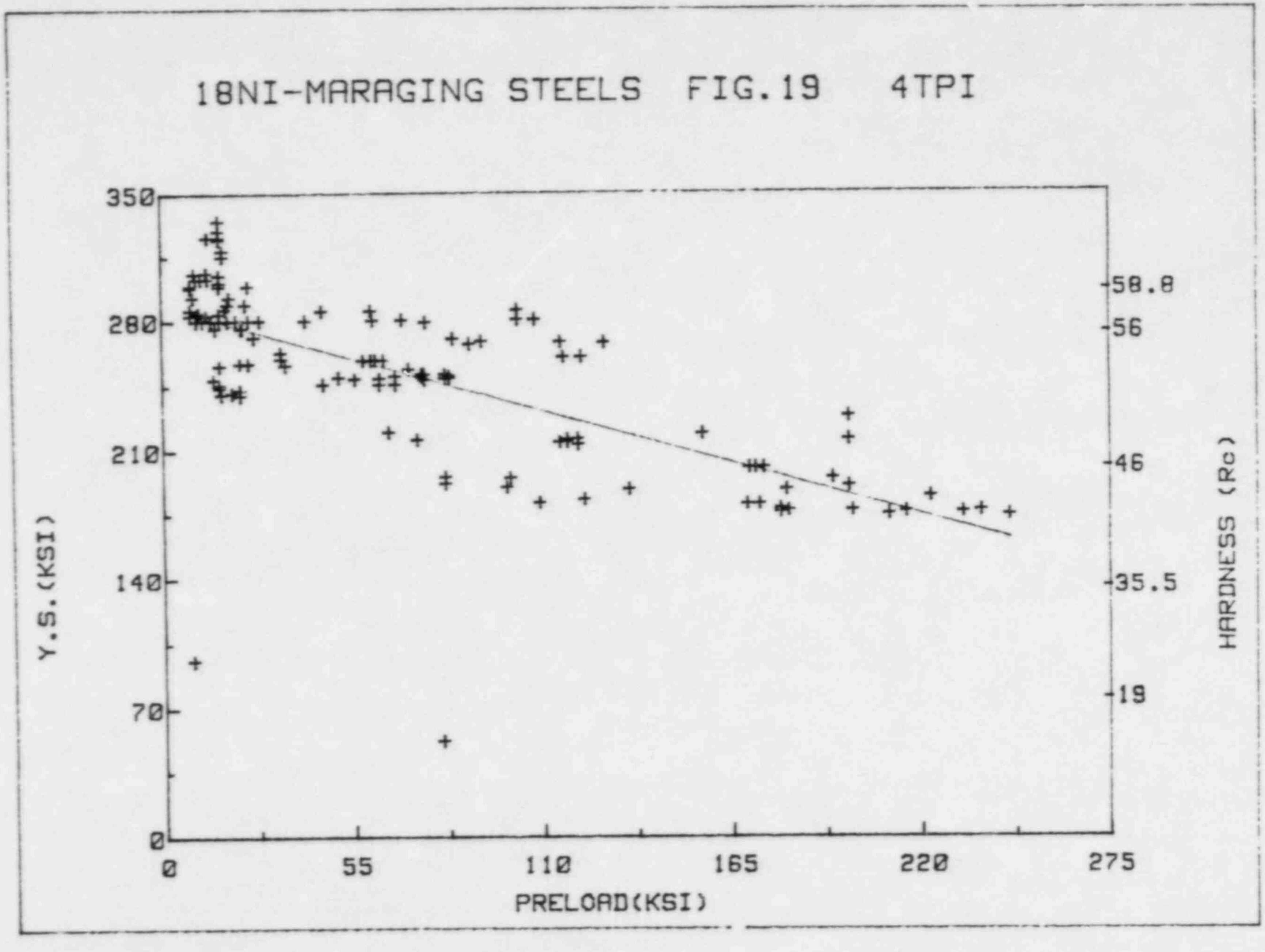
17-4 PH STAINLESS STEEL FIG.17A 8TPI

18NI-MARAGING STEELS FIG.18 4TPI

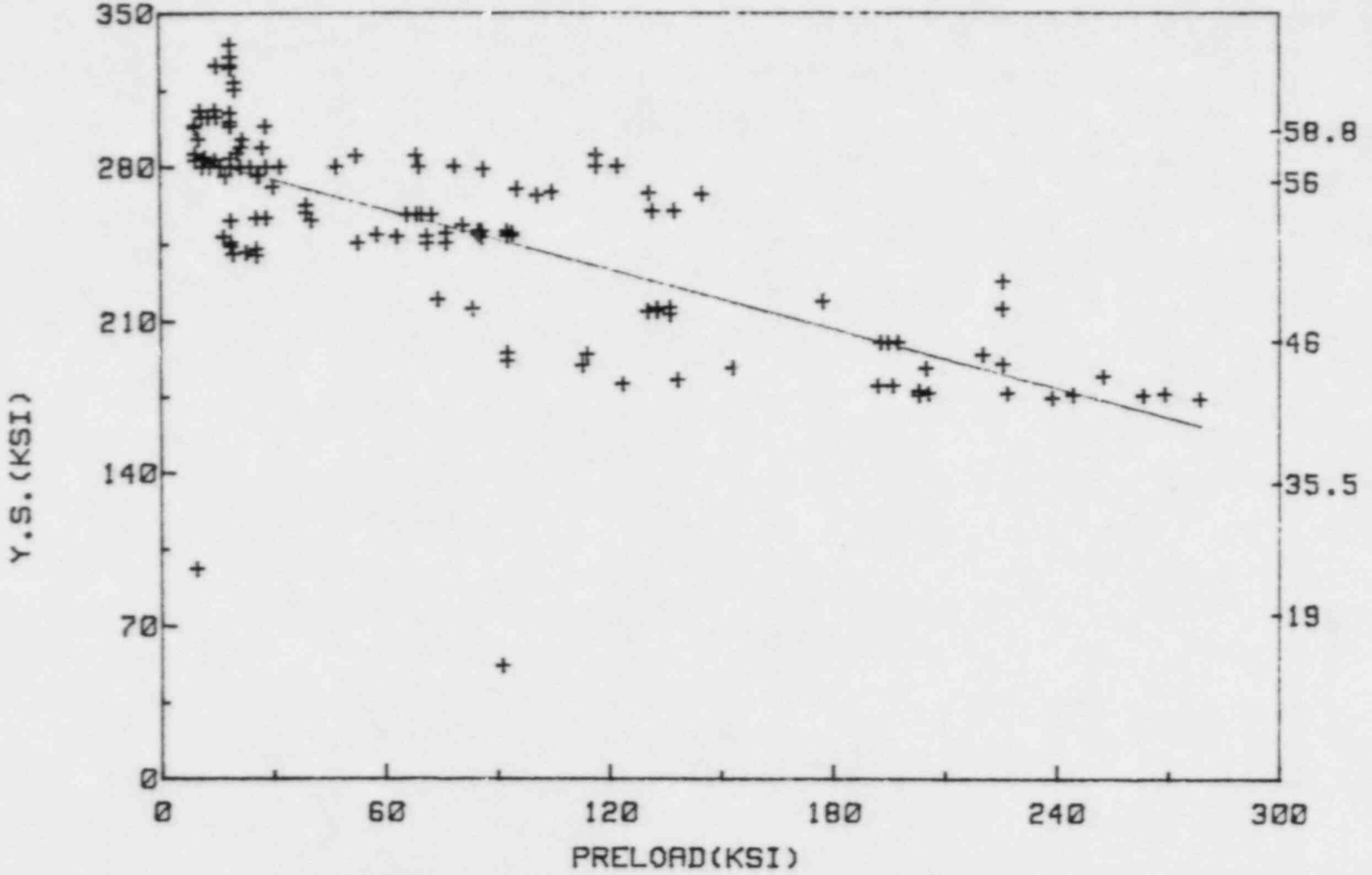


18NI-MARAGING STEELS FIG.18A 8TPI




18NI-MARAGING STEELS FIG.19 4TPI
350
280
210
140
70
0
Y.S.(KSI)
0
55
110
165
220
275
PRELOAD(KSI)
58.8
56
46
35.5
19
HARDNESS (Rc)

18NI-MARAGING STEELS FIG. 19A 8TPI



An extensive literature search only produced one reference [4] which correlated X-750 yield strength versus K_{ISCC} in a simulated PWR primary coolant environment. It was quite fortunate that this reference encompassed twenty-four heats of X-750 and generated a large data base. This particular study was divided into four separate series of tests. A commercial heat of Alloy X-750 was evaluated in the first series using different age-hardening heat treatments. The most common heat treatment recommended for Alloy X-750 is a solution anneal at approximately 1093°C, water quench and then aged for 20 hours at 704°C. This is referred to as the HTH treatment.

The second series of tests involved 16 laboratory heats of high purity alloys which were used to study the high and low levels of four minor elements using a solution annealed at 1093°C for 2 hours, water quenched and aged 20 hours at 704°C. The test matrix for this series was used to evaluate the following levels of minor alloying elements:

Element	Nominal Low Level %	Nominal High Level %
C	0.02	0.07
S	0.003	0.008
Mg	0.0005	0.03
Zr	0.005	0.08

The third test series involved 7 heats of laboratory prepared alloy which were used to explore the effects of P, N, La and La plus Ce alloy additions. These heats were solution annealed at 1093°C for 2 hours, water quench and aged 20 hours at 704°C.

The fourth series of tests were performed to see if the benefits of higher Zirconium contents and the following alternate heat treatments would enhance the alloys' SCC resistance:

a) 1093°C solution anneal for 2 hours, water quench

b) 1093°C solution anneal for 2 hours, air cooled, 704°C age for 20 hours, then air cool

c) 1093°C solution anneal for 2 hours, furnace cooled, 704°C age for 20 hours then air cool

d) 1093°C solution anneal for 2 hours, water quench + 760°C age for 96 hours then air cooled.

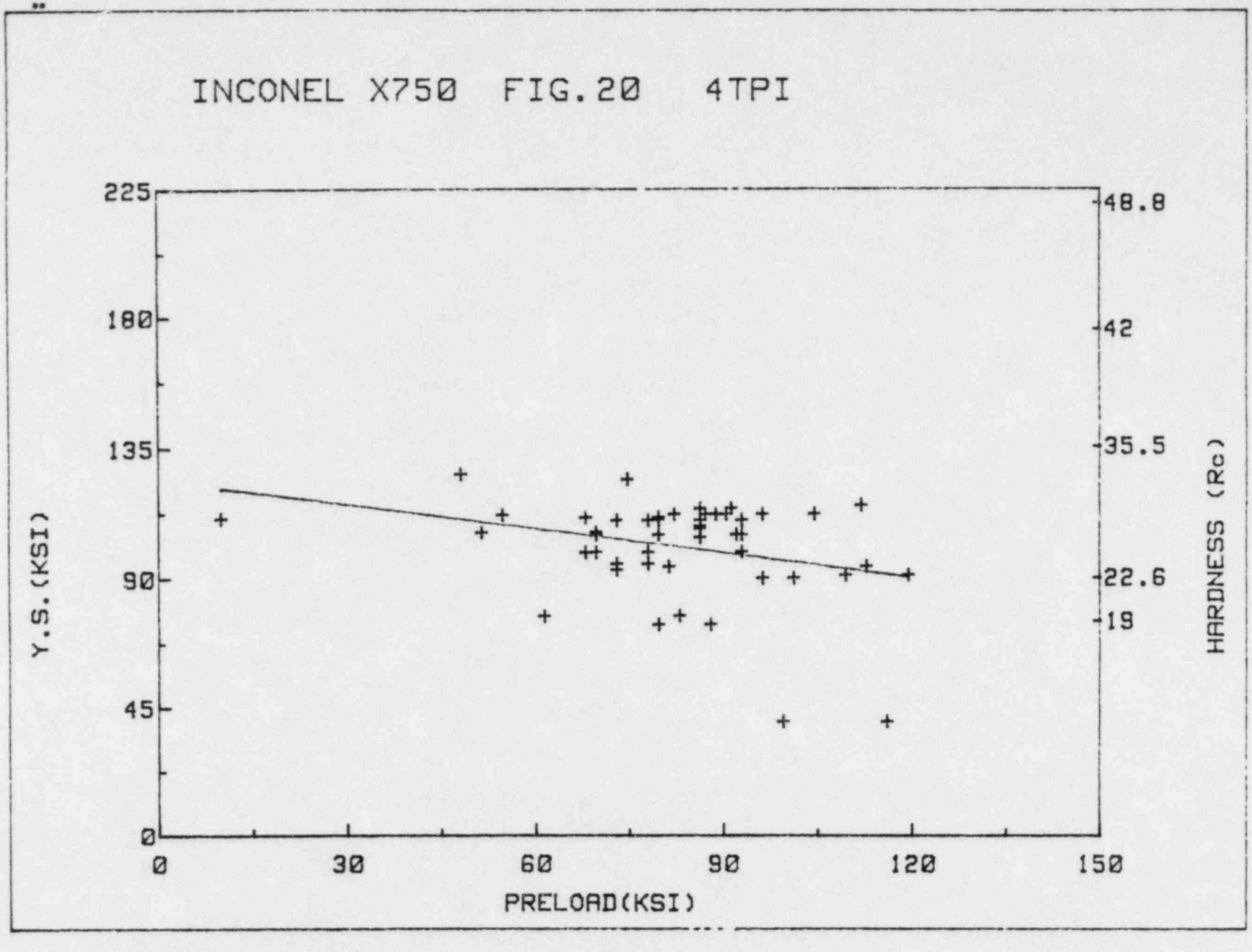
The stress corrosion specimens for these tests were 12.7 mm thick, wedge opening loading (WOL) samples, oriented so that the crack ran down the plates' length. The testing was carried out in flowing deaerated pH 10 water at 360°C. The O_2 level was kept to less than 10 ppb while the pH of the solutions at room temperature were adjusted with NH_4OH. Neither LiOH nor NaOH were added to the test solutions.

All of the data generated for these tests have been plotted on Figures 20 and 20a. As can be seen on the graphs, there is a significant amount of scatter above the 75 Ksi preload level. Note - It was felt that all of the generated data could be plotted on two graphs as one of the objectives of the test program was to stay within the compositional ranges of commercial grade X-750 alloy so that a new material need not be qualified for service.

It should be noted that these may <u>not</u> be relevant to BWR environments or to PWR at the low pH end of the operating cycle.

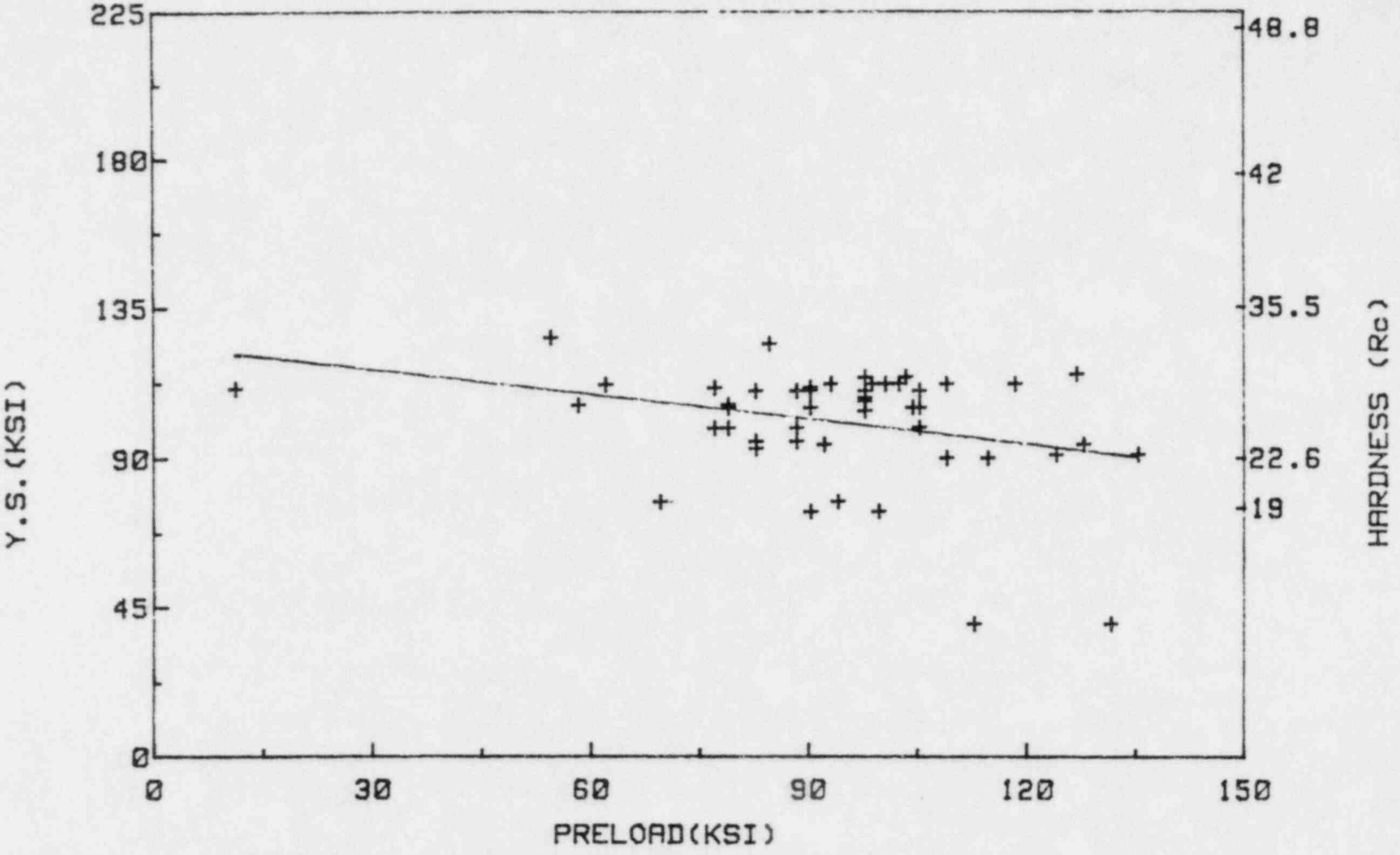
3.2 <u>Inconel Alloy 722</u>

Some data were also found [5] on another precipitation hardened nickel-base alloy -- Inconel Alloy 722. The chemical composition of the alloy was as follows: (wt. %)



INCONEL X750 FIG.20 4TPI

INCONEL X750 FIG.20A 8TPI



Cr - 16.02
Fe - 8.19
Ti - 2.36
Al - 0.53

Si - 0.28
Mn - 0.15
C - 0.08
S - 0.007
Ni - balance

Various heat treatments were investigated using 12.2 mm thick wedge opening loaded (WOL) specimens in two environments. The environments tested were: 1) a deaerated 50% NaOH solution at 316°C 2) undeaerated high purity pH 10 water at 316°C. (The high purity water tests had approximately 6 ppm O_2 at the start of the test with no attempt at either aeration or deaeration.)

The results of the tests follow:

	Threshold Stress Intensity ($MPa\sqrt{m}$)		Yield Strength
Heat Treatment	50% NaOH	Undeaerated Water	(MPa)
1) 1093°C solution anneal, 1 hour, water quench	37	36	310
2) 1093°C solution anneal, 1 hour, water quench + 649°C age for 1 hour	41	24	434
3) 1093°C solution anneal, 1 hour, water quench + 704°C age for 24 hours	17	18	751

Heat Treatment	Threshold Stress Intensity ($MPa\sqrt{m}$) 50% NaOH	Threshold Stress Intensity ($MPa\sqrt{m}$) Undeaerated Water	Yield Strength (MPa)
4) 1093°C solution anneal, 1 hour, water quench + 704°C age for 240 hours	20	14	696
5) 1093°C solution anneal, 1 hour, water quench + 760°C age for 96 hours	43	67	676

The primary conclusions drawn from this series of tests is that the stress corrosion resistance of an age hardened nickel-base alloy can be significantly improved in both environments tested through selective heat treatments. This appears to be consistent with the previously discussed data on the X-750 alloy.

3.3 A286

Although an extensive literature search was performed for information relative to K_{ISCC} versus yield strength data for Alloy A286, none could be found. One reference [6] was found, however, which at least provided some information regarding the SCC resistance of this alloy.

The A286 alloy used in this test program received a solution heat treatment of 1 hour at 1800°F followed by a 1325°F age for 16 hours then air cooled.

The chemical analysis of the alloy tested: (wt. %)

C - 0.053
Mn - 1.18
P - 0.02
Si - 0.71
Cr - 14.82
Ni - 24.68
Mo - 1.38
Ti - 1.93
V - 0.28
Al - 0.21
B - 0.004

The typical mechanical properties of the alloy are:

Ultimate tensile strength, psi	143,000
0.2% yield strength, psi	93,000
Elongation in 2 in, %	24
Hardness (R_c)	29

The majority of the testing was done in typical BWR environments with some tests performed to determine the effects of higher oxygen and chloride levels in high temperature water.

The test results for this program were as follows:

Applied Stress lb/in^2	Test Environment	No. of Specimens	Remarks
Overyield (0.7 % strain)	1.2 ppm O_2	3	3 failed in 700 hrs.
	0.2 ppm O_2	3	No failures 4700 hrs.
	0.02 ppm O_2	9	No failures 4500 hrs.
173,000 (overyield)	1.5 ppm Cl^-	2	2 failed 1800 hrs.
	1.2 ppm O_2	3	No failures 2200 hrs.
	0.2 ppm O_2	3	No failures 2200 hrs.

Applied Stress lb/in^2	Test Environment	No. of Specimens	Remarks
100,000	1.5 ppm Cl^-	2	1 failure 2600 hrs.
120,000	0.02 ppm O_2	18	No failures 4800 hrs.

The conclusions drawn from this testing program were that although the A286 had greater SCC resistance than 17-4 PH (H900) alloy in BWR environments, it exhibited a greater susceptibility to SCC than 17-7 PH, AM-350, cold worked Type 304 stainless steel, Type 405 stainless steel and boron stainless steel alloys. The wear properties were also considered poor and difficulties were encountered in fabrication. The final conclusion was that A286 be disregarded as a reactor structural material since safer materials are available.

4.0 PROVIDE VERIFICATION THAT THE INFORMATION PRESENTED IN NUREG/CR 2467 FOR CHLORINE IS REPRESENTATIVE OF THE ENVIRONMENT OF BOLTING EMBEDDED IN CONCRETE (i.e. HIGH PH)

Concrete has simply been described [7] as an inhomogeneous mixture of approximately 50% silica (SiO_2) by weight with additions in lesser amounts of Al, Fe, Ca, K and Na oxides, complex aluminum and magnesium silicates (cement) and a percentage of fixed water (approximately 7%) hydrated to the cementing agent. Additionally, there is free water present which evaporates with time.

The corrosion of steel in concrete requires the presence of an electrolyte and available oxygen. In the normally alkaline (pH 10-13) environment in set cement, a protective oxide film forms on the steel making it passive in the concrete. Normally corrosion starts at a localized breakdown in this film with available oxygen present. The stability of this passive film is dependent upon the matrix pH of the concrete. If the pH is high enough, the oxygen access is effectively neutralized. This pH value can be affected by CO_2 ingress (combining with moisture to form carbonic acid) which can lower the value to pH 10 or less allowing corrosion to occur and by the presence of chloride ions which have been reported [8] to raise the pH required to stabilize the passive film to a value exceeding that of a saturated calcium hydroxide solution, again, allowing corrosion to occur.

Although this discussion is primarily concerned with the chloride levels found in concrete, the effect of CO_2 (carbonation) on the pH level in concrete and the subsequent effect of the low pH level in concrete has on corrosion is significant to embedded bolts. This type of phenomenon has been reported [9] as being of minimal concern in good reinforced concrete of normal water-cement ratios after being exposed to weathering for many years. However, it is worthy to note that excessive water-cement ratios, excessive concrete cracks, or insufficient concrete covering of steels can lead to corrosion by local decreases in pH in the concrete.

As previously mentioned, the concrete environment, although normally ideal for corrosion prevention of steels, can be greatly influenced by the presence or chloride. Chlorides may enter concrete by various mechanisms [8,10-11]. The chlorides may be present in fresh concrete, (chlorides may permeate the concrete from an environment containing chlorides, occasionally sea water (salt water) may be added when fresh water is unavailable for making the batch) and finally, the most frequent cause of chloride in concrete is the use of calcium chloride ($CaCl_2.2H_2O$) as an accelerator for strength of the concrete. The normal practice is to use between 2-3% calcium chloride by weight in the concrete mixture [8,9].

The amount of calcium chloride is normally offset with tricalcium aluminate (C_3A), a constituent in portland cement, which reacts with the calcium chloride to form an insoluble ($C_3A.CaCl_2.10H_2O$) compound. The amount of chloride removed in this manner is dependent upon the amount of C_3A in the concrete. Figures 21 and 22 show the effect of cement composition (1% and 9% C_3A concrete) on the chloride concentration in the aqueous phase of the mixture with time. It is clearly seen that the chloride concentration is extremely dependent on the amount of C_3A available in the concrete. Others [9] have shown that, when 2% $CaCl_2$ added to a 12% C_3A concrete (initial mix), the $CaCl_2$ level will drop as low as 0.37% after 28 days. It would seem that aqueous chloride levels in concrete would then be much lower in concentration than the chloride levels reported in NUREG/CR-2467 (e.g. 2-5% NaCl). This is not necessarily the case, as there is a competing ion effect in cements due to the normal addition of sulfate in the form of gypsum ($CaSO_4.2H_2O$), used for regulation of time of set. This competition of both sulfate and chloride ions for available aluminate forms compounds in this order [8]: formation of trisulfoaluminate hydrate until the sulfate is consumed, then formation of chloroaluminate hydrate until the chloride is consumed and then formation of monosulfoaluminate hydrate from the trisulfoaluminate and excess aluminate or aluminoferrites present in the concrete.

Since concrete batches will vary from location to location and since the amount of sulfate available will also vary by amount of gypsum added and the amount of sulfate present in the water used, it is extremely difficult if not impossible to state that the chloride levels in concrete will be extremely low and of no concern to the corrosion of embedded bolts. It is therefore concluded that, although the levels used in NUREG/CR-2467 may be conservative in some instances, they are probably representative of the levels of chloride which may be present in concrete at a nuclear site.

5.0 REVIEW TEST SAMPLE REQUIREMENTS OF FREQUENTLY USED FASTENER SPECIFICATIONS AND PROVIDE RECOMMENDATIONS ON STATISTICAL SAMPLING OF FASTENERS.

In a given SCC environment, it is known that a high strength low alloy steel's resistance to SCC decreases with increasing tensile strength of the material. This has been amply shown in NUREG/CR-2467 [1] where K_{ISCC} vs. yield strength plots for various alloys prove the validity of this relationship.

This being the case, it is to a utility's benefit to have an idea of the tensile strength of its bolts. This can be difficult as the bolting specifications specify minimum tensile requirements, not maximum and a utility's only indicator of maximum tensile strength may be the material's hardness values.

The specifications reviewed for this section included:

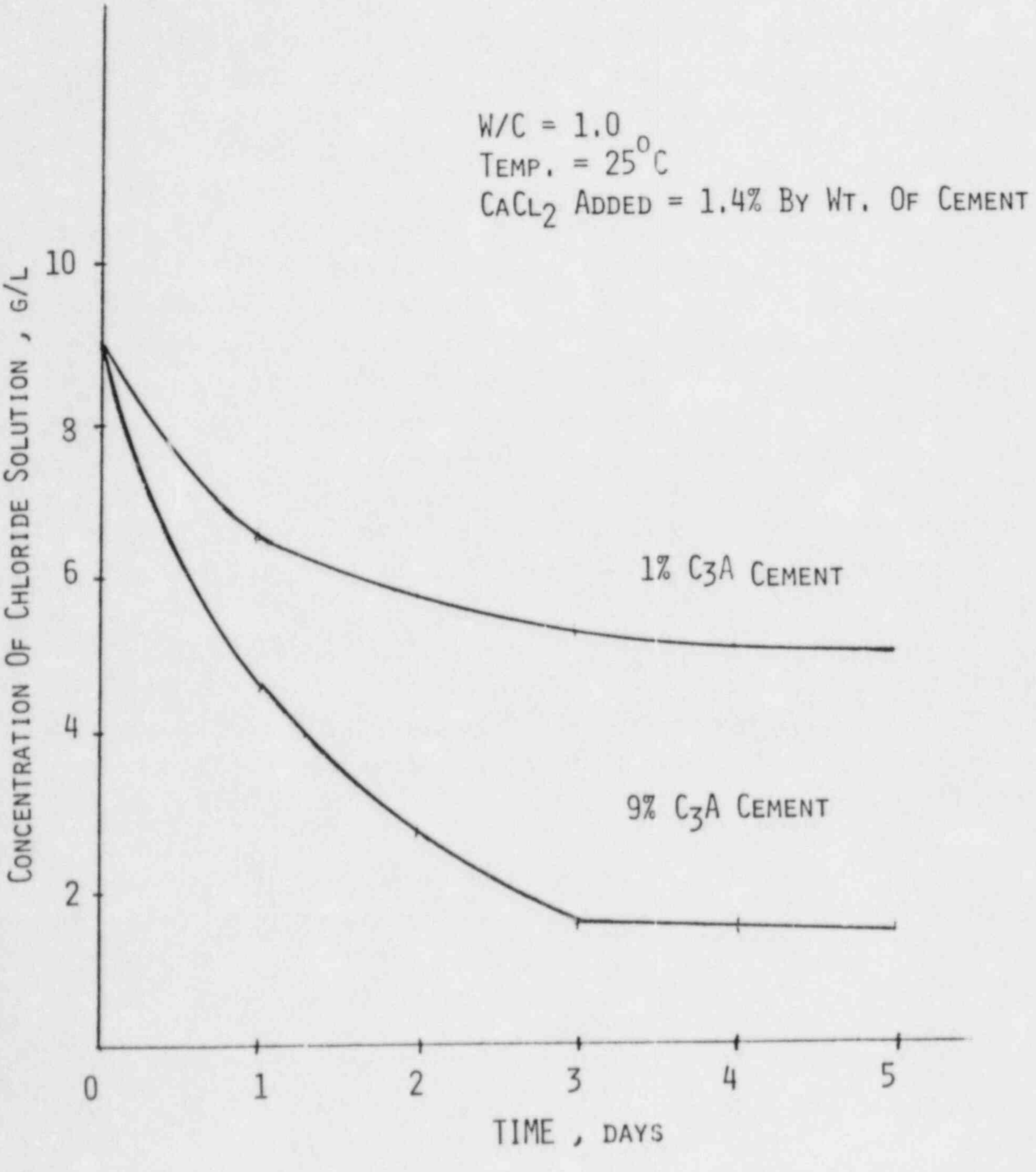


Figure 21. Effect of cement composition on the chloride concentration of the aqueous phase.

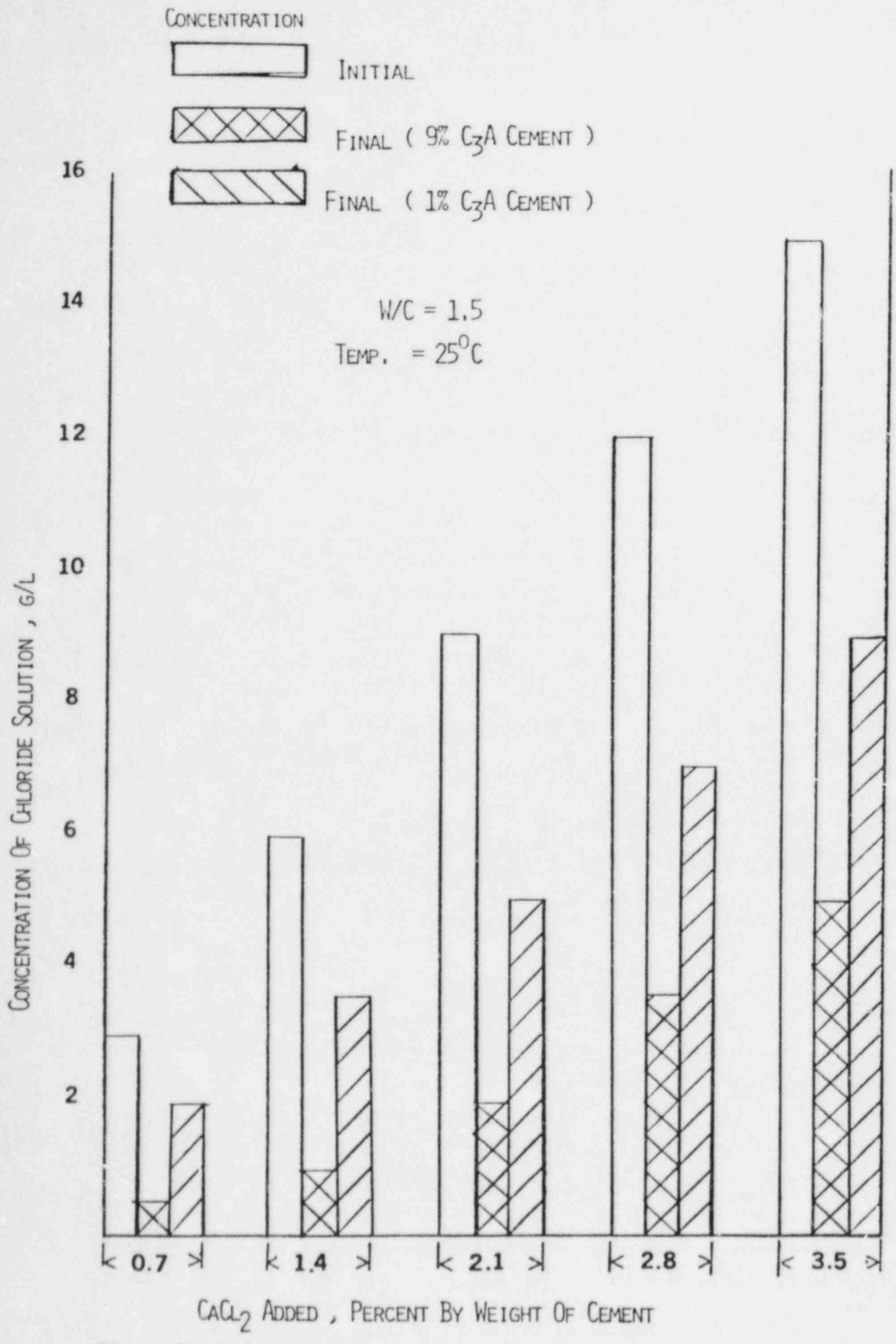


Figure 22. Effect of cement composition on the chloride concentration of the aqueous phase.

A-193 Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service

A-194 Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service

A-307 Carbon Steel Externally and Internally Threaded Standard Fasteners

A-320 Alloy-Steel Bolting Materials for Low-Temperature Service

A-325 High-Strength Bolts for Structural Steel Joints Including Suitable Nuts and Plain Hardened Washers

A-354 Quenched and Tempered Alloy Steel Bolts and Studs with Suitable Nuts

A-540 Alloy Steel Bolting Materials for Special Applications

A-564 Hot-Finished or Cold-Finished Precipitation-Hardening Stainless and Heat-Resisting Steel Bars and Shapes

A-637 Precipitation Hardening Nickel Alloy Bars, Forgings, and Forging Stock for High-Temperature Service

A-638 Precipitation Hardening Iron Base Superalloy Bars, Forgings, and Forging Stock for High-Temperature Service

Hardness measurments are a reliable method of estimating tensile strengths on carbon and low alloy steels. This is due to the fact that there exists a reasonably close relationship between compressive strength and tensile strength of these steels and that resistance to indentation (hardness testing) is directly related to the steel's compressive strength. Estimates of a material's tensile strength can be approximated in most cases to ± 5000 psi with a hardness test. These tests, when performed on bolting materials are normally nondestructive in nature and would not affect the bolts' or nuts' primary function. This indirect measurement of the materials' tensile strength without impairment of its primary function is extremely important in determining the susceptibility of a material to SCC, as shown earlier in this report. Since the hardness test is nondestructive in nature, it is the hardness sampling requirements which will be discussed.

The number of hardness tests (manufacturer) required by the aforementioned specifications use a statistically small sample size in order to qualify a test lot. For example:

ASTM-A194 requires hardness testing of only one nut in order to accept a lot size of up to 800. The maximum number of samples required is 5 in order to accept lots of over 22,000 nuts.

ASTM-A540 requires hardness tests be accomplished near each end of each mill treated length for bars 2 inches and over. For bars under 2 inches, not less than 10% of the bars must be tested near each end.

For most applications, these standards would be acceptable but, in light of the fact that one inspection at a nuclear site [3] found that of 384 bolts reviewed (comprising 12 heats of material) all of the heats were essentially in violation of the hardness specifications, they need upgrading for critical nuclear applications.

Due to the fact that A540 bolts have failed [12,13] in nuclear applications by SCC mechanisms attributed to the sulfur compounds used in various lubricants, it is reasonable to apply the industry standards for hardness testing requirements of bolts for "sour gas" service. "Sour gas" has as its major corrodent, H_2S which has been found to be a byproduct of MoS_2 dissociation (with moisture).

These corrosion resistant bolts have as their hardness requirements (ASTM-A193-B7M paragraph 10.2.2):

10.2.2 Grade B7M - Provided an in-process sampling plan is used, a final sampling of 100 pieces selected at random per lot, as defined in 11.1.2, not exceeding 10,000 lb. shall be tested for hardness, using an acceptance number of zero. The hardness of this grade shall be determined on the end of the bolt or stud by the Brinell or Rockwell B test methods as described in Sections 16, 17, and 18 of Methods A 370. Conversion of Rockwell B readings shall be based on Table 3B of Methods A 370. If any one sample exceeds the specified maximum hardness, the lot shall be rejected and either reprocessed and resampled, or tested 100% to reject nonconforming material. In the event that an in-process sampling plan is not used (Supplementary Requirement S3), the hardness shall be measured on the end of each bolt or stud as outlined above.

Supplementary Requirement S3 for this specification states "Each Grade B7M bolt or stud shall be tested for hardness and shall meet the requirements specified in Table 2." This requirement is often invoked if the application is critical.

There are currently discussions by ASTM committees [14] regarding the use of electromagnetic sorting techniques as an alternative to 100% indentation hardness testing. Electromagnetic sorting of ferrous materials is accomplished using eddy-current instrumentation. These instruments measure impedance changes in a test coil. Once the system is balanced, any change in the tested part will affect the impedance measurement. This type of inspection is generally of the "go, no go" variety.

ASTM E-566 recommends this type of inspection (Eddy Current) primarily for repetitive tests on material, "identical in shape, composition, and metallurgical structure, and not for tests on grossly different materials," which would appropriately lend itself to bolting inspections.

This change, if adopted, would require 100% electromagnetic examination of the bolts in accordance with ASTM E-566 with a supplemental indentation measurement of 100 pieces of each heat in each purchase lot. The indentation tests must have a 100% acceptance of the 100 pieces in order to qualify the lot.

A third alternative to the current specifications for number of hardness tests is to require indentation testing in accordance with a sample size consistent with Mil Standard 105. The type of inspection would be most easily facilitated as a receiving inspection of already purchased bolts/nuts. In order to implement this type of plan, an appropriate Acceptable Quality Level would have to be established which would be acceptable to the regulatory agency.

6.0 PROVIDE RECOMMENDATIONS FOR RECEIVING AND INSERVICE INSPECTION OF BOLTING

6.1 Receiving Inspection

There are currently no definitive rules for the receiving inspection of bolts at nuclear sites. The only requirements are general in nature e.g. 10CFR50 App B- Section VII, Control of Purchased Material, Equipment, and Services, states in Part "Measures shall be established to assure that purchased material, equipment, and services, whether purchased directly or through contractors or subcontractors, conform to the procurement documents..." It is therefore up to the individual utility to tailor a receiving inspection program for its own purchased material.

In addition to the previously mentioned reference [3] regarding studs being out of specification for hardness measurement, Koo [15] has cited at least six other instances where either a improper heat treatment of material, fabrication quench cracks, or use of the wrong material were contributing factors to premature failure of fasteners. If a more extensive receiving inspection had been in effect; possibly these problems may have been avoided.

A possible intensified receiving inspection plan for bolting/fastener material could consist of:

1) A visual inspection of all incoming bolting material.

2) Hardness testing of 5-10% (at random) of the "as received" bolts/studs. If any fall outside the specified hardness range of the material, all bolts should either be returned to vendor or 100% hardness tested to eliminate non-conforming items.

3) A surface nondestructive examination (dye penetrant or magnetic particle) of a percentage (1-5%) of the "as received" bolts in order to preclude the possibility of pre-existing flaws in the bolts. This to supplement 1 and 2.

In all cases, the higher percentage of inspection would be used in the more critical bolting structures/installations.

6.2 Inservice Inspection

Although the ASME Boiler and Pressure Vessel Code Section XI Inservice Inspection Requirements governs all inservice inspections on nuclear power plants, this code is still a minimum requirement and not an optimum inspection standard. This statement is not made to denigrate the Code; but to amplify the fact that additional inspections could and in some cases probably "should" be added to the normal inservice inspection program to provide assurance of continued plant reliability and safety.

An example where possibly more comprehensive examinations might be required:

The only circumstance where both a volumetric examination and a surface examination are jointly required in evaluating a bolt/stud (ASME Section XI) is during the inservice inspection of reactor vessel closure studs (when removed). In all other pertinent sections of Table IWB-2500-1, volumetric examination alone for bolts 2" in diameter and greater, and visual inspection alone for bolting 2" and less in diameter are the only required inspections. Between these two modes of examination lies the surface inspection methods (dye penetrant or magnetic particle) which even performed on a sample basis would provide considerable supplemental assurance of continued trouble free operation.

7.0 PROVIDE WRITTEN RECOMMENDATIONS FOR ACCEPTABLE METHODS OF COTTERING THAT WOULD NOT DEFEAT THE PRIMARY PURPOSE OF FASTENERS

In this section, the term "cottering" is used in the broad sense as a method of securing a bolt/stud or nut in place in order to maintain the required preload. Since preload on the bolt is the primary method of preventing joint separation under external loading; "cottering" without impairment of function is of primary importance for fasteners in the nuclear industry. For purposes of this discussion, two general methods of cottering will be discussed: mechanical and welding methods.

7.1 Mechanical Methods

These would include: cotter pins, self locking nuts, staking of bolts, and self locking bolts. To date, no failures have been directly attributed to any of these methods; however, in at least one instance, staked bolts (which had failed in service) [16, 17] had many of the heads broken off the bolts during the failure which allowed the small stakes to become potential additional impediments to the reactor coolant pumps' operation. It is recommended that if mechanical methods are used, an evaluation be made of the potential for additional loose parts in a critical system or component.

7.2 Welding Methods

During the review, one instance was found of tack welds on bolts causing failures. This instance occurred in 1975 on the Sequoya Units 1 and 2. An improper welding procedure was used to weld the steam generator and reactor coolant pump anchor bolts to embedment plates, which resulted in underbead cracking in the bolts. Tack welding of bolts is considered unadvisable for the following reasons:

1) The shrinkage force of tack welds may cause relaxation of the bolt which may reduce the preload on the joint. This could make the joint more susceptible to a fatigue failure.

2) The main reason for not tack welding a bolt is that there is no means of controlling the heat input into a tack weld. This lack of heat input control can easily cause detrimental microstructures to be developed in the bolt/weld metal heat affected zone which might make the bolt susceptible to hydrogen embrittlement on SCC.

Possible altenatives to welding the bolt would be welding the nut or weld locking tabs adjacent to the nut. Either of these methods would provide a less potentially detrimental joint configuration.

8.0 PROVIDE RECOMMENDATIONS FOR WRITTEN IMPROVEMENTS IN BOLTING AND BOLTING MATERIALS SPECIFICATIONS

In the first quarter of 1983, Koo [15] reported a total of 44 significant incidents of bolting degradation at nuclear power stations between October 1964 to March 1982. Of these 44 incidents, 19 involved a SCC mechanism, 13 boric acid wastage corrosion, 3 fatigue, 1 erosion-corrosion; and the other 8 incidents were either materials related problems or the cause could not be determined.

Even though the number of incidents of bolting degradation has been on the rise (over the past several months) at nuclear power plants; they must be viewed with the perspective that there are probably millions of fasteners which have been installed on the 100 or so nuclear power stations in the United States with only a few instances of significant failures.

Specifically, this report did bring to light areas which needs "evaluation." The term "evaluation" is used in lieu of "improvement" as these areas should be discussed with the utilities, EPRI, and bolting consultants in order to determine if "improvement" is required owing to the safety significance of a particular bolting application.

The first area of "evaluation" is the data compiled in the first section of this report. Serious consideration should be given as to the data's validity in various areas of a nuclear reactor. If it is determined that the probability of a particular environment being encountered is negligible, then the data should be refined to reflect this low probability. This would also hold true for the Inconel X-750 data provided, if a new standard heat treatment is decided upon for reactor environments.

There is one area in which it is believed that "improvements" should be made after appropriate evaluations; this is the area of fastener specifications. The extremely small sample sizes used for qualifying huge lots of material is currently considered unacceptable for any bolts which would have a safety related function at a nuclear station. The tightening up of the specifications to require at least the minimum standards of A193-B7M bolts would be a large step in assuring more uniform tensile strength bolting materials for nuclear applications.

An "evaluation " of the more widespread use of surface inspections (dye penetrant or magnetic particle) to supplement the visual inspections and volumetric examinations of critical components during inservice inspections is deemed appropriate.

Cottering methods should be discussed and perhaps a more uniform method of cottering be used industry wide. The elimination of tack welding bolts is considered to be a first priority in this area. In the area of cottering, the consequence of having loose components free in the system if a bolt failure occurs (cotter pins, staking pins) must be evaluated for each new bolt design.

An area of definite concern not specifically expanded upon in the report is the use of lubricants in bolting connections. The judicious application or non-application of moly-disulfide type lubricants is considered a priority item for evaluation. Additionally the coefficient of friction (a necessary known for determining preload in a given joint) of an applied lubricant must be determined in the environment in which it is applied. Most manufacturers give a large range of coefficients depending on the environment; (if it is allowed to dry, temperature, etc.)

9.0 ACKNOWLEDGEMENTS

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Appendix A

NUREG/CR-3604

BNL/NUREG-51735

SPS TECHNICAL REPORT

by
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January 17, 1984

REPORT NO. 6247

Recommendations for Bolting Improvements in the Nuclear Industry --- Prepared for Brookhaven National Laboratory under Contract No. 122694-S

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PURPOSE:

1. To make recommendations, based on aerospace bolting experience, to improve bolting inspections and acceptance practices.

2. To review methods commonly used to prevent loosening of threaded fasteners.

3. To provide broad recommendations, based on knowledge of bolting practices in other industries.

RECOMMENDATIONS:

1. Establish Joint-Design Methods and Joint-Analysis Techniques

   Standardization will insure that everyone in the industry designs each joint to the same accepted methods. The appendix includes several industry-accepted analysis methods.

   Proper joint design will help:

   a. Control, or in many cases, completely eliminate fastener fatigue.

   b. Control fastener overload.

   c. Control stress corrosion cracking.

   d. Control hydrogen embrittlement.

   e. Control corrosion.

   f. Eliminate the problem of fastener self-loosening.

2. Upgrade Fastener Design to Utilize Modern Practices and Materials

   a. Materials should be specified for various classes of fastener applications.

   b. The design of the head-to-shank fillet should be improved to utilize larger radii.

   c. The juncture of the thread with the shank, known as the thread runout area, should be improved so that large notches are not permitted in this highly stressed area.

   d. Modern thread forms, such as MIL-STD-8879, should be used. Large radii thread forms will reduce the stress concentration factor in this area.

3. Specify Fastener Manufacturing Documentation

    a. Require material heat identification.

    b. Require fastener lot identififcation.

    c. Establish and insist on in-process inspection requirements.

    d. Establish an in-house inspection and shipping authorization requirement by the vendors.

    e. Establish AQL inspection levels per MIL-STD-105.

    f. Require manufacturing documentation for all critical fasteners to be kept on record.

4. Require that Receiving Inspection Standards and Documentation be Established

    a. Require that physical measurements of fasteners be verified.

    b. Require that fastener mechanical properties be verified:

        - Hardness measurements, surface and core, should be taken.
        - Tensile strength should be verified.
        - Fastener yield per Johnson's Two-Thirds Law should be verified.
        - Plating thickness and adhesion should be verified, where applicable.
        - Tests for hydrogen embrittlement should be established, where applicable.
        - All testing should be performed per MIL-STD-1312 or a similar document.

5. Establish Fastener Preloading Methods and Standards

    a. Torque-tension.

    b. Load-elongation measurements.

    c. An angle-of-turn tightening method.

    d. A yield-control tightening method.

    e. An ultrasonic measurement standard that includes proper specimen preparation.

    f. Other preload-measuring methods should be identified and, where applicable, should be evaluated so that additional preloading standards can be established.

g. A requirement of the preloading method should be on the assembly drawings.

6. Identify and Evaluate Fastener Preload Verification Methods; Delineate Standards for their Use and Shortcomings

   The methods listed below are for inspection at a period later thar initial assembly.

   a. Ultrasonic length measurement.

   b. Mechanical length measuring methods.

   c. Load-indicating washers.

   d. Use of residual torque as an indication of fastener preload.

   e. Preload-indicating pins.

   f. Other methods as may be found for use in other industries.

7. Establish a Fastener Failure Documentation Procedure and Indentify a Central Evaluation Location

   a. Classes of fasteners failure modes should be established.

   b. Problem areas should be identified and the severity of fastener problems quantified.

   c. Corrective action should be taken.

      - Emergency reports should be published and distributed to identify problems and mandate corrective action.

      - Upgrade design and manufacturing methods where necessary.

      - Upgrade assembly and maintenance records.

8. Perform an In-Depth Study into the Physics of Fastening

   The time allotted for this study was not sufficient to cover all aspects of the fastening problem in great detail.

BACKGROUND:

Recently, the number of reported bolting failures in reactor vessels has increased drastically. These failures have occurred in reactor main-pressure boundary components, such as the steam generator, manway closures, reactor coolant pumps, pressurizers, reactor vessel closures, lower thermal-shield bolts, and upper core barrel bolts; they have degraded a number of plants and required extensive and expensive replacement of fasteners.

All types of fastener failures have occurred -- stress corrosion cracking, fatigue, borated-water corrosion, and erosion-corrosion failures have been documented. Bolt failures due to quench cracks caused by improper heat treatment, incorrect materials and improper torque have been observed.

Because of the large number of fastener failures and the broad range of failure mechanisms, Brookhaven National Laboratory was asked to prepare a report on bolting applications. SPS Technologies Corporate R&D, Jenkintown, PA received a subcontract from Brookhaven to look at several aspects of bolting and to provide recommendations to improve bolting inspection and means to to prevent loosening of fasteners. SPS is providing a system of sample requirements and recommendations for receiving inspection. As the result of a literature survey on bolting failures, SPS Technologies is also providing recommendations based on their knowledge of bolting practices in other industries.

PROCEDURES:

A search of the report and journal literature published by the nuclear power industry, the Nuclear Regulatory Commission and other pertinent sources was conducted. For the sake of accuracy and expediency, the NTIS database (produced by the National Technical Information Service) and the COMPENDEX database (produced by Engineering Information, Inc.) were searched on the DIALOG Information Service available in SPS' Corporate Technical Library.

The following subject terms were searched in various combinations, and each combination required either the term "bolt" or "fastener" to appear in either the title of the document or in its abstract.

Locking
Failure
Specification
Steam
Aerospace
Joint
Nuclear
Power

The results of the search were evaluated, and applicable titles were ordered from the appropriate sources where they did not already exist in-house.

The comprehensive, in-house indices to SPS Technologies' report literature was also searched to uncover any documentation of fastener failures in the nuclear or other energy-related industries.

RESULTS:

The results of the investigation are reported in the following sections. Most of the information has come from the bibliography or from SPS' internal report literature; some is a result of the author's twenty years of experience in the fastening industry.

SUMMARY OF FASTENER LOCKING PRACTICES

There are basically two types of nuts a designer may choose from -- normal and locking. Since most are familiar with the function of the normal nuts, only locknuts will be covered here.

The primary function of a locknut is to prevent the nut from backing off the bolt or stud if the tension load is lost. This precludes or lessens the danger of a bolted assembly coming apart during operation. Jam nuts, cotter pins, lock wires and similar devices also prevent backing off but incur added weight, inconvenience and cost. Weight savings are particularly important in aircaft where each pound saved is worth $100 or more. In missiles, the weight savings may be worth much more.

A locknut must resist rotation not only on the first installation but also after reuse. Most aircraft specifications call for a minimum reusability of fifteen cycles on and off while maintaining torque within certain limits.

Retention of locking torque has received a great deal of attention from various bodies concerned with fasteners. The Industrial Fastener Institute, for example, requires that the actual prevailing torque on first removal be "not less than 40% of the actual prevailing torque during first installation."

An effective locknut also should enhance the bolt's fatigue properties. Seldom is there a question about the ability of a bolt or stud to carry its service load when tight. More often the fastener will fail when preload fails and the joint becomes loose. A major function of the locknut then is to help maintain a tight joint and to prevent fatigue failure in the bolt.

Prevailing torque locknuts should be used in applications requiring short bolts, which quickly lose tensile load with shrinkage of the joined parts; where imbedding of the bolt head or locknut in soft materials may cause loss of tension and allow the nut to become loose; if adjustment of locknut position on bolt or screw threads is needed; and when safety and reliability are desired.

TABLE I

Functions of a Locknut

1. Support load
2. Be wrenchable
3. Resist rotation
4. Enhance bolt properties

Essentially, there are two types of locknuts: the free-spinning nut that locks when the nut is tightened on the bolt and the prevailing-torque locknut that locks before the nut is seated.

Prevailing-torque locknuts create controlled friction between the mating flanks of the external and internal threads, causing the nut to resist rotation. Locking action is maintained even with no load on the seating surface; however, maximum holding and locking power is attained when the nut is tightened on the bolt at a clamp load.

The prevailing-torque locknuts available may be grouped into two classes -- those requiring inserts to obtain the locking action and the all-metal, one-piece locknut.

Insert types have a locking device such as nylon or fiber, a soft metal, or spring wire or pin. The nonmetallic or soft-metal inserts are plastically deformed by the bolt threads to produce a frictional interference fit. Nonmetallic inserts may be either a ring set in the locking portion of the nut or a patch (or plug) in the threaded portion. They are used extensively in both the commercial fields and in the aircraft industry. They provide vibration dampening characteristics and have good reusability but are limited to 250°F maximum.

The spring wire or pin engages the bolt threads to produce a wedging or ratchet locking effect. They are better for higher temperature use than nonmetallic inserts but sometimes require a release mechanism to remove.

The all-metal, one-piece locknut is the most practical for the great majority of self-locking applications. The temperature range is much higher than for nonmetallic-insert locknuts and is limited only by the material from which it is made.

All metal, one-piece locknuts are available in three types: deflected beam, deflected thread and out-of-round threaded collar.

In the deflected beam, the locking section is slotted and squeezed radially inward, providing a spring which produces a frictional drag on the bolt (Figure 1). As the bolt enters the locking area, the slotted section is expanded, and the nut starts to lock.

The high-beam type of nut is preferred for most applications since the higher beam provides maximum flexibility in the locking section. It has greater reusability and is more tolerant of variations in bolt size. This type of locking device has the least tendency to gall of the all-metal types. If, however, space requirements limit the height of the nut, the beam height must be compromised.

The deflected-thread type of locknut may be deformed at the end of the nut or in the center. The latter type may screw onto the bolt from either end and requires no orientation. This simplifies assembly and eliminates the need for complicated hoppers in automated assembly work. Deflected-thread locknuts have a cost advantage over the deflected-beam and out-of-round threaded-collar types but with some sacrifice in reusability and resistance to galling.

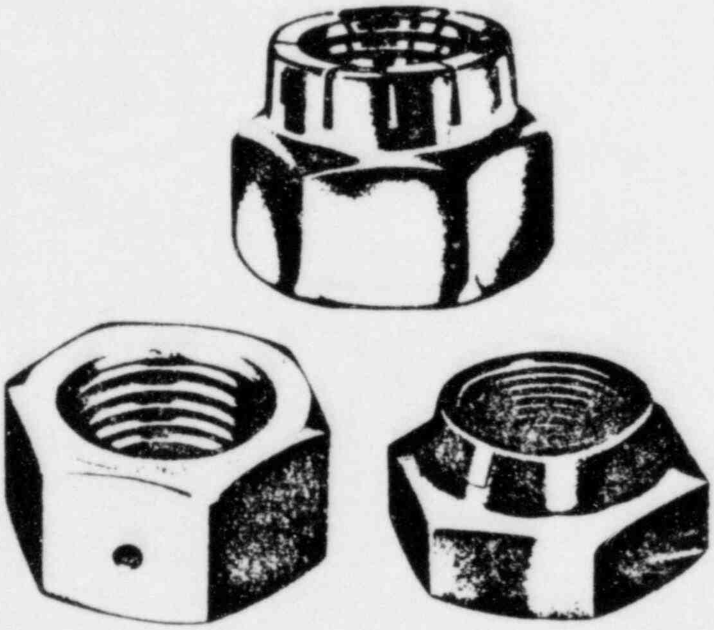


Figure 1. Three types of one-piece, all-metal, prevailing-torque locknuts -- deflected beam (top), deflected thread (left) and out-of-round threaded collar (right).

The out-of-round threaded-collar locknut is the most commonly used; in this type, the locking collar is squeezed in either two or three places, giving an elliptical or triangular displacement of the collar. The triangular displacement provides somewhat more bearing area of locking section against mating bolt threads and thus reduces the tendency to gall. As the bolt enters the locking section, the out-of-round collar is displaced to a more circular form, and the resistance of this displacement produces the locking action.

Choice of a locknut with an out-of-round collar versus one with a deflected beam depends on the application. The out-of-round collar doesn't require as large an outside diameter of the locking section as does a deflected beam nut in the same thread size. Therefore, the diameter (or width) of the wrench flats may be reduced to provide a smaller nut when space or weight is at a premium. For maximum reusability, nuts with out-of-round collars should be made of heat-treatable material.

The three types of drives (Figure 2) on industrial and aerospace nuts and their principal applications and functions are:

Hexagon drives are good to 160 ksi inclusive and possess good automatability.

External 12-point and spline drives are used for nuts from 180 to 300 ksi but also are desirable for 125 and 160 ksi nuts. Automatability is good for the 12-point and moderate for the spline.

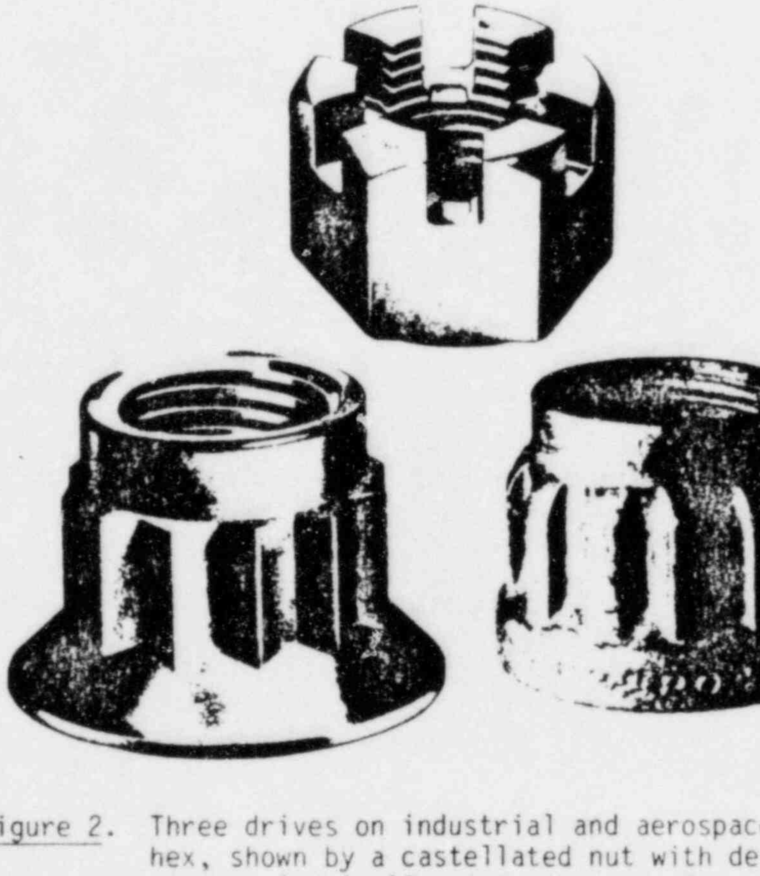


Figure 2. Three drives on industrial and aerospace nuts: hex, shown by a castellated nut with deflected threads (top), 12-point with out-of-round collar (left) and spline, also with out-of-round collar (right).

Prevailing-torque locknuts are available in almost all the common forms of standard nuts such as acorn, flange, jam or washer face. In some applications, however, the nuts cannot be wrenched on the bolts and self-retained; self-wrenching nuts must be used. These are held in place on or in the structure by riveting, welding, swaging, or other means and are used primarily where the structure is accessible from one side only and function as blind or semi-blind fasteners.

Another type of locking mechanism is the cotter pin or lock wire. The stud (or bolt) is cross-drilled to receive a cotter pin after the nut has been tightened to correct torque, angle-of-rotation or preload. A slot in the nut is lined up coincident with the cross-drilled hole, and the cotter pin (or lock wire) is installed.

Bend tabs are often used to prevent the nut from turning relative to the male thread. These tabs are part of a washer which is installed under the threaded member. After the nut or bolt has been tightened, the tabs are bent up to rest firmly against the flats of the drive of the locked member. A disadvantage of the bend tabs is that the material must be ductile enough to bend; therefore, the washer part under the nut or bolt head will almost always relax and cause a loss in fastener preload.

In power plants nuts are sometimes welded to the bolts to prevent loosening. This is poor practice as overheating may distort the nut or soften either member, causing a loss in load-carrying ability. Fastener relaxation may also occur and result in a loss of joint preload.

Jam nuts are an expensive, but technically satisfactory, method of achieving a locking system. Whereas the nut torque may be limited because of preload maximum limits due to stress-corrosion-cracking considerations or other joint-design limitations, the differential torque between the two locking nuts is limited only by the male thread's yield point. Of course the bolt thread must be long enough to accommodate the additional nut.

Chemical locks are used in places where the upper-temperature limit is rather low. These adhesives are of a number of types: thermoplastic, thermosetting patches, anaerobic adhesives, microencapsulated two-part adhesives.

Ramp-like teeth on the bearing faces of either the nut or bolt are also a popular solution to a locking problem. As the nut or bolt is tightened against the mating part, relatively shallow ramps slide past the mating surface. When the nut or bolt tries to turn in the loosening direction, the other side of the tooth has a ramp essentially perpendicular to the bearing surface. This digs in and causes a very high resistance to turning. This torque to loosen may be as high as twice the torque which was applied to originally preload the fastener.

Interference threads are but another way to prevent self-loosening of threaded fasteners. The interference can be a result of male deflected threads or as a result of the male-thread major-diameter being in contact with the nut thread-root.

FASTENER ACCEPTANCE METHODS USED BY THE AEROSPACE INDUSTRY:

Military specification MIL-D-6812B for aircraft bolts is mandatory for use by all departments and agencies of the Department of Defense. There are federal specifications for cadmium plating, entitled "QQ-P-416"; military specifications such as MIL-H-3982 for hardware, packaging and packing for shipment and storage; military specifications for various aircraft steels and forgings (including ones for heat treatment, screw threads, steel bars, forgings, billets, etc.). There are military specifications such as MIL-STD-105, entitled "Samplings, Procedures, and Tables for Inspection by Attributes"; AN3 through AN20 for aircraft machine bolts; AN315 for plane and frame nuts; AN320 for castellated shear nuts; and MS21083 for self-locking, hexagon nuts. A complete listing of these specifications and a complete listing of MIL-B-6812B appear in the Appendix.

In summary, there are material requirements and geometric requirements for the head of fasteners (i.e., the bearing surface, eccentricity of head-to-shank, and straightness of shank). There are also requirements for the physical properties of fasteners, such as tensile strength, shear strength, hardness and decarburization limits. There are limits for cracks, seams, inclusions, nicks or gouges. There are limits on defects on washer faces, bolt head-shank junction, threads, thread length, after- plating and finishing dimensions, and finish. It is also necessary for the identification of the product to be on each fastener. There are quality assurance provisions, such as responsibility for inspection, classification of inspection, definition of a lot, and sampling plans. There are also definitions of defect classes (such as minor and major defects); defects have been classified and are characterized as critical, minor-A, minor-B, major and noncritical.

Sampling plans for tension, shear and hardness tests are also delineated clearly (such as which inspection level should be used; what AQL; and exactly what table should be used). All attribute sampling plans should be in accordance with MIL-STD-105; a copy of this standard is also included in the Appendix.

A. Summary of Applicable Specifications:

1. MIL-S-4472 -- This specification is for screw threads and includes all the basic data, such as the thread form, dimensions, thread classes, thread series, and a definition of terms. The specification also makes reference to the sections on unified and unified-miniature threads in Handbook H28.

2. MIL-H-7839 -- This is a specification for aircraft structural screws and is included in this report's appendix.

As on reads through these various documents, it becomes clear that a lot of work and thought has gone into the writing of these various specifications. It is only because of hard work by the fastener manufacturer , the users and the military that usable specifications like these exist. Their purpose is to delinieate clearly and precisely the geometry and functionality of aircraft fasteners. These specifications also include quality assurance provisions.

3. MIL-N-7873A -- This specification for 1200°F self-locking nuts describes the requirements as to retention and fastener vibration. The materials, design, construction, condition of the

bearing surface, threads, plating and surface treatment are clearly defined as well as tensile strength and stress-rupture strength. There are tables showing the minimum strength requirements, the recommended wrench torque at room temperature, and the torque after a six-hour bake at the required 1200°F working temperature. The locking torque at ambient temperature is also defined.

4. MIL-B-7874 -- A copy of this specification is also included in the Appendix; it covers machine bolts which are furnished for use where temperatures will not exceed 1200°F. This specification includes a list of other specifications that this fastener must conform to, such as MIL-H-3982 (Hardware packaging and packing for shipment and storage) and MIL-S-8879 (Screw threads, controlled radius with increased minor diameter). Specifications for sampling procedures, tables for inspection by attributes, and test report requirements are also included.

   It is interesting to review the requirements of these fasteners as specified in MIL-B-7874.

   - Qualification: Bolts furnished under the specification shall be a product which is in accordance with the applicable standard and which has been subjected to, passed a qualification test specified herein, and has been listed on or approved for listing on the applicable qualified products list.

   - Material: The bolts should be fabricated with heat- and corrosion-resistant material. Unless otherwise specified, this material shall have a minimum tensile strength of 140 ksi; a minimum .2% yield strength of 95,000 psi; and a minimum stress-rupture strength of 65,000 psi in 23 hours.

   - Design and Construction: The threads must have a specified form and dimensions in accordance with MIL-S-8879. The grain flow of the threads shall be continuous. The heads must be forged. The bearing surface if the bolt heads must be at right angles to the shank within the specified limits of this document.

   In short, the complete geometric, mechanical and metallurgical properties of this fastener are clearly defined. The means and methods of qualifying this product are clearly defined. The standards by which this fastener will be tested are completely defined.

In order to install a good fastener into a joint it is necessary to ensure the following.

1. The fasteners must be manufactured from a material whose heat and origin are known and whose basic material properties are on file. The fastener must be manufactured according to a well-defined and controlled manufacturing process.

2. In-process inspection is the only way to obtain a final product which meets all specifications.

3. The fastener must be heat treated properly under controlled conditions (temperature, temperature profile, atmosphere).

4. The parts must must be inspected to an agreed upon specification before leaving the manufacturer's plant.

5. The parts must be packaged in such a way so that they are not damaged in transit to where they will be assembled into a larger product.

6. There must be a procedure for incoming inspection to insure that the fasteners received are the same as the fasteners which were procured.

The aerospace industry has found through many years of practice that there are a number of elements necessary to ensure that a fastener meets the appropriate standards. The simplest of these tests is the hardness test; the next is tensile (to ensure that there is no embrittlement of the material). If a fastener has been plated, it should be in accordance with QQ-P-416. Lastly, the fastener must be installed correctly into the joint using a well-defined method of installation, be it torque, angle-of-rotation, hydraulic tensioning, or some other method.

FASTENER DESIGN AND SELECTION:

SPS Technologies has always considered fasteners to be a structural design problem. In bolts and nuts there can be found all of the classic problems associated with highly stressed, high-strength materials which have high stress concentration factors. The strength properties of the part and its functional usefulness depend on the dimensions. If the part is too large, it will not assemble; if it is too small, it may not carry the required service loads. Here will be presented some of the problems associated with the design of fasteners and those characteristics incorporated to overcome them.

As is obvious, bolt configuration, illustrated in Figure 3, consists of three major components -- heads, shanks and threads. In the following discussion, each will be treated separately. This will be followed by sections on selection of those components, materials and finishes. The nut section will also consist of recommendations for their selection, materials and finishes.

The bolt head must perform numerous functions. It must first support the service load and, in most cases, it also contains the drive or wrenching surface. Its bearing area must be adequate enough to support the required load without causing indentation in the components that are holding it together. Suprisingly, this problem appears from time to time as parts are installed in soft materials and an unexpectedly heavy load is imposed on

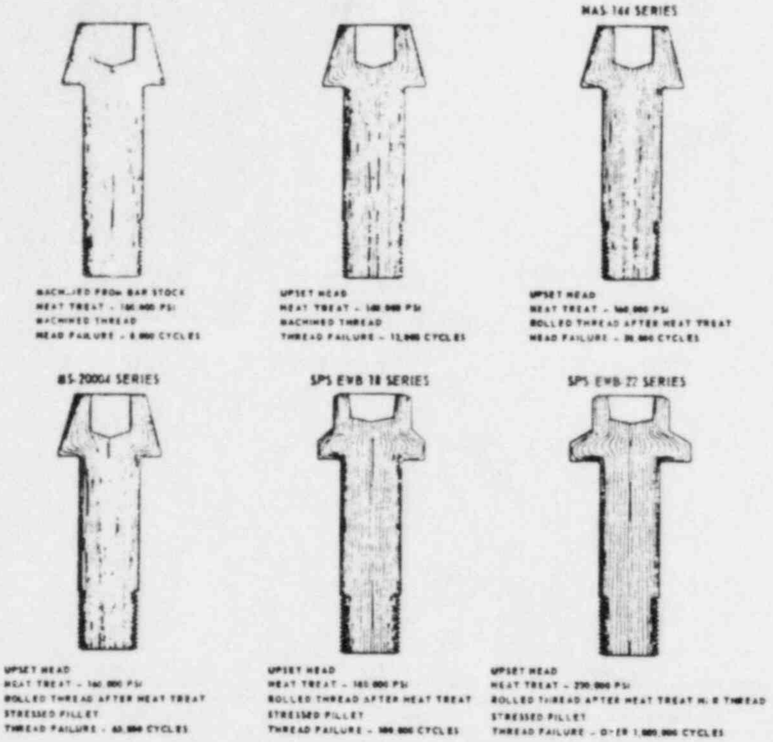


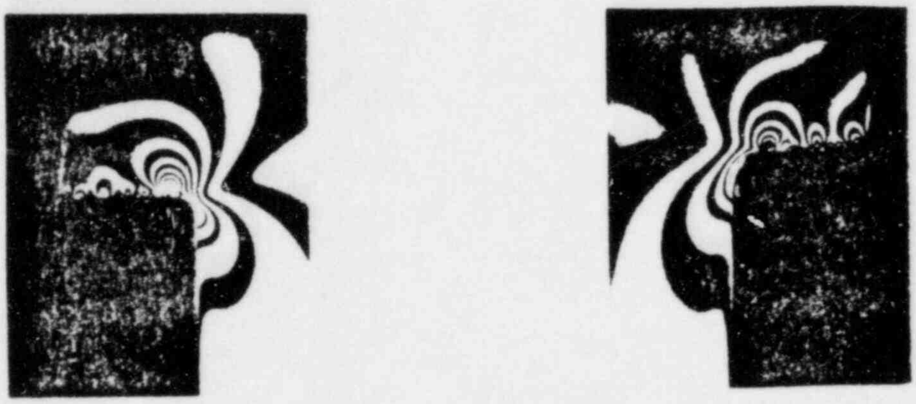
Figure 3. Bolt evolution.

the components. Some must be smooth and round for better appearance. An additional feature may be added to make it a lockbolt.

The proper drive must be selected. Some drives are economical but relatively weak; some are more adaptable to automatic installation equipment. Double hexagons offer high wrenchability. Spline drives give the highest torque values of all but need special wrenches.

The strongest heads are forged. In forging, the metal fibers are made to closely follow the contour of the part. This produces a head with uninterrupted flowlines to increase the tensile strength and fatigue life.

Increasing the size of the fillet radius will also improve properties. Photoelastic studies of fasteners with different size fillet radii are illustrated in Figure 4. In this study, a flat model of the part is made in direct proportion from plastic. The model is stressed and viewed with polarized light. Each black band represents a plane of equal shear stress. The greater the number of changes from black to white from a neutral point to a point on the surface, the greater the magnitude of the stress. The closer the lines are to each other, the more concentrated is the stress. In the upper left view of Figure 4 is shown a part with a 0.010" fillet radius; the fringe lines are closely packed in the fillet area. There are a total of twelve changes from black to white from the neutral axis to the surface



Circular Fillet .012 inch
Fringe Order - 12

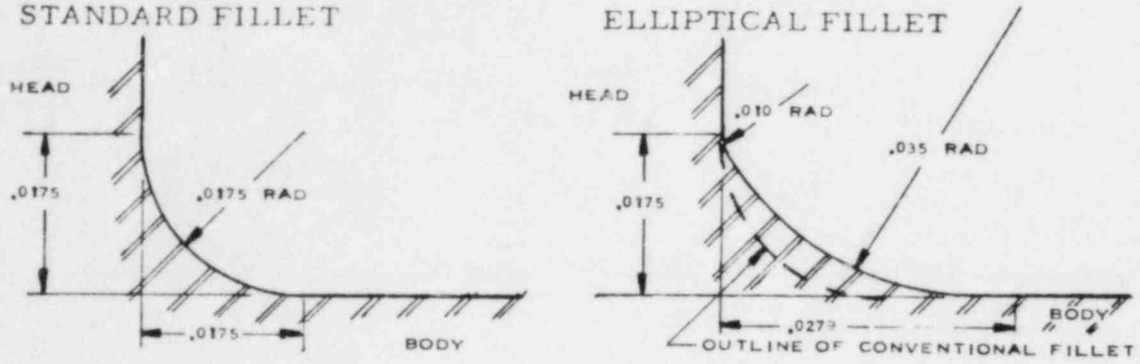
Circular Fillet .025 inch
Fringe Order - 9

Circular Fillet .050 inch
Fringe Order - 6

Figure 4. Photoelastic study of fillet configuration -- 3/8" socket head cap screws.

of the fillet. The upper right view shows a part with a 0.025" radius fillet. In this model, the fringe lines are not packed as closely together, and there are only nine changes from black to white. Thus, the concentration of the stress in this part is less than that shown in the left view. Carrying this concept further, the fringe order has been reduced to six, or one-half of the original amount, by using a circular fillet of 0.050" radius. Through this reduction of stress concentration, the fatigue life of this area can be increased.

However, by increasing the fillet radius, the bearing area under the head is reduced. This can be increased by making the head diameter larger, which would add more weight to the fastener. Through laboratory studies, a shape of the fillet has been developed (Figure 5) which reduces the stress concentration with no sacrifice in bearing area. This is desirable to keep the head from imbedding in the mating surface. The left side of Figure 5 shows the dimensional and stress characteristics of the elliptical, or compound radius, fillet. In the upper views of the preceding



COMPARITOR PHOTOGRAPH OF PRODUCT 32.5 MAGNIFICATION

COMPARITOR PHOTOGRAPH OF PRODUCT 32.5 MAGNIFICATION

PHOTOELASTIC DISTRIBUTION FRINGE ORDER 12

PHOTOELASTIC DISTRIBUTION FRINGE ORDER 10

Figure 5. Research study on fillet configuration -- relation to tension-tension fatigue life.

chart, the comparative dimensions of the circular fillet and the elliptical fillet are shown. The junction of the fillet with the bearing area of the head is the same in both cases at a distance of 0.0175" from the shank. The radius of the circular fillet was 0.0175". The compound-radius fillet shown on the right blends different size radii to form the fillet. The radius which is tangent to the shank is much larger than the circular fillet. Thus, the stress in the critical area -- the junction of the radius to the shank -- should be reduced. The middle views show comparator photographs of parts produced with these fillets. The lower views show photoelastic studies of the two fillet configurations. Notice the difference in the stress distribution at the junction of the fillet to the shank. With the compound radius, the lines are much more spread out than in the case of the circular fillet.

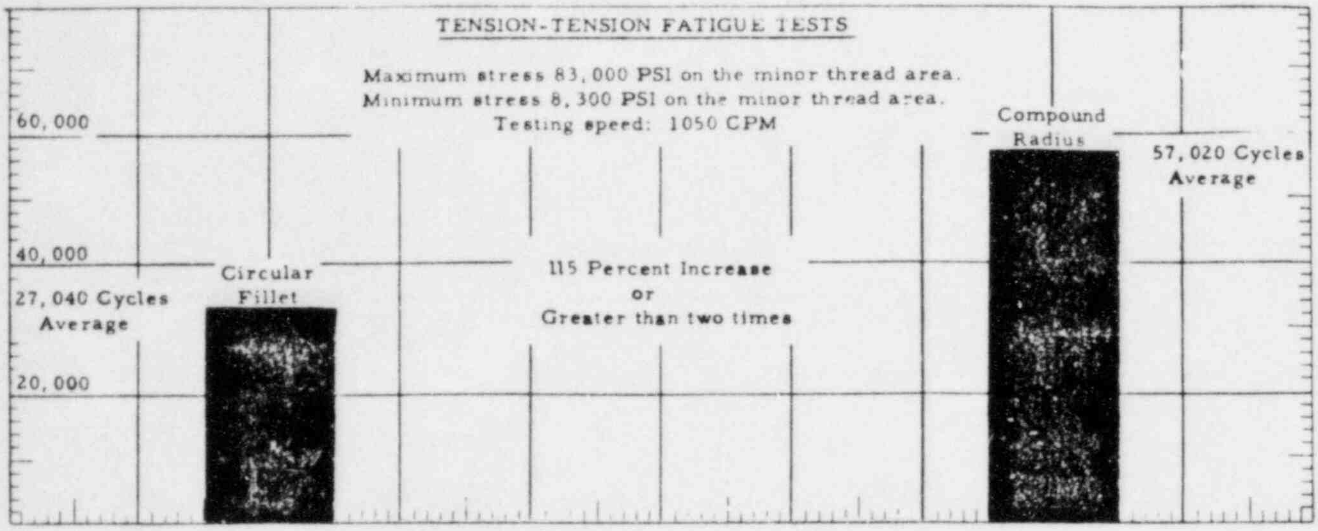


Figure 6. Effect of fillet radii configuration on fatigue life of socket head cap screws.

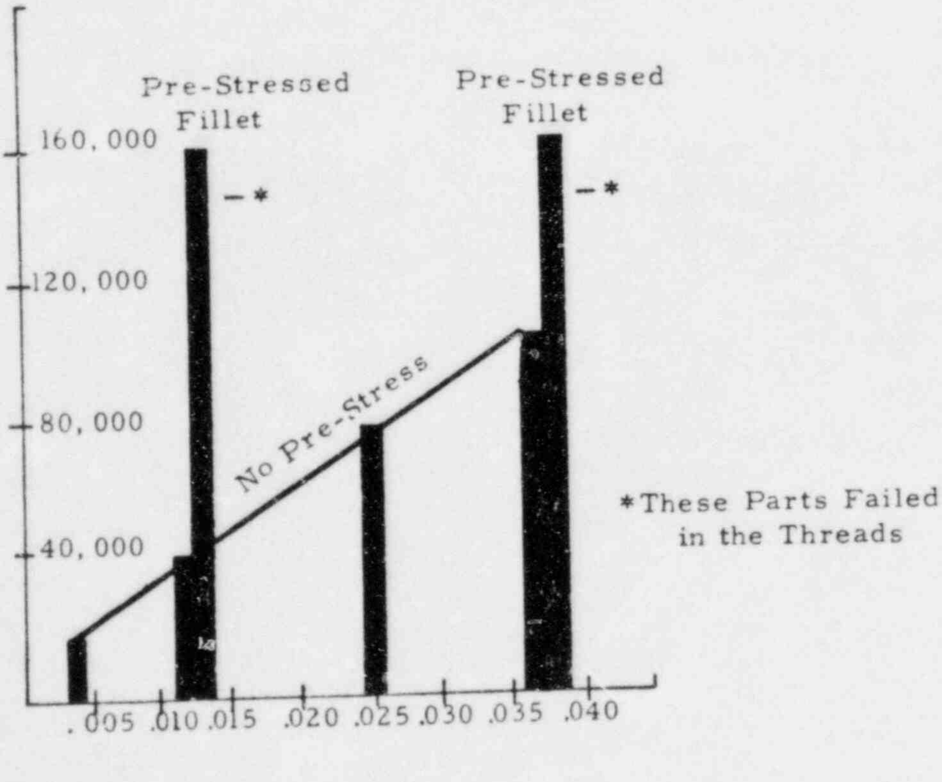


Figure 7. Effect of fillet radii and prestressing on the fatigue life of 160,000 psi alloy-steel bolts tested at 80,000 psi.

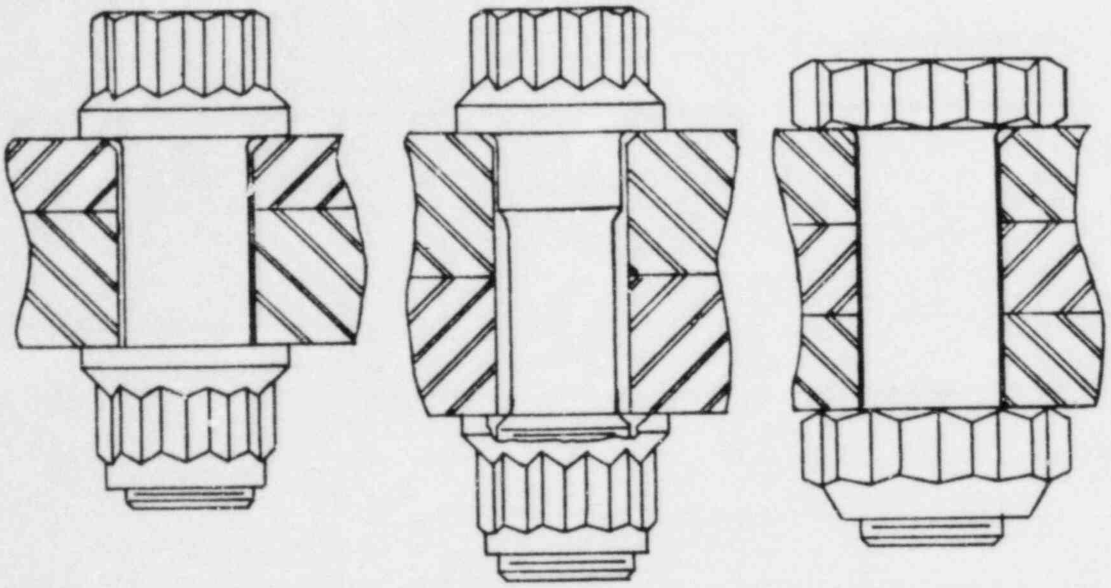
Parts produced with these two configurations were tested in tension-tension fatigue; the results are presented in Figure 6. The vertical scale is the cycles to failure. An average life of 27,000 cycles was obtained on the parts with a circular fillet, and a life of 57,000 cycles was obtained with a compound radius. These pieces were made from the same lot of material and were processed in the same manner in all operations, the only difference being the shape of the fillet. Thus, an increase of two times was obtained in the fatigue life. By changing the fillet's contour, no sacrifice in bearing area was made, and the weight of the two parts was the same.

Another method of increasing head-to-shank fillet life is to prestress it. This is accomplished by cold working the fillet after heat treatment. The combined effect of increased fillet radius and prestressing is shown in Figure 7. It should be noted that, in the case where the fillets were prestressed, the fasteners failed in the threads; therefore, no separation can be seen. Although the stresses with the compound radius are less and better distributed, the form does not lend itself to practical fillet rolling after heat treatment.

Shanks are the most trouble-free part of a fastener. As long as the fastener is made from good material, manufactured within the dimensions specified, and heat treated properly, it gives reliable performance. Shanks for tension bolts normally have some clearance in the hole in which they are installed. This is to allow the bolt to act as a spring more easily. Reduced shanks can be used to increase the fatigue life by allowing the fastener to become still more springy and to absorb some of the cyclical loading. However, this appears to be an advantage only in the thicker sections. Shanks for shear bolts usually are a very close fit. Shear bolts do not feel the tensile loads, therefore, they can fit closely into their holes. This close fitting prevents the components of the joint from sliding. In some cases, it may be beneficial to have the shanks interfere with the hole to increase fatigue life of the surrounding structure, especially in thin-section applications. (Shank clearances are illustrated in Figure 8.)

What are the important elements of a thread? The root is probably one of the most important; it determines not only the fatigue strength but also the stress-rupture characteristics of the bolts. The MIL-S-8879 thread consists of the standard thread form with a much larger radius in the root. The thread permitted by MIL-S-7742 allows the sharp corners at the junction of the flank to the flat root. The first step to improve this point of high stress concentration was the form specified in MIL-B-7838 which was a continuous and smooth radius tangent to the flanks at a depth of 83.33%. The second step was MIL-S-8879 which is tangent at 75%; others have followed and are shown in Figure 9.

The geometry of the 60° screw-thread form is such that the root radius, R, can be designated as a function of either the pitch, p, (the distance between consecutive threads) or the thread form's height, H, more commonly called the thread depth. Actually, these two dimensions are directly interrelated since thread depth is a function of pitch. Thus, in Figure 9,



Normal Tension
Installation

Reduced Shank Tension
Installation

Normal Shear
Installation

Figure 8. Shank clearances.

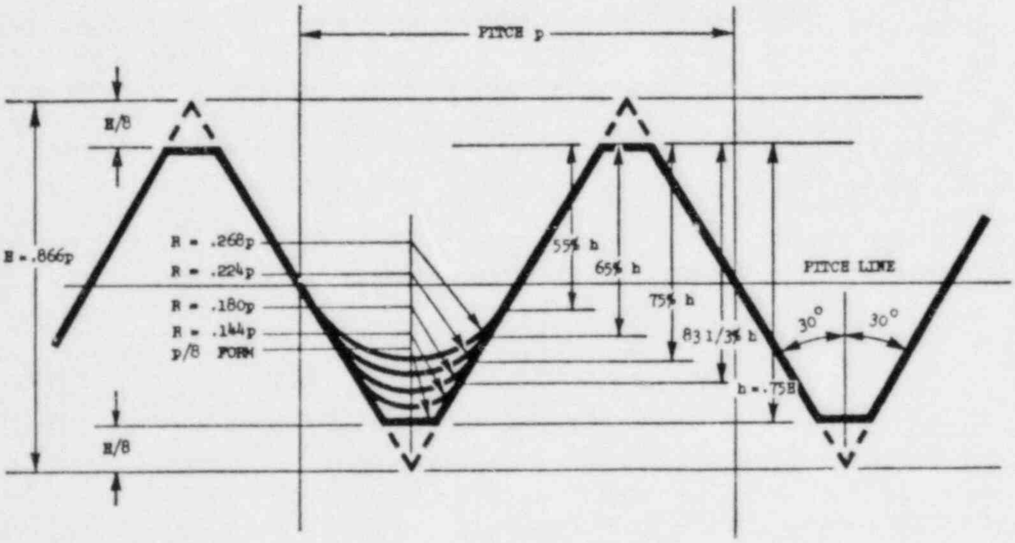


Figure 9. Radius root thread forms.

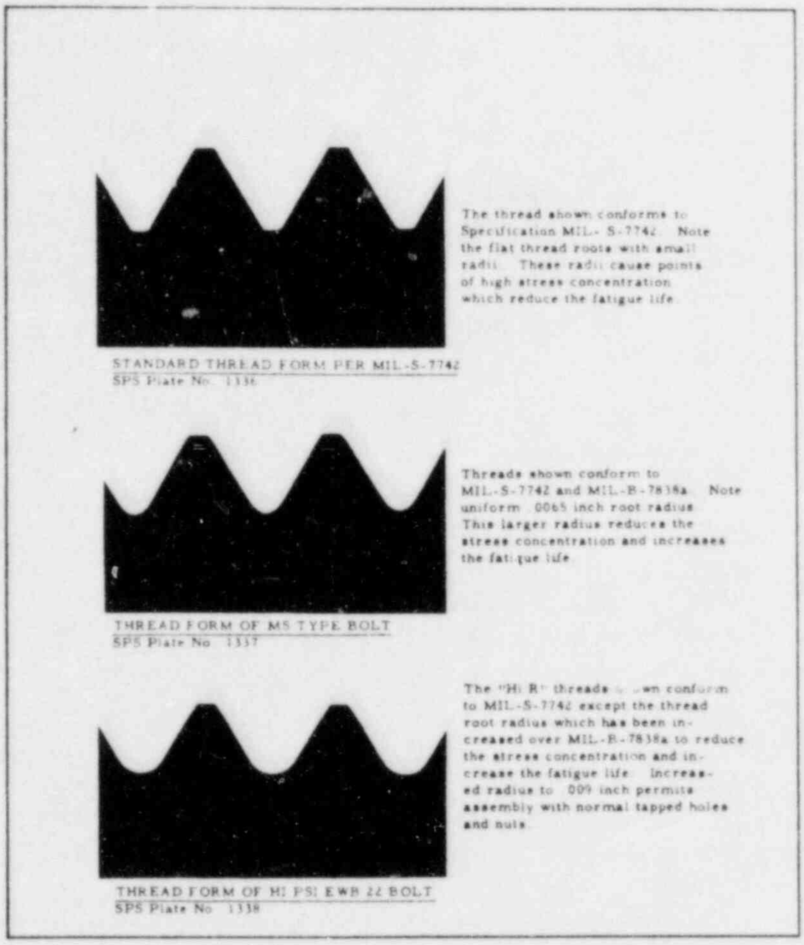
the full theoretical maxmimum height of the thread form, from apex of crest to apex of pointed root, is 0.866p.

The commonly-used standard reference of thread depth is that distance between the crest and root of the truncated thread form, shown by solid lines in Figure 9. This form represents the limits of the present American Unified thread standard. It is this basic difference between the flatted root and crest, h = 0.75H, that is referred to here as 100% thread depth. The flatted root and crest each turn out to have a length of one-eighth of the pitch; hence, the frequent use of "p/8" as the designation for this truncated thread-root form.

Pursuing the interrelationship of radius, pitch and depth further, it will be seen that each root radius has a point of tangency with the flanks of the 60° thread at a specific depth. Thus, the 0.144p radius is tangent at a depth of 83.33% of the full truncated form, measured from the crest down. It is the largest radius that can be used if the thread depth is to be held to a minimum of 83.33%h. Since this depth is a limiting factor in gage engagement, the root -- and the entire radiused thread form -- is often referred to as "83.33% thread." Similar reasoning leads to the 75% thread (0.180p radius), the 65% thread (0.224p radius) and the 55% thread (0.268p radius).

R = 0.144p	This root radius is tangent to the flanks of the thread at at depth of 83.33% of the truncated form. It is comparable to the thread root used on some industrial fasteners and is favored in most aerospace specifications for tension bolts up tp 180,000 psi tensile strength (MIL-B-7838).
R = 0.180p	Also called the 75% thread radius, this root is tangent to the flanks of thread at a depth of 75% of the full truncated form. It is the basic thread form for aerospace bolts of 180,000 psi tensile strength and up (MIL-S-8879).
R = 0.224p	This root form has a still larger radius with a point tangency at 65% of full thread depth. Since most nut threads and mating holes are tapped to a depth of no more than 65%, this is the largest radius that would have any degree of interchangeability with conventional internal threads. This thread form has been used for refractory metal bolts such as columbium and tantalum.
R = 0.268p	This root form, the so-called 55% thread, is comparable to that used on critical bolts made of beryllium and other highly notch-sensitive materials. It perhaps represents the limit in reduction of thread depth before significant loss of thread stripping-strength is encountered with conventional nuts.

Shown in Figure 10 are actual comparator photographs of different thread forms in use today on fasteners. In the top view is shown a thread conforming to MIL-S-7742 which allows a flat root with a small radius joining the root to the flank.



The thread shown conforms to Specification MIL-S-7742. Note the flat thread roots with small radii. These radii cause points of high stress concentration which reduce the fatigue life.

STANDARD THREAD FORM PER MIL-S-7742
SPS Plate No. 1336

Threads shown conform to MIL-S-7742 and MIL-B-7838a. Note uniform .0065 inch root radius. This larger radius reduces the stress concentration and increases the fatigue life.

THREAD FORM OF MS TYPE BOLT
SPS Plate No. 1337

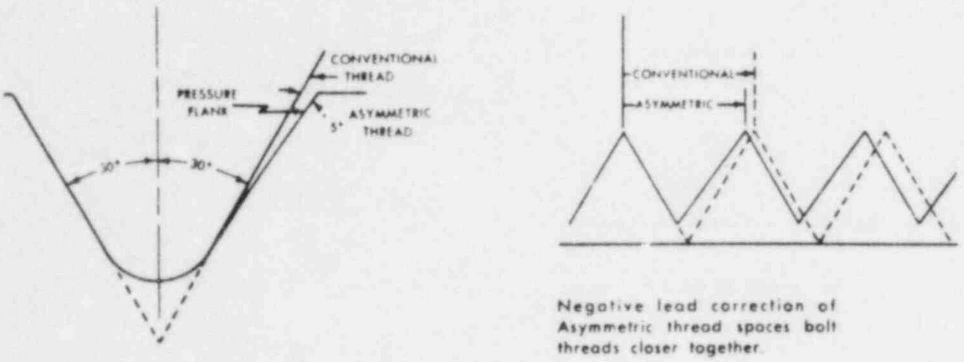
The "Hi R" threads shown conform to MIL-S-7742 except the thread root radius which has been increased over MIL-B-7838a to reduce the stress concentration and increase the fatigue life. Increased radius to .009 inch permits assembly with normal tapped holes and nuts.

THREAD FORM OF HI PSI EWB 22 BOLT
SPS Plate No. 1338

Figure 10. Actual unretouched comparator photographs of 1/2-20 thread forms (approximately 30X magnification).

The asymmetric thread in Figure 11 is a modified thread form having a non-symmetric flank and special lead control. This thread has been patented by Standard Pressed Steel Company and was developed to overcome the uneven load distribution encountered when the bolt is engaged with the internal thread and subsequently stressed dynamically. This thread form has greater fatigue strength than the MIL-B-8879 thread form.

A higher fatigue strength was obtained with UNJ thread when compared to the MIL-B-7838 thread. The S-N curves in Figure 12 were developed on two lots of heat-treated bolts. All threads were rolled subsequent to heat treatment, and the only difference on the two lots was the thread form. The endurance limit for the MIL-B-7838 thread was 55,000 psi, whereas, for the UNJ thread, the endurance limit was 83,000 psi. At all stress levels, the UNJ thread was superior to the MIL-B-7838. This would be true for threads rolled before or after heat treatment.



Negative lead correction of Asymmetric thread spaces bolt threads closer together.

Asymmetric pressure flank angle is five degrees larger.

Figure 11. Asymmetric thread form.

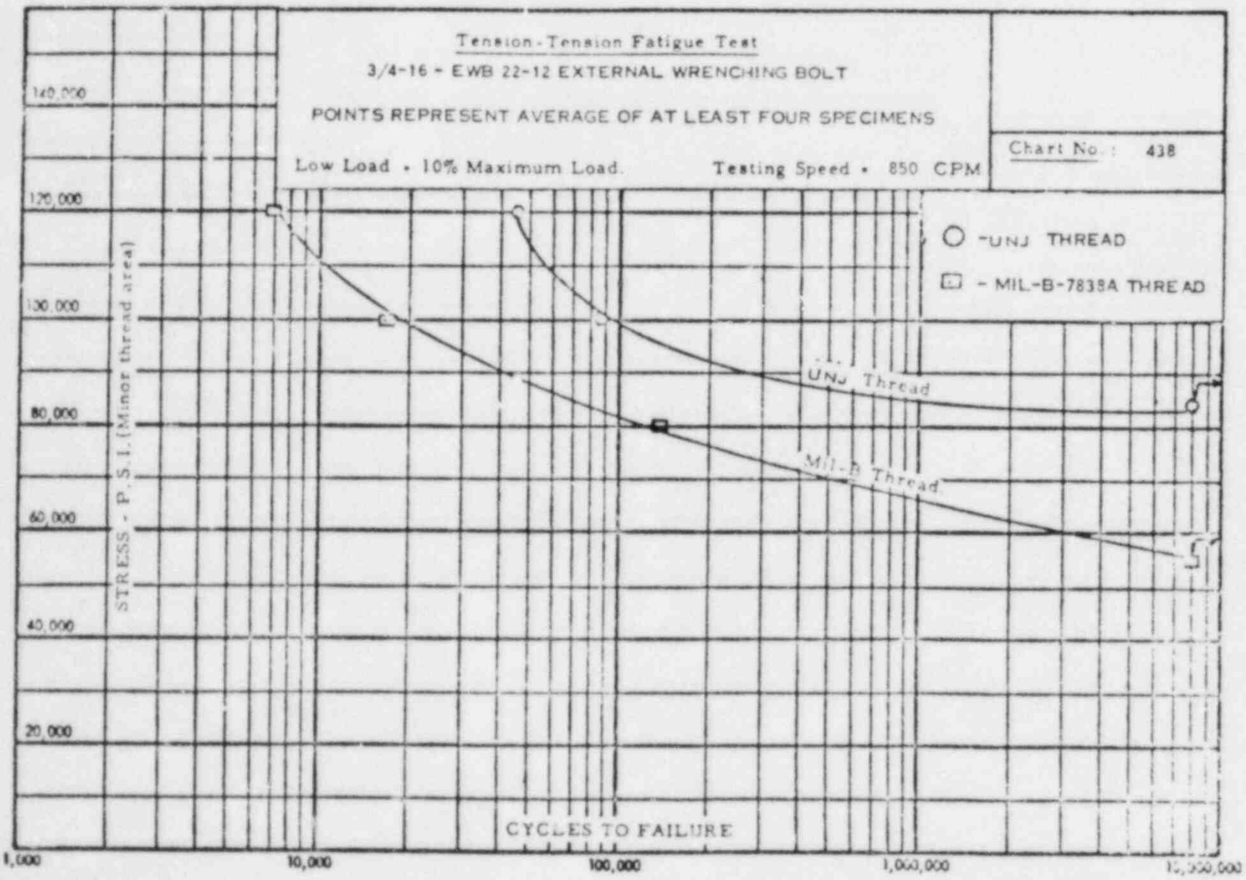


Figure 12. Tension-tension fatigue test of 3/4-16 EWB 22-12 external wrenching bolt.

TABLE II

Thread Form Effect

Thread	Designation	Fatigue Life RBHT*	 RAHT**
83.33% h	MIL-B-7838	100%	100%
75.00% h	MIL-S-8879	110%	146%
65.00% h	SPS-T- 162	180%	162%
55.00% h	SPS-T- 147	240%	230%

* Rolled before heat treatment.
** Rolled after heat treatment.

TABLE III

Effect of Increasing Root Radius According to Fastener Material

Material	Threading Method	Increase in Tensile Strength, %
90,000 psi steel, no heat treatment	Rolled	1
160,000 psi steel, heat treated	Rolled after HT*	6
180,000 psi steel, heat treated	Cut before HT* Rolled before HT*	3 7
180,000 psi steel, heat treated	Rolled after HT*	5

* Heat treatment

The effect of thread form as it is influenced by threading method is graphically presented in Table II. Tests were conducted on 180,000 psi studs manufactured from the same lot of material and heat treated together. The studs thread-rolled-before-heat-treat were tested with a maximum fatigue load of 9,852 lbs.; studs with threads-rolled-after-heat-treatment were tested at 12,900 lbs. maximum load.

As much an effect on fatigue life as has the root radius, it does not have a significant influence on tensile strength. The data in Table III compares the tensile strength of flat root, virtually no radius to the 55% thread form. The increase in tensile strength is a function of the increase in the cross-sectional area of the bolt.

Although room-temperature properties are not significantly increased, the increased root radius does seem to improve elevated properties.

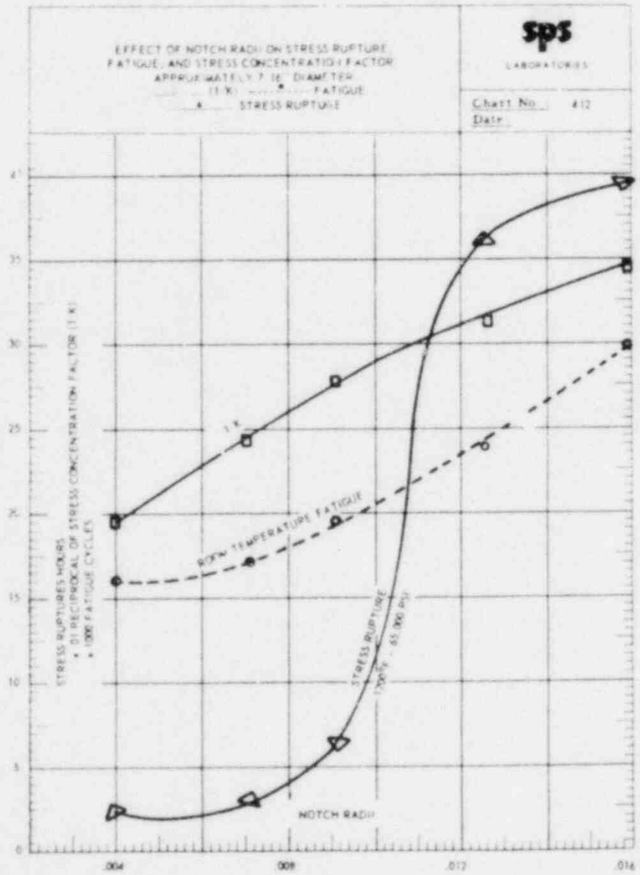


Figure 13. Effect of notch radii on stress rupture, fatigue, and stress concentration factor approximately 7/16" diameter.

In an effort to evaluate the effect of the radius at the root of a thread on stress rupture, tests were conducted on standard stress-rupture specimens in which the notch was established to be equivalent to a 7/16-20 thread. By varying the radius at the base of the notch, a very great change in stress rupture and fatigue occurred. Figure 13 shows the results of this testing. It should be noted that a slight change in this radius had a very marked effect on stress-rupture life at 1200°F and 65,000 psi. We have also plotted the room-temperature fatigue life for specimens of the same configuration and the reciprocal of stress concentration factor "K". These also increased with an increased notch but not in such great proportions.

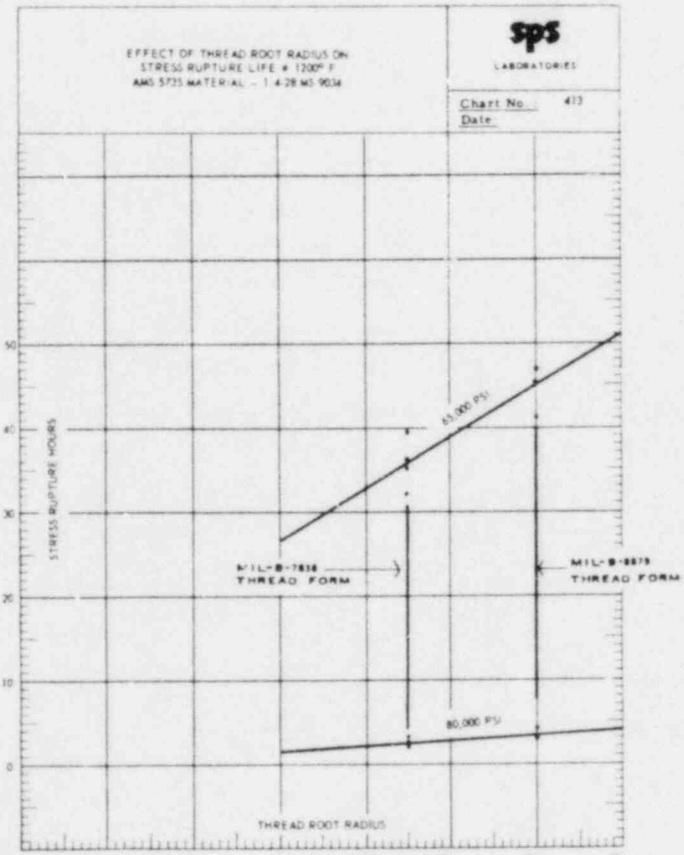


Figure 14. Effect of thread root radius on stress rupture life at 1200°F, AMS 5735 material, 1/4-28 MS9034.

These studies indicated that a marked benefit could be derived from controlling the radius at the root of the thread of a fastener. Figure 14 lists stress-rupture results obtained when testing 1/4-28 A-286 bolts which were fabricated from the same heat of material and in the same lot except for thread rolling. Half of the lot had UNJF threads while the other had UNF threads. Again, a very marked increase in stress rupture was experienced through the use of a larger radius. At 65,000 psi, the UNF thread failed after 33 hours while the UNJF thread withstood 45 hours without failure. These facts have been substantiated in many other tests.

Similar improvement is observed in the stress-relaxation properties of fasteners when the root radius is increased (Figure 15). As opposed to a stress-rupture test where a constant load is held until failure, the stress-relaxation test maintains a constant gage length and reduces the load with respect to time.

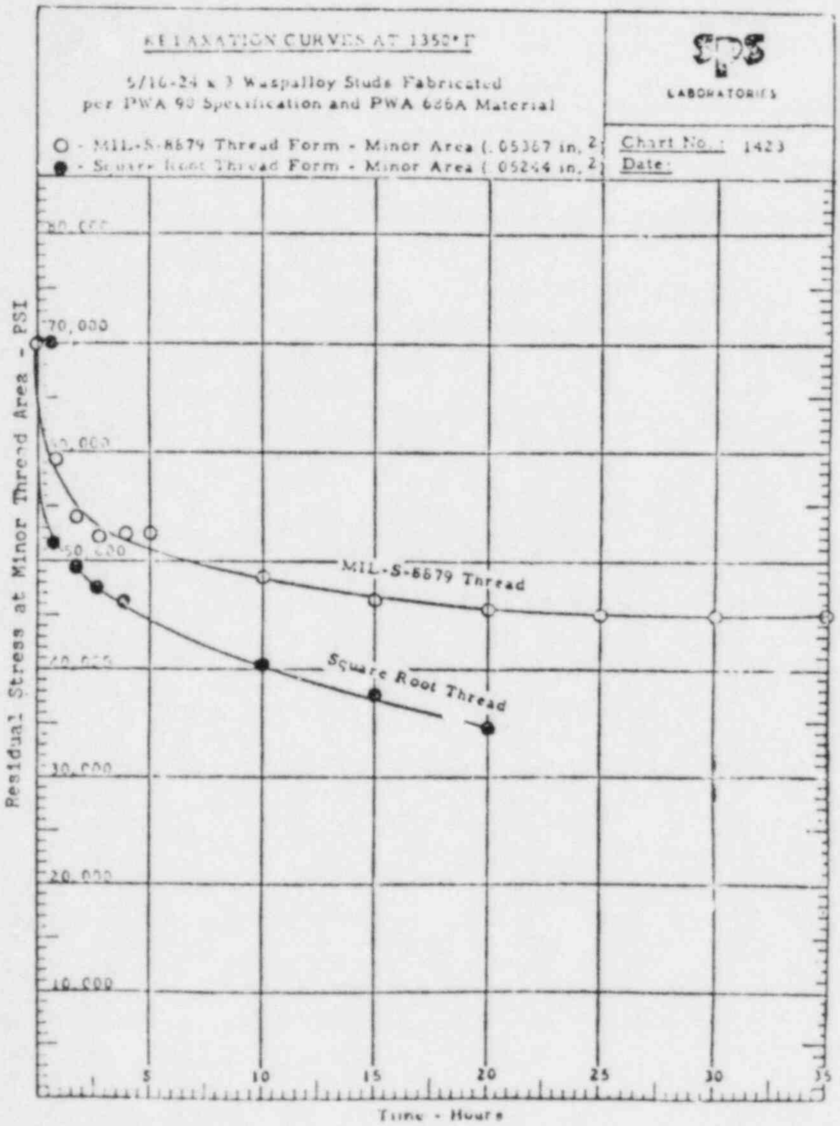
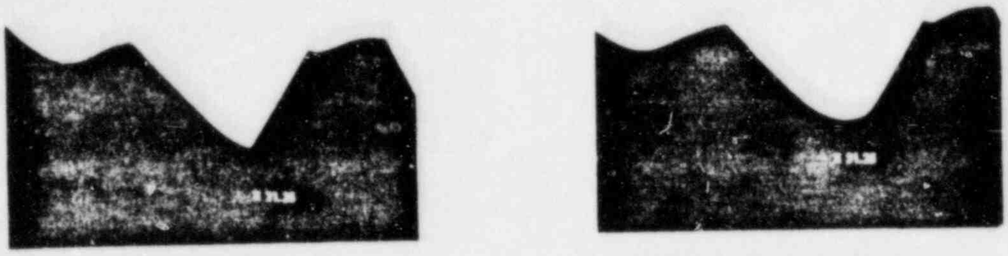


Figure 15. Relaxation curves of 5/16-24 x 3 Waspaloy studs at 1350°F, fabricated per PWA 90 specification and PWA 686A material.

Another area of importance to be considered is the thread runout section of the bolt. This is an excellent example of a highly stressed area. In addition to a sharp notch, there exists a cross-sectional change along with an inherent nonaxial load.



Standard thread form

Radius root runout

Figure 16. Comparison of a standard thread form and the radius root runout.

Laboratory tests have shown that fatigue life of screws along with the tensile strength can be influenced by the configuration of this section. In ductile materials, fatigue strength is the concern, whereas significant changes in tensile strength have been noted with high-strength titanium and 300,00-psi steel bolts; sample results are reported in Table IV.

TABLE IV

Typical Test Results, 1/2-13 Socket Head Cap Screws, 180,000 psi Screws

R = 0.1
Maximum 65,000 psi

	Average Cycles to Failure, 10 Tests	Failure Location
Sharp Runout	30,740	9 TRO, 1 T
Radiused Runout	57,300	10 T

Whenever male threads are engaged and loaded, the stress is not uniformly distributed over all of the engaged threads. The stress tends to concentrate on the threads near the bearing face of the nut. Figure 17 shows the stress distribution in a conventional nut. The bearing face is at the bottom of the figure, and the load is being applied dowrward. The stress concentration is greatest in the first two or three threads at the bottom and then rapidly decreases further up the nut to the top thread which carries very little load. The shape of this curve is affected by the hardness of the material, by the number of metallic threads and the amount of material around the threads. With fewer metallic threads, the stress would be greater in the bottom for a given load because the stress per thread would be increased. The more material around the tapped hole, the more rigid the threads. Therefore, the stress in the bolt is greatly dependent upon the mating threads.

The adverse load distribution is caused by the difference in the axial strains in the internal vs. the external thread. As the load is applied to the fasteners, the nut tends to compress while the bolts want to stretch. An uneven force distribution is encountered to allow internal and external threads to seek an equilibrium displacement condition (Figure 18).

The top S-N curve in Figure 19 was developed on unengaged threads. The lower group of curves were developed on a single lot of bolts using various styles of locknuts. The endurance limit of the unengaged threads was only 40,000 psi. In the lower curves, the effect of fatigue on the style of locknut used on the bolt is shown. The greatest fatigue strength was obtained by using full-height, all-metal locknuts. The next curve below in Figure 19 was developed on the same group of bolts using a locknut of similar height and dimensions which had a nonmetallic insert for the locking element. Lower fatigue life resulted because there were fewer metallic threads to carry the load, resulting in a high stress concentration.

JOINT DESIGN CONSIDERATIONS:

Joint design and component selection is influenced by many factors. The loads and the environment are the two basic considerations. Once these have been determined, then the other constituents, such as material, configuration, temperature, servicability, reliability and repairability, can be taken into account.

Joints may be fastened together mechanically, chemically or metallurgically. In this discussion, however, only mechanically-fastened joints will be considered.

In a well-designed mechanically-fastened joint, the strength of all the members is in balance. All joint members, including the fasteners, may be subjected to tension, torsion, shear, bending and compression, and they may feel those factors singularly or in any combination.

In the ideal joint design, the fastener is used to clamp together two non-elastic members. A load diagram for this type of joint indicates that the fastener will not feel any increase in load until the working load of the joint exceeds the preload or clamping force. Actually, this is not the case, because all materials are slightly elastic. The more realistic case is -- the working load is applied to the joint and the fastener senses an

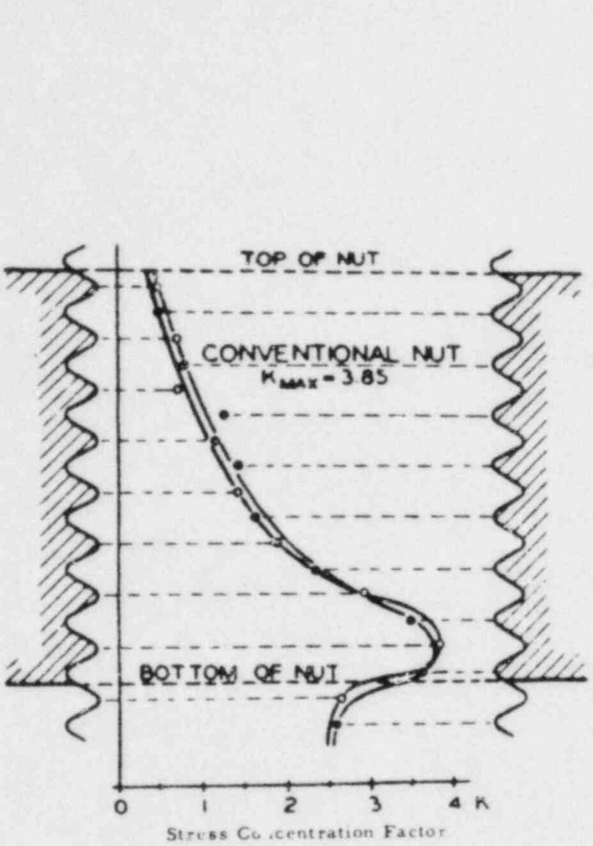


Figure 17. Stress at thread roots due to nut engagement.

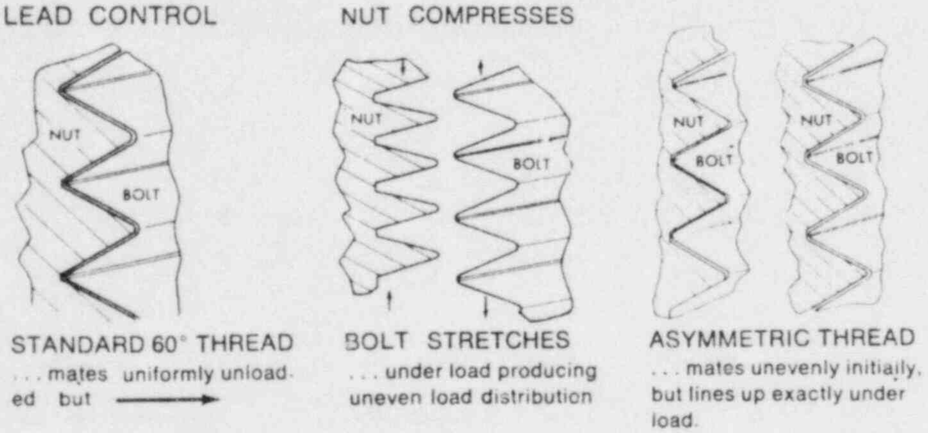


Figure 18. Effect of thread form on load distribution.

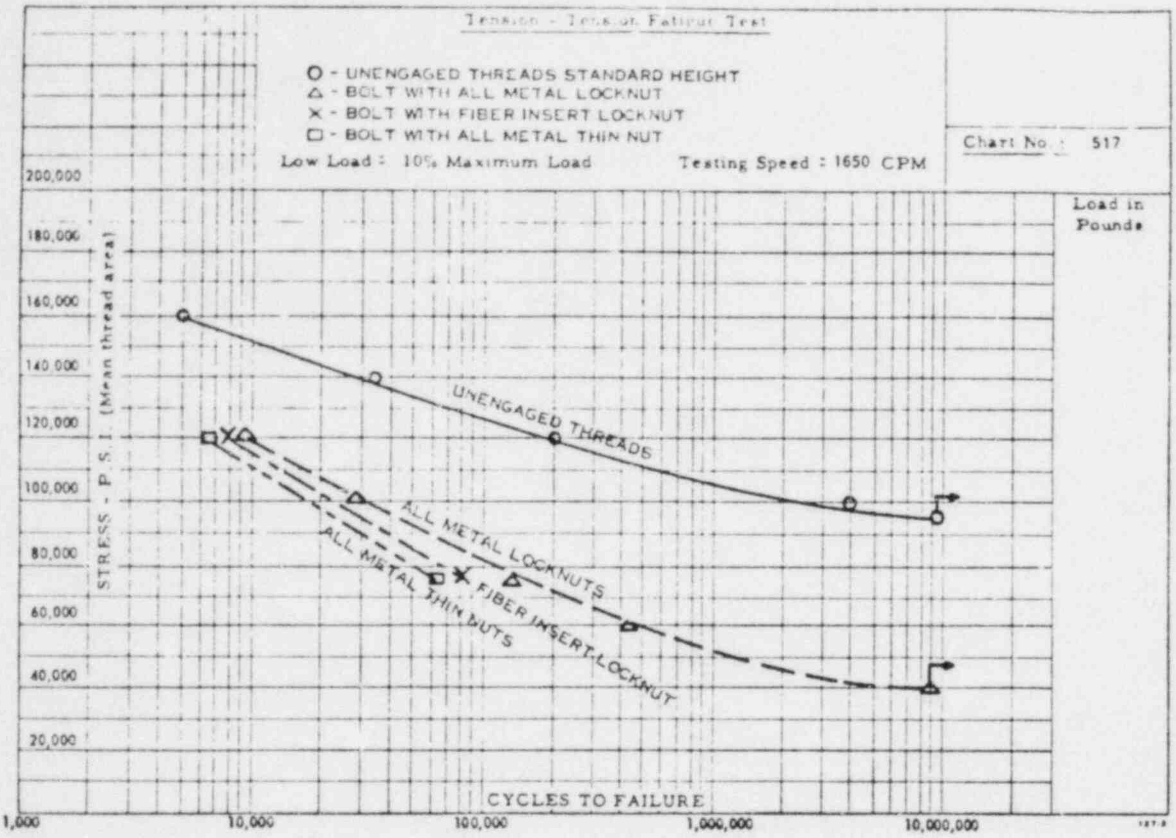


Figure 19. Effect of nut design on fatigue.

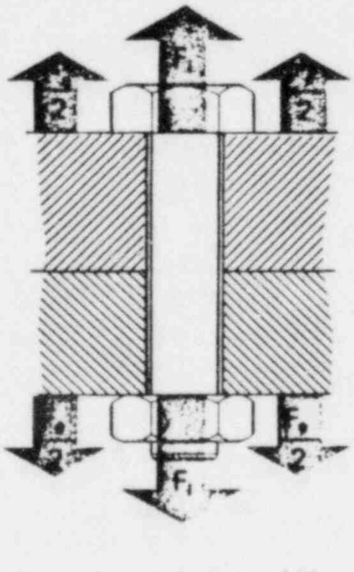


Figure 20. Simple bolted joint with axial tensile preload on bolt F_1 and axial tensile extrenal load on joint F_e.

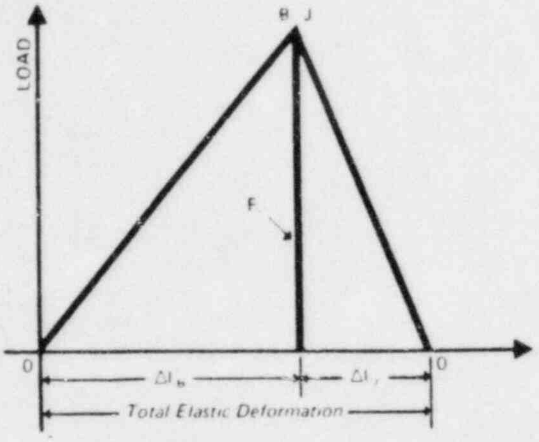


Figure 21. Load diagrams of bolt elongation and joint deformation.

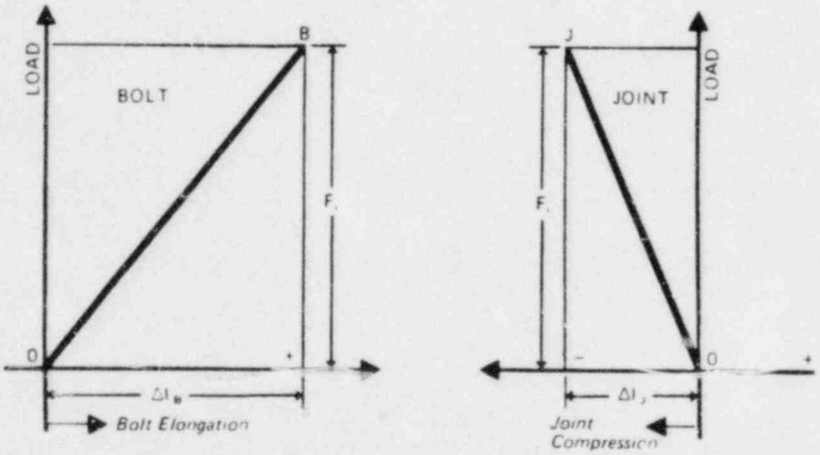


Figure 22. Joint diagram is obtained by combining load vs. deformation diagrams of bolt and joint.

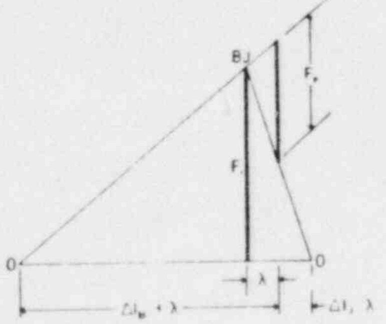


Figure 23. Simple joint diagram showing external load F_e added.

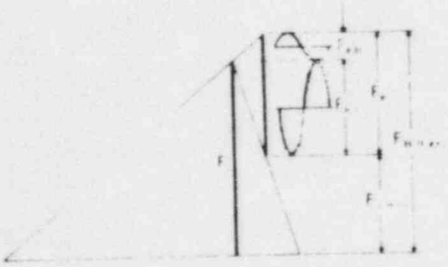


Figure 24. The external load divided into an additional bolt load, F_{eB}, and reduction in joint compression, F_{eJ}.

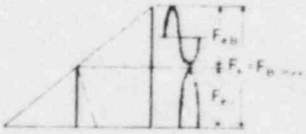


Figure 25. Joint diagram shows how insufficient preload F_i causes excessive additional bolt load, F_{eB}.

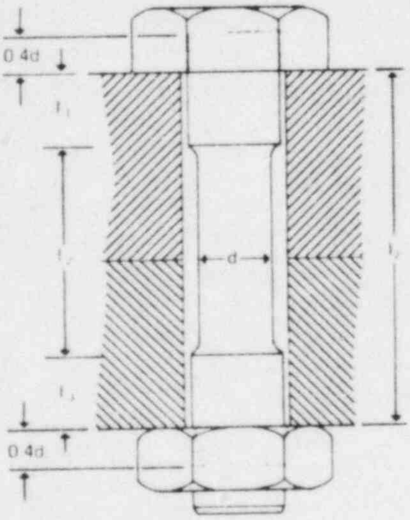


Figure 26. Analyses of bolt lengths contributing to the bolt spring rate.

increase in load at a level below the preload. As the working load is applied and they move, the fastener senses the change. Another type of problem centers around the joint in which an elastic member, such as a gasket, is used at the interface. Under conditions such as these, it becomes impossible to achieve metal-to-metal contact, and external joint loading is directly additive to the fastener preload.

The designer's problem is to calculate what elastic deformations and forces actually exist in the bolt when the joints are subjected to external tensile loads. To solve this problem, the designer may use a joint diagram.

The most important deformations within a joint are elastic bolt elongation and elastic joint compression in the axial direction. If the bolted joint in Figure 20 is subjected to the preload, F_1, the bolt elongates as shown by the line OB in Figure 21, and the joint compresses as shown by the line OJ.

These two lines, representing the spring characteristics of the bolt and joint, are combined into one diagram in Figure 22 to show total elastic deformation.

If a concentric external load, F_e, is applied under the bolt head and nut in Figure 20, the bolt elongates an additional amount while the compressed joint members partially relax. These changes in deformation with external loading are the key to interaction of forces in bolted joints.

In Figure 23, the external load, F_e, is added to the joint diagram. F_e is located on the diagram by applying the upper end of an extension of OB and moving it in until the lower end contacts OJ. Since the total amount of elastic deformation (bolt plus joint) remains constant for a given preload, the external load changes the total bolt elongation to $\Delta l_B + \lambda$ and the total joint compression to $\Delta l_J - \lambda$.

In Figure 24, the external load, F_e, is divided into an additional bolt load, F_{eB}, and the joint load, F_{eJ}, which unloads the compressed joint members. The maximum bolt load is the sum of the preload and the additional bolt load:

$$F_{B\ max} = F_1 + F_{eB}$$

If the external load, F_e, is an alternating load, F_{eB} is that part of F_e working as an alternating bolt load, as shown in Figure 24. This joint diagram also illustrates that the joint absorbs more of the external load than the bolt, a fact that is very important to the fatigue life of a bolt subjected to an alternating external load.

The importance of adequate preload is shown in Figure 25. Comparing Figures 24 and 25, it can be seen that F_{eB} will remain relatively small as long as the preload, F_1, is greater than F_{eJ}. Figure 25 represents a joint with insufficient preload. Under this condition, the amount of external load that the joint can absorb is limited, and the excess load must then be applied to the bolt. If the external load is alternating, the increased stress levels on the bolt produce a greatly shortened fatigue life.

When seating requires a certain minimum force or when transverse loads are to be transformed by friction, the minimum clamping load, $F_{J\ min}$, is important.

$$F_{J\ min} = F_{B\ max} - F_e$$

To construct a joint diagram, it is necessary to determine the spring rates of both the bolt and joint. In general, spring rate is defined as:

$$K = \frac{F}{\Delta l}$$

From Hook's law:

$$\Delta l = \frac{lF}{EA}$$

Therefore:

$$K = \frac{EA}{l}$$

To calculate the spring rate of bolts with different cross sections, the reciprocal spring rates, or compliances, of each section are added.

$$\frac{1}{K_B} = \frac{1}{K_1} + \frac{1}{K_2} + \ldots\ldots + \frac{1}{K_n}$$

Thus, for the bolt shown in Figure 26:

$$\frac{1}{K_B} = \frac{1}{E}\left(\frac{0.4d}{A_1} + \frac{l1}{A_1} + \frac{l2}{A_2} + \frac{l3}{A_m} + \frac{0.4d}{A_m}\right)$$

where: d = the minor thread diameter and
A_m = the area of the minor thread diameter

This formula considers the elastic deformation of the head and the engaged thread with a length of 0.4d each.

Calculation of the spring rate of the compressed joint members is more difficult because it is not always obvious which parts of the joint are deformed and which are not. In general, the spring rate of the clamped part is:

$$K_J = \frac{EA_s}{l_J}$$

where: A_s = the area of the substitute cylinder to be determined.

When the outside diameter of the joint is smaller than or equal to the bolt head diameter, for example, as in a thin bushing, the normal cross-sectioned area is computed:

$$A_s = \frac{\pi}{4}\left(D_c^2 - D_h^2\right)$$

where: D_c = outer diameter of cylinder or bushing and
D_h = hole diameter

When the outside diameter of the joint is larger than the head or washer diameter, D_H, the stress distribution is in the shape of a barrel, Figure 27.

A series of investigations proved that the areas of the following substitute cylinders are close approximations for calculating the spring constants of concentrically loaded joints.

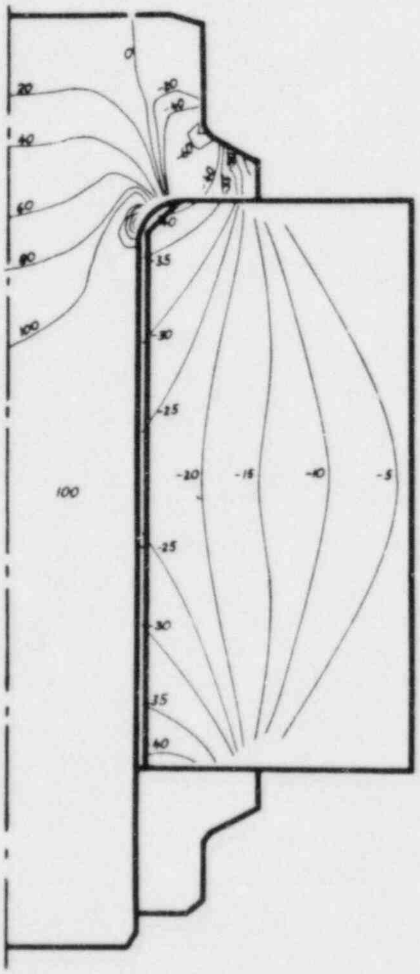


Figure 27. Lines of equal axial stresses in a bolt joint obtained by the axisymmetric finite-element method are shown for a 9/16-18 bolt preloaded to 100 ksi. Positive numbers are tensile stresses (ksi); negative numbers are compressive stresses (ksi).

When the joint diameter, D_J, is greater than D_H but less than $3D_H$:

$$A_s = \frac{\pi}{4}\left(D_H^{\,2} - D_h^{\,2}\right) + \frac{\pi}{8}\left(\frac{D_J}{D_H} - 1\right)\left(\frac{D_H\, l_J}{5} + \frac{l_J^{\,2}}{100.}\right)$$

When the joint diameter, D_J, is equal to or greater than $3D_H$:

$$A_s = \frac{\pi}{4}\left[\left(D_H + 0.1\, l_J\right)^2 - D_h^{\,2}\right]$$

These formulae have been verified in laboratories by the finite-element method and by experiments.

Figure 28 shows joint diagrams for a springy bolt and stiff joint and for a stiff bolt and springy joint. These diagrams demonstrate the desirability of desiging with a springy bolt and a stiff joint to obtain a low additional bolt load, F_{eB}, and thus a low alternating stress.

Due to the geometry of the joint diagram:

$$F_{eB} = \frac{F_e\, K_B}{K_B + K_J}$$

Defining $\Phi = \dfrac{\text{[illegible]}}{K_B + K_J}$

$F_{eB} = F_e\,\Phi$ and Φ, called the force ratio, $\dfrac{F_{eB}}{F_e}$

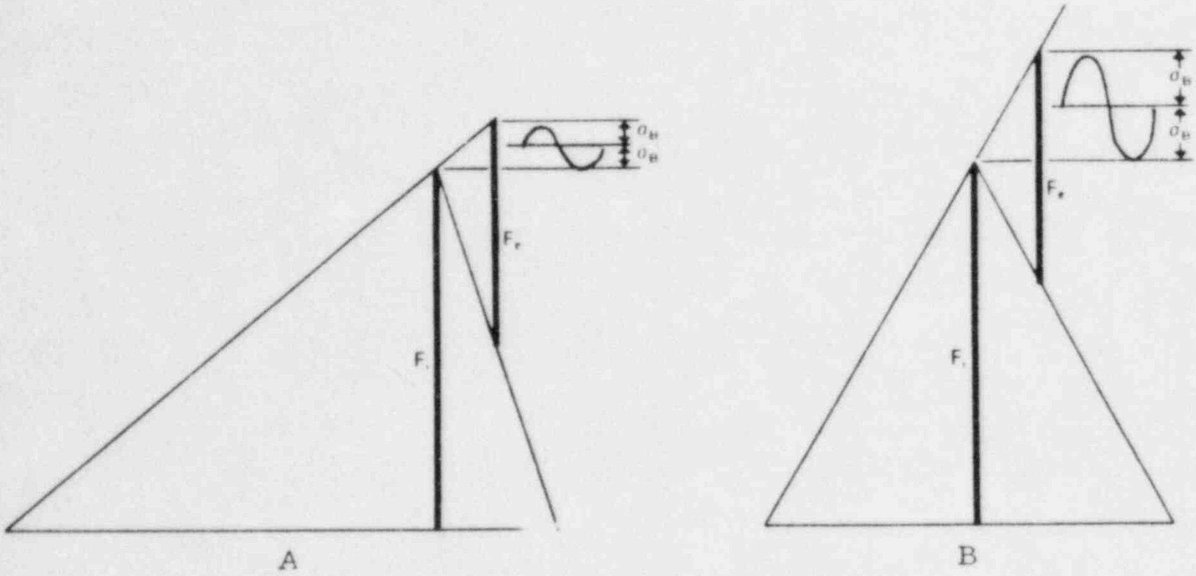


Figure 28. Joint diagram of a springy bolt in a stiff joint (A) is compared to a diagram of a stiff bolt in a springy joint (B). Preload F_1 and external load F_e are the same, but diagrams show that alternating bolt stresses are significantly lower with a spring bolt in a stiff joint.

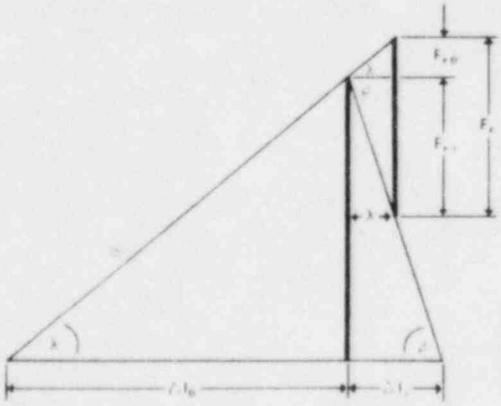


Figure 29. Analysis of external load, F_e, and derivation of force ratio.

For a complete derivation of Φ , see Figure 29.

To assure adequate fatigue strength of the selected fastener, the fatigue stress amplitude of the bolt resulting from an external load, F_e is computed:

$$\sigma_B = \pm \frac{F_{eB}}{A_m} \quad \text{or} \quad \sigma_B = \pm \frac{F_e}{2A_m}$$

$$\tan = \frac{F_i}{\Delta I_B} = K_B \quad \text{and} \quad \tan = \frac{F_i}{\Delta I_J} = K_J$$

$$\lambda = \frac{F_{eB}}{\tan a} = \frac{F_{eJ}}{\tan B} = \frac{F_{eB}}{K_B} = \frac{F_{eJ}}{K_J} \quad \text{or}$$

$$F_{eJ} = \lambda \tan B \quad \text{and} \quad F_{eB} = \lambda \tan a$$

Since $$F_e = F_{eB} + F_{eJ}$$

$$F_e = F_{eB} + \lambda \tan B$$

Substituting $\frac{F_{eB}}{\tan a}$ for λ produces:

$$F_e = F_{eB} + \frac{F_{eB} \tan B}{\tan a}$$

Multiplying both side by tan a:

$$F_e \tan a = F_{eB} (\tan a + \tan B) \quad \text{and} \quad F_{eB} = \frac{F_e \tan a}{\tan a \quad \tan B}$$

Substituting K_B for tan a and K_J for tan B:

$$F_{eB} = F_e \frac{K_B}{K_B + K_J}$$

Defining $$\Phi = \frac{K_B \quad K_B}{K_B + K_J}$$

$$F_{eB} = \Phi F_e$$

$$\Phi = \frac{F_{eB}}{F_e}$$ and it becomes obvious why Φ is called the force ratio.

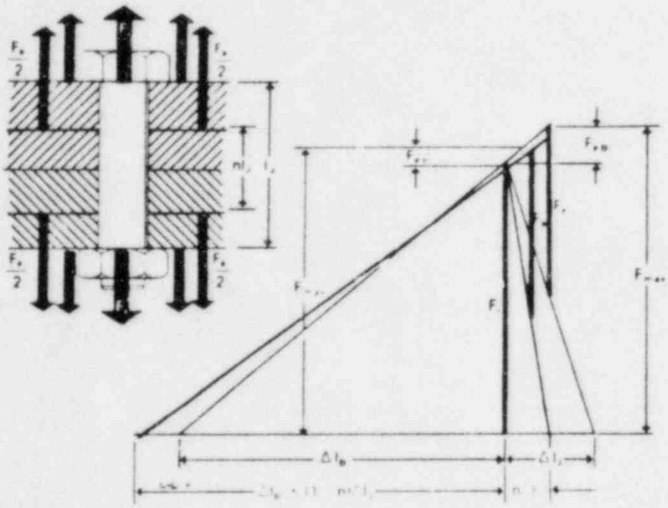


Figure 30. Joint diagram shows effect of loading planes of F_e on bolt loads F_{eB} and $F_{b\ max}$ resulting from F_e applied in planes 1 and 4. The diagram shows reduced bolt loads when F_e is applied in planes 2 and 3.

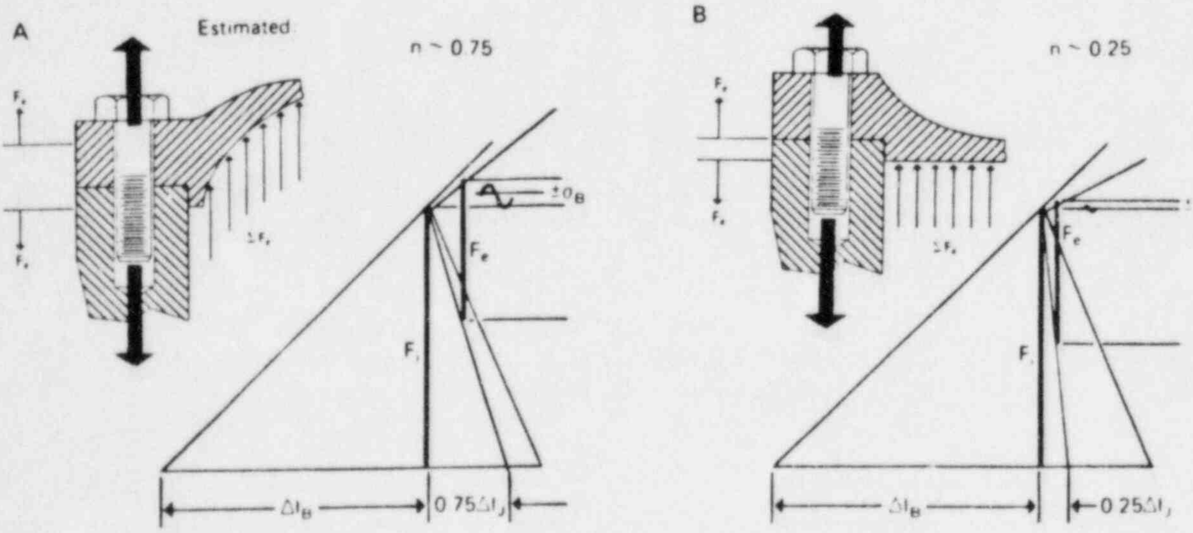


Figure 31. When external load is applied relatively near the bolt head, the joint diagram shows the resulting alternating stress $_B$ (A). When the same value of external load is applied relatively near the joint's center, lower alternating stress results (B).

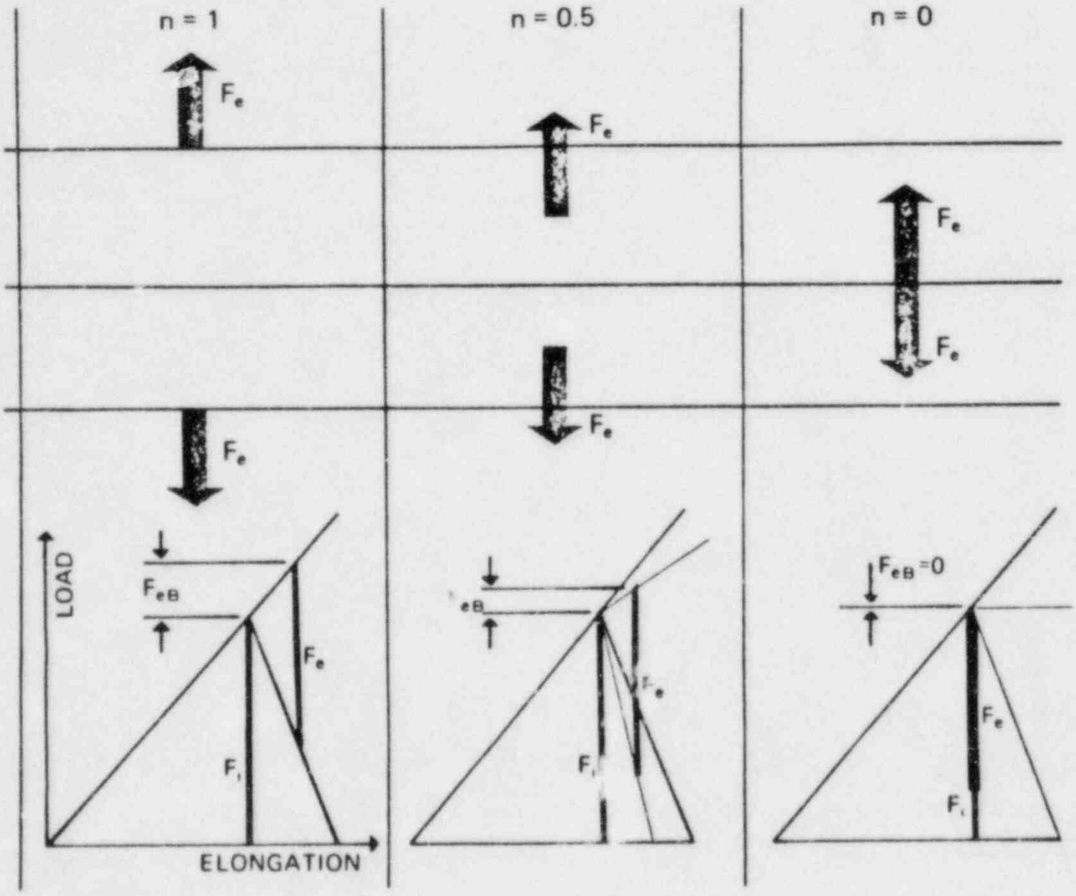


Figure 32. Force diagrams show the effect of the loading planes to the external load on the bolt load.

The joint diagrams in Figures 25, 28 and 29 are applicable only when the external load, F_e, is applied at the same loading planes as the preload, F_1, under the bolt head and nut. However, this is a rare case because the external load usually affects the joint somewhere between the center of the joint and the head and the nut.

When a preloaded joint is subjected to an external load, F_e, at loading planes 2 and 3 in Figure 30, F_e relieves the compression load of the joint parts between planes 2 and 3.

The remainder of the system (the bolt and the joint parts between planes 1-2 and 3-4) feels additional load due to F_e. Therefore, it is necessary to distinguish between clamped and clamping parts. In the case of external load F_e applied in planes 2 and 3, the joint material between planes 2 and 3 is the clamped part, and all other joint members, fastener and remaining joint material, are the clamping parts. Because of the location of the loading planes, the joint diagram changes from the short line to the long line. Consequently, both the additional bolt load, $F_{eB\ max}$, decreases significantly when the loading planes of F_e shift from under the bolt head and nut toward the joint's center.

Determination of the length of the clamped part is, however, not that simple. First, it is assumed that the external load is applied at a plane perpendicular to the bolt axis. Second, the distance of the loading planes from each other must be estimated. This distance may be expressed as the ratio of the length of clamped parts to the total joint length. Figure 31 shows the effect of two different loading planes on the bolt load, both joints having the same preload, F_1. The lengths of the clamped parts are estimated to be $0.75l_J$ for joint A and $0.25l_J$ for joint B.

In general, the external bolt load is somewhere between $F_{eB} = 1\,\Phi\,F_e$ for loading planes under head and nut, and $F_{eB} = 0\,\Phi\,F_e = 0$ when loading planes are in the joint center (Figure 32). To consider the loading planes in calculations, the formula, $F_{eB} = \Phi F_e$ must be modified to $F_{eB} = n\Phi F_e$ where n equals the ratio of the length of the clamped parts due to F_e to the joint length, $_J$. The value of n can range from one, when F_e is applied under the head and nut, to zero, when F_e is applied at the joint's center. Consequently, the stress amplitude:

$$\sigma_B = \pm \frac{\Phi F_e}{2A_m} \quad \text{becomes}$$

$$B = \pm \frac{n\,\Phi\,F_e}{2A_m}$$

Previously, construction of the joint diagram has assumed linear resilience of both the bolt and joint members. However, investigations have shown that this assumption is not quite true for compressed parts. Considering this, the joint diagram is modified to Figure 33. The lower portion of the joint's spring rate is nonlinear, and the length of the linear portion depends on the preload level, F_1. The higher F_1, the longer the linear portion. By choosing a sufficiently high minimum load, $F_{min} > 2F_e$, the nonlinear range of the joint's spring rate is avoided, and a linear relationship between F_{eB} and F_e is maintained.

Also from Figure 33 the following formula is derived:

$$F_{1\ min} = F_{J\ min} + (1 - \Phi)F_e + \Delta F_1$$

where F_1 is the amount of preload loss to be expected. For a properly designed joint, a preload loss, $F_1 = -(0.005 \text{ to } 0.10)F_1$, should be expected.

The fluctuation in bolt load that results from tightening is expressed by the ratio:

$$a = \frac{F_{1\ max}}{F_{1\ min}}$$

where a varies between 1.25 and 3.0 depending on the tightening method.

General design formula are:

$$F_{1\ nom} = F_{J\ min} + (1 - \Phi)F_w$$

$$F_1\ max = a\left[F_{J\ min} + (1 - \Phi)F_e + \Delta F_1\right]$$

$$F_B\ max = a\left[F_{J\ min} + (1 - \Phi)F_e + \Delta F_1\right] + \Phi F_e$$

The three requirements of concentrically-loaded joints that must be met for an integral bolted joint are:

1. The maximum bolt load, $F_{B\ max}$, must be less than the bolt's yield strength.
2. If the external load is alternating, the alternating stress must be less than the bolt's endurance limit to avoid fatigue failures.
3. The joint will not lose any preload due to permanent set or vibration greater than the value assumed for ΔF_1.

TABLE V

Symbols Used in Joint Diagrams and Analysis

A	Area (in.^{2})
A_m	Area of minor thread diameter (in.^{2})
A_s	Area of substitute cylinder (in.^{2})
A_x	Area of bolt part l_x (in.^{2})
d	Diameter of minor thread (in.)
D_c	Outside diameter of bushing (cylinder) (in.)
D_w	Diameter of Bolt head (in.)
D_h	Diameter of hole (in.)
D_J	Diameter of Joint
E	Modulus of Elasticity (psi)
F	Load (lb)
F_e	External load (lb)
F_{eB}	Additional Bolt Load due to external load (lb)
F_{eJ}	Reduced Joint load due to external load (lb)
F_i	Preload on Bolt and Joint (lb)
ΔF_i	Preload loss (- lb)
$F_{i\,min}$	Minimum preload (lb)
$F_{i\,max}$	Maximum preload (lb)
$F_{i\,nom}$	Nominal preload (lb)

$F_{B\,max}$	Maximum Bolt load (lb)
$F_{J\,min}$	Minimum Joint load (lb)
K	Spring rate (lb/in.)
K_B	Spring rate of Bolt (lb/in.)
K_J	Spring rate of Joint (lb/in.)
K_x	Spring rate of Bolt part l_x (lb/in.)
l	Length (in.)
Δl	Change in length (in.)
l_B	Length of Bolt (in.)
Δl_B	Bolt elongation due to F_i (in.)
l_J	Length of Joint (in.)
Δl_J	Joint compression due to F_i (in.)
l_x	Length of Bolt part x (in.)
n	$\frac{\text{Length of clamped parts}}{\text{Total Joint length}}$ (---)
α	Tightening factor (---)
Φ	Force ratio (---)
λ	Bolt and Joint elongation due to F_e (in.)
σ_B	Bolt stress amplitude (± psi)

FASTENED JOINT PERMANENT SET THEORY :

There are many factors which tend to destroy the initial preload -- to name a few: permanent set, alternating load, vibration, bending and temperature.

The designer must be aware of these influences in order to avoid their detrimental effect on the finished product.

Permanent set is defined as all plastic deformation within the mating and exposed threads, on bolt and nut bearing surfaces, and on all other interfaces. Permanent set can occur from elongating the bolt beyond its yield point during tightening, overloading from external loads, and embedding the relaxation due to normal service conditions.

TABLE VI

Main Effects and their Order of Influence on
the Amount of Permanent Set "S"

	Range of Factors		Effect on "S"	Order of Influence
	High	Low		
Joint Hardness, HB	180	260	18.3	1
Preload, ksi	180	100	11.8	2
Thread Fit	0.44	0.75	10.3	3
Number of Interfaces	6	2	9.1	4
Nut Type	6	1	8.7	5
Bearing Stress, ksi	100	70	8.6	6
Nut Hardness, R_C	26	46	4.4	7
Bending, ^{o}/inch	1	0	2.8	8

Load distribution in loaded nut and bolt threads is nonuniform and causes very high stresses in the higher-loaded thread elements. These stresses can result in local plastic deformations and bending of the threads, the amount of deformation being a function of the thread clearance.

F. O. Kwami proved that there is no significant difference in preload loss whether the applied external load is static or dynamic. The greatest amount of permanent set occurs during tightening. Approximately 80% of the set occurs after the first loading by a stati or dynamic service load, while the remaining 20% is caused by further loading or relaxation.

Published guidelines suggest a permanent set of 80 $_u$in. per joint interface for smooth surfaces, (less than 60 $_u$in. rms) 160 $_u$in. per interface for rough surfaces, and an average of 200 $_u$in. for the nut and bolt threads should be expected.

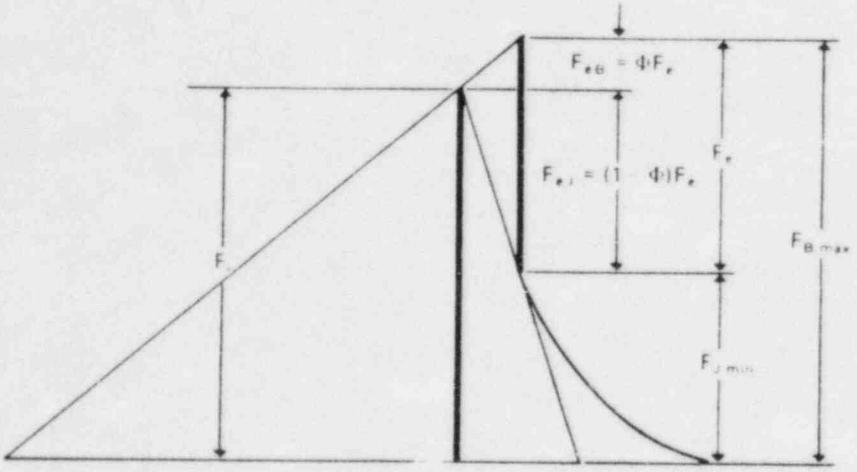
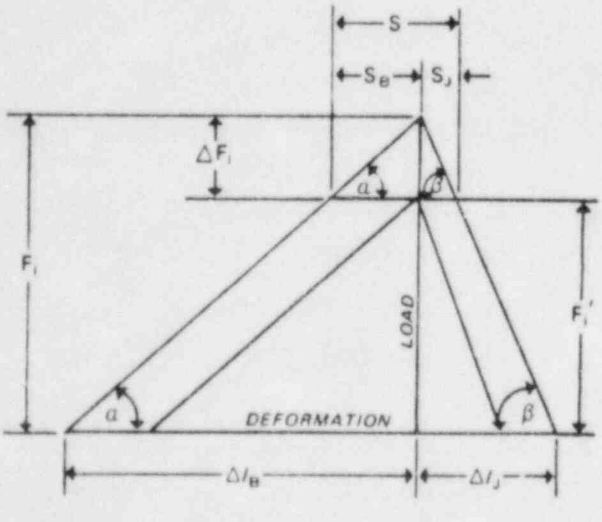


Figure 33. Modified joint diagram shows nonlinear compression of joint at low preloads.



$$\tan \alpha = K_B = \frac{\Delta F_i}{S_B}\text{, therefore } S_B = \frac{\Delta F_i}{K_B}$$

$$\tan \beta = K_J = \frac{\Delta F_i}{S_J}\text{, therefore } S_J = \frac{\Delta F_i}{K_J}$$

$$S = S_B + S_J = \frac{\Delta F_i}{K_B} + \frac{\Delta F_i}{K_J}$$

$$SK_B = \Delta F_i + \frac{\Delta F_i K_B}{K_J}$$

$$S(K_B K_J) = \Delta F_i K_J + \Delta F_i K_B$$

$$= \Delta F_i (K_J + K_B)$$

$$\Delta F_i = S\left(\frac{K_B K_J}{K_B + K_J}\right) \quad \text{defining} \left(\frac{K_B K_J}{K_B + K_J}\right) = K$$

$$\Delta F_i = SK$$

Figure 34. Diagram shows joint diagram immediately after preloading and after preload loss due to permanent set. Derivation shows that preload loss F_i is equal to permanent set, S, times spring rate ratio, K.

The sum of these plastic deformations, the permanent set, has to be compensated by the elastic elongation and compression of the preloaded bolt and joint. As shown in Figure 34, the preload loss, AF_i, is directly proportional to the amount of permanent set, S, and the total joint spring rate, K: $AF_i = SK$.

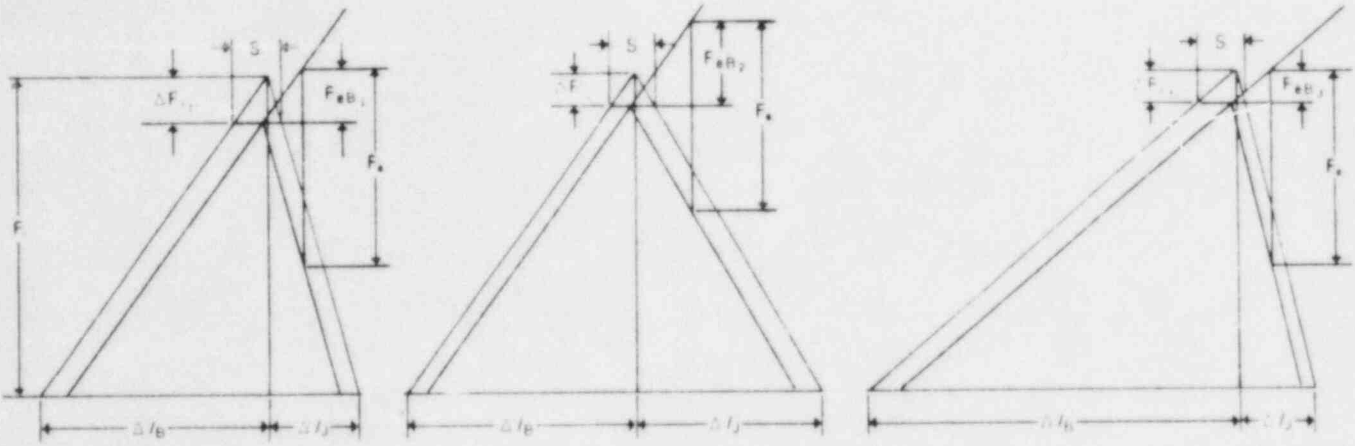
How can the effect of permanent set on preload be minimized? Figure 35 shows diagrams of three bolted joint designs, all having the same preload, F_i; the same external load, F_e; and the same permanent set, S. Increasing the flexibility of both the bolt and clamped parts reduces the preload loss caused by the permanent set, ($\Delta F_{i2} < \Delta F_{i1}$).However, if the elasticity is created mostly by the clamped joint members, the additional bolt load, F_{eB}, increases significantly, ($F_{eB2} > F_{eB1}$) raising the possibility of bolt fatigue failures, Figure 35b. Therefore, a springy bolt and stiff clamped parts as in Figure 35c, are the best design for minimizing preload loss as well as dynamic bolt loads, ($F_{eB3} < F_{eB1}$ and $\Delta F_{i3} < \Delta F_{i_1}$).

Confusion exists on how much preload loss will occur when a bolt is tightened beyond its yield strength. Various papers indicate that bolted joints can be tightened safely beyond the yield strength of the bolt. The main advantage of this is the assurance that the bolt is always tightened to the highest possible preload. When tightening beyond the yield strength, an additional amount of plastic bolt elongation is created, but this is compensated immediately by further tightening. However, an additional external load causes further plastic elongation, S', which creates a preload loss, $\Delta F'_i$.

Figure 36 shows that the total amount of preload loss in the elastic-plastic joint is greater than the elastic joint due to the plastic bolt elongation, S'. However, the remaining load, $F_{j\ min}$, (which is the important clamping load), is significantly higher than in the elastic joint because of the high (maximum) preload. A similar situation exists when a bolt is tightened to the end of the elastic range and external loading causes plastic elongation. If the bolt has enough ductility to yield without crack initiation, this preloading technique is a safe method to achieve good functional joint.

To develop an equation to calculate the amount of permanent set, a test program was designed to use the joint and fastener configuration, surface finish, hardness levels, and load application as functions of permanent set.

The technique used to plan the tests and analyze the results is known as a "factorial experiment." This method allows the influence of many variables to be evaluated quantitatively. After the independent variables of interest are selected, a high and a low value are chosen for each variable. The particular values chosen should have a large



A Medium stiff bolt and joint: Average values for ΔF_i and F_{eB}

B Medium stiff bolt but springy joint. Small ΔF_i but large F_{eB}

C Springy bolt with medium stiff joint. Small ΔF_i and small F_{eB}

Figure 35. The effect of bolt and joint stiffness on preload loss and external load absorbed by the bolt.

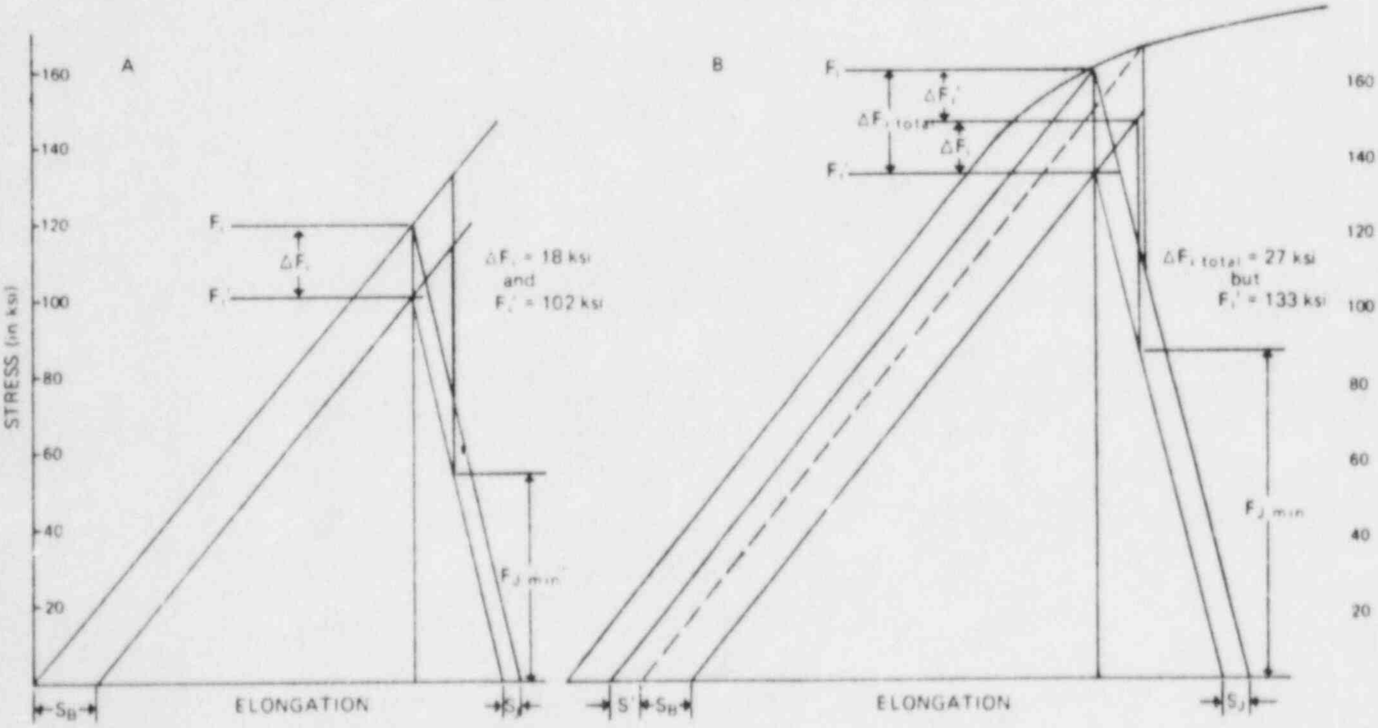


Figure 36. Comparison of preload loss and remaining load in elastic joint (left) and elastic-plastic joint (right).

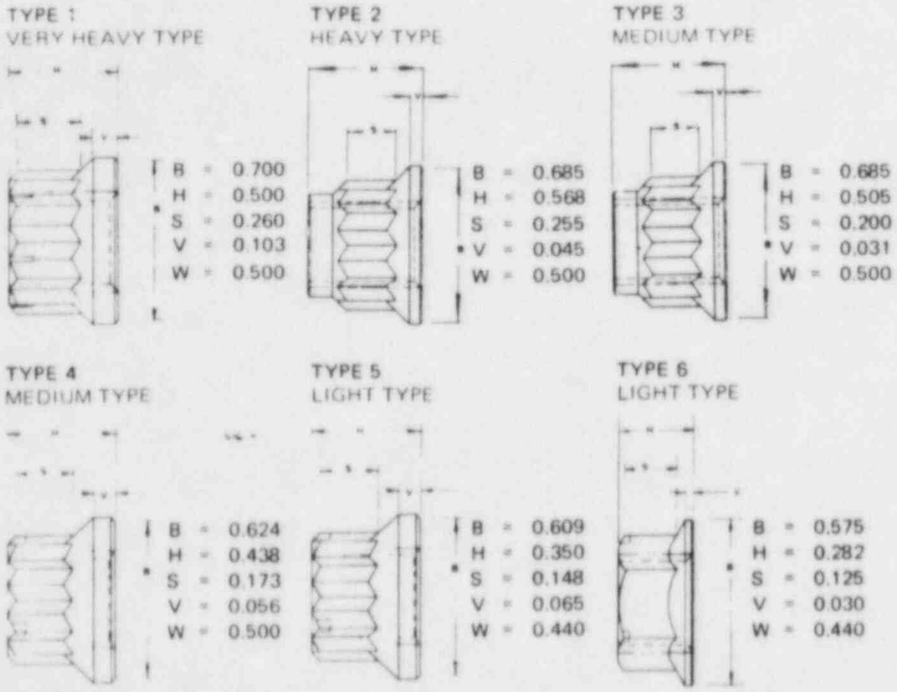


Figure 37. For the purpose of calculating preload loss due to permanent set, aircraft nuts are classified into six types. (Measurements refer to 3/8" nut.)

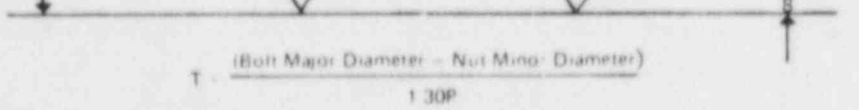
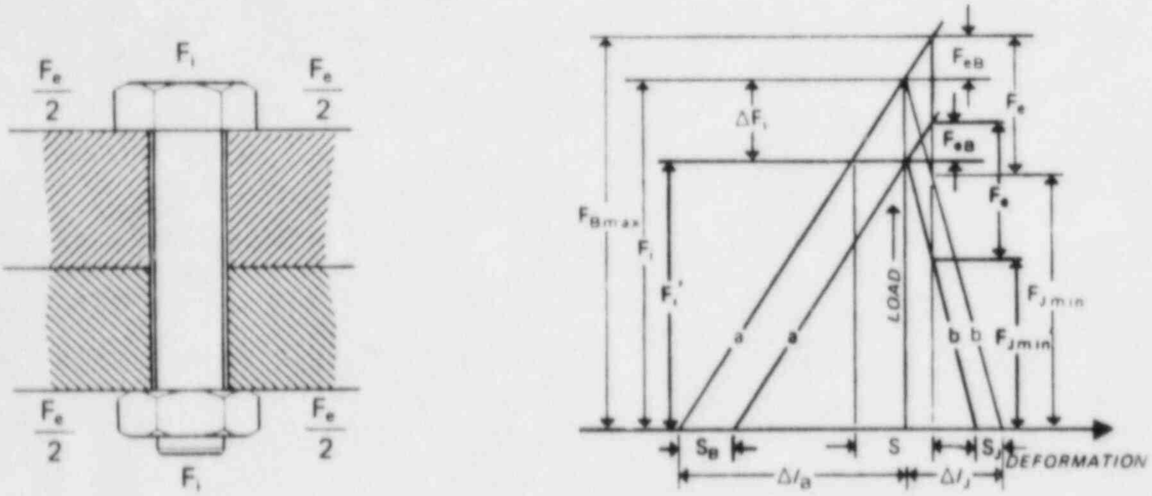


Figure 38. Derivation of thread overlapping ratio, T.

TABLE VII

Reaction of Preload, F_i, and External Load, F_e, on Bolted Joint (Left) and Load vs. Elongation Diagram for Bolted Joint (Right)



Symbols	
a	Load vs. Elongation curve of Bolt
A_m	Area of minor thread diameter (in.^{2})
A_S	Stress area (in.^{2})
b	Load vs. Compression curve of Joint
$^\circ B$	Bending effect–Angle between joint and bolt head or nut per inch of joint length ($^\circ$/in.)
C_n	Nut Configuration, type
D	Nominal Bolt Diameter (in.)
$F_{B\,max}$	Maximum Bolt Load (lb) ($F_{B\,max} = F_i + F_{eB}$)
F_e	External Load (lb)
F_{eB}	Additional Bolt load from External Load (lb)
F_i	Preload on Bolt and Joint (lb)
F_i'	Remaining preload after loss due to permanent set (lb) ($F_i' = F_i - \Delta F_i$)
ΔF_i	Preload Loss due to Permanent Set (lb)
$\Delta F_i'$	Preload Loss due to Permanent Set from plastic deformation of bolt (in.)
$\Delta F_{i\,total}$	Total Preload loss due to Permanent Set (in.) (ΔF_i total $= \Delta F_i + \Delta F_i'$)
$F_{J\,min}$	Minimum clamping force on joint (lb) ($F_{J\,min} = F_{B\,max} - F_e$)
$F_{J\,min}'$	Remaining minimum clan ping force on joint after preload loss (lb) ($F_{J\,min}' = F_{J\,min} - \Delta F_i$)
h	Nut height (in.)

Symbols	
h/D	Nut height ratio
H_J	Joint Hardness (Brinell)
H_N	Nut Hardness (Brinell or R_c)
K	Spring Rate Ratio (lb/in.) $\left(K = \frac{K_B K_J}{K_B + K_J}\right)$
K_B	Spring Rate of Bolt (lb/in.)
K_J	Spring Rate of Joint (lb/in.)
Δl_B	Elastic Bolt Elongation due to Preload (in.)
Δl_J	Elastic Joint Compression due to Preload (in.)
N	Number of interfaces in bolted joint
P	Thread Pitch (in.)
R	Surface finish (μin. rms)
S	Permanent Set (μin.)
S_B	Permanent Set in Bolt (μin.)
S_J	Permanent Set in Joint (μin.)
S'	Permanent Set due to Plastic Deformation of Bolt (μin.)
T	Ratio of Diametrical thread overlapping to theoretical thread depth.
σ_a'	Fatigue Stress Amplitude (ksi) $\left(\sigma_a = \pm \frac{F_{eB}}{2\,A_m}\right)$
σ_b	Bearing Stress (ksi)
σ_i	Prestress due to Preload (ksi) $\left(\sigma_i = \frac{F_i}{A_s}\right)$

TABLE VIII

Factors and Range of Factors Tested for Industrial Fasteners

Test Factors	Test Range High	 Low	 Average
Preload stress in ksi	110	90	100
Number of interfaces	4	2	3
Thread overlapping ratio	0.61	0.78	0.7
Nut height ratio	0.9	1.1	1.0
Surface finish in uin. rms.	70	50	60
Joint hardness in Brinell	216	264	240
Nut hardness in Brinell	204	257	230
Bending slope in degress per in. length	1.2	0.0	0.6
Fatigue stress amplitude in ksi	---	---	± 9

TABLE IX

Factors and Range of Factors Tested for Aircraft Fasteners

Test Factors	Test Range High	 Low	 Average
Preload stress in ksi	130	110	120
Number of interfaces	5	3	4
Thread overlapping ratio	0.56	0.64	0.60
Nut configuration, type	5	3	4
Bearing stress in ksi	95	85	90
Joint hardness in Brinell	185	255	220
Nut hardness in Rockwell C	36	44	40
Bending slope in degrees per in. length	1.0	0.0	0.5
Surface finish in uin. rms.	---	---	50
Fatigue stress amplitude in ksi	---	---	+15

and a small influence respectively on the independent variable, which, for the tests in question, was permanent set. While the high and low values are selected arbitrarily, they should be chosen with judgement and respect to realistic conditions.

Separate factorial experiments were conducted for industrial and aircraft joints. The factors selected and the high and low test values are shown in Tables VIII and IX. Since preliminary tests showed no significant influence from thread pitch, that is, coarse or fine threads, this factor was not investigated.

Nut height was expressed as the ratio of nut height to nominal thread diameter in the industrial-joint study. The aircraft-joint study rated nuts according to their height, flange diameter, and mass, in order from one to six, Figure 37. Because of the existing variety of aircraft nuts, nut height was included in this rating. When using the resultant formula, a designer must estimate which nut type (shown in Figure 37) best approximates the nut he intends to use. Thread engagement for both studies was expressed as the ratio of the diametrical overlapping of bolt and nut threads to the thoretical thread overlapping of bolt and nut threads to the theoretical thread depth, h, as explained in Figure 38.

The test plan selected limits the number of variables to eight. For this reason, and because the surface finish had proved to be of negligible influence in the industrial-joint study, surface finish was eliminated as a variable in the aircraft-joint study and replaced by the bearing stress in the nut which it was felt would strongly affect permanent set due to the higher loads common in an aircraft joint. The surface finish was kept constant at 50 $_{u}$in. for the aircraft-joint tests.

In the experimental plan, a series of tests generally is designed to use all possible combinations of the eight test variables at their high and low test levels. Since the number of resulting test conditions was too large to be performed under reasonable uniform conditions, a fractional factorial design was used for the test evaluations, and the results were analyzed according to the Yates analysis. Each test group consisted of five test joints and, since the factorial design required sixteen test groups, eighty tests were run for both the industrial and aircraft joints.

The tests were performed on 1/2-13 industrial fasteners and on 3/8-24 aircraft fasteners. The results for industrial fasteners were later verified by tests on 3/8-16 and 3/4-10 fasteners. A photograph of the test joint is shown in Figure 39. The joint consists of a strain-gaged load cell and two hardened threaded bushings in which the test material was inserted. The preloaded joint was installed in a 60,000 lb. tensile test machine and loaded five times with an external load. Preload loss due to permanent set, as measured by the load cell, was recorded with a digital strain indicator.

Figure 40 shows typical curves of preload loss due to permanent set as a function of the number of external load applications depending on the test conditions; the expected preload loss is smaller or larger as indicated by the band. Both amount and range of preload loss are larger in aircraft fasteners than in industrial fasteners, because of the higher bolt loads experienced in aircraft joints. For unfavorable conditions, that is, stiff fastener joints and a large amount of set, the preload loss can reach as high as 25%. Figure 40 further proves that most of the set, about 95% occurs during the very first cycles of an external load.

From the data evaluated by the Yates method of analysis, two equations were derived to predict the amount of permanent set as a function of eight variables and the applied alternating load. These equations, shown in Tables X and XI, were the most significant result of this investigation and were arranged in the order of influence of the eight variables on permanent set. The first term represents the most influential variable and the last term, the least.

The factors with the greatest effect are the number of joint interfaces in an industrial connection and the joint hardness in an aircraft connection. Fastener preload has the second highest effect on the set in both industrial and aircraft joints. The remaining clamp load, however, will always be higher for a high preloaded joint than it will be for a low preloaded joint.

Since all test results are based on experimental data obtained under predetermined conditions, certain correction factors are required for conditions outside the test limits. The following factors were determined experimentally.

1. Because the main tests for industrial fasteners were performed with 1/2-13 socket head cap screws, the maximum bearing stress under the bolt head due to the maximum preload and the alternating load was 90 ksi. If bearing stresses are higher than 90 ksi because of smaller bearing areas, more permanent set will occur, and the predicted set must be corrected by a factor F minus actual bearing stress, 90 ksi.

2. Additional tests with fasteners in 3/8-16 and 3/4-10 sizes indicated that the formulae give correct values of permanent set for fasteners smaller than 1/2", but for larger sized fasteners, the calculated set must be corrected by a factor of 1.25.

3. If the nut material is aluminum 2024T3, more set will occur than with steel nuts, and the calculated set should be corrected by a factor of 1.15.

4. Joint material has no significant influence on permanent set as long as the appropriate hardness values are considered and the material's compressive yield strength is sufficient to stand the applied bearing stress.

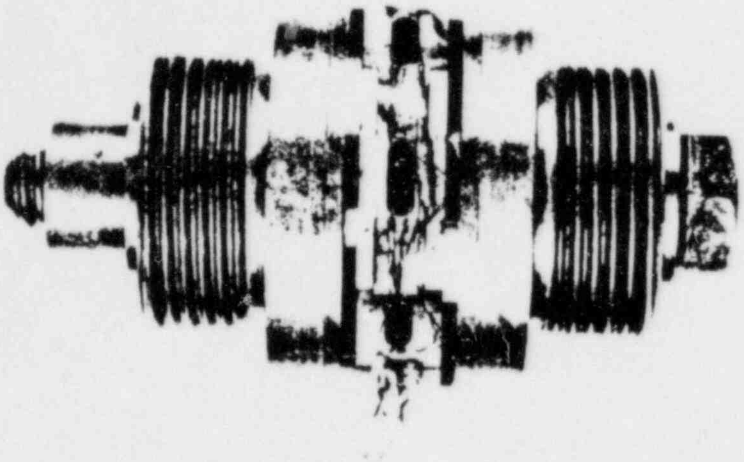


Figure 39. Strain-gaged test joint used in deriving preload and preload-loss formulae.

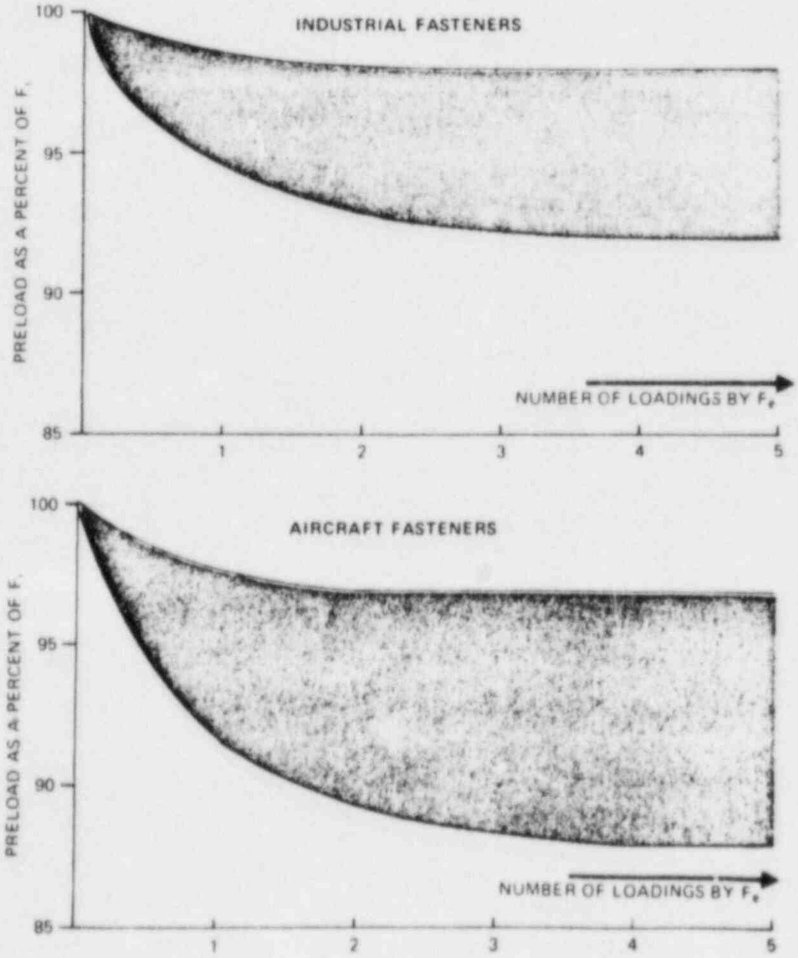


Figure 40. Typical ranges of preload loss due to permanent set as a function of loadin by F_e.

TABLE X

Equation for Calculating Permanent Set in Industrial Fasteners

$$S\,\mu\text{in.} = \left[\begin{array}{l} 32.6 \\ +\ 4.8\,(N - 3) \\ +\ 0.44\,(\sigma_i - 100) \\ +\ 11.2\,(^\circ B - 0.6) \\ +\ 22.8\,(0.7 - T) \\ +\ 0.10\,(230 - H_N) \\ +\ 0.06\,(240 - H_J) \\ +\ 13.4\,(1 - \frac{h}{D}) \\ +\ 0.40\,(R - 60) \end{array}\right] \sigma_a$$

TABLE XI

Equation for Calculating Permanent Set in Aircraft Fasteners

$$S\,\mu\text{in.} = \left[\begin{array}{l} 48.C \\ +\ 0.48\,(220 - H_J) \\ +\ 0.24\,(\sigma_i - 120) \\ +\ 71.0\,(0.6 - T) \\ +\ 4.8\,(N - 4) \\ +\ 3.2\,(C_N - 4)\,4) \\ +\ 0.58\,(\sigma_b - 90) \\ +\ 0.44\,(40 - H_N) \\ +\ 7.0\,(^\circ B - 0.5) \end{array}\right] \sigma_a$$

where:

A_m	Area of minor thread diameter (in.^{2})
A_s	Stress area (in.^{2})
$^\circ B$	Bending effect—Angle between joint and bolt head or nut per inch of joint length (°/in.)
C_N	Nut Configuration, type
D	Nominal Bolt Diameter (in.)
F_e	External Load (lb.)
F_{eL}	Additional bolt load from External load (lb)
F_i	Preload on Bolt and Joint (lb)
h	Nut height (in.)
h/D	Nut height ratio
H_B	Bolt Hardness (Brinell or R_c)
H_J	Joint Hardness (Brinell)
H_N	Nut Hardness (Brinell or R_c)
l_B	Bolt length (in.)
l_J	Joint length (in.)
l_T	Length of engaged threads (in.)
N	Number of interfaces in bolted joint
R	Surface finish (μin. rms)
S	Permanent Set (μin.)
T	Ratio of diametrical thread overlapping to theoretical thread depth.
σ_a	Fatigue Stress Amplitude (ksi) $\sigma_a = \frac{\pm F_{eB}}{2A_m}$
σ_b	Bearing Stress (ksi)
σ_i	Prestress due to Preload (ksi) $\sigma_i = \frac{F_i}{A_s}$

The equation for aircraft fasteners does not contain a term for the surface finish. However, the equation does contain the effect of a surface roughness 50 $_u$inch.

Transverse and combined external loads which have little or no axial components cause higher preload loss than pure axial external loads. Therefore, for these joints, considering the various joint properties, but assuming a high alternating load, that is, σ_a = +10 ksi for industrial fasteners and about +20 ksi for aircraft fasteners.

If a joint consists of materials with different hardness levels under the bolt and nut, an average hardness value should be used for calculating permanent set. For industrial joints, if the Brinell hardness of the nut or joint is higher than HB = 260, use 260 for the preload loss prediction. The corresponding values for aircraft joints are Rc 45 for the nut and HB 260 for the joint. If the nut height exceeds 1.4 times the nominal diameter, use h = 1.4D for the calculation. For minimum values in height and hardness, the nut must stand the proof load test.

In order to facilitate the determination of permanent set for a given joint, nomographs were designed, based on the developed equations (Figures 41 and 42).

The equations in Tables X and XI are based on a linear relationship between permanent set and alternating bolt stress. The test results show, however, that the true relationship is nonlinear, so that the equation only approximates the true behavior and is absolutely correct only at the test levels of +9 ksi and +15 ksi for industrial and aircraft joints, respectively. The predictions of permanent set tend to be slightly too high for bolt stress values smaller than the test levels and slightly too low for bolt stress values larger than the test levels. This fact has been considered in the nomographs, Figures 41 and 42, by spreading the bolt stress curves about +9ksi and +15 ksi, respectively.

To convert the permanent set to preload loss values, it is necessary to consider the bolt and joint stiffness. Therefore, Figures 43 and 44 present nomographs to determine preload loss from permanent set as a function of the joint stiffness. These nomographs were designed for socket head cap screws and hex-head screws installed in steel plates (Figure 43) and for aircraft fasteners with bolt and nut flange diameters of 1.8 times bolt diameter (Figure 44). The holes are assumed to be equal to the bolt diameter plus twice the fillet radius. For other joint types, that is, bolts with reduced shanks or other materials such as aluminum, the spring rate is different and must be adjusted accordingly.

The joint conditions required to minimize permanent set are:

1. Small number of interfaces.
2. Perpendicular parts with no bending.
3. Tight thread engagement.
4. Sufficient nut hardness, $H_N > 0.75H_B$.
5. Sufficient joint hardness to avoid embedding during tightening if $\sigma_a > 10$ ksi. If $\sigma_a < 10$ ksi, 0.002 embedding during tightening is permitted.
6. Low bearing stresses, < 90 ksi over large bearing areas.
7. Sufficient length of engaged thread for steel: $l_T > 0.8D$.
8. Heavy nut type (see Figure 37, type I).
9. Smooth surface finish.
10. No gaskets or plastics within joint interfaces.
11. No spring washers for high-strength bolts.

Joint designs to minimize preload loss due to permanent set are:

1. Use of high-strength bolts and high preload.
2. Long bolts, $l_B > 5D$.
3. Reduced bolt shank diameter.
4. Longer joint length or additional bushing.
5. Elastic bolt head and/or elastic nut.
6. Materials with low moduli of elasticity.
7. Hardened washer, if bearing stress is very high (> 90 ksi).

With the development of the "preload loss equation" it is possible to predict the amount of permanent set and thus the preload loss for a given joint. The nomographs given in Figures 41 - 44 facilitate the prediction of preload loss in either industrial or aircraft fasteners.

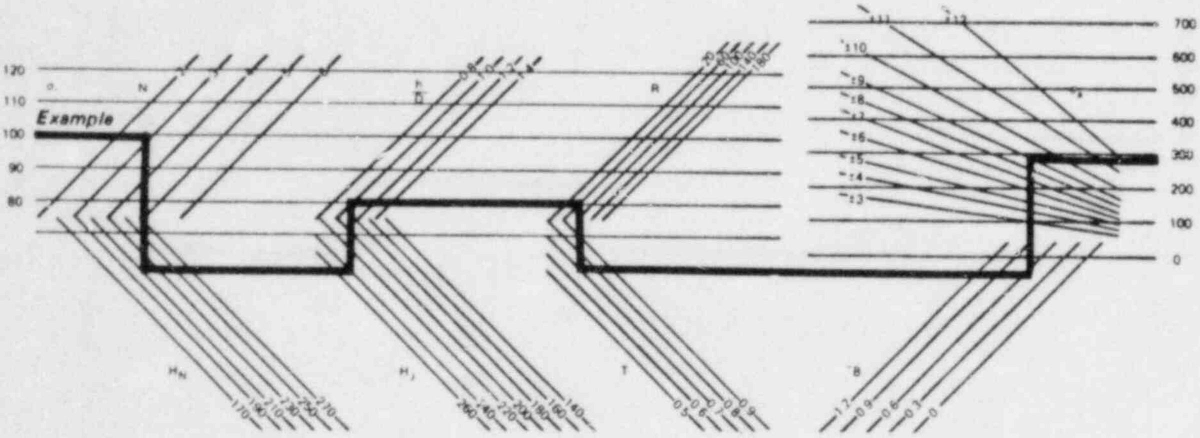


Figure 41. Amount of permanent set in industrial fasteners smaller than 1" in diameter as a function of eight variables.

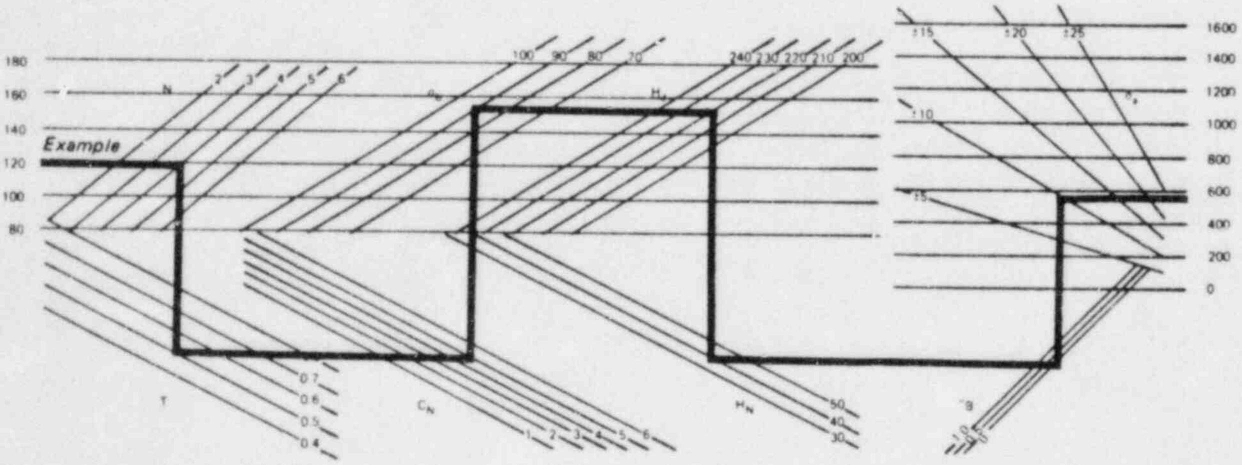


Figure 42. Amount of permanent set in aircraft fasteners smaller than 1" in diameter as a function of eight variables.

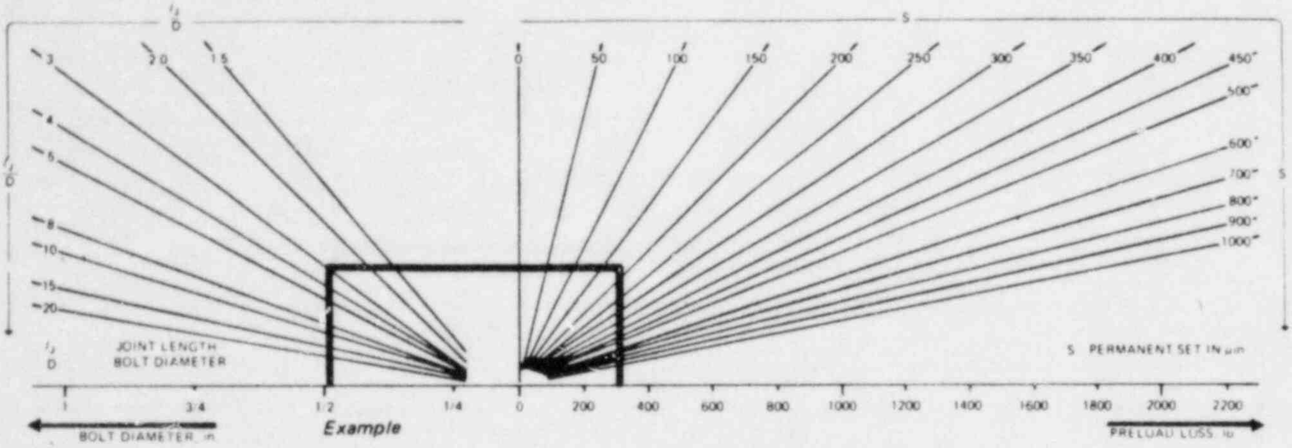


Figure 43. Nomograph converts permanent set into preload loss as a function of joint stiffness ($\imath_J$D) for socket head cap screws and hex-head screws installed in steel plates.

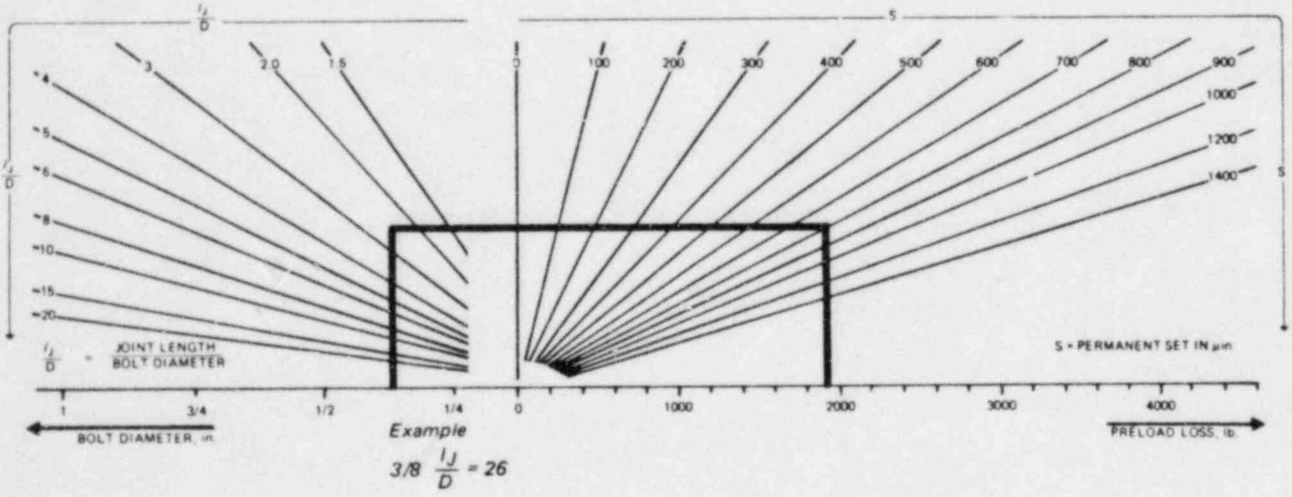


Figure 44. Nomograph converts permanent set into preload loss as a function of joint stiffness ($\imath_J$/D) for aircraft fasteners with bolt and nut flange diameters of 1.8 bolt diameters and holes equal to bolt diameter plus twice the fillet radius.

THEORY OF THREADED FASTENER SELF-LOOSENING FROM TRANSVERSE VIBRATION:

The theory of the mechanism of self-loosening is based on a well-known law of physics that defines the effects of friction on two interacting solid bodies. As soon as the friction force between two solid bodies is overcome by an external force working in one direction an additional movement in any other direction can be caused by the action of forces that can be essentially smaller than the friction force. Figure 45 illustrates the principle involved. A solid body, having weight L, lies on a slope and does not move if the slope angle is smaller than the friction angle. As the figure shows, weights can be regarded as a simplified model of a tightened fastener.

The slope angle represents the thread, and the hoizontal plane represents the bolt head (or nut) bearing surface. The resulting transverse force, Q, is given by the equation:

$$Q = L \tan(-\varphi + \ell) + L \tan \ell$$

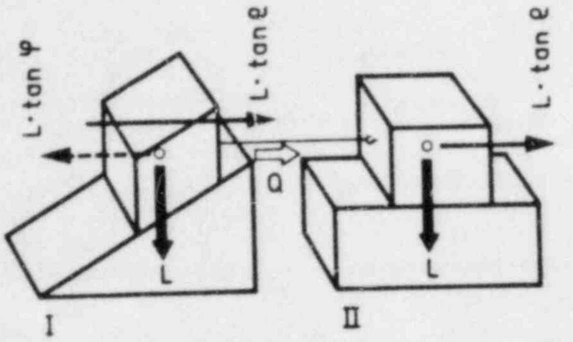
As long as Q is greater than zero, the system does not move. It will move, however, as soon as the slope underneath the solid body is vibrated to the extent that the inertial force created exceeds the friction force so that the interface between the solid body and the slope becomes apparently free of friction. As Figure 46 shows, the transverse force, L tan, then injects motion in the system.

This effect can be demonstrated by examples from daily life: A cork can be more easily removed from a bottle if torque is applied while pulling. If a car is braked in a curve, the car loses its sideway grip on the road. The example of the slope is also applicable to a bolted connection; the thread is the slope, spirally mounted, and the clamping load is the weight that causes the pressure between the two solids in contact. Additional friction forces originate from the clamping load on the bearing surface of the bolt head or the nut, as shown in Figure 47.

Similar to a load lying on a fixed slope, self-locking exists in a bolted connection as long as no relative motion arises between the thread flanks and the contact surfaces of clamping and clamped parts. The following off-torque is needed for loosening the bolt or the nut:

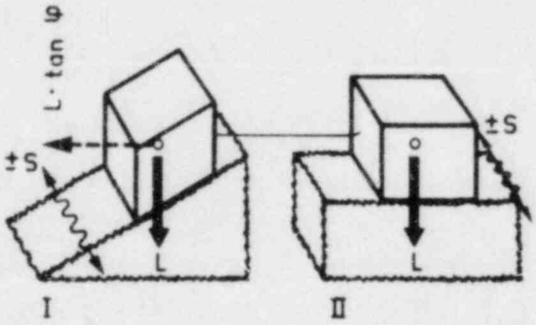
$$\begin{aligned} T_{off} &= F_V \left[d_2/2 \tan(-\varphi + p) + D_H/2 \cdot \mu H \right] \\ &= F_V \left[d_2/2 (\tan - \varphi + 1.15\mu) + D_H/2 \ \mu H \right] \end{aligned}$$

The bolt could loosen by itself (without the application of external off-torque) only if T_{off} were to become either zero or a negative



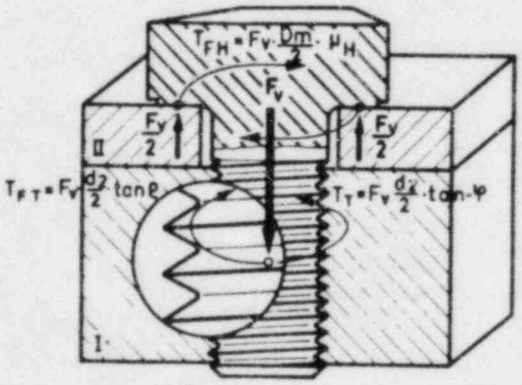
$$Q = L \cdot \tan(-\varphi + \varrho) + L \cdot \tan \varrho$$

Figure 45. Transverse force equation.



$$Q = L \cdot \tan(-\varphi) = -L \cdot \tan \varphi$$

Figure 46. Transverse force dynamics.



$$T_{off} = F_v \left[\frac{d_2}{2} \tan(-\varphi + \varrho) + \frac{D_m}{2} \cdot \mu \right]$$

Figure 47. Transverse force free-body diagram.

value. Even under ideally lubricated conditions, the thread friction angle will not be less then six degrees and the helix angle will not exceed 3^{0} 20' on sizes down to M5 diameter (equivalent to 3/16"). Therefore, the sum between the square brackets in equation 2 can never become smaller than, or equal to, zero; that is, the product of the equation can become zero only if the preload drops to zero. This case, which exists only if no relative motion occurs in the threads or at the bearing area interfaces, has been very widely generalized.

However, if relative motion occurs between the threaded surfaces and/or other contact surfaces of the clamped and clamping parts because of an external force, the direction of which is either tangential or radial, the bolted connection will become free of friction in a circumferential direction, as shown in Figure 48.

This means that the preload acting on the thread, which is a slope, creates a force in a circumferential direction and results in the rotational loosening of the bolt or the nut. The maximun value for total elimination of the circumferential friction force resisting the existing internal off-torque is then equal to:

$$T_{off} = F_V \frac{d_2}{2} \tan(-\rho) = -F_V \frac{d_2}{2} \tan \varphi$$

For axially loaded joints, Goodier and Sweeney have pointed out that pulsating tension of a clamped bolted connection creates radial sliding motions between the thread flanks of the bolt and nut or at the interface of the clamped bearing surfaces. The reasons for this are the contraction of the bolt according to Poisson's ratio and the dilation of the nut's walls caused by axial tension.

For dynamically transverse loaded joints, the relative motion between the threaded flanks and the contact surface of the bearing areas can occur in magnitudes up to a maximum allowance of the thread. These large effects appear when transverse loadings, which have to be transmitted by grip friction, exceed the friction force between the clamped parts, μF, the friction force being delivered by the clamping force, F. The resultant transverse slippage between the clamped parts forces the bolt to assume a pendulum movement, which leads to relative motion in the thread hole and thus between the thread flanks.

If the amplitude of such transverse slippage of the bolt is large enough, slippage of the nut or bolt head bearing surface will finally occur and make the joint totally free of friction in a circumferential direction. It can be easily realized too that, contrary to the conditions of axial loadings, relative motion between the flanks will occur in all parts of the nut thread when the joint slips under transverse force. Thus, the internal off-torque force becomes sufficient to turn the bolt or nut completely loose as soon as the friction is eliminated in the bearing area as well as in the thread area. Such transverse slippages are more common in practice than is usually accepted. Experience shows that these joints most frequently fail by self-loosening.

Many variables affect the ability of fasteners to retain preload while experiencing dynamic loading. Some of the basic factors which are common to many bolted joints were investigated. The factors examined were: amplitude of dynamic motion (generated by the dynamic load); initial preload; thread-pitch series; prevailing torque (of the locking fastener); and hardness of the bearing surface.

The dynamic motions experienced by bolted joints are generated by forces which lead to relative movement in the joint. The amplitude and frequency of occurrence of these forces and motions control the rate of loosening experienced by the fastener. The effect of vibration amplitude on the preload loss of a fastener was investigated by use of the transverse vibration machine, which produces dynamic loading at a constant frequency of 750 cycles per minute.

On the transverse vibration machine, the transverse force and motion input is controlled by the test amplitude. The test amplitude, normally defined by the displacement of the unclamped test joint, is proportional to the maximum transverse force at zero displacement. A portion of the displacement amplitude is absorbed by the load transmitting member of the machine and the remainder goes into the joint motion. By varying the test amplitude for a given fastener, joint slippage is varied. This produces a large effect on the number of cycles required to generate a fixed amount of preload loss.

The result of varying the joint slippage motion is in Figure 49. The test amplitude is plotted against the vibration life of three different 3/8-24 size self-locking nuts. The vibration life data used in the figure is determined by the number of vibration cycles which reduce the initial preload (7000 lbs.) to 80% of this value. Other vibration lives can be established, but the characteristic shape of the curves are illustrated.

The effect of increasing the preload in a fastener is to increase the friction forces in the joint and thereby increase its vibration resistance. If the dynamic environment is not severe, the increased friction forces may be sufficient to resist motion and loosening will be overcome.

However, if the dynamic environment is severe enough to overcome the increased friction forces obtained by the higher preload, the greater internal loosening torque will produce loosening. (According to theory, the loosening torque is proportional to the preload induced. It is equal in magnitude to the torque required to load the fastener in the absence of friction but is opposite in direction.) The net result will be a slight increase in vibration life under these more severe conditions.

The effect of initial preload is demonstrated in Figure 50. This graph shows the average vibration life results for a 3/8-16 nonlocking hex

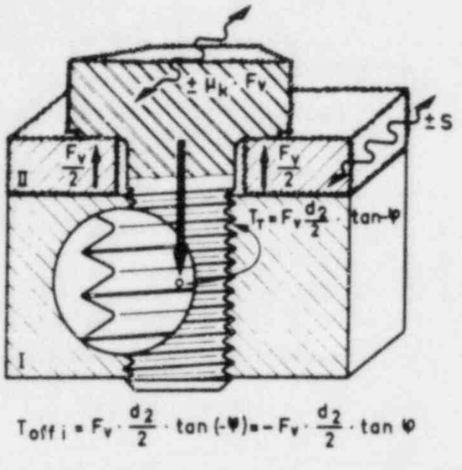


Figure 48. Transverse force relative motion diagram.

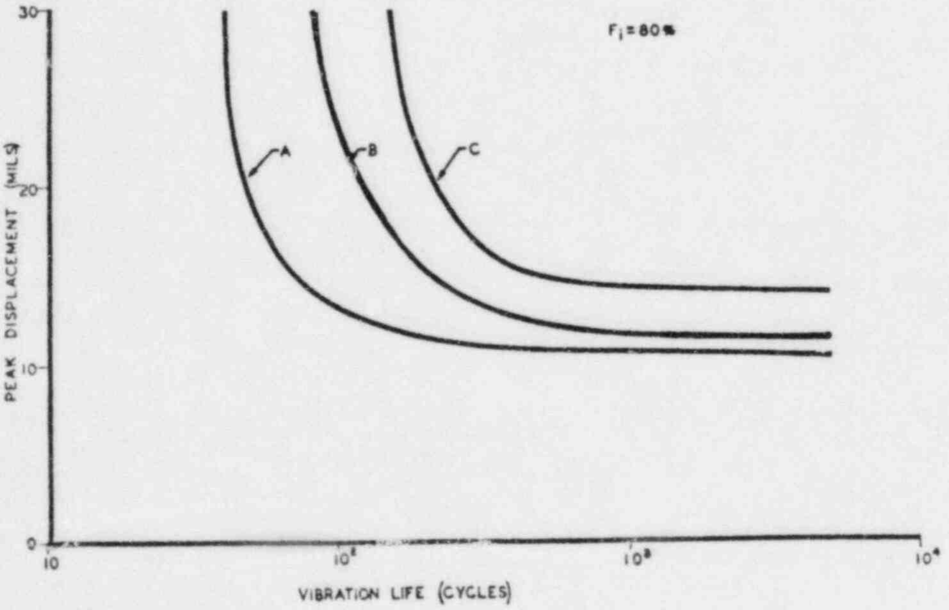


Figure 49. Effect of vibration amplitude on the vibration life of 3/8-24 fasteners.

nut sample which was tested at two different preload levels. This graph demonstrates the effect of preload under a somewhat severe (± .030") amplitude condition.

Since the theoretical internal loosening torque is directly proportional to the helix of the thread, it was expected that a coarse-pitch thread having a larger helix angle would generate a greater internal loosening torque and be less vibration resistant than the fine-pitch thread. Comparing the 3/8" size coarse and fine threads, the 16-pitch coarse thread would produce an internal loosening torque which is 1.49 times that of the fine 24-pitch thread for an equal preload condition. This means that the internal torque acting to loosen the 16-pitch thread is considerably larger than that of the 24-pitch thread. In order to investigate this relationship, a test series was conducted in which 3/8-16 and 3/8-24 self-locking nuts were tested under the same conditions of preload and test amplitude. The results are shown in Figure 51.

The experimental results show that 3/8" fine-pitch locknuts endured a greater number of vibration cyycles (under a severe condition) than that of a corresponding number of coarse-thread nuts with all other conditions being equal. These results correlate well within the difference in loosening torque caused by the thread-pitch relationship. Besides demonstrating the thread-pitch effect, the results include a combined effect of pitch and prevailing torque because self-locking nuts were tested.

A common type of self-locking fastener is one that uses a prevailing-torque feature which generates a frictional resistance to rotation between mating threads.

The locking torque developed is a measure of vibration resistance since it counteracts the internal loosening torque induced by the fastener preload. The role that prevailing torque plays in maintaining preload in a joint was not previously documented.

The effect of prevailing torque is demonstrated in Figure 52 for two thread-pitch series of locknuts. These are predicted values based on a sequence of experiments conducted using a factorial analysis to determine the main factors and interactions. The curves for each pitch series are designated by high and low boundaries which would be influenced by other processing conditions.

Common to both pitch series is the large rate of change or increase in vibration life in the low values of prevailing torque. Although relative vibration life increases as prevailing torque increases, the influence appears to be less as the absolute value increases.

The hardness, roughness, and material properties of the mating-thread surfaces and those surfaces of the clamped members can influence the preload loss in joints undergoing dynamic loading. Any relaxation in these surfaces will reduce bolt elongation and thus reduce the joint

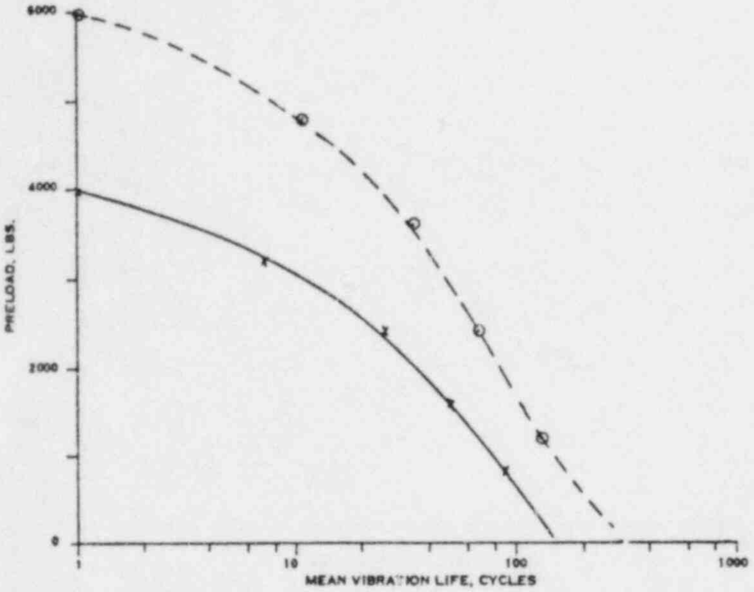


Figure 50. Effect of preload on the vibration life of free-spinning nuts.

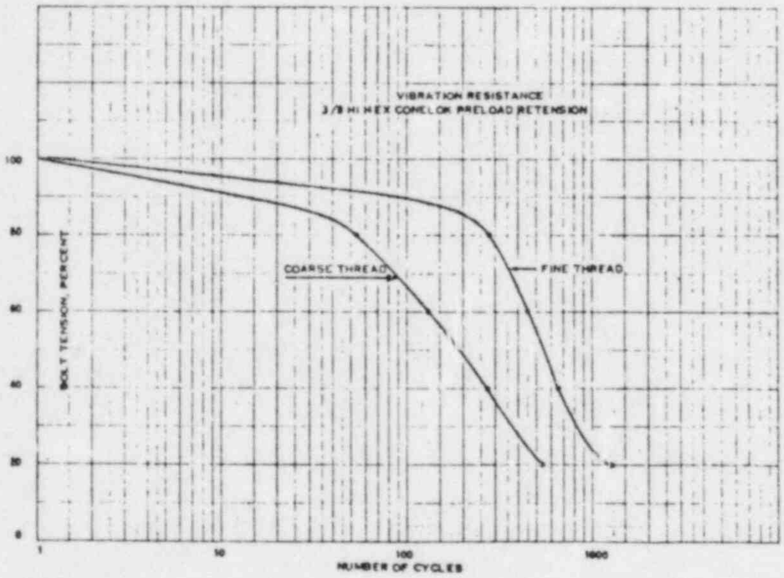


Figure 51. Effect of thread pitch on the vibration life of 3/8 HI-HEX CONELOK nuts.

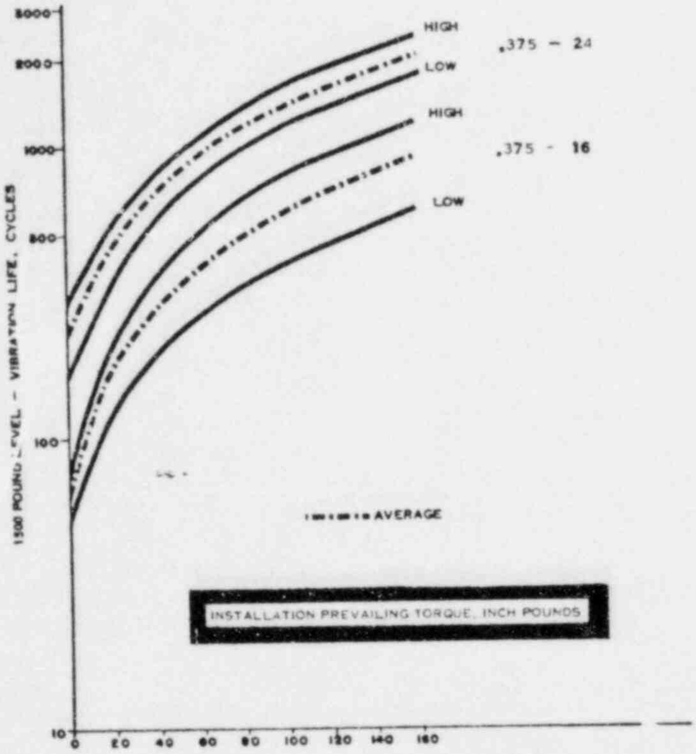


Figure 52. Predicted effects of prevailing torque and thread pitch on 1500 pound level vibration life.

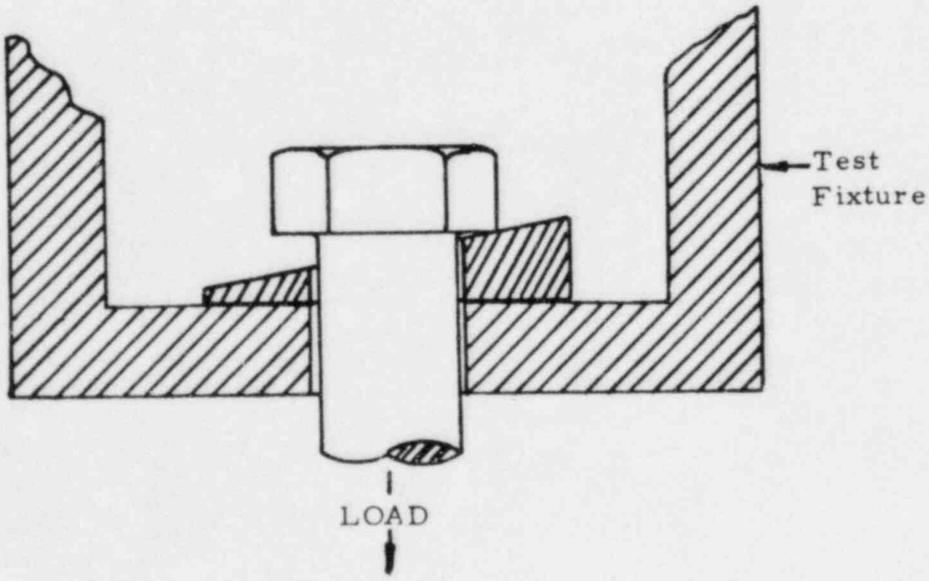


Figure 53. Wedge test.

preload. Roughness and prior processing treatments can affect the frictional properties, which may add to the resistance to fastener rotation. While some of these characteristics cannot be controlled, the hardness of the bearing surface of the clamped member and the bearing area of the fastener can be selected to minimize preload loss.

While some degree of brinelling (embedding) of the clamped surfaces takes place statically, dynamic loading could cause an additional plastic flow of the joint surface. The total preload loss attributed to brinelling effects measured in tests of conventionally-used fasteners is as much as 20% for relatively soft steel (R_B 90) and 5% for relatively hard steels (R_C 40). This preload loss generally occurs within the first ten cycles of dynamic loading until a stable load carrying surface is developed.

Other factors such as characteristics of coating, plating, and fastener design can also influence the dynamic performance of a fastener with respect to preload loss due to rotation. However, these factors are minor compared to the factors discussed herein. The relative influence of the more important factors on fastener vibration resistance are listed in decreasing order of importance:

1. Joint design and loading
2. Effectiveness of fastener locking method
3. Thread pitch
4. Initial preload
5. Bearing surface hardness

Thus, the trend in modern design toward lighter structures with higher energy outputs makes fastener design and application more critical.

If the bearing surfaces of a bolted joint are not parallel, bending stresses are introduced into the fastener. Severe bending will cause premature fastener failure from tensile loading alone. However, subtle bending may not cause the endurance limit to be lowered.

Bending stresses have purposely been induced in some tests as a measure of bolt quality, for example, the SAE wedge test (Figure 53). However, evidence has shown that hard, high-strength parts are more susceptible to this test than the more ductile ones.

Bending stresses introduced into the threads do not seem to have as severe a result as bending stresses introduced into the headed end of a fastener, when tested in tension. The use of ductile material permits plastic yielding, hiding the results of mismatches in the fixtues and stress concentrations in the fastener. The use of brittle materials will not make these compensations.

The wedge test then seems to be a good test for headed-end defects and ductility, but fatigue testing, which will show up localized stresses, should be used for total design form.

Long bolts are less affected than short ones. They have more spring and as such can distribute the bending loads over a greater area, thus effectively lowering the stress. Thus, care must be taken when designing the joint. The location and tolerancing of the components and holes should be such that any bending stress is held to a minimum. It is inevitable that there will be some bending in many joints. The bending stresses may be calculated by the following formula:

$$S_B = Ea/2L$$

where:

S_B = Bending stress, psi
E = Modulus of elasticity, psi
a = Gap between bearing surfaces, in.
L = Length of bolt, in.

Operating temperatures for commercial, industrial and aerospace applications have been steadily increasing. With this increase, there is a better "need to know" the factors influencing the selection of fasteners. Time at temperature can reduce the clamping force induced in the joint through relaxation. Size changes due to the coefficient of thermal expansion must be considered. High temperatures can also affect the corrosion protection properties of barrier coatings. Consequently, as the temperature goes up so do the design requirementsThere is much information on the development of high-temperature fasteners. It has been the subject of a great deal of study. Fast-eners have been developed and are available up through 2000°F and higher.

JOINT ELEVATED-TEMPERATURE CONSIDERATIONS:

In addition to the normal factors of bolt design, two more must be added -- time and temperatue. Thus, the designer must know how long the joint will be exposed to the elevated temperature, the strength of the material at that temperature, the results of oxidation and the cycling properties (up to and down from the operating temperature).

These three principal factors tend to change the initial room-temperature preload when exposed to elevated temperatures. The factors are:

1. As temperature increases, less stress or load is needed to impart a given amount of elongation or strain to a material at lower temperatures. This means that a fastener stretched a certain amount, e, at room temperature to develop preload, A, will exert a lower clamping force, B, at higher temperature. The effect of a change in modulus is to reduce clamping force whether or not bolt and structure are the same material, and is strictly a function of the bolt metal. There is a significant change in modulus of elasticity with increasing temperature as

2. With most materials, the size of the part grows as temperature increases. In a joint, both the structure and the fastener grow with an increase in temperature. If the coefficient of expansion of the bolt is greater than that of the joined material, a predictable amount of clamping force will be lost as temperature increases. Conversely, if the coefficient of the joint material is greater, the bolt may be stressed beyond its yield or even fracture strength, or cyclic thermal stressing may lead to thermal fatigue failure. Thus, matching materials in joint design can assure sufficient clamping force at both room- and elevated temperatures.

3. At elevated temperatures, a material subjected to constant stress below its yield strength will flow plastically and permanently in the direction of the stress. This phenomenon is called creep. In a joint at elevated temperature, a fastener with a fixed distance between the bearing surface of the head and nut will produce less and less clamping force with time. This characteristic is called relaxation. It differs from creep in that stress changes because the elongation (or strain) remains constant. Such elements as material, temperature, initial stress, manufacturing method and design affect the rate of relaxation.

Relaxation is the most important of the three factors. It is also the most critical consideration in the design of elevated-temperature fasteners. A bolted joint at 1200°F can lose as much as 50% preload. Failure to compensate for this could lead to fatigue failure or a loose joint even though the bolt was tightened properly initially.

Since the temperature, environment and the material of the structure are normally "fixed," the design objective is to select a bolt material that will give the desired clamping force at all critical points in the operating range of the joint. To do this, it is necessary to balance out the time-and-temperature related factors (relaxation, thermal expansion and modulus) with a fourth, the amount of initial tightening or clamping force.

Other considerations include environment, servicability, coatings and manufacturing. The designer must ask: Will the part be in a vacuum, or orbiting space in a satellite? Will it be a member of a transoceanic jet with possibly severe problems of salt-water corrosion encountered in the atmosphere around coastal jet ports? Or will the part operate in a severe chemical environment, as might be the case in processing equipment?

Then there is the matter of galling and seizing -- a serious factor if there is to be subsequent disassembly, as usually is the case with threaded connections. Many of the materials with elevated-temperature properties, such as stainless steels, are inherently prone to galling during sliding contact of one member over another -- even at room temperature. These materials require protective lubricating coatings, such as silver plating. Additional problems of seizing of mating materials develop after exposure to temperature. Ease of disassembly requires use of a suitable coating and, in some cases, a clearance at the pitch diameter.

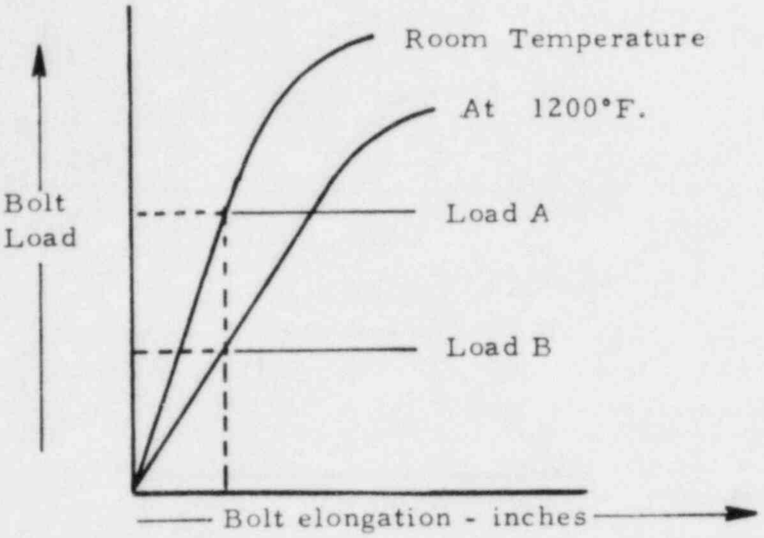


Figure 54. Typical plot of change of modulus of elasticity with temperature.

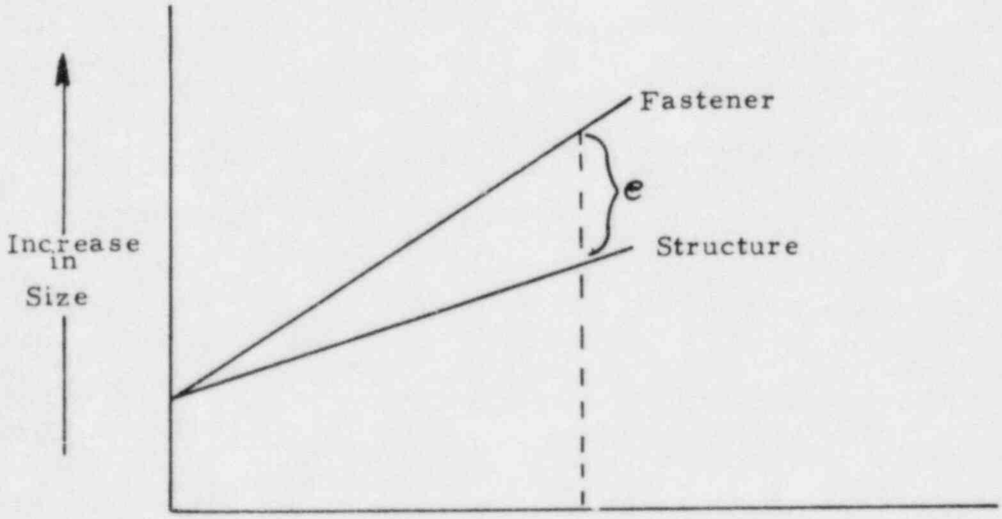


Figure 55. Plot of coefficient of thermal expansion.

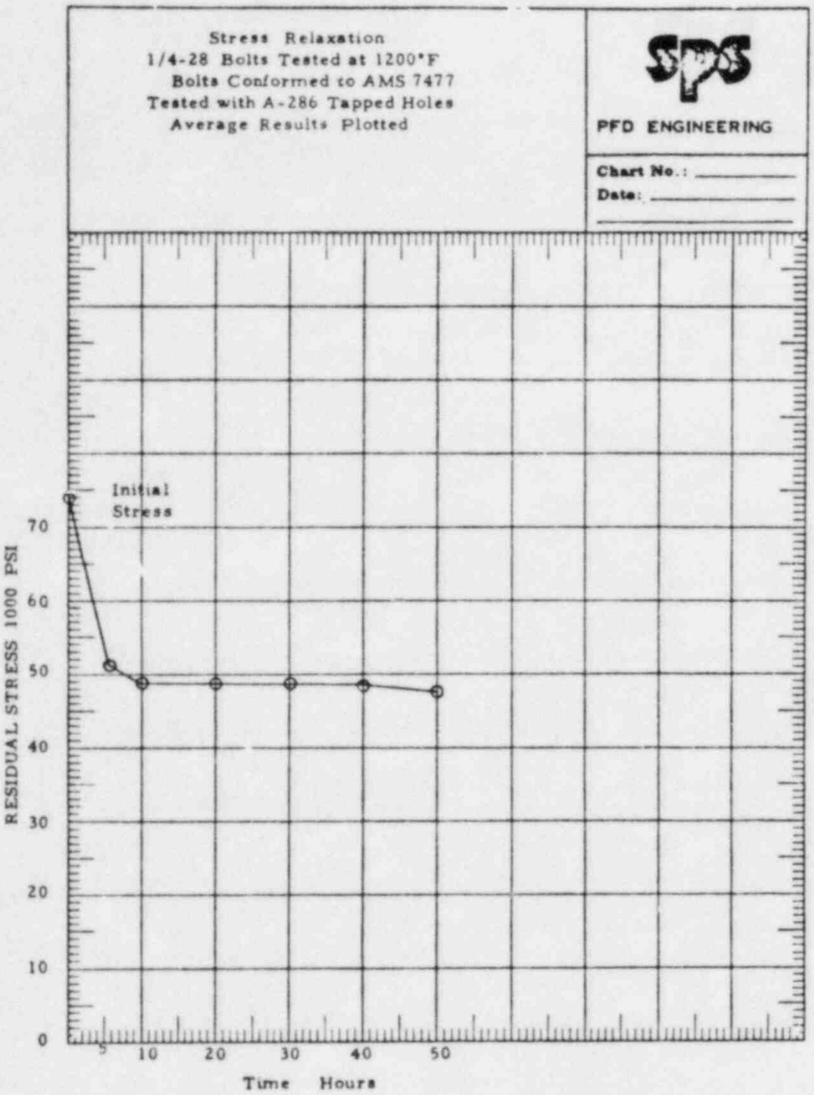


Figure 56. Stress relaxation of 1/4-28 bolts tested at 1200°F. (Typical relaxation curve.)

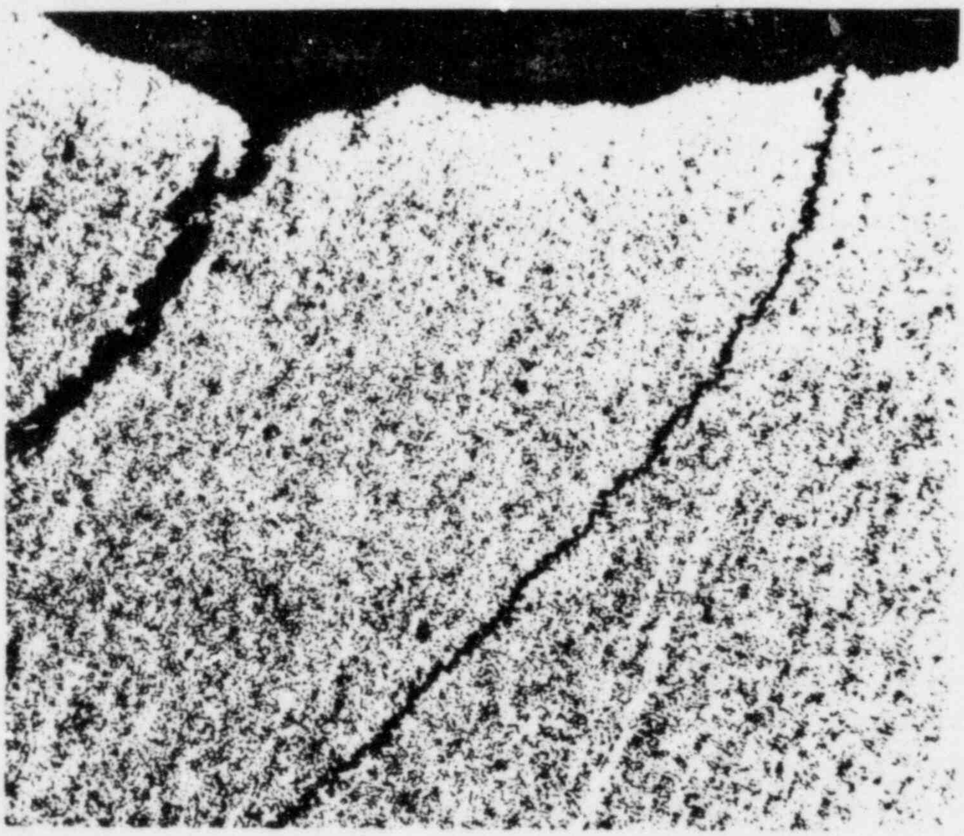


Figure 57. Photomicrograph of stress-alloy cracks resulting from use of cadmium-plated bolts over 610^{O}F.

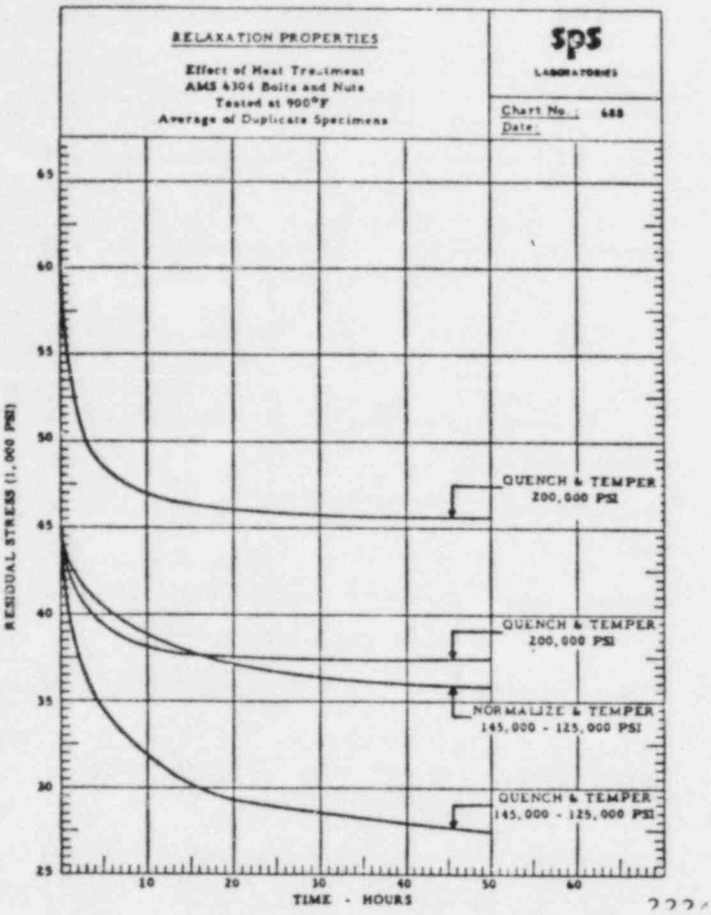


Figure 58. Effect of heat treatment on relaxation properties.

At moderate temperatures, where cadmium and zinc anti-corrosion platings might normally be used, the phenomenon of stress-alloying becomes an important consideration. Conventional cadmium plating, for example, is usable only to about 450°F. At somewhat above that temperature, the cadmium tends to melt and diffuse into the base material along the grain boundaries, creating a condition of cracking that can lead to rapid failure (Figure 57). Since the high-strength alloy fastener steels used to 900°F require corrosion protection, nickel-cadmium platings are specified for use beyond 450°F.

At the extremely high temperatures, coating also becomes a problem. In the case of refractory materials, coatings must be applied to prevent oxidation of the base material. These must be selected on the basis of the environments as shown. In static air, suitable coatings are available; however, at partial pressure or in dynamic air, it must be recognized that there will be a significant loss in service life. As indicated, in dynamic air, the life would be only a few hours.

Fastener manufacturing methods can also be critical to bolt performance at elevated temperatures. This is shown in the series of relaxation curves for bolts and nuts made from AMS 6304 and tested at 900°F (Figure 58). Take the curve for bolts heat treated by conventional quench-and-temper methods to a

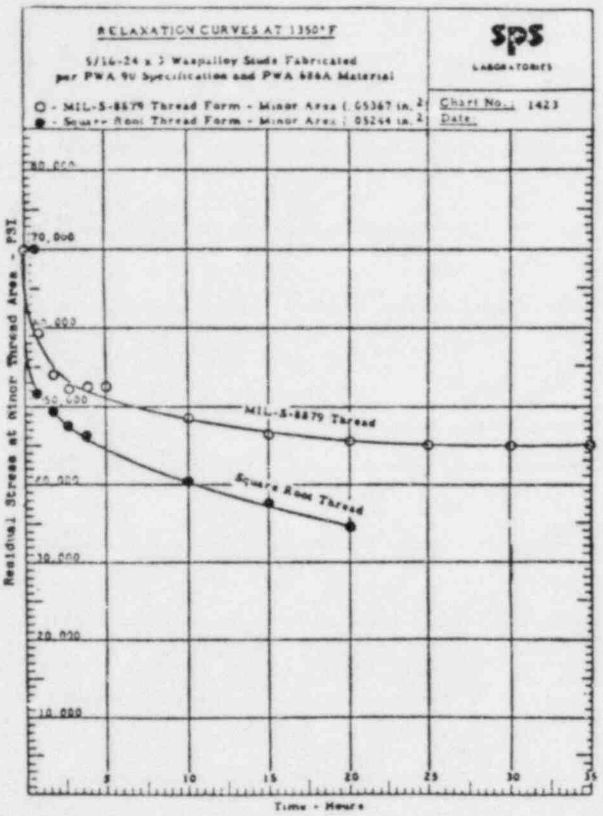


Figure 59. Effect of thread form on relaxation.

tensile strength range of 125 to 145,000 psi. After exposure to 900^{o}F for 50 hours, bolt preload has relaxed from an initial clamping force of 45,000 psi all the way down to 27,000 psi. Forty percent of the preload has been lost. As you can see in the next curve, the same material normalized and tempered to the same strength level drops down only to 37,000 psi from the initial 45,000 psi.

Now let us go back to the quench and temper, but this time heat treat to a higher strength level of 200,000 psi ultimate tensile strength. Starting from the same initial preload, the higher strength part relaxes relatively little and winds up with about the same residual stress as the normalize-and-temper treatment. But this higher strength part is capable of initial tightening at a much higher level. Thus, as shown in the top curve, when the 200,000 psi fastener is tightened to a preload of 62,000 psi, it drops off more sharply but still leaves a clamping force of 46,000 psi after 50 hours relaxation. In spite of the fact that it has lost twice as much on a percentage basis at the higher level of tightening, a 30% greater residual force remains. In this case, you end up with the same clamping force after 50 hours as that initially induced in the three other cases.

The actual design and shape of the threaded fastener is also a factor at elevated temperatures Most particularly, the thread root is a critical area. Of course, a radiused root in the thread is a major consideration in room-temperature design too, being a requisite for good fatigue performance. But at elevated temperatures, a generously radiused thread root is also a beneficial factor in relaxation performance, as Figure 59 indicates. Starting from the same initial preload of 70,000 psi, a Waspaloy stud with square root threads lost a full 50% of its clamping force after 20 hours, with the curve continuing downward, indicating a further loss. A similar part made with the large radiused root of MIL-S-8879 specification lost only 36% of its preload after 35 hours. The difference in residual clamping force between the two cases was 35,000 psi and 45,000 psi.

In summary, mechanical fastening encompasses two basic concepts:

1. Proper joint design and fastener selection,
2. Proper assembly procedures to maximize fatigue resistance to maintain fastener tightness by prudent use of a locking scheme that is compatible with the environment of the structure.

The theory of bolted joint design is much better understood today than it was even ten years ago. Therefore, designers should make it a point to become up-to-date in the latest thinking. Several good finite-element stress-analysis computer programs are available to assist the modern designer in proper stress analysis of bolted assemblies. Many legitimate fastener suppliers will provide fastener-property information to the designer upon request. This information will assist the designer in the establishment of joint safety factors so that a fastener with sufficient load capacity, fatigue resistance and locking ability can be specified and procured.

NOMENCLATURE OF FASTENERS AND SCREW THREADS:

Over the years there have been many names, nicknames, terms and many descriptive phrases to describe fasteners. In an effort to create some order, eliminate some confusion and to put you on a common ground, the following is a list of terms and definitions.

A. Fastener Product Terminology:

1. Bolt: An externally threaded fastener designed for insertion through holes in assembled parts and is normally intended to be tightened or released by torquing a nut.

2. Screw: An externally threaded fastener capable of being inserted into holes in assembled parts for mating with a preformed internal thread or forming its own thread, and of being tightened or released by torquing the head.

3. Stud: A cylindrical rod of moderate length, threaded on either one or both ends or through its full length.

4. Nut: A block or sleeve having an internal thread designed to assemble with the external thread on a bolt, screw, stud or other threaded part.

5. Rivet: A headed fastener of malleable material used to join parts by inserting the shank through aligned holes in each piece and forming a head on the headless end by upsetting.

6. Tapping Screw: A hardened screw that cuts or forms its own thread in an untapped hole.

7. Drive Screw: A hardened screw designed with an extremely fast lead thread which permits it to be pressed or hammered into place without the necessity of torquing.

8. Blind Rivet (or Bolt): A fastener which can be inserted and driven, or otherwise tightened, from one side of the work. The head is formed on the far blind side by manipulation of the fastener from the front.

9. Locking Screw: An externally threaded fastener which has a special means within itself for gripping an internal thread so that rotation of the threaded parts relative to each other is resisted in service.

10. Locknut: A nut which has a special means within itself for gripping a threaded fastener or the connected material so that rotation is resisted in service. A free-spinning locknut can be turned freely on the threaded fastener and develop its locking action only after being tightened against a base surface. A prevailing-torque locknut locks at any position on the threaded fastener, whether or not it is seated against a base surface; usually, it has a locking element that resists rotation as soon as it engages the externally threaded part.

11. Insert: An internally threaded bushing or thread insert designed to be molded in, or otherwise assembled into, soft or brittle materials to prvide greater strength and to minimize wear of the threaded assembly.

12. External Wrenching Fastener: A fastener designed to be assembled by a wrench applied to its external surfaces.

13. Internal Wrenching Fastener: A fastener which can be assembled using an internal wrench in a socket or recess in the fastener.

14. Aircraft-Quality Fastener: A fastener produced under closely controlled, restricted methods of manufacture and inspection, and intended for use in highly critical applications.

15. Finished Fastener: A fastener made to close tolerances and having surfaces other than the threads and bearing surface finished to provide general, high-grade appearance.

16. Semifinished Fastener: A fastener made to the same basic dimensions as a finished fastener but having greater tolerances on most dimensions and only the bearing surface and threads finished.

17. Unfinished Fastener: A fastener made to the same basic dimensions as a finished fastener but having relatively wide tolerances and all surfaces in their formed condition.

18. Nominal Size: Designation used for the purpose of general identification. For externally threaded fasteners, nominal size usually is the basic major diameter of the thread; for unthreaded fasteners, nominal size is usually the basic body diameter.

19. Fastener Length: The length of a headed fastener is the distance from the intersection of the largest diameter of the head with the bearing surface to the extreme end of the fastener, measured parallel to the axis of the fastener. The length of a headless fastener is the distance from one extreme end to the other in a line parallel to the axis.

20. Shank: That portion of a headed fastener which lies between the head and the extreme end of the fastener.

21. Body: The unthreaded portion of the shank of a threaded fastener.

22. Body, Reduced Diameter: Fastener body with the diameter equal to or greater than the minimum pitch diameter of a thread but not greater than the minimum major diameter of the thread. This definition applies primarily to externally threaded parts with rolled threads.

23. Body, Externally Relieved: Fastener body in which diameter is reduced to less than the minimum pitch diameter of the thread.

24. Body, Internally Relieved: A fastener with an axial hole drilled through a portion of the body to relieve stresses under load.

25. Shoulder: An enlarged portion of the body or shank, usually adjacent to the head.

26. Bearing Face (or Surface): The supporting or loacting surface of a fastener with respect to the part it fastens or mates; the underside of a bolt or nut.

27. Washer Face: A circular boss on the bearing surface of a nut or bolt.

28. Driving Recess: The indented portion of the bolt or screw head which is shaped to accept a driving tool.

29. Grip: The thickness of material or parts which the fastener is designed to secure when assembled.

B. Screw Thread Terminology:

1. Screw Thread: A ridge of uniform section in the form of a helix on the external or internal surface of a cylinder, or in the form of a conical spiral on the external or internal surface of a cone.

2. Unified Screw Threads: The standard screw-thread system in the United States, the United Kingdom and Canada.

3. Thread Series: In the unified screw thread system, there are eleven standard series of threads, classified and distinguished by the number of threads per inch on a given diameter. They are: coarse-thread series; fine-thread series; extra- fine-thread series; four-thread series; six-thread series; eight-thread series; twelve-thread series; twenty-thread series; twenty-eight-thread series; and thirty-two-thread series.

4. Thread Class: Screw threads are classified or distinguished from each other by the amount of manufacturing tolerance and allowance, if any, permissible for externally- or internally-threaded components. The required assembly fit may be obtained by selecting the proper thread class for each component. Thread classes are: 1A, 1B; 2A, 2B; 3A, 3B; and 5.

   The letter A designates tolerances and allowances applicable to externally-threaded fasteners, such as studs and bolts. The letter B denotes tolerances which apply to internally-threaded elements, such as nut..

- Classes 1A/1B: Provide a loose fit. These threads are used where parts must be assembled quickly and easily, even though the threads are slightly bruised or dirty.

- Classes 2A/2B: By far the most popular class for screws, bolts, nuts and other commercially-manufactured threaded fasteners. Maximum dimensions of class 2A are reduced from the basic size by an allowance for clearance to minimize galling and seizure in high-temperature applications or high-cycle wrench-assembly operations. This allowance also accommodates plated finishes and coatings up to a thickness of 1/16 of the allowance without the plating increasing the maximum material limit beyond the basic size.

- Classes 3A/3B: Designed for no allowance, these threads are intended for use on parts where close fit and accuracy of lead and angle of thread are required.

- Class 5: Interference fit used primarily for tap-end stud threads.

5. Single Thread: A single or single-start thread has a lead equal to the pitch.

6. Multiple Thread: Also called a multiple-start thread. This thread has a lead which is an integral multiple of the pitch.

7. External Thread: A thread on the external surface of a cylinder or cone, often referred to as the "male" thread.

8. Internal Thread: A thread on the internal of a hollow cylinder or cone, often referred to as the "female" thread.

9. Right-Handed Thread: A thread which winds in a clockwise and receding direction from the starting end, when viewed from that end.

10. Left-Handed Thread: A thread which winds in a counterclockwise and receding direction from the starting end, when viewed from that end.

11. Complete Thread: That part of the thread having full form at both crest and root.

12. Incomplete Thread: That part of the thread having either crests or roots or both crests and roots not fully formed.

13. Total Thread: Includes the complete and all of the incomplete threads.

14. Flank: The thread surface connecting the crest with the root.

15. Crest: The outermost tip of a male thread as seen in a thread profile, or the innermost tip of a female thread.

16. Root: Identical with or immediately adjacent to the cylinder or cone from which the thread projects.

17. Pitch: The distance, measured parallel to the thread axis, between corresponding points on adjacent thread forms in the same axial plane and on the same side of the axis.

18. Lead: The distance a thread part moves axially in one complete revolution with respect to a fixed mating part.

19. Threads per Inch: The reciprocal of the pitch in inches.

20. Turns per Inch: The reciprocal of the lead in inches.

21. Flank Angle: The angle between the individual flanks and the perpendicular to the axis of the thread measured in an axial plane. A flank angle of a symmetrical thread is known as the half-angle of thread.

22. Lead Angle: The angle made by the helix of a thread at the pitch line with a plane perpendicular to the axis.

23. Helix Angle: The angle made by the helix of the thread at the pitch line with the axis. Helix angle is the complement of the lead angle.

24. Height (or Depth) of Thread: The distance measured radially between the major and minor cylinders or cones.

25. Major Diameter: For a straight thread, this is the diameter of the imaginary cylinder bounding the crest of an external thread or the root of an internal thread. For a taper thread, the major diameter, in a given position on the thread axis, is the diameter of the major cone at that position.

26. Minor Diameter: For a straight thread, this diameter is the imaginary cylinder bounding the root of an external thread or the crest of an internal thread. For a taper thread, the minor diameter, in a given position on the thread axis, is the diameter of the minor cone at that position.

27. Pitch Diameter: For a straight thread, this is the diameter of the imaginary cylinder whose surface passes through the thread profiles in such a way to make the widths of the thread ridge and the thread groove equal. On a theoretically perfect thread, these widths are equal to one-half of the basic pitch. For a taper thread, the pitch diameter, in a given position on the thread axis, is the diameter of the pitch cone at that position.

28. Length of Thread Engagement: The distance that one part is engaged or screwed into the other.

29. Depth of Thread Engagement: The radial distance by which the thread forms of two mating threads overlap or the difference between the major radius of the external thread and the minor radius of the internal thread.

30. Tensile Stress Area: The circular cross-sectional area normal to the axis of a theoretical cylinder which would fail under tension at the same load at which an externally-threaded part fails if the materials of both were to have the same mechanical properties.

31. Thread Shear Area: The effective area in shear of an external thread at a specified diameter of the mated internal thread. For an internal thread, it is the effective area in shear at a specified diameter of the mated external thread. The specified diameters are usually maximum minor diameter of the mated internal thread and the minimum major diameter of the mated external thread, respectively.

C. Fastener Application Terminology:

1. Mechanical Properties: The properties of a fastener involving the relationship between stress and strain.

2. Proof Test: Any specified test required of a fastener to verify its suitability for the fastening job.

3. Proof Load: The specified load which the fastener must withstand in a proof test without any indication of failure.

4. Torquing: The act of tightening a fastener by turning either the bolt or the nut.

5. Joint Efficiency: The ratio of the strength of a joint to the coupon strength of the connected material.

6. Faying Surface: The contact surface between adjacent parts in a joint.

7. Quality: Quality denotes the suitability of a fastener for the purpose for which it is intended. Quality should not be confused with precision or workmanship as it is possible that precision parts of good workmanship can be of poor quality if they fail to perform the function for which they are intended.

8. Tension Joint: A joint in which the fastener has the load applied to the longitudinal direction and which tends to elongate it.

9. Shear Joint: A joint in which the fastener has the load applied across the axis and which tends to sever it.

D. Terms Relating to Fastener Calculations:

1. Bearing Stress of the Material: The compressive load per square inch which the joined members can withstand.

2. Bearing Stress of the Fastener: The load per square inch which the fasteners can carry on the bearing surface.

3. Torsion-Tension Yield Point: The point at which additional applied torque will cause the fastener to yield, normally 90% of the ultimate tensile strength.

4. Safe Torsion-Tension Yield Point: The safe point to which the fastener may be tightened without yielding, normally 80% of the torsion-tension yield point or 72% of the ultimate tensile strength.

5. Unit Shear Height: The internal thread width at the bolt major diameter or the external thread width at the nut major diameter.

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APPENDIX

Military Specifications

MIL-B-6812B
23 AUGUST 1967

Superseding
MIL-B-6812A
26 May 1955

MILITARY SPECIFICATION

BOLTS, AIRCRAFT

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope.- This specification covers bolts used in the manufacture of aircraft and aircraft accessories.

1.2 Classification.- The bolts covered by this specification shall be of the types and sizes designated (see 6.2).

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Federal

QQ-A-200	Aluminum Alloy Bar, Rod, Shapes and Tubes, Extruded, General Specification for
QQ-A-225	Aluminum Alloy Bar, Rod, Wire for Special Shapes, Rolled, Drawn, or Cold Finished, General Specification for
QQ-P-416	Plating, Cadmium (Electrodeposited)
QQ-A-430	Aluminum Alloy Rod and Wire, for Rivets and Cold Heading

Military

MIL-H-3982	Hardware (Fasteners and Related Items), Packaging and Packing for Shipment and Storage of
MIL-C-5541	Chemical Films and Chemical Film Materials for Aluminum and Aluminum Alloys
MIL-S-5626	Steel, Chrome-Molybdenum (4140) Bars, Rods, and Forging Stock (for Aircraft Applications)

FSC 5306

MIL-S-6049	Steel, Chrome-Nickel-Molybdenum (8740) Bars, Rods, and Forging Stock (for Aircraft Applications)
MIL-S-6050	Steel, Chrome-Nickel-Molybdenum (8630) Bars, Rods, and Forging Stock (for Aircraft Applications)
MIL-H-6088	Heat Treatment of Aluminum Alloys
MIL-S-6098	Steel, Chrome-Nickel-Molybdenum (8735) Bars, Rods, and Forging Stock (for Aircraft Applications)
MIL-S-6758	Steel, Chrome-Molybdenum (4130) Bars, Rods, and Forging Stock (for Aircraft Applications)
MIL-I-6866	Inspection, Penetrant Method of
MIL-I-6868	Inspection Process, Magnetic Particle
MIL-H-6875	Heat Treatment of Steels (Aircraft Practice) Process for
MIL-S-7742	Screw Threads, Standard, Optimum Selected Series, General Specification for
MIL-A-8625	Anodic Coatings, for Aluminum and Aluminum Alloys
MIL-S-18732	Steel Bars, Billets, Forgings, Tubing, (431) Special Quality

STANDARDS

Federal

FEDERAL TEST METHOD STANDARD NO. 151	Metals, Test Methods

Military

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-143	Specifications and Standards, Order of Precedence for the Selection of
MIL-STD-410	Qualification of Inspection Personnel (Magnetic Particle and Penetrant)
MIL-STD-414	Sampling Procedures and Tables for Inspection by Variables for Percent Defective
AN3 thru AN20	Bolt - Machine, Aircraft
AN21 thru AN36	Bolt - Clevis
AN42 thru AN49	Bolt, Eye
AN73 thru AN81	Bolt, Machine, Aircraft, Drilled Head
AN173 thru AN185	Bolt, Machine, Close Tolerance, Aircraft
AN315	Nut, Plain, Airframe
AN320	Nut, Castle Shear
MS20073	Bolt, Machine, Aircraft, Drilled Head, Fine Thread
MS20074	Bolt, Machine, Aircraft, Drilled Head, Coarse Thread
MS21083	Nut, Self-Locking, Hexagon, Non-Metallic Insert, Low Height, 250° F

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications.- The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply:

Society of Automotive Engineers Aerospace Material Specification

AMS6300 Steel, .25Mo (.35-.40C)

(Copies of SAE publications may be obtained from the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York, New York 10017.)

3. REQUIREMENTS

3.1 Material.-

3.1.1 Non-corrosion-resistant steel.- Non-corrosion-resistant steel bolts shall be manufactured from steel conforming to MIL-S-5626, MIL-S-6049, MIL-S-6050, MIL-S-6098, MIL-S-6758, or AMS 6300. (See 6.1.1.)

3.1.2 Corrosion-resistant steel.- Corrosion-resistant steel bolts shall be manufactured from material conforming to MIL-S-18732.

3.1.3 Aluminum alloy.- Aluminum alloy bolts shall be manufactured from material conforming to QQ-A-200, QQ-A-225, or QQ-A-430.

3.1.4 Selection of materials.- Specifications and standards for all materials, parts, and Government certification and approval of processes and equipment, which are not specifically designated herein and which are necessary for the execution of this specification, shall be selected in accordance with MIL-STD-143.

3.2 Heat treatment.- Heat treatment of steel shall be in conformance with MIL-H-6875. Heat treatment of aluminum alloy shall be in conformance with MIL-H-6088.

3.2.1 Material conforming to MIL-S-18732 shall not be tempered in the range of 700° to 1,000° F.

3.3 Heads.-

3.3.1 Bearing surface.- The bearing surface of bolt heads shall be at right angles to the shank within 2 degrees for bolts 1/2 inch in diameter and less, and within 1 degree for bolts larger than 1/2 inch in diameter.

3.3.2 Eccentricity of head to shank.- Eccentricity of head to shank shall be within a tolerance of 3 percent of the width across flats, or 3 percent of the diameter of the head in the case of clevis and eye bolts.

3.3.3 Top surface.- The top surface of hexagon head bolts shall be flat and chamfered with the diameter of the top flat circle from 85 to 100 percent of the width across flats.

3.3.4 Depth of slots.- The depth of slots in the heads of clevis bolts is measured from the highest part of the head to the intersection of the bottom of the slot with the head surface.

3.4 Straightness of shank.- The straightness of shank shall be within the values specified in table I when the bolt is rolled on a surface plate and the point of greatest deviation is measured with a feeler gage of 1/4 inch width.

TABLE I. Straightness of shank

Bolt size	Deviation of bolt shank from plate, max (inches per inch of bolt length)
No. 10 and smaller	0.0040
1/4, 5/16	.0030
3/8, 7/16	.0025
1/2 and larger	.0020

3.5 Physical properties.-

3.5.1 Tensile strength.- The tensile strength of hexagon head, eye, and clevis bolts shall be as specified in table II when tested in accordance with 4.5.2.

3.5.2 Shear strength.- The shear strength of all bolt types shall be as specified in table II when tested in accordance with 4.5.3.

3.5.3 Bend.- Bolts shall withstand cold bending when tested in accordance with 4.5.4.

3.5.4 Hardness.— All corrosion and non-corrosion-resistant steel bolts shall be within the Rockwell hardness range C-26 to C-32 when tested in accordance with 4.5.5.

3.6 Decarburization.- Decarburization of non-corrosion-resistant steel bolts shall not exceed the limits shown in table III when tested in accordance with 4.5.6.

TABLE II. Strength requirements

Size	Ultimate tensile strength (min) 1/ (pounds)				Double shear strength (min) 2/ (pounds)	
		Hexagon head bolts			All types of bolts	
		Steel				
	Eyebolts steel	Fine 3/ thread	Coarse 3/ thread	Al 3/ alloy fine thread	Steel	Al alloy
No. 6	-	-	-	-	2,120	1,080
No. 8	-	-	-	-	3,000	1,570
No.10	1,150	2,210	1,800	1,100	4,250	2,092
1/4	2,450	4,080	3,360	2,030	7,360	3,650
5/16	3,910 (AN44)					
5/16 4/	5,290 (AN45)	6,500	5,660	3,220	11,500	5,700
3/8	7,015	10,100	8,470	5,020	16,560	8,250
7/16	9,200	13,600	11,680	6,750	22,500	11,200
1/2	14,375	18,500	15,730	9,180	29,400	14,600
9/16	20,125	23,600	20,300	11,700	37,400	18,500
5/8	-	30,100	25,100	14,900	46,000	22,800
3/4	-	44,000	37,800	21,800	66,300	33,000
7/8	-	60,000	-	29,800	90,100	45,000
1	-	80,700	-	40,000	117,800	58,500
1-1/8	-	101,800	-	50,500	147,500	74,000
1-1/4	-	130,200	-	64,400	182,100	91,000

1/ The values shown for the ultimate tensile strength are for minimum values and are based on:

(a) 125,000 psi for non-corrosion-resistant and corrosion-resistant steel.

(b) 62,000 psi for aluminum alloy.

The strength values shown for the eyebolts are based on the strength of the eye. The root area of the thread is the basis of calculation for the tensile strength of hexagon head bolts.

Clevis bolts shall have tensile strengths equal to one-half of the requirements for hexagon-head bolts when used with AN320 or MS21083 nuts. Clevis bolts are intended primarily for use in shear applications.

2/ Ultimate shear strengths are computed on the basis of 60 percent of the ultimate tensile strengths.

3/ Class of thread is as specified on the applicable standard drawing.

4/ Different from size 5/16 above in the design of the eye section.

TABLE III. Decarburization limits

Size	Complete decarburization (inches)	Complete plus partial decarburization (inches) 1/
Up to 3/8 incl.	0.004	0.010
Over 3/8 to 1/2 incl.	.005	.012
Over 1/2 to 5/8 incl.	.006	.014
Over 5/8 to 3/4 incl.	.006	.017

1/ The permissible values shown are based on measurements of the entire periphery of the cross section and the average depth determined. The decarburization limits apply to the shank.

3.7 Head structure.- A section of the head shall show no detrimental defects when inspected in accordance with 4.5.7.

3.8 Cracks.- Bolts shall be free of cracks in any direction and location. A crack is defined as a clean crystalline break passing through the grain or grain boundary without the inclusion of foreign elements.

3.9 Seams.- Bolts may possess seams, except in the locations noted hereinafter, which do not exceed the tolerances in table IV. Seams extending through fillets or threads as shown in figure 1 that exceed the limits shown in table IV shall not be acceptable. Seams up to the depth indicated which have been rolled beneath the root of the threads shall not be cause for rejection.

TABLE IV. Limits for seam depth

Bolt size (inches)	5/16 and under	3/8	7/16	1/2 through 1-1/4
Depth in shank (inches)	0.005	0.006	0.007	0.008

3.10 Inclusions.- Bolts possessing surface or sub-surface inclusions, as revealed by any of the methods noted herein, and not indicative of unsatisfactory quality, shall be accepted.

3.11 Defects on bolt heads.- Bolt heads shall not possess more than three openings such as are described in 3.11.1.

3.11.1 Seams, inclusions, nicks, or gouges.- Bolt heads shall not possess seams, inclusions, nicks, or gouges on the following:

(a) On the top of the bolt head exceeding twice the depth limits shown in table IV, or

(b) On the periphery of the bolt head exeeding twice the depth limits shown in table IV for hexagon-head bolts or four times the depth limits shown in table IV for bolts with other than hexagon heads.

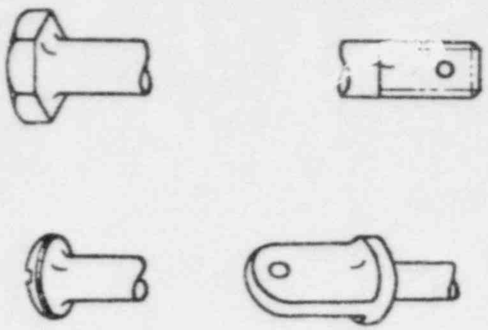


FIGURE 1. Seams extending through fillets or threads

3.11.2 Defects on washer faces.- Washer faces shall not possess seams exceeding the limits shown in table IV. Bolts shall not possess mutilation of the washer face sufficient to prevent firm seating.

3.12 Bolt head shank junction.- Only longitudinal seams of the depths permitted in table IV shall be permitted. Slight longitudinal or transverse tool marks or undercuts of depth not to exceed the limits in table V will be permitted, provided they fair into the shank with no sharp scratches, gouges, or corners.

TABLE V. Limits for depth of tool marks or undercuts

Bolt size (inches)	Depth of tool marks or undercuts (inches, max)
Up to 3/8 incl.	0.003
Over 3/8 to 5/8 incl.	.004
Over 5/8 to 7/8 incl.	.005
Over 7/8	.006

3.13 Threads.- Threads of all bolts shall conform to MIL-S-7742 and shall be of the sizes specified on the applicable standard drawing. Unless otherwise specified, threads shall be right-hand. Threads may be formed by rolling, cutting, or grinding.

3.13.1 Length of thread.- The length of the thread shall be the shank length minus the grip length, as specified on the applicable standard drawings. The grip length of bolts shall be measured from the underside of the head to the end of the full cylindrical portion of the shank.

3.14 Dimensions.- After plating and finishing, the dimensions shall conform to those specified in the following standards: AN3 thru AN20, AN21 thru AN36, AN42 thru AN49, AN73 thru AN81, AN173 thru AN186, MS20073, and MS20074.

3.15 Finish.- Non-corrosion-resistant steel bolts shall be cadmium plated in accordance with QQ-P-416, type II, class 3. When plating is specified, the entire bolt, including the threaded portion, shall be plated, unless otherwise specified on the applicable standard drawings. Aluminum alloy bolts shall be anodized in accordance with MIL-A-8625 or chemically surface treated in accordance with MIL-C-5541. Corrosion-resistant steel bolts shall be passivated.

3.15.1 Passivating process for corrosion-resistant steel bolts.- This process shall be the final manufacturing operation and consists of immersing the bolts for a period of 20 minutes in the following manner:

(a) In a solution containing 25 percent (by weight) of nitric acid at room temperature followed by a thorough rinse in hot water, or

(b) In a solution of 6 to 8 percent (by weight) of nitric acid plus 1 to 2 percent (by weight) of hydrofluoric acid heated to a temperature of 120° to 130° F (49° to 54° C) followed by a thorough rinse in hot water.

3.16 Identification of product.- When required, bolts shall be marked for identification purposes as shown on the applicable standard drawing. It is permissible for the bolt manufacturer to include his identification marking on the bolt heads.

3.17 Workmanship.- Bolts shall be made in conformance with high-grade bolt manufacturing practice.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection.- Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any other commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of inspection.- The examination and testing of bolts shall be classified as quality conformance inspection.

4.3 Lot.- A lot shall consist of finished bolts which are of the same type and size, fabricated by the same process, heat treated in the same manner, and produced as one continuous run or order, or part thereof.

4.4 Sampling.-

4.4.1 Sampling for visual and dimensional attributes.- Sampling for visual and dimensional attributes shall be at random in accordance with MIL-STD-105. The Acceptable Quality Levels (AQL's) for major, minor A, and minor B classes of characteristics shall be as follows:

(a)	Major	2.5 percent
(b)	Minor A	6.5 percent
(c)	Minor B	10 percent

The total defective items for all characteristics of a given class (e.g., major, minor A, minor B) shall be combined in order to apply the acceptance and rejection provisions of MIL-STD-105.

4.4.1.1 Definitions of defect classes.- Major and minor defects are defined in MIL-STD-105. Minor defects are broken down into two classes, minor A and minor B. Definitions for minor A and minor B defects are as follows:

4.4.1.1.1 Minor A.- A minor A defect is classified as a defect which has a slight effect on usability.

4.4.1.1.2 Minor B.- A minor B defect is classified as a defect which has no effect on usability but which does not conform to workmanship standards.

4.4.1.2 Classification of defects.- All dimensional characteristics are considered defective when out of tolerance.

4.4.1.2.1 AN3 thru AN20 Bolt - aircraft and AN173 thru AN186 Bolt - aircraft, close tolerance.- The classification of defects for AN3 thru AN20 and AN173 thru AN186 bolts shall be as follows:

Critical:
  None
Major:
  101 Thread size and form (see 4.5.1)
  102 Shank diameter, oversize (unthreaded portion)
  103 More than two imperfect threads
  104 Grip length
  105 Fillet under head
  106 Cotter pin hole location (where required)
  107 Hole in head missing (where required)
  108 Dimension across flats
  109 Straightness of shank
  110 Angle of bearing surface to shank
  111 Plating (where required) (visual inspection)
  112 Identification
  113 Burrs in cotter pin hole or on washer face

Minor A:
  201 Length
  202 Head thickness
  203 Shank diameter, undersize (unthreaded portion)
  204 Hole in head, diameter and location (where required)
  205 Cotter pin hole diameter (where required)
Minor B:
  301 30-degree chamfer on head
  302 45-degree chamfer on thread end
  303 Eccentricity of head to shank
  304 Burrs, general
  305 Washer face diameter and thickness

4.4.1.2.2 AN21 thru AN36 Bolt - Clevis.- The classification of defects for AN21 thru AN36 bolts shall be as follows:

Critical:
  None
Major:
  101 Thread size and form (see 4.5.1)
  102 Shank diameter (unthreaded portion)
  103 Grip length
  104 Fillet under head
  105 Slot missing
  106 Cotter pin hole location (where required)
  107 Straightness of shank
  108 Angle of bearing surface to shank
  109 Plating (where required) (visual inspection)
  110 Identification
  111 Burrs in cotter pin hole or under head

Minor A:
  201 Length
  202 Head diameter
  203 Slot dimensions
  204 Flat on OD of head
  205 Head thickness
  206 Cotter pin hole diameter (where required)
  207 Thread undercut dimensions
Minor B:
  301 45-degree chamfer on thread end
  302 Eccentricity of head to shank
  303 Burrs, General

4.4.1.2.3 AN42 thru AN49 Bolt - eye.- The classification of defects for AN42 thru AN49 bolts shall be as follows:

Critical:
  None
Major:
  101 Thread size and form (see 4.5.1)
  102 Shank diameter, oversize (unthreaded portion)
  103 More than two imperfect threads
  104 Grip length
  105 Fillet under head
  106 Cotter pin hole location
  107 Eye hole diameter and location
  108 Diameter of flange
  109 Length of tongue and flange
  110 Tongue end radius
  111 Thickness of tongue
  112 Radius tongue to flange
  113 Straightness of shank
  114 Angle of bearing surface to shank
  115 Surface finish, plating (visual inspection)
  116 Identification
  117 Burrs
Minor A:
  201 Length
  202 Shank diameter undersize
  203 Eccentricity of head to shank
  204 Cotter pin hole diameter
  205 Flange thickness
Minor B:
  301 Chamfer, thread end

4.4.1.2.4 AN73 thru AN81, MS20073, and MS20074 Bolt, machine, aircraft, drilled head.- The classification of defects for AN73 thru AN81, MS20073, and MS20074 bolts shall be as follows:

Critical:
  None
Major:
  101 Thread size and form (see 4.5.1)
  102 Shank diameter, oversize (unthreaded portion)
  103 More than two imperfect threads
  104 Grip length
  105 Fillet under head
  106 One or more radial holes in head missing
  107 Dimension across flats
  108 Straightness of shank
  109 Angle of bearing surface to shank
  110 Plating (where required) (visual inspection)
  111 Identification
  112 Burrs in cotter pin hole or on washer face
  113 Radial holes in head, diameter and location
  114 Axial hole in head, diameter, depth, and location

Minor A:
  201 Length
  202 Shank diameters, undersize (unthreaded portion)
  203 Head thickness
Minor B:
  301 30-degree chamfer on head
  302 45-degree chamfer on thread end
  303 Eccentricity of head to shank
  304 Burrs, general
  305 Washer face diameter and thickness

4.4.2 Sampling for tension, shear, and hardness tests.- For each of the tension, shear, and hardness tests a separate sample shall be randomly selected in accordance with MIL-STD-414, inspection level IV, with an AQL of 1.5 percent, using table C-1. The alternate attribute sampling plan shall be in accordance with MIL-STD-105, inspection level I, with an AQL of 1.5 percent. In the case of resubmitted lots over 100,000 in size use the next highest sample size than that used on original inspection.

4.4.3 Sampling for head structure, bend, and decarburization tests.- Sampling shall be in accordance with MIL-STD-105, inspection level S-3, acceptance number zero. For resubmitted lots over 100,000 in size use the next largest sample size than that used in original inspection.

4.4.4 Sampling for magnetic particle inspection.- Sampling for magnetic particle inspection shall be at random in accordance with MIL-STD-105, with an AQL of 1.5 percent. The acceptance and rejection numbers of this sampling plan shall apply to those bolts which are judged defective or in nonconformance with the requirements contained herein after microexamination has been performed on those samples revealing magnetic particle indications. Magnetic particle inspection shall not be required for bolts less than 1/4 inch in diameter.

4.4.5 Sampling for penetrant inspection.- Sampling for penetrant inspection shall be at random in accordance with MIL-STD-105, with an AQL of 1.5 percent. The acceptance and rejection numbers of this sampling plan shall apply to those bolts which are judged defective or in nonconformance with the requirements contained herein after microexamination has been performed on those samples revealing penetrant indications. Penetrant inspection shall not be required for bolts less than 1 [illegible] inch in diameter.

4.5 Inspections.-

4.5.1 Dimensions.- Dimensions shall be measured by suitable gages or measuring instruments. In case of controversy, gages and instruments certified by Government laboratories shall be employed. Screw threads shall be checked as specified in MIL-S-7742. Consideration should be given to the possibility of minor differences between various gages which could result in borderline discrepancies.

4.5.2 Tension.-

4.5.2.1 Hexagon-head bolts.- Hexagon-head bolts shall be tested in accordance with the applicable requirements of Federal Test Method Standard No. 151 in tension between the head of the bolt and an AN315 nut of the corresponding size, heat treated to 180,000 psi.

4.5.2.1.1 The acceptability of non-corrosion-resistant steel bolts having a grip less than the diameter of the bolt shank shall be based on the hardness test.

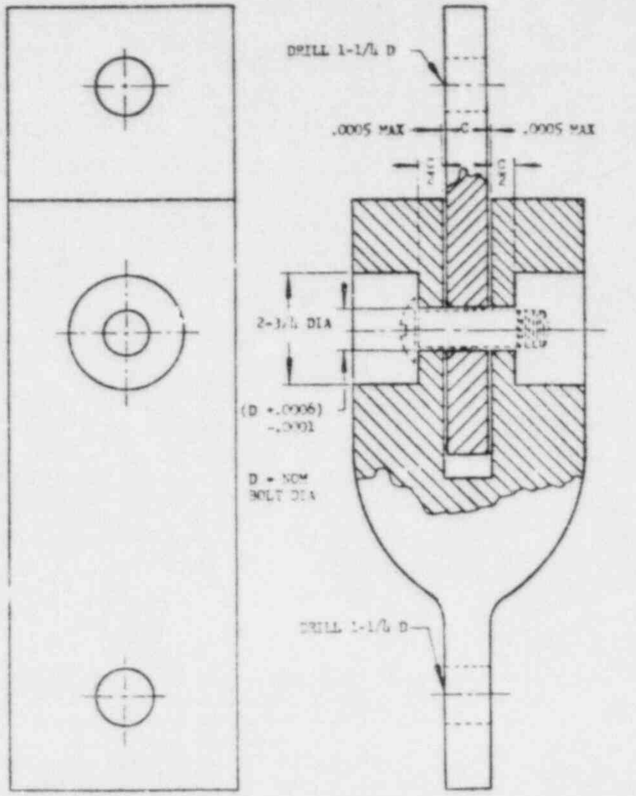
4.5.2.1.2 The acceptability of corrosion-resistant steel bolts and aluminum alloy bolts having a grip less than the diameter of the bolt shank shall be based on a test coupon of the same material, diameter, and heat treatment.

4.5.2.2 Eye bolts.- Eye bolts shall be tested in accordance with the applicable requirements of Federal Test Method Standard No. 151 in tension between the eye of the bolt and a nut of sufficient thickness to develop the full strength of the bolt without stripping the threads.

4.5.2.3 Clevis bolts.- Clevis bolts shall be tested in accordance with the applicable requirements of Federal Test Method Standard No. 151 in tension between the head of the bolt and an AN320 or MS21083 nut of the corresponding size.

4.5.3 Shear.- The shear test shall be performed in a jig conforming substantially to that shown in figure 2. Other types of shearing jigs may be used if acceptable to the procuring activity. The acceptability of the bolts which are of insufficient length in the unthreaded portion to conduct the shear test shall be based on the hardness test.

4.5.4 Bend.- Bolts shall be bent cold in the unthreaded portion through an angle of 180 degrees over a diameter equal to the bolt diameter for steel bolts and equal to six times the bolt diameter for aluminum alloy bolts. The bending shall be accomplished by the gradual application of pressure in a suitable fixture. The acceptability of the bolts which are of insufficient length in the unthreaded portion to conduct the bend test shall be based on the hardness test.



BOLT SIZE	C
Under 7/16	1/4
7/16 to 5/8, incl	1/2
3/4 to 1, incl	13/16
1-1/8 and 1-1/4	1-3/16

DIMENSIONS IN INCHES.

FIGURE 2. Double shear jig for clevis bolts

4.5.5 Hardness.- Rockwell hardness readings shall be taken on a smooth, flat, prepared surface at any location on the bolt.

4.5.6 Decarburization.- Decarburization shall be determined by microexamination. Specimens shall be taken from a transverse section of the shank of the finished bolt. The etchant shall be 5 percent nital. Microscopic examination shall be made at a magnification of 100 diameters.

4.5.7 Head structure.- A longitudinal macrosection of the head, not less than 1/4 inch from the upper portion of shank, after the head-forming and heat-treating process, shall be examined for internal structure.

4.5.7.1 Steel bolts.- Steel bolts shall be etched in an aqueous solution containing 50 percent (by volume) of hydrochloric acid held at 160° to 180° F (71° to 82° C) for a time sufficient to reveal the macrostructure properly.

4.5.7.2 Aluminum alloy bolts.- Aluminum alloy bolts shall be etched in a 5- to 15-percent (by weight) aqueous caustic soda (NaOH) solution at approximately 180° F (82° C) for a time sufficient to reveal the macrostructure properly. This shall be followed by washing in water and dipping in a 10-percent (by weight) nitric acid solution to remove black stains. Water washing and drying shall follow.

4.5.8 Magnetic particle inspection.- The indication of discontinuities in ferromagnetic bolts, such as cracks, seams, and inclusions, shall be determined by magnetic particle inspection. Magnetic particle indications of themselves shall not be cause for rejection. If, in the opinion of the inspector, the indications may be cause for rejection, representative samples shall be taken from those bolts showing indications which shall be further examined by microexamination to determine whether the indicated discontinuities are in accordance with the limits specified herein.

4.5.8.1 Method.- Magnetic particle inspection shall be performed in accordance with MIL-I-6868. Such inspection shall, in general, be performed on finished bolts, but in any case subsequent to any processing operations which could adversely affect the part. The magnetizing field shall be parallel to the longitudinal axis of the bolt, primarily for the indication of transverse defects. Bolts shall not be dyed as an indication of magnetic particle inspection in accordance with the sampling requirements of this specification. Personnel conducting magnetic particle inspection shall be certified in accordance with MIL-STD-410.

4.5.9 Penetrant inspection.- The indication of discontinuities in aluminum alloy bolts, such as cracks, seams, and inclusions open to the surface shall be determined by penetrant inspection. Penetrant indications of themselves shall not be cause for rejection. If, in the opinion of the inspector, the indications may be cause for rejection, representative samples shall be taken from those bolts showing indications which shall be further examined by microexamination to determine whether the indicated discontinuities are in accordance with the limits specified herein.

4.5.9.1 Method.- Penetrant inspection shall be performed in accordance with MIL-I-6866. Such inspection shall in general be performed on finished bolts, but in any case subsequent to any processing operations which could adversely affect the part. Bolts shall not be dyed as an indication of penetrant inspection in accordance with the sampling requirements of this specification. Personnel conducting penetrant inspection shall be certified in accordance with MIL-STD-410.

4.6 Resubmitted lots.- Paragraph titled "Resubmitted lots" of MIL-STD-105 shall apply, except that a resubmitted lot shall be inspected by the contractor under supervision of the Government inspector using tightened inspection. For attribute plans of MIL-STD-105, where the original acceptance number was zero, a sample size represented by the next higher sample size code letter shall be chosen with the acceptance number remaining zero. Before a lot is resubmitted, full particulars concerning the cause of previous rejection and the action taken to correct the defects found in the lot shall be furnished by the contractor to the Government inspector.

5. PREPARATION FOR DELIVERY

5.1 Cleaning, preservation, packaging, packing and marking.- Unless otherwise specified, preparation for delivery (cleaning, preservation, packaging, packing, and marking) shall conform to the applicable requirements of MIL-H-3982 at the level of protection specified in the contract or order (see 6.2).

6. NOTES

6.1 Intended use.- The bolts covered by this specification are intended for use in the manufacture of aircraft and aircraft accessories.

6.1.1 Non-corrosion-resistant steel conforming to MIL-S-6050 and AMS6300 may not be suitable for bolts larger than 1/2 inch in diameter.

6.2 Ordering data.- Procurement documents should specify:

(a) Title, number, and date of this specification.
(b) Part number of the bolt desired (type, material, thread, lengths).
(c) Quantity.
(d) Selection of applicable preservation, packaging, and packing (see 5.1).

6.3 Standard and nonstandard bolt designs that are approved for use in design and construction of aerospace vehicles; that are specified by reference by this specification; and that have all descriptive factors that affect universal interchangeability, the same except for the type of plating in accordance with QQ-P-416 are considered to have the following interchangeability relationship:

(a) Those bolts with type II plating can be used to replace those bolts with type I plating in all applications.
(b) In other applications, those bolts with type I plating can be used in place of those bolts with type II plating until present stocks are depleted, but may not be procured later than 1 October 1966.

MIL-S-7839A
19 FEBRUARY 1965

Superseding
MIL-S-7839
31 January 1952

MILITARY SPECIFICATION

SCREWS, STRUCTURAL, AIRCRAFT

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers aircraft structural screws.

1.2 Classification. Screws shall be of the types and sizes designated by the part numbers on the military standard (MS) as specified (see 6.2).

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

FEDERAL

- QQ-A-225/6—Aluminum Alloy Bar, Rod, and Wire, Rolled, Drawn, or Cold Finished 2024
- QQ-A-430—Aluminum Alloy Rod and Wire, for Rivets and Cold Heading
- QQ-P-35—Passivation Treatments for Austenitic, Ferritic, and Martensitic Corrosion-Resisting Steel (Fastening Devices)
- QQ-P-416—Plating, Cadmium (Electrodeposited)
- QQ-S-763—Steel, Bars, Shapes, and Forgings, Corrosion-Resisting

MILITARY

- MIL-H-3982—Hardware (Fasteners and Related Items) Packaging and Packing for Shipment and Storage of
- MIL-S-6049—Steel; Chrome-Nickel-Molybdenum (8740) Bars, Rods, and Forging Stock (for Aircraft Applications)
- MIL-S-6050—Steel; Chrome-Nickel-Molybdenum (8630) Bars, Rods, and Forging Stock (for Aircraft Applications)
- MIL-H-6088—Heat Treatment of Aluminum Alloys
- MIL-S-6098—Steel; Chrome-Nickel-Molybdenum (8735) Bars, Rods, and Forging Stock (for Aircraft Application)
- MIL-S-6758—Steel; Chrome-Molybdenum (4130) Bars, and Reforging Stock (Aircraft Quality)
- MIL-I-6866—Inspection, Penetrant Method of
- MIL-I-6868—Inspection Process, Magnetic Particle
- MIL-H-6875—Heat Treatment of Steels (Aircraft Practice) Process for
- MIL-S-7742—Screw Threads, Standard, Optimum Selected Series: General Specification for
- MIL-A-8625—Anodic Coatings, for Aluminum and Aluminum Alloys
- MIL-S-18732—Steel Bars, Alloy, Corrosion-Resistant (16Cr-2Ni), Aircraft Quality

STANDARDS

MILITARY

- MIL-STD-105—Sampling Procedures and Tables for Inspection by Attributes
- MIL-STD-410—Qualification of Inspection Personnel (Magnetic Particle and Penetrant)
- MS16999—Head Discontinuities, Bolts and Screws
- MS9006—Cross Recess Heads for Machine, Wood and Tapping Screws

FSC 5305

- MS27039—Screw, Machine—Pan Head, Structural, Cross Recessed
- MS33750—Recess—Hi-Torque, Dimensions of Recess, Gage, and Driver for
- MS33781—Recess—Torq-Set, Dimensions of Recess, Gage, and Driver for

AIR FORCE-NAVY AERONAUTICAL

- AN502—Screw—Machine, Drilled Fillister Head, Fine Thread
- AN503—Screw—Machine, Drilled Fillister Head, Coarse Thread
- AN509—Screw—Machine, Flat Head, 100°, Structural
- AN525—Screw—Washer Head

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply:

SOCIETY OF AUTOMOTIVE ENGINEERS, INC.

AMS 6300—Steel, 25 MO (.35-.40C)

(Application for copies should be addressed to the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York, N.Y., 10017.)

3. REQUIREMENTS

3.1 Data. Unless otherwise specified in the contract or order, no data are required by this specification or any of the documents referenced in section 2 (see 6.2).

3.2. Material.

3.2.1 *Low-alloy steel.* Low-alloy steel screws having ¼-inch body diameter and less shall be manufactured from steel conforming to AMS 6300 or MIL-S-6050. Low-alloy steel screws having a body diameter greater than ¼ inch shall be manufactured from steel conforming to MIL-S-6049, MIL-S-6050, MIL-S-6098, MIL-S-6758, or AMS 6300.

3.2.2 *Corrosion-resistant steel.* Corrosion-resistant steel screws shall be manufactured from material conforming to QQ-S-763, class I, type C, QQ-S-763, class IV, or MIL-S-18732, or equal, or interchangeable with 16-13 chrome-nickel alloy steels.

3.2.3 *Aluminum alloy.* Aluminum-alloy screws shall be manufactured from material conforming to QQ-A-430, alloy 2024, or QQ-A-225/6 in the solution heat-treated T4 temper.

3.3 Design and construction.

3.3.1 *Threads.* Threads of all screws shall conform to MIL-S-7742 and shall be of the sizes specified on the applicable MS. Unless otherwise specified, threads shall be right hand.

3.3.1.1 *Grip.* The grip length shall be measured from the largest diameter of the bearing surface of the head, parallel with the screw axis, to the end of the unthreaded shank.

3.3.2 *Head eccentricity.* Machine screw heads shall not be eccentric with the screw bodies by more than 3 percent of the maximum head diameter. Eccentricity is defined as one-half of the total indicator reading (TIR).

3.3.2.1 *Bearing surface.* The bearing surface of protruding screw heads shall be at right angles to the body within 2 degrees.

3.3.2.2 *Depth of slot.* When a slot is required, the depth of the slot shall be measured as shown on the applicable MS.

3.3.2.3 *Recess.* Recess dimensions shall conform to MS9006, MS33750, and MS33781, as applicable.

3.3.3 *Straightness of shank.* The straightness of the shank shall be within the values specified in table I when the screw is rolled on a surface plate and the point of greatest deviation is measured with a feeler gage of ¼ inch width. The straightness of shank requirements shall apply to size No. 10 and larger screws, and screws smaller than size No. 10 that have a length greater than six times their diameter. For screws under size No. 10, the straightness of shank from table I for size No. 10 shall be used.

3.4 Heat treatment

3.4.1 *Steel.* Low-alloy steel screws shall be heat treated in accordance with MIL-H-6875.

3.4.2 *Aluminum alloy.* Aluminum-alloy screws manufactured from material conforming to QQ-A-430, alloy 2024, shall be heat treated in accordance with MIL-H-6088.

TABLE I. *Straightness of shank*

Screw size	Deviation of screw shank from plane, maximum (inch per inch of screw length)
No. 10	0.0040
1/4, 5/16	.0030
3/8, 7/16	.0025
1/2 and larger	.0020

3.5 Physical properties.

3.5.1 *Tensile strength.* The tensile strength of the screws shall be as specified in table II, when tested in accordance with 4.4.

3.5.2 *Hardness.* All low-alloy steel screws shall be within the Rockwell hardness range C-26 to C-32, when tested in accordance with 4.5.

3.5.3 *Cracks.* Screws shall be free of cracks in any direction and location. A crack is defined as a clean crystalline break passing through the grain or grain boundary without the inclusion of foreign elements.

3.5.4 *Discontinuities.* All structural screws shall be acceptable, provided they do not contain discontinuities which equal or exceed the following limitations. Care must be taken not to confuse cracks (see 3.5.3) with discontinuities.

3.5.4.1 *Longitudinal discontinuities.* Longitudinal discontinuities extending through fillets or threads as shown on figure 1 that exceed the limits shown in table III shall not be acceptable. Seams up to the depth indicated which have been rolled beneath root of thread shall be acceptable.

3.5.4.2 *Transverse discontinuities.* Transverse discontinuities in the shank of the screw as shown on figure 2 that exceed the limits shown in table III shall not be acceptable. Transverse discontinuities shall not be confused with tool marks.

TABLE II. *Strength requirements*

Size	Ultimate tensile strength (minimum)[1] pounds			Ultimate double shear strength (minimum)[2] pounds		
	Low-alloy steel	Corrosion-resistant steel	Aluminum alloy	Low-alloy steel	Corrosion-resistant steel	Aluminum alloy
Coarse thread						
No. 6-32UNC-3	1,120	760	560	2,120	1,480	1,050
No. 8-32UNC-3	1,740	1,180	860	3,000	2,100	1,570
No. 10-24UNC-3	2,170	1,480	1,090	4,250	2,770	2,092
1/4-20UNC-3	3,960	2,700	1,960	7,360	5,000	3,650
5/16-18UNC-3	6,520	4,440	3,230	11,500	7,820	5,750
Fine thread						
No. 6-40UNF-3	1,260	860	630	2,120	1,480	1,050
No. 8-36UNF-3	1,820	1,240	900	3,000	2,100	1,570
No. 10-32UNF-3	2,490	1,690	1,230	4,250	2,770	2,092
1/4-28UNF-3	4,520	3,080	2,240	7,360	5,000	3,650
5/16-24UNF-3	7,240	4,920	3,590	11,500	7,820	5,750
3/8-24UNF-3	10,950	7,450	5,430	16,560	11,250	8,250
7/16-20UNF-3	14,900	10,070	7,350	22,500	15,300	11,250
1/2-20UNF-3	19,950	13,570	9,900	29,400	20,000	14,800
9/16-18UNF-3	25,300	17,200	12,560	37,400	25,300	18,500

[1] The values shown for the ultimate tensile strength are for minimum values and are based on:
125,000 psi for low-alloy steel
85,000 psi for corrosion-resistant steel
62,000 psi for aluminum alloy

The stress area used for the calculation of the tensile strength values are based on the average of the mean pitch and minor diameters of the external thread.

[2] Ultimate shear strengths are computed on the basis of 60 percent of the ultimate tensile strengths.

3.5.4.3 *Screw head shank junction.* Only longitudinal seams of the depths permitted in table III shall be permitted. Slight tool marks or undercuts of depth not to exceed the limits in table III will be permitted, provided they fair into the shank with no sharp scratches, gouges, or corners.

3.5.4.4 *Head discontinuities (seams, inclusions, folds, nicks, or gouges).* Head discontinuities shall not exceed the limits specified on MS16999.

3.5.5 *Decarburization.* Decarburization of low-alloy steel screws shall not exceed the limits shown in table IV, when tested in accordance with 4.6.

3.5.6 *Head structure.* A section of the head shall show no detrimental defects when tested in accordance with 4.7.

3.6 **Finish.** Screws shall be finished as specified in table V unless otherwise noted on the applicable MS.

3.6.1 *Passivating process for corrosion-resistant steel screws.* Corrosion-resistant steel screws shall be passivated in accordance with QQ-P-35.

3.7 **Identification of product.** When required, screws shall be marked for identification purposes as shown on the applicable MS. It is permissible for the screw manufacturer to include his identification marking on the screws.

TABLE III. *Limits for seam depth and tool marks or undercuts*

Screw size in inches	5/16 and under	3/8	7/16	1/2 and over
Depth in shank in inches	0.005	0.006	0.007	0.008

TABLE IV. *Decarburization limits*

Size	Complete decarburization (inch)	Complete plus partial decarburization (inch)[1]
Up to 3/8, incl.	0.004	0.010
Over 3/8 to 1/2, incl.	.005	.012
Over 1/2	.006	.014

[1] The permissible values shown are based on measurements of the entire periphery of the cross section and the average depth determined.

TABLE V. *Finish*

Material	Type of finish	Finish in accordance with
Steel, low-alloy	Cadmium plate	QQ-P-416, type II, class 3
Steel, corrosion-resistant	Passivate	QQ-P-35
Aluminum alloy	Anodize	MIL-A-8625

FIGURE 1. Longitudinal discontinuities extending through fillets or threads.

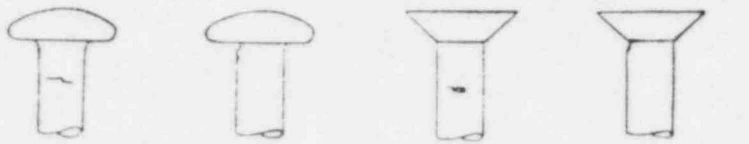


FIGURE 2. Transverse discontinuities in the head or shank.

4. QUALITY ASSURANCE PROVISIONS

4.1 **Responsibility for inspection.** Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 **Quality conformance inspection.** The examination and tests of screws are classified as quality conformance inspection (see 4.3 through 4.10).

4.2.1 *Production lot.* A production lot shall consist of finished screws which are of the same type and diameter, fabricated by the same process, heat treated in the same manner, and produced as one continuous run or order or part thereof.

4.2.2 *Inspection lot.* An inspection lot shall consist of a series of items of production which are judged from previous investigation to have been produced by a process under statistical control. The size of an inspection lot may be equal to, less than, or greater than a production lot.

4.3 **Examination of product.** Sampling for visual and dimensional attributes shall be at random in accordance with MIL-STD-105. AQL's for major A, minor A, and minor B classes of characteristics shall be as follows:

Major A—6.5 percent.
Minor A—6.5 percent.
Minor B—10 percent.

The total defective items for all characteristics of a give [illegible] (e.g., major A, minor A, minor B) shall be combined in order to apply the acceptance and rejection provisions of MIL-STD-105.

4.3.1 *Method.* Finished screws shall be checked for conformance with the following requirements.

4.3.1.1 *Dimensions.* Dimensions shall be measured by suitable gages or measuring instruments. In case of controversy, gages and instruments certified by Government laboratories shall be employed. Screw threads shall be checked as specified in MIL-S-7742.

4.3.1.1.1 *Definition of defects.* All dimensional characteristics are considered defective when out of tolerance.

4.3.1.2 *AN502 and AN503 screws—fillister head.* The classification of defects for AN502 and AN503 screws shall be as follows:

- Critical: None
- Major A
  - Thread size and form
  - Unthreaded shank diameter (A)
  - More than two imperfect threads
  - Grip length (G)
  - Radius under head
  - Hole in head missing
  - Slot in head missing
  - Squareness between head and shank
  - Straightness of shank
  - Surface finish, plating
  - Identification
- Minor A
  - Overall length
  - Head diameter (B)
  - Head height (D)
  - Crown height (C)
  - Slot dimensions and locations
  - Hole diameter and location
  - Burrs and tool marks
  - Eccentricity of head and shank
- Minor B
  - Chamfer on thread end

NOTE: Letters in parentheses correspond to dimensions on applicable drawings.

4.3.1.3 *AN509 screw—machine, flat head, 100°, structural.* The classification of defects for AN509 screws shall be as follows:

- Critical: None
- Major A
  - Thread size and form
  - More than two imperfect threads
  - Grip length
  - Unthreaded shank diameter (A)
  - Head diameter (D)
  - Head angle
  - Slot or recess in head missing
  - Eccentricity of head to shank
  - Straightness of shank
  - Surface finish, plating
  - Identification (where applicable)
- Minor A
  - Overall length
  - Slot or recess dimensions
  - Radius between head and shank
  - Burrs and tool marks
- Minor B
  - Flat on OD of head (F)
  - Chamfer on thread end

4.3.1.4 *MS27039 and AN525 screw—pan head.* The classification of defects for AN525 and MS27039 screws shall be as follows:

- Critical: None
- Major A
  - Thread size and form
  - More than two imperfect threads
  - Grip length (G)
  - Slot or recess in head missing
  - Straightness of shank
  - Squareness between head and shank
  - Surface finish, plating
  - Identification
  - Unthreaded shank diameter
- Minor A
  - Overall length
  - Head thickness (H)
  - Washer thickness (E)
  - Washer diameter (A)
  - Head diameter (A or B)
  - Slot or recess dimensions
  - Eccentricity of head to shank
  - Burrs and tool marks
  - Fillet under head
- Minor B
  - Chamfer on thread end
  - Head crown radius (F)

4.4 Tension.

4.4.1 *Sampling.* Samples for the tension test shall be selected at random in accordance with table VI.

4.4.2 *Method.* The screws shall be tested in tension by applying the load axially on the bearing surface of the head and a nut, or threaded plate into which the screw has been screwed a depth of one diameter. The test load shall be applied at a pulling speed of not more than 2 inches per minute.

4.4.2.1 When the screw is too short for application of the tension test, the number of tension test specimens may be selected from the wire or rod from which the screws are to be made

4.5 Hardness.

4.5.1 *Sampling.* Sampling for the hardness test shall be random in accordance with table VI.

4.5.2 *Method.* Rockwell hardness readings shall be taken on a smooth, flat, prepared surface at any location on the screw.

4.6 **Decarburization.** Decarburization shall be determined by microexamination. Specimens shall be taken from a transverse section of the shank of the finished screw. The etchant shall be 5 percent nital. Microscopic examination shall be made at a magnification of 100 diameters.

4.7 **Head structure.** A longitudinal macrosection of the head and not less than ¼ inch of the upper portion of the shank, after the head forming and heat treating process, shall be examined for internal structure.

4.7.1 *Steel screws.* Steel screws shall be etched in an aqueous solution containing 50

TABLE VI. *Sampling for tension and hardness tests*

Lot size	Sample	Sample size	Cumulative sample size	Accumulated acceptance number	Accumulated rejection number
500 or under	1	3	3	0	2
	2	3	6	1	2
501–3,000	1	4	4	(1)	2
	2	4	8	0	2
	3	4	12	0	3
	4	4	16	1	3
	5	4	20	3	4
3,001–6,000	1	5	5	(1)	2
	2	5	10	0	2
	3	5	15	1	3
	4	5	20	1	3
	5	5	25	3	4
6,001–10,000	1	6	6	(1)	2
	2	6	12	0	3
	3	6	18	1	3
	4	6	24	2	4
	5	6	30	2	4
	6	6	36	3	4
Over 10,000	1	8	8	(1)	2
	2	8	16	0	4
	3	8	24	1	4
	4	8	32	2	5
	5	8	40	3	6
	6	8	48	5	7
	7	8	56	6	7

(1) [illegible]

percent (by volume) of hydrochloric acid held at 70° to 82° C (160° to 180° F) for a time sufficient to reveal the macrostructure properly.

4.7.2 *Aluminum-alloy screws.* Aluminum-alloy screws shall be etched in a 5- to 15-percent (by weight) aqueous caustic soda (NaOH) solution at approximately 82° C (180° F) for a time sufficient to reveal the macrostructure properly. This shall be followed by washing in water and dipping in a 10-percent (by weight) nitric acid solution to remove black stains. Water washing and drying shall follow.

4.8 Magnetic particle inspection. The indicated discontinuities, cracks, seams, and inclusions in low-alloy steel screws shall be determined by magnetic particle inspection unless visual inspection discloses discontinuities which would preclude the necessity for magnetic particle inspection. Magnetic particle indications of themselves shall not be cause for rejection. If in the opinion of the inspector, the indications are cause for rejection, representative samples shall be taken from those screws showing indications which shall be further examined by microexamination to determine whether the indicated discontinuities are in accordance with the limits specified herein.

4.8.1 *Sampling.* Sampling for magnetic particle inspection shall be at random in accordance with MIL-STD-105, with an AQL of 1.5 percent. The acceptance and rejection numbers of this sampling plan shall apply to those screws which are judged defective or in nonconformance with the requirements contained herein after microexamination has been performed on those samples revealing magnetic particle indications. Magnetic particle inspection shall not be required for screws less than ¼ inch in diameter.

4.8.2 *Method.* Magnetic particle inspection shall be performed in accordance with MIL-I-6868. Such inspection shall, in general, be performed on finished screws, but in any case, subsequent to any processing operations which could adversely affect the part. The magnetizing field shall be parallel to the longitudinal axis of the screw, primarily for the indication of transverse defects. Screws shall not be dyed as an indication of magnetic particle inspection in accordance with sampling requirements of this specification. Personnel conducting magnetic particle inspection shall be certified in accordance with MIL-STD-410.

4.9 Fluorescent penetrant inspection. The indicated discontinuities, cracks, seams, and inclusions in aluminum-alloy screws shall be determined by fluorescent penetrant inspection. Fluorescent penetrant indications of themselves shall not be cause for rejection. If in the opinion of the inspector the indications are cause for rejection, representative samples shall be taken from those screws showing indications which shall be further examined by microexamination to determine whether the indicated discontinuities are in accordance with the limits specified herein.

4.9.1 *Sampling.* Sampling for fluorescent penetrant inspection shall be at random in accordance with MIL-STD-105, with an AQL of 1.5 percent. The acceptance and rejection numbers of this sampling plan shall apply to those screws which are judged defective or in nonconformance with the requirements contained herein after microexamination has been performed on those samples revealing fluorescent penetrant indications. Fluorescent penetrant inspection shall not be required for screws less than ¼ inch in diameter.

4.9.2 *Method.* Fluorescent penetrant inspection shall be performed in accordance with MIL-I-6866. Such inspection shall, in general, be performed on finished screws, but in any case subsequent to any processing operations which could adversely affect the part. Screws shall not be dyed as an indication of fluorescent penetrant inspection in accordance with the sampling requirements of this specification. Personnel conducting fluorescent penetrant inspection shall be certified in accordance with MIL-STD-410.

4.10 Packaging, packing, and marking. Preparation for delivery shall be examined for conformance to section 5.

5. PREPARATION FOR DELIVERY

5.1 Preservation, packaging, packing, and marking. Unless otherwise specified, the structural screws shall be preserved, packaged, packed, and marked in accordance with MIL-H-3982.

6. NOTES

6.1 Intended use. The screws are intended for aircraft structural applications.

6.2 Ordering data. Procurement documents should specify:

(a) Title, number, and date of this specification.
(b) Data requirements (see 3.1).
(c) MS part No. of the screw desired (see 1.2).
(d) Levels of packaging and packing required (see 5.1).

Custodians:
Army—WC
Navy—WP
Air Force—69

Reviewer activities:
Army—MO, MI
Navy—WP
Air Force—69

User activities:
Army—WC
Defense Supply Agency—IS

Preparing activity:
Air Force—69

Project No. 5305-0450

Review/user information is current as of the date of this document. For future coordination of changes to this document, draft circulation should be based on the information in the current Federal Supply Classification Listing of DoD Standardization Documents.

MIL-N-7873A
Amendment - 1
5 FEBRUARY 1971

MILITARY SPECIFICATION
NUT, SELF-LOCKING, 1,200°F

This amendment forms a part of Military Specification MIL-N-7873A, dated 17 November 1967, and is mandatory for use by all Departments and Agencies of the Department of Defense.

Page 2: Section 2 - Applicable Documents, under Standards add MIL-STD-1312 Fasteners, Test Methods

Page 2: Add to 3.1

In addition, the retention of qualification on the qualified products list shall be dependent on a periodic verification of continued compliance with the requirements of this specification (See 4.3.2.1).

Page 7: Add 4.3.2.1

Retention - The retention of qualification shall consist of periodic verification to determine compliance of the qualification requirements of the specification. The time and method of periodic verification shall be specified by the activity responsible for the Qualified Products List and shall be included in the Notice of Qualification letter.

Pages 12-13: Delete figures 1 and 2.

Page 14: Paragraph 4.5.5 delete and substitute:

4.5.5 Vibration - Sample nuts with matching bolts of the sizes and quantities specified in Table X shall be vibrated in accordance with MIL-STD-1312, Test 7. Vibration life for each lot of five specimens of less than 30,000 cycles shall be cause for rejection.

FSC 5310

Page 14: Table X delete and substitute:

TABLE X VIBRATION REQUIREMENTS

Nut Size	Bolt Size	Bolts & Nuts req'd (Minimum of each)	Max. Assembly Torque After Bake (In-Lb)
10-32	MS20033-12	10	36
1/4-28	MS20034-12	10	60
5/16-24	MS20035-12	10	120
3/8-24	MS20036-12	10	160
7/16-20	MS20037-12	10	200
1/2-20	MS20038-12	10	300

Page 14: Delete paragraphs 4.5.5.2, 4.5.5.3 and 4.5.5.4 and in their place substitute:

4.5.5.2 Preparation for vibration test -

4.5.5.2.1 Accelerated vibration - The nuts shall be assembled in accordance with Figure 1, of MIL-STD-1312, Test 7 with bolts and torque values as specified in Table X. The nuts shall then be removed and reinstalled to this torque four additional times before being vibrated.

4.5.5.2.2 Baking of Test specimens - Nuts shall be assembled on the appropriate bolts and baked for six hours at 1200°F. The baked specimens shall be allowed to cool slowly in air to room temperature. The nuts shall then be removed and reinstalled to torque values specified in Table X for four additional times before being vibrated.

4.5.5.3 Method - Use MIL-STD-1312, Test 7 procedure.

4.5.5.3.1 Determination shall be made throughout the test to guarantee that assembly is traversing the entire length of the slots in the test fixture. The test shall be run for 30,000 cycles except that it shall be stopped prior to the completion of the 30,000 cycles in the event a nut becomes disassembled from the bolt. The nut samples shall be examined under 10X magnification for cracks.

4.5.5.3.2 The nuts shall be considered to have failed to pass the vibration test under the following conditions:

a. If any structural failure, such as broken segments, locking inserts falling out, or cracks occurring in the nuts during the test, provided failure is not the result of failure of the bolt.

b. If any nut comes completely off the bolt or can be turned completely on or off the bolt with the fingers during or after completion of 30,000 cycles.

c. If relative rotation between any nut and bolt exceeds 360 degrees.

Page 16: Insert paragraph:

6.3.2 For qualification, vibration requirements as specified in MIL-N-7873A without amendment 1, can be used until 31 December 1972.

CUSTODIANS:
Army - AV
Navy - AS
Air Force - 11

Reviewer Activities:
Army - AV
Navy - AS
Air Force - 82

Preparing Activity:
Navy-AS

Project No. 5310-0665

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17 NOVEMBER 1957
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MIL-N-7873
29 February 1952

MILITARY SPECIFICATION

NUT, SELF-LOCKING, 1,200° F

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 This specification covers self-locking nuts and self-locking plate nuts for use where temperatures will not exceed 1,200° F.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Federal

GGG-W-636	Wrenches, Box and Open End (Nonadjustable)
GGG-W-641	Wrench, Sockets, (and Sockets, Handles, and Attachments for Socket Wrenches; Hand)
PPP-B-665	Boxes, Paperboard, Metal Stayed (Including Stay Material)

Military

MIL-H-3982	Hardware (Fasteners and Related Items) Packaging and Packing for Shipment and Storage of
MIL-I-6866	Inspection, Penetrant Method of
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter; General Specification for
MIL-I-17214	Indicator, Permeability, Lo Mu (Go-No-Go)

FSC 5310

STANDARDS

Military

A3503	Screw, Machine, Fillister Head, Coarse Thread
MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-140	Qualification of Inspection Personnel (Magnetic Particle and Penetrant)
MS20033 thru MS20046	Bolt, Machine, Hexagon Head, 1200° F

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications.- The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply:

American Standards Association

ASA B46.1 - 1962	Surface Texture (Surface Roughness, Waviness and Lay)

(Copies of the above publication may be obtained from the American Standards Association, Inc., 10 East 40th Street, New York, N. Y. 10016.)

Society of Automotive Engineers (Aeronautical Material Specifications)

AMS2410	Silver Plating, Nickel Strike - High Bake

(Copies of SAE publications may be obtained from the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York, N. Y. 10017.)

3. REQUIREMENTS

3.1 Qualification.- The nuts furnished under this specification shall be a product which is in accordance with the applicable standard and which has been subjected to and passed the qualification tests specified herein, and which has been listed on or approved for listing on the applicable Qualified Products List.

3.1.1 Product design change.- Any change in product design, material, material hardness, finish, or lubrication will require requalification of the product.

3.2 Data.- Unless otherwise specified in the contract or order, no data (other than reports and drawings accompanying qualification samples) are required by this specification or any of the documents referenced in section 2 (see 6.2).

3.3 Materials.- The material from which the nuts (see 6.4) are fabricated shall be heat-resisting and corrosion-resisting austenitic steel which is not subject to intergranular deterioration at 1,200° F. In the event the applicable standard drawing specifies a particular material for fabrication of the nuts, the specified material, or authorized substitute, shall be used.

3.4 Design.- Self-locking nuts shall conform to that shown on the applicable standard.

3.5 Construction.- The nut shall be of the prevailing torque-type, self-contained, all metal unit, including the self-locking device. The locking device shall not operate by means of separate movement and shall not depend upon pressure on the bearing surface for locking action.

3.5.1 Bearing surface.- The bearing surface shall be normal to the axis of the pitch diameter of the threads within 0.003 inch total indicator reading for sizes up to 1/2 inch, and 0.005 inch for sizes larger than 1/2 inch. The tapped hole shall be concentric with the wrenching surface within 0.010 inch total indicator reading.

3.5.1.1 The surface roughness of the nuts shall not exceed 125 microinches when tested as specified in section 4.

3.5.2 Threads.- The threads shall conform to MIL-S-8879. Threads used on the locking device may be displaced or deformed in any manner which provides self-locking nuts conforming to this specification. The nut shall allow the "go" gage to enter a minimum of 1-1/2 turns before engagement of the locking element.

3.5.3 Plate nut rivet-bolt hole alignment.- Plate nut rivet-bolt hole alignment shall be in accordance with the applicable standard.

3.6 Plating and surface treatment.- The threads of 1,200° F heat and corrosion resistant steel nuts shall be silver plated in accordance with AMS 2410. Application of such finish to the exterior surface of nut or nut retaining cage may be omitted. No plating finish shall be applied in the area of the projection weld nibs of projection weld plate nuts.

3.7 Axial strength.- The nuts shall have a minimum axial strength of not less than the values specified in table I, when tested as specified in 4.5.2.1.

3.8 Stress rupture strength.- The nuts shall satisfactorily pass the stress rupture strength test of 4.5.2.2.

TABLE I. Minimum strength requirements

Thread size	Axial strength at room temp. (lbs. min.)	Axial strength after baking at 1,200° F for 6 hours (lbs. min.)	Stress rupture tensile load 96 hours at 1,200° F (lbs. min.)
6-32	1,130	850	
8-32	[illegible]	1,290	
10-32	2,460	1,840	940
1/4-28	4,580	3,430	1,710
5/16-24	7,390	5,500	2,730
3/8-24	11,450	8,600	4,130
7/16-20	15,450	11,600	5,580
1/2-20	21,110	15,800	7,520
9/16-18	26,800	20,100	[illegible],540
5/8-18	34,130	25,600	12,000
3/4-16	50,020	37,500	17,600
7/8-14	68,440	51,300	23,900
1-12	92,180	69,100	32,000

3.9 Torque.-

3.9.1 Wrench torque.- Hexagon nuts shall withstand the wrench torque listed in table II without any permanent deformation that may interfere with the use of a box or socket wrench conforming to GGG-W-636 and GGG-W-641, respectively.

TABLE II. Wrench torque at room temp. after 6-hour bake at 1,200° F

Size	Wrench torque Inch-Pounds
No. 6	20
No. 8	30
No. 10	60
1/4	150
5/16	360
3/8	650
7/16	1,200
1/2	1,600
9/16	2,300
5/8	4,000
3/4	6,000
7/8	8,000
1	11,000

TABLE III. Locking torque at room ambient temperature

Bolt size	Maximum torque (in.-lbs.) (installation or removal)	Minimum breakaway torque (in.-lbs.) 15th removal
6-32 UNC	10	1.0
8-32 UNC	15	1.5
10-32 UNF	18	2.0
1/4-28 UNF	30	3.5
5/16-24 UNF	60	6.5
3/8-24 UNF	80	9.5
7/16-20 UNF	100	14.0
1/2-20 UNF	150	18.0
9/16-18 UNF	200	24.0
5/8-18 UNF	300	32.0
3/4-16 UNF	400	50.0
7/8-14 UNF	600	70.0
1-12 UNF	800	90.0

3.9.2 Locking torque.- Locking torque tests shall be performed with no axial load on the nut in accordance with 4.5.3.2.

3.9.2.1 Maximum and minimum locking torque.- The nuts shall have a breakaway torque which meets the minimum breakaway torque value specified in table III. The maximum locking torque shall not exceed the torque value specified in table III when tested at room temperature. After baking at 1,200° F, the maximum locking torque of the nut shall not exceed twice the torque value specified in table III.

3.9.3 Torque out.- Torque out values for plate nuts shall be not less than the values listed in table IV, when tested as specified in 4.5.3.3.

TABLE IV. Torque out

Thread size	Torque (inch-pounds)
No. 6	30
No. 8	45
No. 10	60
1/4	100
5/16	160
3/8	240
7/16 and over	350

3.10 Push out.- Push out values for the plate nuts shall be not less than the values listed in table V when tested as specified in 4.5.4.

TABLE V. Push out

Thread size	Pounds
No. 6	60
No. 8	80
No. 10	100
1/4 and over	125

3.11 Vibration.- Self-locking hexagon and plate nuts shall withstand the vibration test as specified in 4.5.5.

3.12 Discontinuities.- Discontinuities in the nuts shall not exceed the depths shown in table VI when tested as specified in 4.5.6. Cracks shall not be permitted in any location. A crack is defined as a clean crystalline break passing through the grain or grain boundary without the inclusion of foreign elements.

TABLE VI. Limits of depths on laps, seams, and inclusions of finished nuts

Thread size of nut	5/16 and under	3/8	7/16	1/2	9/16	5/8	3/4	7/8 and up
Hexagon and plate nuts made from sheet metal	0.005	0.006	0.006	0.007	0.008	0.009	0.010	0.011
Hexagon and plate nuts made from bar or wire	0.010	0.011	0.012	0.014	0.016	0.017	0.019	0.022

3.13 Identification of product.- Nuts shall be identified in accordance with the applicable standard.

3.14 Workmanship.- Workmanship shall be consistent with the type of product, finish, and the class of thread fit specified. The product shall be free from fins, seams, cracks, toolmarks, and other defects which might affect serviceability.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection.- Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the

supplier may utilize his own facilities or any other commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of tests.- The inspection of nuts shall be classified as:

(a) Qualification inspection (4.3)
(b) Quality conformance inspection (4.4)

4.3 Qualification inspection.-

4.3.1 Sampling instructions.- Samples shall consist of 70 hexagon or plate nuts for each size upon which qualification is desired. All bolts, screws, and mandrels necessary for tests specified herein shall be furnished by the manufacturer. Samples shall be identified as required and forwarded to the activity responsible for qualification, designated in the letter of authorization from that activity (see 6.3).

4.3.2 Inspection.- The qualification inspection of self-locking nuts shall consist of all the examinations and tests of this specification, as specified under 4.5.

4.3.3 Certified test report.- The manufacturer shall furnish a certified test report showing that the manufacturer's product satisfactorily conforms to this specification. The test report shall include, as a minimum, actual results of the tests specified herein. When this report is submitted, it shall be accompanied by a dated drawing which completely describes the manufacturer's product by specifying all dimensions and tolerances, composition of material selected, plating applied, and the material hardness. The manufacturer's part number for each size shall be included on the above drawing.

4.4 Quality conformance inspection.- Quality conformance inspection shall consist of the tests specified in 4.4.2.

4.4.1 Sampling.- Sample nuts shall be selected at random from each lot as specified below.

4.4.1.1 Lot.- A lot shall consist of finished nuts which are of the same type and diameter fabricated by the same process, heat treated in the same manner, and produced as one continuous run or order or part thereof.

4.4.1.2 Sampling plan A.- Sampling sizes for examination of product and thread fit, bearing surface squareness, and discontinuities shall be in accordance with MIL-STD-105, inspection level I, as specified in table VII. The acceptance and rejection criteria shall be applied for the following Acceptable Quality Levels (AQL's) pertaining to the corresponding class of characteristics:

Major AA	0.0 percent
Major A	0.4 percent
Major B	1.5 percent
Major C	2.5 percent

4.4.1.2.1 Classification of defects.- The classification of defects for self-locking nuts shall be as follows:

Major AA	Visual inspection of package marking
Major A	Visual presence of locking configuration 103 Bearing surface squareness
Major B	101 Thread fit
Major C	104 Surface plating 203 Loose or hanging burrs 205 All dimensional characteristics which are not covered above

TABLE VII. Sampling plan A - Normal inspection (single sampling)

Lot size	Inspection level I, MIL-STD-105								
	0.4 Percent AQL			1.5 Percent AQL			2.5 Percent AQL		
	Sample size	Ac	Re	Sample size	Ac	Re	Sample size	Ac	Re
2-180	35	0	1	10	0	1	7	0	1
181-300	35	0	1	10	0	1	25	1	2
301-500	35	0	1	35	1	2	25	1	2
501-800	35	0	1	35	1	2	35	2	3
801-1,300	35	0	1	50	2	3	50	3	4
1,301-3,200	110	1	2	75	3	4	75	4	5
3,201 and up	150	2	3	150	5	6	150	8	9

4.4.1.3 Sampling plan B.- For the axial strength test, samples shall be selected in accordance with table VIII.

TABLE VIII. Sampling plan B

Lot size	Sample size	Acceptance number
Under 10,000	5	0
10,000 to 50,000	10	0
50,001 to 100,000	15	0
Over 100,000	27	1

4.4.1.4 Sampling plan C. - For the locking torque, torque out, and push out tests, sampling shall be in accordance with the attribute plan shown in table VIII. The acceptance or rejection numbers shall apply to all the tests for the locking torque, torque out, and push out tests taken separately, i.e. a nut shall be classified defective if it fails to meet any requirements of any one of these tests.

4.4.2 Tests. - Quality conformance inspection of self-locking nuts shall consist of:

(a)	Examination of product	(4.5.1)
(b)	Axial strength room temperature	(4.5.2.1)
(c)	Locking torque (except after bake)	(4.5.3.2)
(d)	Discontinuities	(4.5.6)

In addition, self-locking nuts shall pass any of the other tests specified in this specification which are considered necessary to determine conformance with this specification.

4.4.3 Resubmitted inspection lots. - The paragraph titled "Resubmitted lots or batches" of MIL-STD-105 shall apply, except that a resubmitted inspection lot shall be inspected by the contractor, using tightened inspection. Before an inspection lot is resubmitted, full particulars concerning the cause of previous rejection and the action taken to correct the defects found in the inspection lot shall be furnished by the contractor to the procuring activity.

4.5 Inspection methods.-

4.5.1 Examination of product. - The nuts shall be examined for conformance to this specification with respect to material, workmanship, dimensions, design and construction, and finish.

4.5.1.1 Eccentricity. - The indicator reading to determine the eccentricity of the bearing surface with respect to the tapped hole shall be measured at the outer periphery of the washer face of the nut.

4.5.1.2 Surface roughness. - The surface roughness shall be measured in accordance with publication ASA B46.1 - 1962.

4.5.2 Axial and stress rupture strength. - The bolts for these tests shall be hardened and shall be threaded in accordance with MIL-S-8879, class 3A. When conducting these tests, the bolt hole in the bearing plate shall have a free fit not in excess of 0.016 inch greater than the diameter of the bolt. The thickness of the bearing plate shall be not less than the diameter of the bolt used in the test.

4.5.2.1 Axial strength.- At least three sample nuts shall be assembled on bolts and baked at 1,200° F for 6 hours, cooled to room temperature, then removed from the bolts. These nuts and at least three nuts in the as-received condition shall then be assembled on the mandrels and the load specified in table I applied to the nuts. The threads of the nut shall not strip at the applied load. If the threads on the mandrel are damaged during the test, the results of that test shall be discarded. The tests of the nuts need not be carried to destruction, but may be stopped when the specified load is reached.

4.5.2.2 Stress rupture strength.- The nut shall be tested at 1,200° ±5° F in tension between the head of the bolt and the nut for 96 hours. The load applied shall be as specified in table I. Rupture of the nut before the specified time shall be cause for rejection.

4.5.3 Torque.-

4.5.3.1 Wrench torque.- Steel bolts in accordance with 4.5.2 shall be used for this test. Three of the hexagon nuts shall be subjected to this test after having been baked for 6 hours at 1,200° F, then cooled to room temperature. The nuts shall be tightened against a steel bushing with a box or socket wrench to the torque values specified in table II. Box wrenches shall be type I, class 1 conforming to GGG-W-636 and socket wrenches shall conform to GGG-W-641. Deformation which interferes with the proper application and removal of the nut with the wrench is sufficient cause for rejection.

4.5.3.2 Locking torque.- The locking torque tests shall be run at a rate slow enough to obtain a dependable measurement of torque. The temperature rise of the nut under tests shall not exceed 75° F above room temperature.

4.5.3.2.1 Maximum locking and minimum breakaway torque.- Nuts shall be tested in accordance with the procedure in tests 1 and 2, table IX. New nuts and bolts shall be used for each test.

4.5.3.2.1.1 Bolts or screws for maximum locking torque and minimum breakaway torque tests.- For the maximum locking torque and minimum breakaway torque tests, bolts or screws shall conform to MS20033 through MS20046 for sizes No. 10 and above, and to AN503 for sizes under No. 10, except that the material of the bolts or screws shall be equal or equivalent to the material of the nut. All bolts or screws used shall allow the nut to be assembled fully with the fingers up to the locking element.

TABLE IX. Torque test procedure

Test	No. nuts tested	Pretest assembly position	Condition	Test temperature
1	10	Unassembled	As-received	Room
2	10	Fully assembled	Bake 6 hours fully assembled at 1,200° F, then cooled to room temperature	Room

4.5.3.2.2 Maximum locking and minimum breakaway torque. - The nut shall be installed and removed from the test bolt 15 times checking maximum locking torque and minimum breakaway torque during the first and fifteenth cycles. A bolt will be considered fully installed when two thread pitches (including chamfer) extend through the nut; the removal cycle shall be considered complete when the locking device is disengaged. The minimum breakaway torque shall be determined when a minimum of one and a maximum of two threads extend through the nut.

4.5.3.2.3 Reusability. - At the conclusion of the minimum breakaway torque tests, the nuts and bolts or screws used in this test shall be examined for damage to the threads. Noticeable distortion or scratches deep enough to reduce the efficiency of the threads shall be cause for rejection. The threads on the Bolt or screw, as applicable, shall remain in serviceable condition and permit the installation of a new nut freely with the fingers up to the self-locking element.

4.5.3.3 Torque out. - In table IV, the torque out values for plate nuts listed shall apply to nuts when tested with no axial load on the seat of the nut. The nut or nut assembly shall conform to the values specified without cracking the nut retainer and without becoming malformed sufficiently to preclude the application of the same torque in the opposite direction. The nuts to be subjected to this test shall be riveted or fastened with screws to a steel plate of a thickness equal to or greater than the maximum thread diameter. The bolt hole in the plate shall be located concentric with the nominal position of the thread in the nut within 0.010 inch total indicator reading. The diameter of the torque stud or device shall have a maximum diametral clearance of 0.010 inch in the test plate. The torque stud or device shall be provided with a shoulder to seat against the base of the nut or shall incorporate a suitable bushing to accomplish this. Reverse loading may be accomplished by the addition of a check nut

4.5.4 Push out. - The minimum load required to push out the nut from the retainer of the plate nut or to effect a permanent deformation axial with the nut element of 0.030 inch, measured at the thread centerline between the test plate and the base of the threaded element, shall be not less than the values specified in table V. The nuts shall be prepared for this test as specified in 4.5.3.3, except that the push-out stud or device shall be provided with a hemispherical end of a diameter equal to the thread diameter plus 1/32 inch, minimum, instead of the shoulder or bushing.

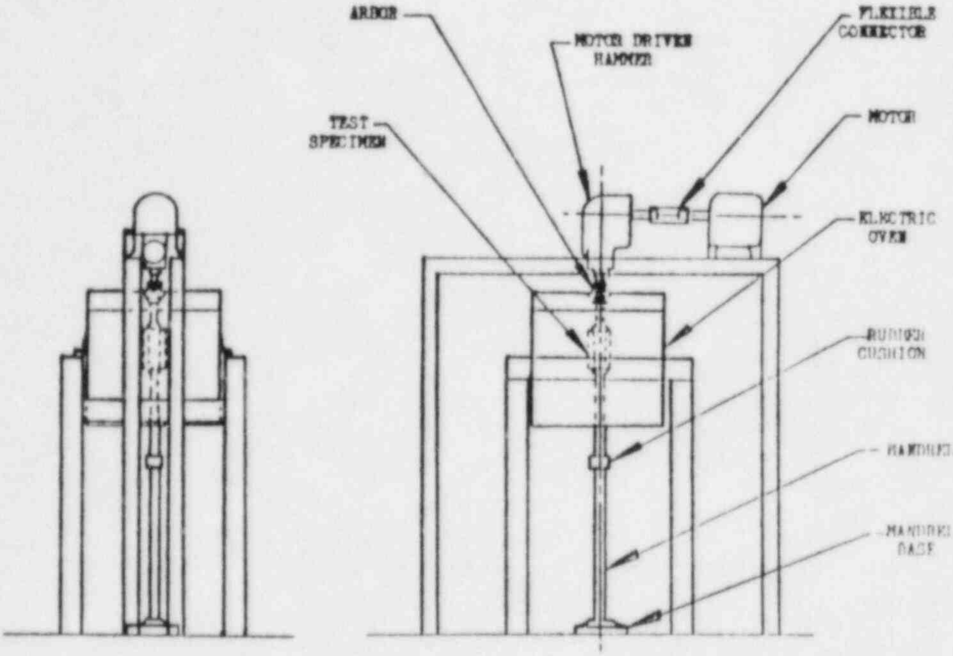
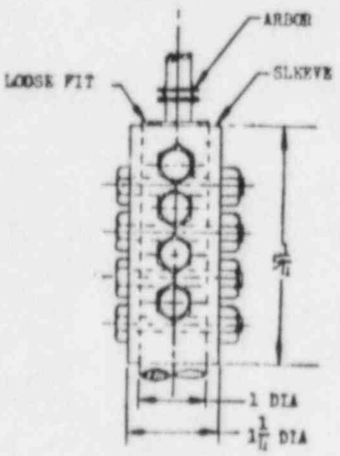


FIGURE 2 Vibration test apparatus - high temperature

SIZE OF NUT TO BE TESTED	SIZE OF BOLT HOLE
# 10-32	.193 +.005 -.000
1/4-28	.257 +.005 -.000
5/16-24	.316 +.006 -.000
3/8-24	.377 +.008 -.000
7/16-20	.453 +.008 -.000
1/2-20	.516 +.008 -.000



DIMENSIONS IN INCHES

FIGURE 1. Test arbor

4.5.5 Vibration.- Sample nuts with matching bolts of the sizes and quantities specified in table X shall be vibrated at 1,200° F on a stand in accordance with figures 1 and 2. Failure of more than two sample nuts of any one size shall be cause for rejection.

4.5.5.1 Vibration test on nuts larger than 1/2-inch size are waived provided that 1/2-inch nuts and smaller of the same type and design of locking device have satisfactorily passed the vibration test. Vibration tests on plate nuts having locking devices identical to qualified hexagon nuts will not be conducted. Plate nuts requiring vibration tests will be vibrated after removal of the plate lugs.

TABLE X. Vibration requirements

Thread size	Basic part No. of bolts	Bolts and nuts required (minimum of each)	Minimum vibration time (minutes)	
			Hex nuts	Plate nuts
10-32	MS20033-13	24	40	30
1/4-28	MS20034-13	24	40	40
5/16-24	MS20035-13	24	90	70
3/8-24	MS20036-13	24	120	90
7/16-20	MS20037-13	24	120	90
1/2-20	MS20038-13	24	120	90

4.5.5.2 The test nuts shall be screwed on the test bolts which pass through the drilled holes in the arbor and sleeve of the test rig. The bolts shall be free to rotate in the arbor and sleeve when the nut is in the test position and at the test temperature. The locking device of the nut shall be the only factor which restrains the nut from turning on the bolt. The thrust load of the test arbor, including the weight of the electrical power unit, shall be 65 pounds. Reference lines shall be scribed and shall be made on both the nuts and the bolts for the purpose of determining if the nut turns on the bolt during the vibration test.

4.5.5.3 Lug removal of plate nuts.- One-piece plate nuts shall have their attaching lugs so trimmed that they are equal to the width of the part and provide symmetry about their threaded axes.

4.5.5.4 A check to determine if the nut has turned on or off the bolt shall be made at 50 percent of the time and after the completion of the vibration time specified in table X. Any two nuts which have rotated 30 degrees in either side with respect to the bolt before the required time of vibration life has elapsed shall be considered unsatisfactory.

4.5.6 Discontinuities.- The presence of discontinuities in nuts, such as laps, seams, and inclusions, shall be determined by one of the following methods of inspection, unless visual inspection discloses discontinuities which would preclude the necessity for these inspection means. The presence of cracks in nuts is cause for rejection. Other indications shall not be cause for rejection, provided they are within the acceptable limits of table VI. If the indications are cause for rejection representative samples shall be taken from those nuts showing indications which shall be further examined by microexamination to determine whether the indicated discontinuities are in accordance with the limits specified herein. In general, discontinuities within the acceptable limits of table VI shall not be cause for rejection.

4.5.6.1 Inspection method for heat- and corrosion-resistant steel.- Fluorescent penetrant inspection shall be performed in accordance with MIL-I-6866. Such inspection shall, in general, be performed on finished nuts, but in any case, subsequent to any processing operations which could adversely affect the part. Nuts shal be dyed as an indication of fluorescent penetrant inspection specified by the sampli requirements of this specification. Personnel conducting fluorescent penetrant insp tion shall be qualified in accordance with MIL-STD-410.

4.5.7 Magnetic permeability.- The magnetic permeability shall be determined b the use of an indicator in accordance with MIL-I-17214, or equivalent. This test shall be performed on the same samples which were used in the axial strength test of 4.5.2.1.

4.6 Packaging, packing, and marking.- Preparation for delivery shall be examined for conformance to section 5.

5. PREPARATION FOR DELIVERY

5.1 Preservation, packaging, packing, and marking.- Self-locking nuts shall be preserved, packaged, packed, and marked for shipment in accordance with MIL-N-3982. Preservation and packaging shall be level A or C, as specified in the contract or order (see 6.2). Packing shall be level A, B, or C, as specified in the contract or order (see 6.2).

6. NOTES

6.1 Intended use.- The nuts and plate nuts are intended for use in applications where maximum temperatures do not exceed 1,200° F.

6.2 Ordering data.- Procurement documents should specify:

(a) Title, number, and date of this specification.
(b) Data requirements (see 3.2).
(c) MS part number.
(d) Quantity.
(e) Applicable levels of packaging and packing (see section 5).

6.3 Qualification.- With respect to products requiring qualification, awards will be made only for such products as have, prior to the time set for opening of bids, been tested and approved for inclusion in the applicable Qualified Products List, whether or not such products have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. The activity responsible for the Qualified Products List is the Naval Air Systems Command, Department of the Navy, Washington, D. C. 20360 (Attention: AIR-530323); however, information pertaining to qualification of products may be obtained from the Naval Air Development Center, Aero Materials Department (MAEM), Johnsville, Warminster, Pennsylvania 18974.

6.3.1 Qualification tests will be authorized only upon presentation of certified test reports indicating that the nuts have met or will meet the requirements of this specification (see 4.3.3).

6.4 Definition.- In this specification the word "nuts", unless qualified by hexagon or plate, refers to both hexagon nuts and plate nuts. When only hexagon nuts or only plate nuts are intended it will be so indicated in the specification.

Custodians:
Army - AV
Navy - AS
Air Force - 82

Reviewer activities:
Army - AV
Navy - AS
Air Force - 82

Preparing activity:
Navy - AS

Project No. 5310-0077

MIL-B-7874A
17 NOVEMBER 1967

Superseding
MIL-B-7874
29 February 1952

MILITARY SPECIFICATION

BOLT, MACHINE, 1200° F

This specification is mandatory for use by all
Departments and Agencies of the Department of
Defense.

1. SCOPE

1.1 This specification covers the requirements for bolts that shall be furnished in one grade only for use where temperatures will not exceed 1200° F.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Military

MIL-H-3982	Hardware (Fasteners and Related Items), Packaging and Packing for Shipment and Storage of
MIL-N-7873	Nut, Self Locking, 1200° F
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification for

STANDARDS

Military

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-831	Test Reports, Preparation of

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

FSC 5306

2.2 Other publications.- The following document forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Standards Association

ASA B46.1 - 1962	Surface Texture (Surface Roughness, Waviness and Lay)

(Copies of the above publication may be obtained from the American Standards Association, Inc., 10 East 40th Street, New York, N. Y. 10016.)

3. REQUIREMENTS

3.1 Qualification.-The bolts furnished under this specification shall be a product which is in accordance with the applicable standard and which has been subjected to and passed the qualification tests specified herein, and which has been listed on or approved for listing on the applicable Qualified Products List.

3.2 Material.- The bolts shall be fabricated from heat and corrosion-resisting material. Unless otherwise specified, this material shall have a minimum tensile strength of 140,000 pounds per square inch (psi), a minimum 0.2 percent yield strength of 95,000 psi and a minimum stress rupture strength of 65,000 psi in 23 hours.

3.3 Design and construction.-

3.3.1 Dimensions.- Dimensions shall be in accordance with applicable standards.

3.3.2 Threads.-

3.3.2.1 Form and dimensions.- Thread dimensions shall be in accordance with MIL-S-8879 and shall be fully formed by any single rolling process after heat treatment.

3.3.2.2 Incomplete thread pitches.- The threads shall be faired into the shank with a thread runout of a maximum of two and a minimum of one imperfect threads, to eliminate an abrupt change in cross-sectional area. The bottom and sides of runout thread pitches may deviate from true thread form but shall be smooth and free of tool marks.

3.3.2.3 Grain flow.- The grain flow in the threads shall be continuous and shall follow the general thread contour with the maximum density at the bottom of the root radius as shown on figure 1.

3.3.3 Heads.- The bolt heads shall be forged.

3.3.3.1 Bearing surface.- The bearing surface of bolt heads shall be right angles to the shank within limits shown on figure 1. The angular variation of the underside of the head shall be uniform around the shank within a tolerance of 10 minutes, as measured between the bearing surface of the head and the shank at a length along the shank equal to the diameter of the bolt.

3.3.3.2 Head structure and grain flow.- A section of the head shall show no detrimental defects and shall show grain-flow lines substantially as shown on figure -. The grain-flow lines may be slightly broken by the finish machining or grinding.

3.4 Surface roughness.- The surface roughness of the bolt shall not exceed the values specified in table I. The surface roughness shall be measured in accordance with publication ASA B46.1 - 1962.

TABLE I. Surface roughness

Area	Roughness height rating (rhr) (maximum)
Shank and underside of head	63
Head to shank fillet	32
Sides of thread and root area	32
Other surfaces	125

3.5 Straightness.- The straightness of the bolt shall be within the values specified in table II when the bolt is rolled on a surface plate and the point of greatest deviation is measured with a feeler gage.

TABLE II. Shank straightness

Bolt size	Deviation of bolt shank from plate (max) (inch per inch of bolt length)
10	0.0040
1/4, 5/16	.0030
3/8, 7/16	.0025
1/2 and larger	.0020

3.6 Mechanical properties.-

3.6.1 Tensile and rupture strength.- The tensile and rupture strength of the bolts shall be as specified in table III.

3.6.2 Shear strength.- The ultimate double shear strength of the bolts shall be as specified in table III.

3.6.3 Hardness.- Hardness shall be Rockwell C27 to C37.

3.7 Metallurgical properties.-

3.7.1 Carburization.- The bolt shall show no decarburization, carburization or recarburization on the bearing surface of the head, head-to-shank fillet, shank or threads.

3.7.2 Discontinuities.- Discontinuities shall not exceed the following limitations.

3.7.2.1 Cracks.- There shall be no cracks in any location. A crack is defined as a clean crystalline break passing through the grain or grain boundary without inclusion of foreign elements.

TABLE III. Tensile and shear strength

Bolt size	Tensile breaking strength (pounds minimum)		Double shear strength (pounds minimum)
	Room temperature	23 hour stress rupture at 1200° F	
10	3,300	1,200	4,700
1/4	5,400	2,200	8,300
5/16	8,600	3,400	13,000
3/8	13,300	5,300	18,800
7/16	18,200	7,100	25,600
1/2	24,300	9,700	33,400
9/16	30,500	12,300	42,200
5/8	38,100	15,600	52,200
3/4	55,300	22,300	75,100
7/8	75,500	31,200	102,000
1	98,400	42,100	133,500
1-1/8	126,700	52,300	169,000
1-1/4	157,100	66,500	208,600

3.7.2.2 Laps and seams.- Bolts may possess laps and seams, except in locations specified in 3.7.2.3. Depth of discontinuities, when measured normal to the surface at the point of greatest penetration, shall not exceed 0.005 inch for No. 10 through 3/8-inch diameter, 0.007 for 7/16 and 0.008 for 1/2 through 1-1/4.

3.7.2.3 Thread discontinuities (laps, seams and surface irregularities).- Thread shall have no multiple or single laps at the root or on the sides, figure 3, except that laps are permissible at the crest which do not exceed 25 percent of the basic thread depth and on the sides outside the pitch diameter. Slight deviation from the thread contour is permissible at the crest of the thread.

3.8 Test nut.- The nut used for the tensile and stress rupture tests shall conform to MIL-N-7873, except that it shall be heat treated to develop the full strength of the bolt and have threads in accordance with MIL-S-8879.

3.9 Identification of product.- Bolts shall be identified in accordance with the applicable drawings.

3.10 Workmanship.- Workmanship shall be in accordance with the design requirements specified herein.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection.- Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any other commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

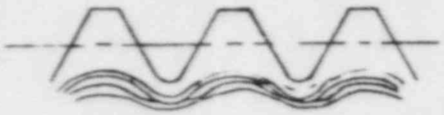


FIGURE 1. Grain flow

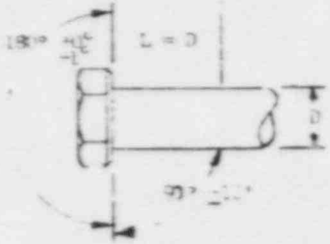


FIGURE 2. Head angularity

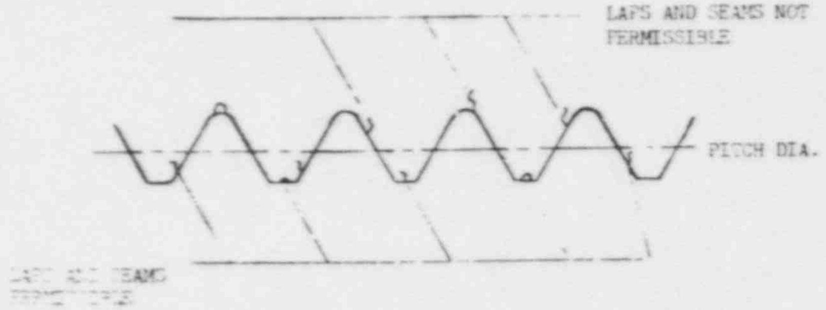


FIGURE 3. Location of permissible and nonpermissible laps, seams, and irregularities

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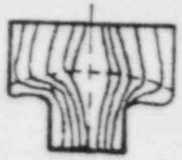

FIGURE 4. Head structure and grain flow

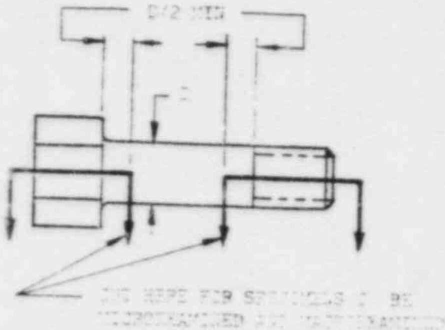

FIGURE 5. Metallurgical specimens

4.1.1 All inspection records of examinations and tests shall be certified and shall be supplied for each production lot or portion thereof. The records and reports shall be submitted to the purchaser with the shipper's list and not in each individual package (see 6.2).

4.2 Classification of tests.- The inspection and testing of 1200° F bolts shall be classified as follows:

(a) Qualification tests (4.3)
(b) Quality conformance tests (4.4)

4.3 Qualification tests.-

4.3.1 Sampling instructions.- Qualification test samples shall consist of 30 bolts for each size and type for which qualification is desired. The grip length of the bolts shall be approximately 2-1/2 inches. The self-locking nuts in accordance with 3.5 shall be furnished with each set of qualification test sample bolts. Samples shall be identified as required and forwarded to the activity responsible for qualification designated in the letter of authorization from that activity (see 6.3).

4.3.2 Tests.- The qualification tests of bolts shall consist of all the tests of this specification as specified under test methods (4.5).

4.3.2.1 Certified test report.- Each set of qualification test samples shall be accompanied by a certified test report showing that the manufacturer's product conforms to the applicable standards and this specification. Test reports shall be prepared in accordance with MIL-STD-831. When the report is submitted it shall be accompanied by a dated drawing which completely describes the manufacturer's product by specifying all dimensions and tolerances, material composition, coating or plating, and heat treatment. The manufacturer's part number for each size and length shall be included on the drawing. Failure of the manufacturer to furnish a satisfactory certified test report with the qualification samples shall be sufficient cause for rejection of the qualification request (see 6.2).

4.4 Quality conformance tests.- The quality conformance testing shall consist of the following tests, as specified under test methods (4.5). In addition, bolts shall be subjected to any of the other tests specified herein which the inspector considers necessary to determine conformance to this specification.

(a) Examination of product (4.5.1)
(b) Tensile strength (4.5.2)
(c) Head structure (4.5.5)

4.4.1 Tests.- The bolt manufacturer shall be responsible for accomplishing the quality conformance tests specified herein.

4.4.2 Lot.- The lot definition, formation, and size shall be in accordance with MIL-STD-105.

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4.4.3 Sampling.- The sample bolt shall be selected for examination of product in accordance with MIL-STD-105, inspection level II, acceptance quality level as follows:

Major defects	2.5 percent
Minor A defects	4.0 percent

For the tensile and macro-etch tests a sample of two bolts from each lot shall be selected to determine conformance with 4.5.2 and 4.5.5. The acceptance number shall be zero.

4.4.3.1 Classification of defects.- Defects shall be classified as shown in table IV.

TABLE IV. Classification of defects

AQL percent defective	Classification	Dimensional characteristics
	Major	
2.5	101	Thread size and form
	102	Shank diameter
	103	Incomplete threads and thread runout
	104	Grip length
	105	Radius under head
	106	Squareness between head and shank
	107	Straightness of shank
	108	Surface roughness
	110	Washer face diameter
	111	Dimension across flats
	112	Nonacceptance discontinuities
	Minor A	
4.0	201	Overall length
	202	Head height
	203	Identification
	204	Chamfer on thread end
	205	Chamfer on head
	206	Burrs and tool marks

4.5 Test methods.-

4.5.1 Examination of product.- The bolts shall be examined for conformance with the requirements of this specification with respect to material, design, workmanship, and dimensions.

4.5.2 Tensile strength.- Sample bolts shall be tested in tension between the head of the bolt and a nut conforming to 3.8. The bearing face of the nut shall be located a minimum of two and a maximum of three pitches from the bolt thread termination. Bolts with a grip length of less than twice the shank diameter need not be tested.

4.5.3 Shear strength.- The double shear strength test shall be performed on the unthreaded portion of the bolt in a fixture conforming to figures 6 and 7. Other types of shearing jigs may be used if acceptable to the procuring activity. The test need not be run to rupture of the bolt. If the bolt length is less than twice the shank diameter, test coupons of the same material, diameter, heat treatment or cold work, or both, shall be prepared and subjected to the shear test.

4.5.4 Stress rupture strength.- Samples of the bolts shall be tested at 1200° F ±10 in tension between the head of the bolt and a nut conforming to 3.8. The rupture test shall consist of the application of a static tensile load as specified in table III to the bolt for 23 hours.

4.5.5 Head structure and grain flow.- Head structure and grain flow shall be determined by macroexamination. Specimens shall be taken from the finished bolt as shown in figure 5. The bolts shall be etched in an aqueous solution containing 50 percent (by volume) of commercial hydrochloric acid at 71° to 82° C (160° to 180° F) for sufficient time to reveal the macrostructure properly.

4.5.6 Hardness.- Each bolt of the random samples shall be inspected for a Rockwell hardness on the end of the bolt. Each bolt of the random sample shall have a Rockwell hardness in the range of C27 to C37 in order for the inspection lot and the production lot to be considered acceptable.

4.6 Packaging, packing, and marking.- Preparation for delivery shall be examined for conformance with section 5.

5. PREPARATION FOR DELIVERY

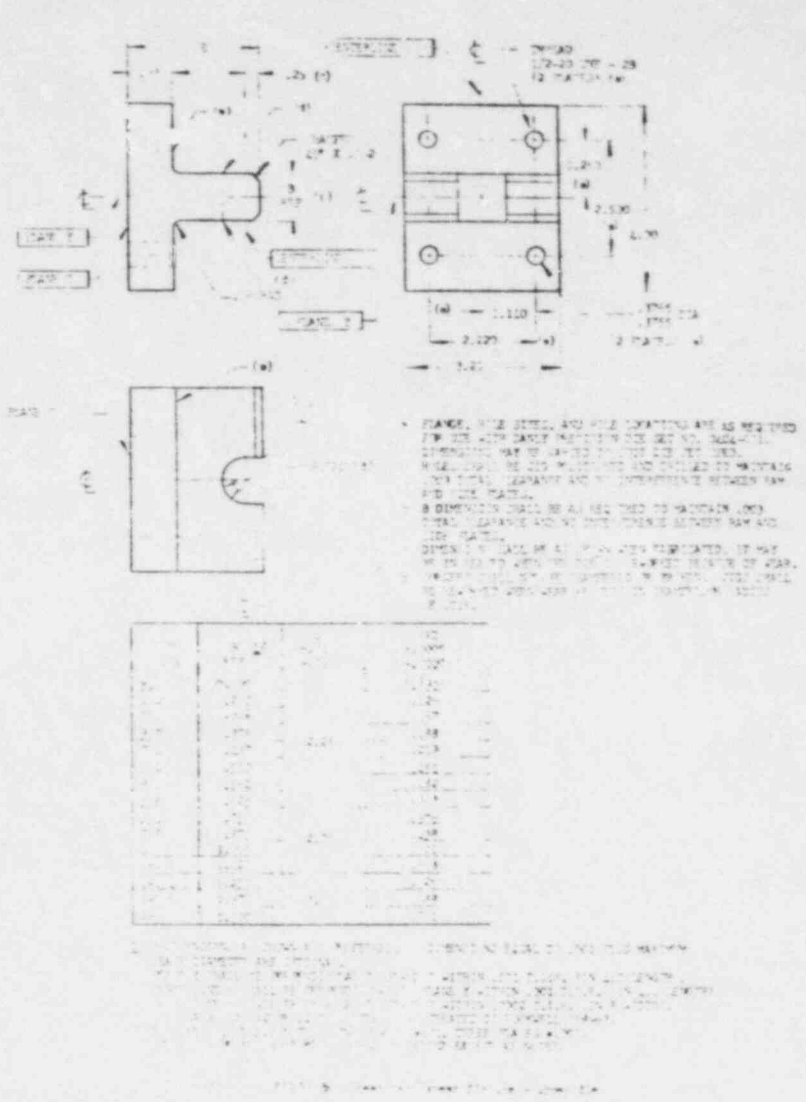
5.1 Bolts shall be preserved, packaged, packed, and marked in accordance with MIL-B-3932.

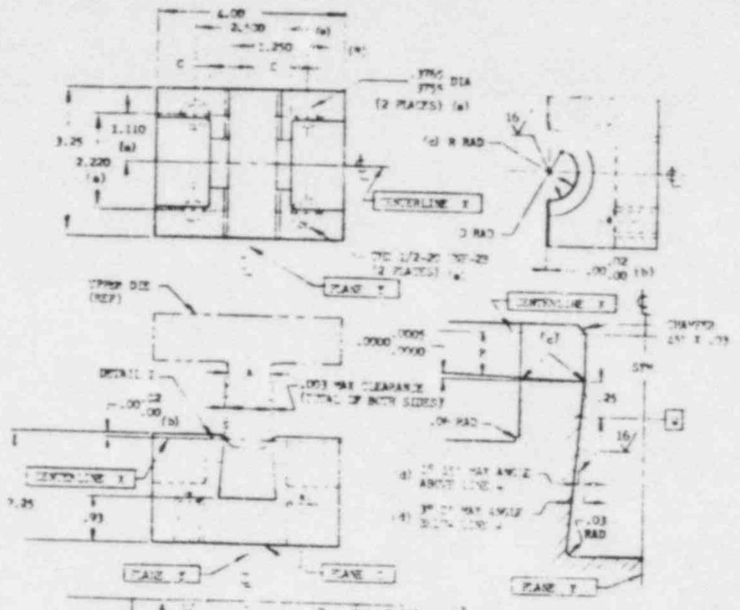
6. NOTES

6.1 Intended use.- The bolts covered by this specification are intended for use with nuts conforming to MIL-N-7873 at temperatures not exceeding 1200° F in aircraft accessories and engines.

6.2 Ordering data.- Procurement documents should specify the following:

(a) Title, number, and date of this specification.
(b) MS part number of the bolt and the quantity desired.
(c) Data requirements (see 4.1.1 and 4.3.2.1).
(d) Applicable levels of preservation, packaging and packing, and unit quantities required.





NOM SIZE	A +.001 -.000	+.002 -.000	D +.03 -.00	P RAD +.0005 -.0000
#10	.191	.192	.25	AS SHOWN ON FIGURE 6
1/4	.251	.252	.38	
5/16	.313	.31[illegible]	.42	
3/8	.376	.377	.44	
7/16	.438	.439	.52	
1/2	.501	.502	.56	
9/16	.563	.564	.64	
5/8	.626	.627	.67	
3/4	.751	.752	.79	
7/8	.876	.877	.89	
1	1.001	1.002	1.0[illegible]	
1-1/8	1.126	1.127	1.12	
1-1/4	1.251	1.252	1.2[illegible]	
1-3/8	1.376	1.377	1.38	
1-1/2	1.501	1.502	1.50	

DETAIL I

(a) THE INDICATED HOLES AND HOLE LOCATION DIMENSIONS ARE REQUIRED FOR USE WITH A DANLY PRECISION DIE SET NUMBER [illegible]. THESE DIMENSIONS MAY BE VARIED TO SUIT THE DIE SET USED. THE HOLES SHALL BE JIG POSITIONED AND DRILLED TO MAINTAIN THE PRESCRIBED .003 TOTAL CLEARANCE AND NO INTERFERENCE BETWEEN THE RAM AND SIDE PLATES.

(b) THE INDICATED DIMENSION SHALL BE AS SHOWN WHEN FABRICATED. IT MAY BE INCREASED WHEN THE DIE IS REWORKED BECAUSE OF WEAR.

(c) CORNERS SHALL NOT BE CHAMFERED OR BROKEN. THE DIE SHALL BE REWORKED WHEN WEAR RESULTS IN A CHAMFER OR RADIUS OF .015.

(d) THE INDICATED CLEARANCE ANGLE IS OPTIONAL WHEN A PRECISION DIE SET IS USED. THIS CLEARANCE IS PROHIBITED WHEN A DIE SET IS NOT USED. IN THE LATTER CASE THE SIDES OF THE SLOT SHALL BE PARALLEL WITHIN .001 T.I.R.

A AND C DIMENSIONS AS SHOWN ARE PREFERRED. A EQUAL TO .002 PLUS MAXIMUM SHANK DIAMETER AND C EQUAL TO .003 PLUS MAXIMUM SHANK DIAMETER ARE OPTIONAL.
PLANE Y SHALL BE PERPENDICULAR TO PLANE Z WITHIN .001 T.I.R. (IN 4.0 LENGTH).
CENTERLINE X SHALL BE PERPENDICULAR TO PLANE Y WITHIN .001 T.I.R. (IN 4.0 LENGTH).
CENTERLINE X SHALL BE PARALLEL TO PLANE Z WITHIN .002 T.I.R. (IN 2" LENGTH).
MATERIAL: [illegible] TOOL STEEL HEAT TREATED TO [illegible] 58-63.
TOLERANCES, UNLESS NOTED: TWO PLACES ±.01, THREE PLACES ±.001.
SURFACE ROUGHNESS: 63 MICROINCHES OR BETTER EXCEPT AS NOTED.

FIGURE 7. Shear test shear fixture - lower die

6.3 Qualification.- With respect to products requiring qualification, awards will be made only for such products as have, prior to the time set for opening of bids, been tested and approved for inclusion in the applicable Qualified Products List, whether or not such products have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. The activity responsible for the Qualified Products List is the Naval Air Systems Command, Navy Department, Washington, D. C. 20360, Attention: AIR-530323. However, information pertaining to qualification of products may be obtained from the Naval Air Engineering Center, Philadelphia, Pennsylvania 19112, Attention: M-52.

Custodians:
Air Force - 82
Navy - AS
Army - AV

Reviewer activities:
Air Force - 82
Navy - AS
Army - AV, MI, EL

Preparing activity:
Navy - AS

Project No. 5310-0085

U.S. GOVERNMENT PRINTING OFFICE: 197[illegible]

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8 December 1965
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21 September 1960

MILITARY SPECIFICATION

SCREW THREADS, CONTROLLED RADIUS ROOT WITH INCREASED MINOR DIAMETER; GENERAL SPECIFICATION FOR

This specification is mandatory for use by all Departments
and Agencies of the Department of Defense.

1. SCOPE

1.1 This specification defines the requirements for Unified screw threads, classes 3A and 3B, altered to include a mandatory continuous radius of from 0.18042p to 0.15011p at the root of the external threads and with the minor diameter of both external and internal threads increased (over Unified thread values) to accommodate the root radius.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal form a part of the specification to the extent specified herein.

Commercial Standard CS8-61	Gage Blanks
National Bureau of Standards Handbook H28, Part I	Screw-Thread Standards for Federal Services

(Application for copies should be addressed to the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.)

3. REQUIREMENTS

3.1 Basic thread data. The basic thread data for all standard pitches of threads are given herein in table I.

3.2 Thread forms

3.2.1 External threads. All external screw threads defined in this specification are of Unified form in accordance with Handbook H28, class 3A only, altered at the root so that the flanks of the adjacent threads are joined by one continuous smoothly blended curve tangent to the flanks at a thread depth of 9H/16. The radius of curvature adjacent to the flanks shall be between 0.18042p and 0.15011p (see figures 1 and 3).

3.2.2 Internal threads. The internal threads shall be of Unified form, modified at the minor diameter to the values given in tables II through VII herein, and shall be class 3B tolerance only (see figures 2 and 3).

FSC MISC

3.3 Thread series. Series of threads are classified and distinguished from each other by the number of threads per inch applied to a specific diameter (diameter-pitch combination). The sizes and series for which limits of size are given in tables II through VII comprise a selection from Handbook H28.

3.3.1 Preferred selection. To encourage maximum usage of a limited number of screw threads, the fine thread series of diameter pitch combinations (table III) shall be used when design requirements permit practical application.

3.4 Limits of size. Screw threads, in accordance with this specification, shall be within the limits of size specified in tables II through VII, for the selected diameter-pitch combinations shown therein. The specified limits of size are considered exact and are inviolable unless specific exceptions are made. The pitch diameter equivalent of the variation in any given element, except pitch diameter shall not exceed 0.4 of the pitch diameter tolerance. Flank angle equivalents are based on a depth of thread engagement "h" which is equal to 3H/4. (See figure 1.) The deviations in lead and flank angle that are equivalent to 0.4 of the pitch diameter tolerance are determined from formulas in the appendix. Values of 0.4 of the pitch diameter tolerance and lead and angle variations equal thereto are tabulated in the appendix.

3.4.1 Length of engagement. Tolerances specified herein are based on a length of thread engagement equal to the basic major diameter for the UNJC, UNJF, and 8UNJ series and a length of engagement of nine pitches for the UNJEF, 12UNJ, and 16UNJ series.

3.5 Incomplete threads. Unless otherwise specified, the runout threads on externally threaded parts shall be no less than one nor more than two pitches in length. The threads shall run out onto the shank, eliminating any abrupt change in cross sectional area. The root of the runout threads shall be radiused. The radius, as it approaches the unthreaded portion of the shank, shall be no less than the radius of the full thread portion.

3.5.1 Lead threads. Unless otherwise specified, the entering end of external threads and the entering end of internal threads may be outside the specified limits of size for a length not to exceed two pitches, including chamfer. In no case shall the lead threads exceed the specified maximum material condition.

3.5.2 Material limits for coated threads. Coating is one or more applications of additive finish of any material including dry film lubricants, but not including soft or liquid lubricant. When externally threaded parts are to be coated, the minimum pitch diameter may be reduced by not more than 0.001 inch on all threads for which the tolerance specified herein does not exceed 0.0035 inch. For threaded parts for which the pitch diameter tolerance specified herein is greater than 0.0035 inch, the minimum pitch diameter may be reduced by an amount equal to 0.3 times the pitch diameter tolerance but not more than 0.0015 inch. The material limits for coated external threads shall be as specified herein. All thread elements shall be within tolerance before coating. After coating, the threads shall be within the maximum material limits specified herein.

3.5.2.1 Internal threads. Internal threads to be coated may be increased by the same amount permitted for external threads. After coating, the threads shall be within the minimum material limits specified herein.

3.6 Gages. Gage tolerances shall conform to the unilateral tolerance system and shall be within the product limits. The gages used for the inspection of screw threads shall conform to the applicable requirements of Handbook H28 and shall be made to "X" tolerances. The lead, angle, and pitch diameter of setting plugs shall be made to "W" tolerances.

3.6.1 Gaging internal threads. Functional size final conformance gages for internal threaded products are Commercial Standard 8 (CS8), AGD plain and threaded plug gages; or indicating type gages may be used if procedures require variable type inspection. The lead, angle, and uniformity of helix of internal threads are subject to inspection by sectioning or by making a cast and inspecting by single element methods or by differential analysis. Inspection by variables forms the basis of final conformance gaging of individual thread elements of the product.

3.6.1.1 Full form gages. Full form threaded plug gages may also be used for internal thread gaging. The use of full form threaded plug gages eliminates the requirement for a minimum minor diameter plain plug gage check. Full form gages shall be made to the maximum material limits of the product external thread with a plus gagemakers tolerance. Full form threaded plug gages may be used as a referee gage for the minor diameter.

3.6.2 Gaging external threads. External threads require single element gaging in order to ascertain that all elements are within the required limits of size. Gages for external thread inspection shall be checked or set with setting plugs.

3.6.2.1 Thread snap gages. Thread snap gages having adjustable gaging anvils or indicating type gages shall be used to inspect the minimum material limits of external threads. The gaging elements shall engage the thread over a length of not more than two pitches. Gaging elements that engage one pitch may also be used and have the advantage of minimizing the effect of lead and angle deviations.

3.6.2.2 Indicating type gages. The lead, angle, and uniformity of helix of external threads may be inspected and analyzed by a set of indicating type gages. This type of gaging is known as differential analysis and is used to determine the extent of deviation in any of the elements of the thread. The deviations in various elements shall not exceed that specified in 3.4.

3.6.2.3 Ring gages. Threaded ring gage inspection may be used only to determine functional size and will prove only that a part accepted by the Go threaded ring gage will assemble with a part accepted by a Go threaded plug gage. Acceptance by Go threaded ring gages does not preclude the necessity of determining the accuracy of individual elements by single element gaging.

3.6.2.4 Root radius inspection. The radius of the root of external threads may be inspected by optical means. No portion of the root shall have a radius of less than 0.15011p or greater than 0.18042p.

3.6.3 Referee procedure. The referee procedure for both internal and external threads involves the measurement of the various thread elements as outlined herein. Any element of the thread that exceeds the allowable tolerance is justification for rejection of the part. The fact that the part is accepted by a Go threaded plug or ring gage does not alter the justification for rejection determined by single element inspection.

3.7 Surface roughness. On certain parts it may be necessary to control the surface roughness of the thread flanks, roots, or crests. This requirement shall be specified, if necessary, on the part drawing or specification. Due consideration shall be given to the practical method of production and the surface roughness commensurate with that method.

3.8 Definitions. The identifying letter "J" is restricted to use in the designation of threads as defined by this specification. For terms, symbols, and data not defined or specified herein see Handbook H28.

3.9 Designations. The threads described herein shall be designated in accordance with the following examples:

External thread - .2500-28 UNJF-3A
MIL-S-8879
Internal thread - .2500-28 UNJF-3B
MIL-S-8879

3.9.1 Designation of special threads. Special diameter pitch combinations developed in accordance with this specification shall be designated as follows:

Example

External thread:

8.750 - 8 UNJS-3A

Major diameter	8.735-8.750
Pitch diameter	8.6625-8.6688
Minor diameter	8.5918-8.6056
Root radius	0.0188-0.0226

MIL-S-8879

Internal thread:

8.750 - 8 UNJS-3B

Major diameter	8.750 MIN
Pitch diameter	8.6688-8.6769
Minor diameter	8.6283-8.6433

MIL-S-8879

3.10 High temperature applications. In some instances it may be desirable to provide an allowance for applications in excess of 900°F. In these instances the allowance shall be provided in the internal thread.

3.10.1 Amount of allowance. The amount of allowance for internal threads for high temperature applications will be determined as follows:

a. The internal thread pitch diameter, major diameter, and minor diameter for all threads 0.190 inch in diameter and larger that have pitches 32 and coarser will be increased by 0.003 inch.

b. The internal thread pitch diameter, major diameter, and minor diameter for all threads smaller than 0.190 inch or for pitches finer than 32 will be increased by 0.001 inch.

For plated parts, the dimensions shall apply after plating.

3.10.2 Internal allowance thread designation. The internal threads requiring an allowance as defined in 3.10.1 shall be designated in accordance with the following example:

.2500-28 UNJF-3BG
MIL-S-8879

The symbol "G" denotes that the allowance is required.

3.11 Special diameter-pitch combinations. Dimensions for threads of special diameter-pitch combinations shall be computed by the following formulas:

External threads:

Maximum major diameter = Basic major diameter
Minimum major diameter = Maximum major diameter minus tolerance specified in table I, column 20
Maximum pitch diameter = Basic major diameter minus 0.649519p. See table I, column 14
Minimum pitch diameter = Maximum pitch diameter minus tolerance specified in table IV .6 titled "Pitch diameter tolerances for external threads of special diameters, pitches, and lengths of engagement, class 3A" of Handbook H28
Maximum minor diameter = Maximum pitch diameter minus 0.50518p. See table I, column 18
Minimum minor diameter = Minimum pitch diameter minus 0.56580p. See table I, column 19
Maximum root radius = 0.18042p. See table I, column 8
Minimum root radius = 0.15011p. See table I, column 7

Internal threads:

Minimum major diameter = Basic major diameter
Minimum pitch diameter = Basic major diameter minus 0.649519p. See table I, column 14
Maximum pitch diameter = Minimum pitch diameter plus tolerance specified in table IV .9 titled "Pitch diameter tolerances for internal threads of special diameters, pitches, and lengths of engagement, class 3B" of Handbook H28
Minimum minor diameter = Basic major diameter minus 0.97428p table I, column 16 rounded up to the next larger fourth place decimal, unless the fifth place is zero.
Maximum minor diameter = Minimum minor diameter plus the internal thread minor diameter tolerance.
Minor diameter tolerance = $\left[0.05\sqrt[3]{p2} - 0.03p/D\right] - 0.002$ except that the tolerance shall be not greater than 0.259809p nor less than 0.135315p for threads 13 threads per inch and finer. For threads 12 threads per inch and coarser the tolerance is equal to 0.120p.

Where p = Pitch
D = Basic major diameter

Dimensions of special threads shall be rounded off to 4 decimal places as required after all computations are made.

3.12 Use of existing tools and gages. Threads defined in this specification may utilize the following tools and gages that are used for the manufacture and inspection of Unified class 3A and 3B threads except that 3BG threads require tools and gages made expressly for 3BG threads:

a. Taps and thread plug gages for class 3B

b. Thread gages for class 3A that have had the crest reworked to a 5p/16 truncation.

3.13 Changes in values of internal threads. The minor diameter of the internal threads covered by this specification have been changed from the values specified in the superseded specification. Internal threads made to present values may be used on external threads made in accordance with either this specification or the superseded specification.

3.14 Workmanship. Workmanship shall be consistent with the tolerances specified herein. The threads shall have a smooth finish, be free from flaws and other defects that would make them unsuitable for the purpose intended.

4. QUALITY ASSURANCE PROVISIONS

4.1 Inspection. **Products having threads in accordance with this specification shall be inspected as stated herein and as specified on the detail standard, specification or production drawing.**

5. PREPARATION FOR DELIVERY

5.1 **Not applicable.**

6. NOTES

6.1 Intended use. Threads covered by this specification are recommended for high temperature use and for applications requiring very high fatigue life and stress levels commensurate with the physical size and weight of the product. Applications are found in aircraft engine and airframe, missile, space vehicle, and similar design areas where size and weight are critical.

6.2 International standardization agreement. Certain provisions of this specification are the subject of international standardization agreement ABC AIR STD 17/16 and 17/40. When amendment, revision, or cancellation of this specification is proposed, the departmental custodians will inform their respective Departmental Standardization Offices so that appropriate action may be taken respecting the international agreement concerned.

Custodians:

Army - WC
Navy - WP
Air Force - 11

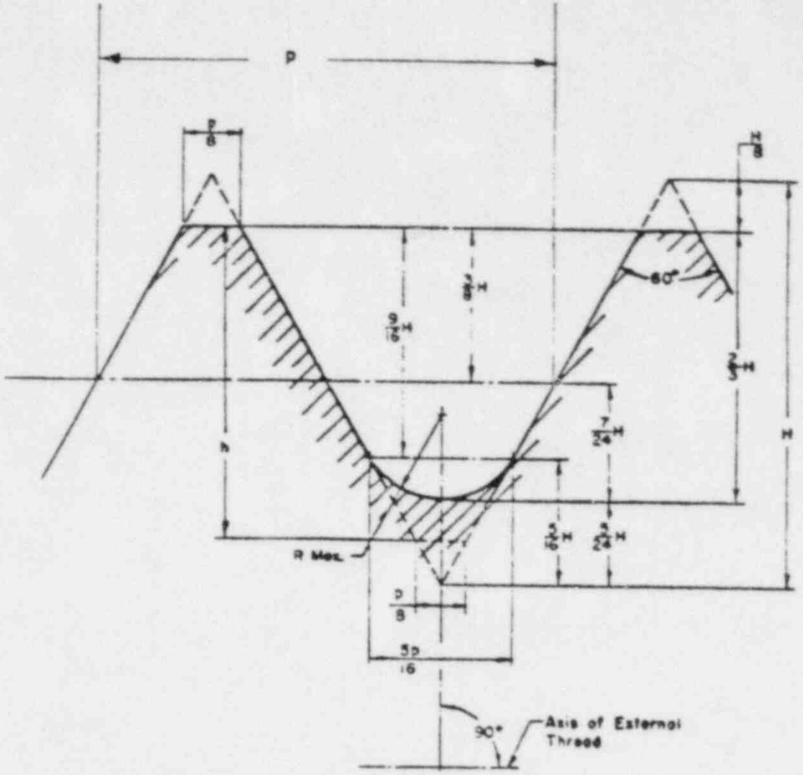
Review activities:

Army - EL, WC
Navy - WP
Air Force - 69, 84

User activities:

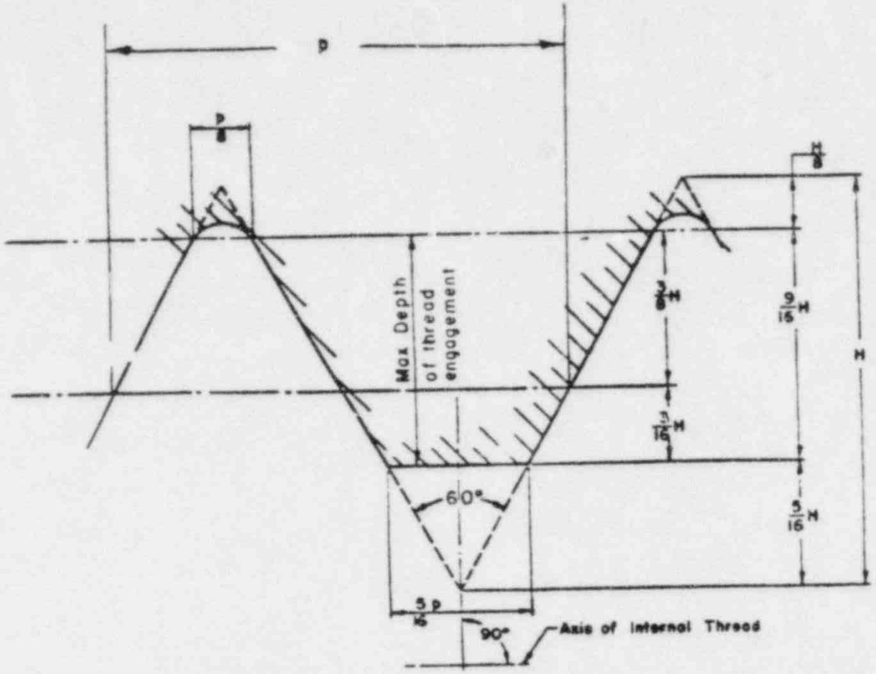
Army - MO, MU
Navy - WP
Air Force - 70, 71

Preparing activity:
Air Force - 11
Project No. MISC-0145



p = Pitch = 1/n
n = number of threads per inch
H = 0.866025p
h = 0.649519p

FIGURE 1. External Thread Maximum Material Condition



p = Pitch = 1/n
n = number of threads per inch
H = 0.866025p

FIGURE 2. Internal Thread Maximum Material Condition

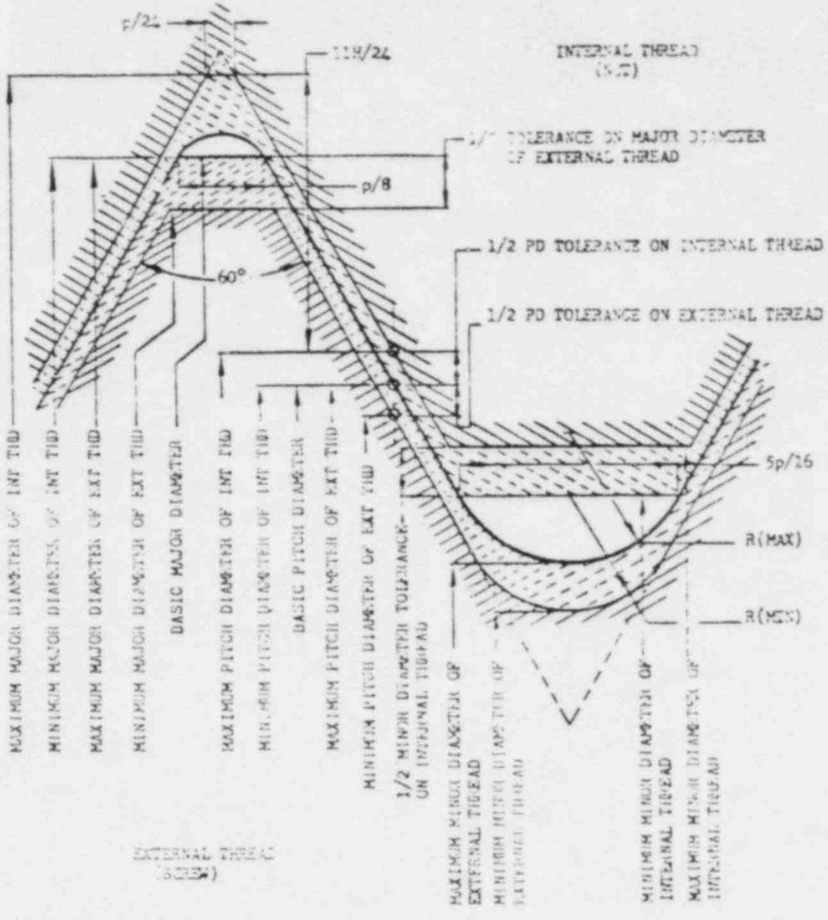


FIGURE 3. Disposition of tolerances and crest clearances

TABLE II. Coarse Thread Series

BASIC SIZE			EXTERNAL THREAD - UNJC CLASS 3A								INTERNAL THREAD - UNJC CLASS 3B					INTERNAL THREAD - UNJC CLASS [illegible]				
			MAJOR DIAMETER		PITCH DIAMETER		MINOR DIAMETER		ROOT RADIUS		MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA	MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA
PRIMARY	SECONDARY	THDS PER INCH	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MAX	MIN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	0.0730	64	0.0692	0.0730	0.0614	0.0629	0.0526	0.0550	0.0023	0.0028	0.0578	0.0619	0.0629	0.0648	0.0730	0.0588	0.0629	0.0639	0.0658	0.0740
0.0860		56	0.0819	0.0860	0.0728	0.0744	0.0627	0.0654	0.0027	0.0032	0.0687	0.0732	0.0744	0.0765	0.0860	0.0697	0.0742	0.0754	0.0775	0.0870
	0.0990	48	0.0945	0.0990	0.0838	0.0855	0.0720	0.0750	0.0031	0.0038	0.0788	0.0841	0.0855	0.0877	0.0990	0.0798	0.0851	0.0865	0.0887	0.1000
0.1120		40	0.1069	0.1120	0.0939	0.0958	0.0798	0.0832	0.0038	0.0045	0.0877	0.0942	0.0958	0.0982	0.1120	0.0887	0.0952	0.0968	0.0992	0.1130
0.1250		40	0.1199	0.1250	0.1069	0.1088	0.0928	0.0962	0.0038	0.0045	0.1007	0.1072	0.1088	0.1113	0.1250	0.1017	0.1082	0.1098	0.1123	0.1260
0.1380		32	0.1320	0.1380	0.1156	0.1177	0.0979	0.1019	0.0047	0.0056	0.1076	0.1157	0.1177	0.1204	0.1380	0.1086	0.1167	0.1187	0.1214	0.1390
0.1640		32	0.1580	0.1640	0.1415	0.1437	0.1238	0.1279	0.0047	0.0056	0.1336	0.1417	0.1437	0.1465	0.1640	0.1346	0.1427	0.1447	0.1475	0.1650
0.1900		24	0.1828	0.1900	0.1604	0.1629	0.1368	0.1419	0.0063	0.0075	0.1495	0.1600	0.1629	0.1661	0.1900	0.1525	0.1630	0.1659	0.1691	0.1930
	0.2160	24	0.2088	0.2160	0.1863	0.1889	0.1627	0.1679	0.0063	0.0075	0.1755	0.1857	0.1889	0.1922	0.2160	0.1785	0.1887	0.1919	0.1952	0.2190
0.2500		20	0.2419	0.2500	0.2147	0.2175	0.1864	0.1922	0.0075	0.0090	0.2013	0.2121	0.2175	0.2211	0.2500	0.2043	0.2151	0.2205	0.2241	0.2530
0.3125		18	0.3038	0.3125	0.2734	0.2764	0.2420	0.2483	0.0083	0.0100	0.2584	0.2690	0.2764	0.2803	0.3125	0.2614	0.2720	0.2794	0.2833	0.3155
0.3750		16	0.3656	0.3750	0.3311	0.3344	0.2957	0.3028	0.0094	0.0113	0.3142	0.3251	0.3344	0.3387	0.3750	0.3172	0.3281	0.3374	0.3417	0.3780
0.4375		14	0.4272	0.4375	0.3876	0.3911	0.3472	0.3550	0.0107	0.0129	0.3680	0.3795	0.3911	0.3957	0.4375	0.3710	0.3825	0.3941	0.3987	0.4405
0.5000		13	0.4891	0.5000	0.4463	0.4500	0.4028	0.4111	0.0115	0.0139	0.4251	0.4368	0.4500	0.4548	0.5000	0.4281	0.4398	0.4530	0.4578	0.5030
0.5625		12	0.5511	0.5625	0.5045	0.5084	0.4574	0.4663	0.0125	0.0150	0.4814	0.4934	0.5084	0.5135	0.5625	0.4844	0.4964	0.5114	0.5165	0.5655
0.6250		11	0.6129	0.6250	0.5619	0.5660	0.5105	0.5201	0.0136	0.0164	0.5365	[illegible]	0.5660	0.5713	0.6250	0.5395	[illegible]	0.5690	0.5743	0.6280
0.7500		10	0.7371	0.7500	0.6806	0.6850	0.6240	0.6345	0.0150	0.0180	0.6526	0.6646	0.6850	0.6907	0.7500	0.6556	0.6676	0.6880	0.6937	0.7530
0.8750		9	0.8611	0.8750	0.7981	0.8028	0.7352	0.7467	0.0167	0.0200	0.7668	0.7801	0.8028	0.8089	0.8750	0.7698	0.7831	0.8058	0.8119	0.8780
1.0000		8	0.9850	1.0000	0.9137	0.9188	0.8430	0.8557	0.0188	0.0226	0.8783	0.8933	0.9188	0.9251	1.0000	0.8813	0.8963	0.9218	0.9281	1.0030
1.1250		7	1.1086	1.1250	1.0268	1.0322	0.9460	0.9600	0.0214	0.0258	0.9859	1.0030	1.0322	1.0393	1.1250	0.9889	1.0060	1.0352	1.0423	1.1280
1.2500		7	1.2336	1.2500	1.1517	1.1572	1.0709	1.0850	0.0214	0.0258	1.1109	1.1280	1.1572	1.1643	1.2500	1.1139	1.1310	1.1602	1.1673	1.2530
1.3750		6	1.3568	1.3750	1.2607	1.2667	1.1664	1.1825	0.0250	0.0301	1.2127	1.2327	1.2667	1.2745	1.3750	1.2157	1.2357	1.2697	1.2775	1.3780
1.5000		6	1.4818	1.5000	1.3856	1.3917	1.2913	1.3075	0.0250	0.0301	1.3377	1.3577	1.3917	1.3996	1.5000	1.3407	1.3607	1.3947	1.4026	1.5030
1.7500		5	1.7295	1.7500	1.6131	1.6201	1.5002	1.5191	0.0300	0.0361	1.5552	1.5792	1.6201	1.6288	1.7500	1.5582	1.5822	1.6231	1.6318	1.7530
2.0000		4.5	1.9780	2.0000	1.8486	1.8557	1.7229	1.7434	0.0334	0.0401	1.7835	1.8102	1.8557	1.8650	2.0000	1.7865	1.8132	1.8587	1.8680	2.0030
2.2500		4.5	2.2280	2.2500	2.0984	2.1057	1.9727	1.9934	0.0334	0.0401	2.0335	2.0602	2.1057	2.1152	2.2500	2.0365	2.0632	2.1087	2.1182	2.2530
2.5000		4	2.4762	2.5000	2.3298	2.3376	2.1884	2.2113	0.0375	0.0451	2.2565	2.2865	2.3376	2.3477	2.5000	2.2595	2.2895	2.3406	2.3507	2.5030
2.7500		4	2.7262	2.7500	2.5797	2.5876	2.4382	2.4613	0.0375	0.0451	2.5065	2.5365	2.5876	2.5979	2.7500	2.5095	2.5395	2.5906	2.6009	2.7530
3.0000		4	2.9762	3.0000	2.8296	2.8376	2.6882	2.7113	0.0375	0.0451	2.7565	2.7865	2.8376	2.8480	3.0000	2.7595	2.7895	2.8406	2.8510	3.0030
3.2500		4	3.2262	3.2500	3.0794	3.0876	2.9380	2.9613	0.0375	0.0451	3.0065	3.0365	3.0876	3.0982	3.2500	3.0095	3.0395	3.0906	3.1012	3.2530
3.5000		4	3.4762	3.5000	3.3293	3.3376	3.1878	3.2113	0.0375	0.0451	3.2565	3.2865	3.3376	3.3484	3.5000	3.2595	3.2895	3.3406	3.3514	3.5030
3.7500		4	3.7262	3.7500	3.5792	3.5876	3.4378	3.4613	0.0375	0.0451	3.5065	3.5365	3.5876	3.5985	3.7500	3.5095	3.5395	3.5906	3.6015	3.7530
4.0000		4	3.9762	4.0000	3.8291	3.8376	3.6876	3.7113	0.0375	0.0451	3.7565	3.7865	3.8376	3.8487	4.0000	3.7595	3.7895	3.8406	3.8517	4.0030

TABLE I. Basic Thread Data

Threads per inch n	Pitch $p = \frac{1}{n}$	Truncation of internal thread crest $\frac{5H}{16} = 0.27063p$	Flat at internal thread root and external thread crest $\frac{p}{8} = 0.125p$	Height of sharp V thread $H = 0.866025p$	Truncation of internal thread root and external thread crest $\frac{H}{8} = 0.10825p$	Minimum root radius $0.15011p$	Height from sharp "V" to external thread root and max. root radius $\frac{5H}{24} = 0.18042p$	Half addendum of external thread $\frac{3H}{16} = 0.16238p$	Flat at internal thread crest $\frac{5p}{16} = 0.3125p$	Addendum of external thread $\frac{3H}{8} = 0.32476p$	Height of internal thread and depth of thread engagement $\frac{9H}{16} = 0.48714p$	Height of external thread $\frac{2H}{3} = 0.57735p$	Twice the external thread addendum $\frac{3H}{4} = 0.649519p$	Difference between max minor and pitch diameters of internal thread $\frac{11H}{12} = 0.79386p$	Double height of internal thread $\frac{9H}{8} = 0.97428p$	Double height of external thread $\frac{4H}{3} = 1.1547p$	Difference between max pitch diameter and max minor diameter external thread $\frac{7H}{12} = 0.50518p$	Difference between min pitch diameter and min minor diameter of external thread $.6531H = 0.56560p$	Max. Tolerance $.06\sqrt[3]{p^2}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
80	0.012500	0.00338	0.00156	0.010825	0.00135	0.0019	0.00226	0.00203	0.00391	0.00406	0.00609	0.00722	0.008119	0.00992	0.01218	0.01443	0.00631	0.00707	0.0032
72	0.013889	0.00376	0.00174	0.012028	0.00150	0.0021	0.00251	0.00226	0.00434	0.00451	0.00677	0.00802	0.009021	0.01103	0.01353	0.01604	0.00702	0.00786	0.0035
64	0.015625	0.00423	0.00195	0.013532	0.00169	0.0023	0.00282	0.00254	0.00488	0.00507	0.00761	0.00902	0.010149	0.01240	0.01522	0.01804	0.00789	0.00884	0.0038
56	0.017857	0.00483	0.00223	0.015465	0.00193	0.0027	0.00322	0.00290	0.00558	0.00580	0.00870	0.01031	0.011599	0.01418	0.01740	0.02062	0.00902	0.01010	0.0041
48	0.020833	0.00564	0.00260	0.018042	0.00226	0.0031	0.00376	0.00338	0.00651	0.00677	0.01015	0.01203	0.013532	0.01654	0.02030	0.02406	0.01052	0.01178	0.0045
44	0.022727	0.00615	0.00284	0.019682	0.00246	0.0034	0.00410	0.00369	0.00710	0.00738	0.01107	0.01312	0.014762	0.01804	0.02214	0.02624	0.01148	0.01285	0.0048
40	0.025000	0.00677	0.00312	0.021651	0.00271	0.0038	0.00451	0.00406	0.00781	0.00812	0.01218	0.01443	0.016238	0.01985	0.02436	0.02887	0.01263	0.01414	0.0051
36	0.027778	0.00752	0.00347	0.024056	0.00301	0.0042	0.00501	0.00451	0.00868	0.00902	0.01353	0.01604	0.018042	0.02205	0.02706	0.03208	0.01403	0.01571	0.0055
32	0.031250	0.00846	0.00391	0.027063	0.00338	0.0047	0.00564	0.00507	0.00977	0.01015	0.01522	0.01804	0.020297	0.02481	0.03045	0.03608	0.01579	0.01768	0.0060
28	0.035714	0.00967	0.00446	0.030929	0.00387	0.0054	0.00644	0.00580	0.01116	0.01160	0.01740	0.02062	0.023197	0.02835	0.03480	0.04124	0.01804	0.02020	0.0065
24	0.041667	0.01128	0.00521	0.036084	0.00451	0.0063	0.00752	0.00677	0.01302	0.01353	0.02030	0.02406	0.027063	0.03308	0.04059	0.04811	0.02105	0.02357	0.0072
20	0.050000	0.01353	0.00625	0.043301	0.00541	0.0075	0.00902	0.00812	0.01562	0.01624	0.02436	0.02887	0.032476	0.03969	0.04871	0.05774	0.02526	0.02828	0.0081
18	0.055556	0.01504	0.00694	0.048113	0.00601	0.0083	0.01002	0.00902	0.01736	0.01804	0.02706	0.03208	0.036084	0.04410	0.05413	0.06415	0.02807	0.03142	0.0087
16	0.062500	0.01691	0.00781	0.054127	0.00677	0.0094	0.01128	0.01015	0.01953	0.02030	0.03045	0.03608	0.040595	0.04962	0.06089	0.07217	0.03157	0.03535	0.0094
14	0.071429	0.01933	0.00893	0.061859	0.00773	0.0107	0.01289	0.01160	0.02232	0.02320	0.03480	0.04124	0.046394	0.05670	0.06959	0.08248	0.03608	0.04040	0.0103
13	0.076923	0.02082	0.00962	0.066617	0.00833	0.0115	0.01388	0.01249	0.02404	0.02498	0.03747	0.04441	0.049963	0.06107	0.07494	0.08882	0.03886	0.04351	0.0109
12	0.083333	0.02255	0.01042	0.072169	0.00902	0.0125	0.01503	0.01353	0.02604	0.02706	0.04059	0.04811	0.054127	0.06615	0.08119	0.09623	0.04210	0.04713	0.0114
11	0.090909	0.02460	0.01136	0.078730	0.00984	0.0136	0.01640	0.01476	0.02841	0.02952	0.04429	0.05249	0.059047	0.07217	0.08857	0.10497	0.04593	0.05142	0.0121
10	0.100000	0.02706	0.01250	0.086603	0.01083	0.0150	0.01804	0.01624	0.03125	0.03248	0.04871	0.05774	0.064952	0.07939	0.09743	0.11547	0.05052	0.05656	0.0129
9	0.111111	0.03007	0.01389	0.096225	0.01203	0.0167	0.02005	0.01804	0.03472	0.03608	0.05413	0.06415	0.072169	0.08821	0.10825	0.12830	0.05613	0.06284	0.0139
8	0.125000	0.03383	0.01562	0.108253	0.01353	0.0188	0.02255	0.02030	0.03906	0.04059	0.06089	0.07217	0.081190	0.09923	0.12178	0.14434	0.06315	0.07070	0.0150
7	0.142857	0.03866	0.01786	0.123718	0.01546	0.0214	0.02577	0.02320	0.04464	0.04639	0.06959	0.08248	0.092788	0.11341	0.13918	0.16496	0.07217	0.08080	0.0164
6	0.166667	0.04511	0.02083	0.144338	0.01804	0.0250	0.03007	0.02706	0.05208	0.05413	0.08119	0.09623	0.108253	0.13231	0.16238	0.19245	0.08420	0.09427	0.0182
5	0.200000	0.05413	0.02500	0.173205	0.02165	0.0300	0.03608	0.03248	0.06250	0.06495	0.09743	0.11547	0.129904	0.15877	0.19486	0.23094	0.10104	0.11312	0.0205
4.5	0.222222	0.06014	0.02778	0.192450	0.02406	0.0334	0.04009	0.03608	0.06944	0.07217	0.10825	0.12830	0.144338	0.17641	0.21651	0.25660	0.11226	0.12569	0.0220
4	0.250000	0.06766	0.03125	0.216506	0.02706	0.0375	0.04510	0.04059	0.07812	0.08119	0.12178	0.14434	0.162380	0.19846	0.24357	0.28868	0.12630	0.14140	0.0238

TABLE IV. Extra Fine Thread Series

BASIC SIZE			EXTERNAL THREAD - UNJEF CLASS 3A								INTERNAL THREAD - UNJEF CLASS 3B					INTERNAL THREAD - UNJEF CLASS 3B				
			MAJOR DIAMETER		PITCH DIAMETER		MINOR DIAMETER		ROOT RADIUS		MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA	MINOR DIAMETER		PITCH DIAMETER		MAJOR DIAMETER
PRIMARY	SECONDARY	THDS PER INCH	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MAX	MIN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	0.216	32	0.2100	0.2160	0.1933	0.1957	0.1756	0.1799	0.0047	0.0056	0.1856	0.1929	0.1957	0.1988	0.2160	0.1886	0.1959	0.1987	0.2018	0.2190
0.2500		32	0.2440	0.2500	0.2273	0.2297	0.2096	0.2139	0.0047	0.0056	0.2196	0.2263	0.2297	0.2328	0.2500	0.2226	0.2293	0.2327	0.2358	0.2530
0.3125		32	0.3065	0.3125	0.2898	0.2922	0.2721	0.2764	0.0047	0.0056	.2820	0.2880	0.2922	0.2953	0.3125	0.2850	0.2910	0.2952	0.2983	0.3155
0.3750		32	0.3690	0.3750	0.3522	0.3547	0.3345	0.3389	0.0047	0.0056	0.3446	0.3501	0.3547	0.3580	0.3750	0.3476	0.3531	0.3577	0.3610	0.3780
0.4375		28	0.4310	0.4375	0.4116	0.4143	0.3914	0.3963	0.0054	0.0064	0.4027	0.4066	0.4143	0.4178	0.4375	0.4057	0.4096	0.4173	0.4208	0.4405
0.5000		28	0.4935	0.5000	0.4740	0.4768	0.4538	0.4588	0.0054	0.0064	0.4652	0.4708	0.4768	0.4804	0.5000	0.4682	0.4738	0.4798	0.4834	0.5030
0.5625		24	0.5553	0.5625	0.5325	0.5354	0.5089	0.5144	0.0063	0.0075	0.5219	0.5281	0.5354	0.5392	0.5625	0.5249	0.5311	0.5384	0.5422	0.5655
0.6250		24	0.6178	0.6250	0.5949	0.5979	0.5714	0.5768	0.0063	0.0075	0.5844	0.5904	0.5979	0.6018	0.6250	0.5874	0.5934	0.6009	0.6048	0.6280
	0.6875	24	0.6803	0.6875	0.6574	0.6604	0.6339	0.6394	0.0063	0.0075	0.6469	0.6527	0.6604	0.6643	0.6875	0.6499	0.6557	0.6634	0.6673	0.6905
0.7500		20	0.7419	0.7500	0.7142	0.7175	0.6859	0.6922	0.0075	0.0090	0.7013	0.7081	0.7175	0.7218	0.7500	0.7043	0.7111	0.7205	0.7248	0.7530
	0.8125	20	0.8044	0.8125	0.7767	0.7800	0.7484	0.7547	0.0075	0.0090	0.7638	0.7706	0.7800	0.7843	0.8125	0.7668	0.7736	0.7830	0.7873	0.8155
0.8750		20	0.8669	0.8750	0.8392	0.8425	0.8109	0.8172	0.0075	0.0090	0.8263	0.8331	0.8425	0.8468	0.8750	0.8293	0.8361	0.8455	0.8498	0.8780
	0.9375	20	0.9294	0.9375	0.9016	0.9050	0.8733	0.8797	0.0075	0.0090	0.8888	0.8956	0.9050	0.9094	0.9375	0.8918	0.8986	0.9080	0.9124	0.9405
1.0000		20	0.9919	1.0000	0.9641	0.9675	0.9358	0.9422	0.0075	0.0090	0.9513	0.9581	0.9675	0.9719	1.0000	0.9543	0.9611	0.9705	0.9749	1.0030
	1.0625	18	1.0538	1.0625	1.0228	1.0264	0.9914	0.9983	0.0083	0.0100	1.0084	1.0159	1.0264	1.0310	1.0625	1.0114	1.0189	1.0294	1.0340	1.0655
1.1250		18	1.1163	1.1250	1.0853	1.0889	1.0539	1.0608	0.0083	0.0100	1.0709	1.0784	1.0889	1.0935	1.1250	1.0739	1.0814	1.0919	1.0965	1.1280
	1.1875	18	1.1788	1.1875	1.1478	1.1514	1.1164	1.1233	0.0083	0.0100	1.1334	1.1409	1.1514	1.1561	1.1875	1.1364	1.1439	1.1544	1.1591	1.1905
1.2500		18	1.2413	1.2500	1.2103	1.2139	1.1789	1.1858	0.0083	0.0100	1.1959	1.2034	1.2139	1.2186	1.2500	1.1989	1.2064	1.2169	1.2216	1.2530
	1.3125	18	1.3038	1.3125	1.2728	1.2764	1.2414	1.2483	0.0083	0.0100	1.2584	1.2659	1.2764	1.2811	1.3125	1.2614	1.2689	1.2794	1.2841	1.3155
1.3750		18	1.3663	1.3750	1.3353	1.3389	1.3039	1.3108	0.0083	0.0100	1.3209	1.3284	1.3389	1.3436	1.3750	1.3239	1.3314	1.3419	1.3466	1.3780
	1.4375	18	1.4288	1.4375	1.3977	1.4014	1.3663	1.3733	0.0083	0.0100	1.3834	1.3909	1.4014	1.4062	1.4375	1.3864	1.3939	1.4044	1.4092	1.4405
1.5000		18	1.4913	1.5000	1.4602	1.4639	1.4288	1.4358	0.0083	0.0100	1.4459	1.4534	1.4639	1.4687	1.5000	1.4489	1.4564	1.4669	1.4717	1.5030
	1.5625	18	1.5538	1.5625	1.5227	1.5264	1.4913	1.4983	0.0083	0.0100	1.5084	1.5159	1.5264	1.5312	1.5625	1.5114	1.5189	1.5294	1.5342	1.5655
1.6250		18	1.6163	1.6250	1.5852	1.5889	1.5538	1.5608	0.0083	0.0100	1.5709	1.5784	1.5889	1.5937	1.6250	1.5739	1.5814	1.5919	1.5967	1.6280
	1.6875	18	1.6788	1.6875	1.6476	1.6514	1.6162	1.6233	0.0083	0.0100	1.6334	1.6409	1.6514	1.6563	1.6875	1.6364	1.6439	1.6544	1.6593	1.6905

TABLE III. Fine Thread Series

BASIC SIZE			EXTERNAL THREAD - UNJF CLASS 3A								INTERNAL THREAD - UNJF CLASS 3B					INTERNAL THREAD - UNJF CLASS 3B				
			MAJOR DIAMETER		PITCH DIAMETER		MINOR DIAMETER		ROOT RADIUS		MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA	MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA
PRIMARY	SECONDARY	THDS PER INCH	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MAX	MIN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0.0600		80	0.0568	0.0600	0.0506	0.0519	0.0435	0.0456	0.0019	0.0023	0.0479	0.0511	0.0519	0.0536	0.0600	0.0489	0.0521	0.0529	0.0546	0.0610
	0.0730	72	0.0695	0.0730	0.0626	0.0640	0.0547	0.0570	0.0021	0.0025	0.0595	0.0631	0.0640	0.0659	0.0730	0.0605	0.0641	0.0650	0.0669	0.0740
0.0860		64	0.0822	0.0860	0.0744	0.0759	0.0656	0.0680	0.0023	0.0028	0.0708	0.0749	0.0759	0.0779	0.0860	0.0718	0.0759	0.0769	0.0789	0.0870
	0.0990	56	0.0949	0.0990	0.0858	0.0874	0.0757	0.0784	0.0027	0.0032	0.0816	0.0862	0.0874	0.0895	0.0990	0.0826	0.0872	0.0884	0.0905	0.1000
0.1120		48	0.1075	0.1120	0.0967	0.0985	0.0849	0.0880	0.0031	0.0038	0.0917	0.0971	0.0985	0.1008	0.1120	0.0927	0.0981	0.0995	0.1018	0.1130
0.1250		44	0.1202	0.1250	0.1083	0.1102	0.0954	0.0987	0.0034	0.0041	0.1029	0.1088	0.1102	0.1126	0.1250	0.1039	0.1098	0.1112	0.1136	0.1260
0.1380		40	0.1329	0.1380	0.1198	0.1218	0.1057	0.1092	0.0038	0.0045	0.1137	0.1202	0.1218	0.1243	0.1380	0.1147	0.1212	0.1228	0.1253	0.1390
0.1640		36	0.1585	0.1640	0.1439	0.1460	0.1282	0.1320	0.0042	0.0050	0.1370	0.1442	0.1460	0.1487	0.1640	0.1380	0.1452	0.1470	0.1497	0.1650
0.1900		32	0.1840	0.1900	0.1674	0.1697	0.1497	0.1539	0.0047	0.0056	0.1596	0.1675	0.1697	0.1726	0.1900	0.1626	0.1705	0.1727	0.1756	0.1930
	0.2160	28	0.2095	0.2160	0.1904	0.1928	0.1702	0.1748	0.0054	0.0064	0.1812	0.1896	0.1928	0.1959	0.2160	0.1842	0.1926	0.1958	0.1989	0.2190
0.2500		28	0.2435	0.2500	0.2243	0.2268	0.2041	0.2088	0.0054	0.0064	0.2152	0.2229	0.2268	0.2300	0.2500	0.2182	0.2259	0.2298	0.2330	0.2530
0.3125		24	0.3053	0.3125	0.2827	0.2854	0.2591	0.2644	0.0063	0.0075	0.2719	0.2799	0.2854	0.2890	0.3125	0.2749	0.2829	0.2884	0.2920	0.3155
0.3750		24	0.3678	0.3750	0.3450	0.3479	0.3214	0.3268	0.0063	0.0075	0.3344	0.3418	0.3479	0.3516	0.3750	0.3374	0.3448	0.3509	0.3546	0.3780
0.4375		20	0.4294	0.4375	0.4019	0.4050	0.3736	0.3797	0.0075	0.0090	0.3888	0.3970	0.4050	0.4091	0.4375	0.3918	0.4000	0.4080	0.4121	0.4405
0.5000		20	0.4919	0.5000	0.4643	0.4675	0.4360	0.4422	0.0075	0.0090	0.4513	0.4591	0.4675	0.4712	0.5000	0.4543	0.4621	0.4705	0.4742	0.5030
0.5625		18	0.5538	0.5625	0.5230	0.5264	0.4916	0.4983	0.0083	0.0100	0.5084	0.5166	0.5264	0.5308	0.5625	0.5114	0.5196	0.5291	0.5338	0.5655
0.6250		18	0.6163	0.6250	0.5854	0.5889	0.5540	0.5608	0.0083	0.0100	0.5709	0.5788	0.5889	0.5934	0.6250	0.5739	0.5818	0.5919	0.5964	0.6280
0.7500		16	0.7406	0.7500	0.7056	0.7094	0.6702	0.6778	0.0094	0.0113	0.6892	0.6977	0.7094	0.7143	0.7500	0.6922	0.7007	0.7124	0.7173	0.7530
0.8750		14	0.8647	0.8750	0.8245	0.8286	0.7841	0.7925	0.0107	0.0129	0.8055	0.8152	0.8286	0.8339	0.8750	0.8085	0.8182	0.8316	0.8369	0.8780
1.0000		12	0.9886	1.0000	0.9415	0.9459	0.8944	0.9038	0.0125	0.0150	0.9189	0.9298	0.9459	0.9516	1.0000	0.9219	0.9329	0.9489	0.9546	1.0030
1.1250		12	1.1136	1.1250	1.0664	1.0709	1.0192	1.0288	0.0125	0.0150	1.0439	1.0539	1.0709	1.0768	1.1250	1.0469	1.0569	1.0739	1.0798	1.1280
1.2500		12	1.2386	1.2500	1.1913	1.1959	1.1442	1.1538	0.0125	0.0150	1.1689	1.1789	1.1959	1.2019	1.2500	1.1719	1.1819	1.1989	1.2049	1.2530
1.3750		12	1.3636	1.3750	1.3162	1.3209	1.2690	1.2788	0.0125	0.0150	1.2939	1.3039	1.3209	1.3270	1.3750	1.2969	1.3069	1.3239	1.3300	1.3780
1.5000		12	1.4886	1.5000	1.4411	1.4459	1.3940	1.4038	0.0125	0.0150	1.4189	1.4289	1.4459	1.4522	1.5000	1.4219	1.4319	1.4489	1.4552	1.5030

TABLE VI. Twelve Thread Series

BASIC SIZE		EXTERNAL THREAD - 12UNJ CLASS 3A ROOT RADIUS 0.0125 MIN 0.0150 MAX						INTERNAL THREAD - 12 UNJ CLASS 3B					INTERNAL THREAD - 12 UNJ CLASS 3BG				
		MAJOR DIAMETER		PITCH DIAMETER		MINOR DIAMETER		MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA	MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA
PRIMARY	SECONDARY	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MAX	MIN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0.6250		0.6136	0.6250	0.5668	0.5709	0.5196	0.5288	0.5439	0.5539	0.5709	0.5762	0.6250	0.5469	0.5569	0.5739	0.5792	0.6280
	0.6875	0.6761	0.6875	0.6293	0.6334	0.5822	0.5913	0.6064	0.6164	0.6334	0.6387	0.6875	0.6094	0.6194	0.6364	0.6417	0.6905
0.7500		0.7386	0.7500	0.6918	0.6959	0.6436	0.6538	0.6689	0.6789	0.6959	0.7017	0.7500	0.6719	0.6819	0.6985	0.7043	0.7530
	0.8125	0.8011	0.8125	0.7543	0.7584	0.7072	0.7163	0.7314	0.7414	0.7584	0.7638	0.8125	0.7344	0.7444	0.7614	0.7668	0.8155
0.8750		0.8636	0.8750	0.8168	0.8209	0.7696	0.7788	0.7939	0.8039	0.8209	0.8263	0.8750	0.7969	0.8069	0.8239	0.8293	0.8780
	0.9375	0.9261	0.9375	0.8792	0.8834	0.8320	0.8413	0.8564	0.8664	0.8834	0.8889	0.9375	0.8594	0.8694	0.8864	0.8919	0.9405
	1.0625	1.0511	1.0625	1.0042	1.0084	0.9570	0.9663	0.9814	0.9914	1.0084	1.0139	1.0625	0.9844	0.9944	1.0114	1.0169	1.0655
	1.1875	1.1761	1.1875	1.1291	1.1334	1.0820	1.0913	1.1064	1.1164	1.1334	1.1390	1.1875	1.1094	1.1194	1.1364	1.1420	1.1905
	1.3125	1.3011	1.3125	1.2541	1.2584	1.2070	1.2163	1.2314	1.2414	1.2584	1.2640	1.3125	1.2344	1.2444	1.2614	1.2670	1.3155
	1.4375	1.4261	1.4375	1.3790	1.3834	1.3318	1.3413	1.3564	1.3664	1.3834	1.3891	1.4375	1.3594	1.3694	1.3864	1.3921	1.4405
	1.5625	1.5511	1.5625	1.5040	1.5084	1.4568	1.4663	1.4814	1.4914	1.5084	1.5141	1.5625	1.4844	1.4944	1.5114	1.5171	1.5655
1.6250		1.6136	1.6250	1.5665	1.5709	1.5194	1.5288	1.5439	1.5539	1.5709	1.5766	1.6250	1.5469	1.5569	1.5739	1.5796	1.6280
	1.6875	1.6761	1.6875	1.6289	1.6334	1.5818	1.5913	1.6064	1.6164	1.6334	1.6392	1.6875	1.6094	1.6194	1.6364	1.6422	1.6905
1.7500		1.7386	1.7500	1.6914	1.6959	1.6442	1.6538	1.6689	1.6789	1.6959	1.7017	1.7500	1.6719	1.6819	1.6989	1.7047	1.7530
	1.8125	1.8011	1.8125	1.7539	1.7584	1.7068	1.7163	1.7314	1.7414	1.7584	1.7642	1.8125	1.7344	1.7444	1.7614	1.7672	1.8155
1.8750		1.8636	1.8750	1.8164	1.8209	1.7692	1.7788	1.7939	1.8039	1.8209	1.8267	1.8750	1.7969	1.8069	1.8239	1.8297	1.8780
	1.9375	1.9261	1.9375	1.8789	1.8834	1.8318	1.8413	1.8564	1.8664	1.8834	1.8893	1.9375	1.8594	1.8694	1.8864	1.8923	1.9405
2.0000		1.9886	2.0000	1.9414	1.9459	1.8942	1.9038	1.9189	1.9289	1.9459	1.9518	2.0000	1.9219	1.9319	1.9489	1.9548	2.0030
	2.1250	2.1136	2.1250	2.0664	2.0709	2.0192	2.0288	2.0439	2.0539	2.0709	2.0768	2.1250	2.0469	2.0569	2.0739	2.0798	2.1280
2.2500		2.2386	2.2500	2.1914	2.1959	2.1442	2.1538	2.1689	2.1789	2.1959	2.2018	2.2500	2.1719	2.1819	2.1985	2.2048	2.2530
	2.3750	2.3636	2.3750	2.3163	2.3209	2.2692	2.2788	2.2939	2.3039	2.3209	2.3269	2.3750	2.2969	2.3069	2.3239	2.3299	2.3780
2.5000		2.4886	2.5000	2.4413	2.4459	2.3942	2.4038	2.4189	2.4289	2.4459	2.4519	2.5000	2.4219	2.4319	2.4489	2.4549	2.5030
	2.6250	2.6136	2.6250	2.5663	2.5709	2.5192	2.5288	2.5439	2.5539	2.5709	2.5769	2.6250	2.5469	2.5569	2.5739	2.5799	2.6280
2.7500		2.7386	2.7500	2.6913	2.6959	2.6442	2.6538	2.6689	2.6789	2.6959	2.7019	2.7500	2.6719	2.6819	2.6985	2.7049	2.7530
	2.8750	2.8636	2.8750	2.8162	2.8209	2.7690	2.7788	2.7939	2.8039	2.8209	2.8271	2.8750	2.7969	2.8069	2.8239	2.8301	2.8780
3.0000		2.9886	3.0000	2.9412	2.9459	2.8940	2.9038	2.9189	2.9289	2.9459	2.9521	3.0000	2.9219	2.9319	2.9489	2.9551	3.0030
	3.1250	3.1136	3.1250	3.0662	3.0709	3.0190	3.0288	3.0439	3.0539	3.0709	3.0771	3.1250	3.0469	3.0569	3.0739	3.0801	3.1280
3.2500		3.2386	3.2500	3.1912	3.1959	3.1440	3.1538	3.1689	3.1789	3.1959	3.2021	3.2500	3.1719	3.1819	3.1985	3.2051	3.2530

TABLE V. Eight Thread Series

BASIC SIZE		EXTERNAL THREAD - 8UNJ CLASS 3A ROOT RADIUS 0.0188 MIN 0.0226 MAX						INTERNAL THREAD - 8UNJ CLASS 3B					INTERNAL THREAD - 8UNJ CLASS 3BG				
		MAJOR DIAMETER		PITCH DIAMETER		MINOR DIAMETER		MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA	MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA
PRIMARY	SECONDARY	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MAX	MIN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	1.0625	1.0475	1.0625	0.9762	0.9813	0.9055	0.9182	0.9408	0.9558	0.9813	0.9880	1.0625	0.9438	0.9588	0.9843	0.9910	1.0655
1.1250		1.1100	1.1250	1.0368	1.0438	0.9661	0.9806	1.0033	1.0183	1.0438	1.0505	1.1250	1.0063	1.0213	1.0468	1.0535	1.1280
	1.1875	1.1725	1.1875	1.1011	1.1063	1.0304	1.0432	1.0658	1.0808	1.1063	1.1131	1.1875	1.0688	1.0838	1.1093	1.1161	1.1905
1.2500		1.2350	1.2500	1.1635	1.1688	1.0928	1.1056	1.1283	1.1433	1.1688	1.1757	1.2500	1.1313	1.1463	1.1718	1.1787	1.2530
	1.3125	1.2975	1.3125	1.2260	1.2313	1.1553	1.1682	1.1908	1.2058	1.2313	1.2382	1.3125	1.1938	1.2088	1.2343	1.2412	1.3155
1.3750		1.3600	1.3750	1.2884	1.2938	1.2177	1.2306	1.2533	1.2683	1.2938	1.3008	1.3750	1.2563	1.2713	1.2968	1.3038	1.3780
	1.4375	1.4225	1.4375	1.3509	1.3563	1.2802	1.2932	1.3158	1.3308	1.3563	1.3634	1.4375	1.3188	1.3338	1.3593	1.3664	1.4405
1.5000		1.4850	1.5000	1.4133	1.4188	1.3426	1.3556	1.3783	1.3933	1.4188	1.4259	1.5000	1.3813	1.3963	1.4218	1.4289	1.5030
	1.5625	1.5475	1.5625	1.4758	1.4813	1.4051	1.4182	1.4408	1.4558	1.4813	1.4885	1.5625	1.4438	1.4588	1.4843	1.4915	1.5655
1.6250		1.6100	1.6250	1.5382	1.5438	1.4675	1.4806	1.5033	1.5183	1.5438	1.5510	1.6250	1.5063	1.5213	1.5468	1.5540	1.6280
	1.6875	1.6725	1.5875	1.6007	1.6063	1.5300	1.5432	1.5658	1.5808	1.6063	1.6136	1.6875	1.5688	1.5838	1.6093	1.6166	1.6905
1.7500		1.7350	1.7500	1.6631	1.6688	1.5924	1.6056	1.6283	1.6433	1.6688	1.6762	1.7500	1.6313	1.6463	1.6718	1.6792	1.7530
	1.8125	1.7975	1.8125	1.7256	1.7313	1.6549	1.6682	1.6908	1.7058	1.7313	1.7387	1.8125	1.6938	1.7088	1.7343	1.7417	1.8155
1.8750		1.8600	1.8750	1.7881	1.7938	1.7174	1.7306	1.7533	1.7683	1.7938	1.8013	1.8750	1.7563	1.7713	1.7968	1.8143	1.8780
	1.9375	1.9225	1.9375	1.8505	1.8563	1.7798	1.7932	1.8158	1.8308	1.8563	1.8638	1.9375	1.8188	1.8338	1.8593	1.8668	1.9405
2.0000		1.9850	2.0000	1.9130	1.9188	1.8423	1.8556	1.8783	1.8933	1.9188	1.9264	2.0000	1.8813	1.8963	1.9218	1.9291	2.0030
	2.1250	2.1100	2.1250	2.0379	2.0438	1.9672	1.9806	2.0033	2.0183	2.0438	2.0515	2.1250	2.0063	2.0213	2.0468	2.0545	2.1280
2.2500		2.2350	2.2500	2.1628	2.1688	2.0921	2.1056	2.1283	2.1433	2.1688	2.1766	2.2500	2.1313	2.1463	2.1718	2.1796	2.2530
	2.3750	2.3600	2.3750	2.2878	2.2938	2.2171	2.2306	2.2533	2.2683	2.2938	2.3017	2.3750	2.2563	2.2713	2.2968	2.3047	2.3780
2.5000		2.4850	2.5000	2.4127	2.4188	2.3420	2.3556	2.3783	2.3933	2.4188	2.4268	2.5000	2.3813	2.3963	2.4218	2.4298	2.5030
	2.6250	2.6100	2.6250	2.5376	2.5438	2.4669	2.4806	2.5033	2.5183	2.5438	2.5518	2.6250	2.5063	2.5213	2.5468	2.5548	2.6280
2.7500		2.7350	2.7500	2.6625	2.6688	2.5918	2.6056	2.6283	2.6433	2.6688	2.6769	2.7500	2.6313	2.6463	2.6718	2.6799	2.7530
	2.8750	2.8600	2.8750	2.7875	2.7938	2.7168	2.7306	2.7533	2.7683	2.7938	2.8020	2.8750	2.7563	2.7713	2.7968	2.8050	2.8780
3.0000		2.9850	3.0000	2.9124	2.9188	2.8417	2.8556	2.8783	2.8933	2.9188	2.9271	3.0000	2.8813	2.8963	2.9218	2.9301	3.0030
	3.1250	3.1100	3.1250	3.0374	3.0438	2.9667	2.9806	3.0033	3.0183	3.0438	3.0522	3.1250	3.0063	3.0213	3.0468	3.0552	3.1280
3.2500		3.2350	3.2500	3.1623	3.1688	3.0916	3.1056	3.1283	3.1433	3.1688	3.1773	3.2500	3.1313	3.1463	3.1718	3.1803	3.2530
	3.3750	3.3600	3.3750	3.2872	3.2938	3.2165	3.2306	3.2533	3.2683	3.2938	3.3023	3.3750	3.2563	3.2713	3.2968	3.3053	3.3780
3.5000		3.4850	3.5000	3.4122	3.4188	3.3415	3.3556	3.3783	3.3933	3.4188	3.4274	3.5000	3.3813	3.3963	3.4218	3.4304	3.5030
	3.6250	3.6100	3.6250	3.5371	3.5438	3.4664	3.4806	3.5033	3.5183	3.5438	3.5525	3.6250	3.5063	3.5213	3.5468	3.5555	3.6280
3.7500		3.7350	3.7500	3.6621	3.6688	3.5914	3.6056	3.6283	3.6433	3.6688	3.6776	3.7500	3.6313	3.6463	3.6718	3.6806	3.7530
	3.8750	3.8600	3.8750	3.7870	3.7938	3.7163	3.7306	3.7533	3.7683	3.7938	3.8026	3.8750	3.7563	3.7713	3.7968	3.8056	3.8780
4.0000		3.9850	4.0000	3.9120	3.9188	3.8413	3.8556	3.8783	3.8933	3.9188	3.9277	4.0000	3.8813	3.8963	3.9218	3.9307	4.0030

TABLE VII. Sixteen Thread Series

BASIC SIZE		EXTERNAL THREAD 16 UNJ CLASS 3A ROOT RADIUS 0.0094 MIN 0.0113 MAX						INTERNAL THREAD 16 UNJ CLASS 3B					INTERNAL THREAD 16 UNJ CLASS 3BG				
		MAJOR DIAMETER		PITCH DIAMETER		MINOR DIAMETER		MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA	MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA
PRIMARY	SECONDARY	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MAX	MIN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0.4375		0.4281	0.4375	0.3935	0.3969	0.3581	0.3653	0.3767	0.3869	0.3969	0.4014	0.4375	0.3797	0.3899	0.3999	0.4044	0.4405
0.5000		0.4906	0.5000	0.4559	0.4594	0.4206	0.4278	0.4392	0.4480	0.4594	0.4640	0.5000	0.4422	0.4510	0.4624	0.4670	0.5030
0.5625		0.5531	0.5625	0.5184	0.5219	0.4830	0.4903	0.5017	0.5109	0.5219	0.5265	0.5625	0.5047	0.5139	0.5249	0.5295	0.5655
0.6250		0.6156	0.6250	0.5808	0.5844	0.5454	0.5528	0.5642	0.5731	0.5844	0.5890	0.6250	0.5672	0.5761	0.5874	0.5920	0.6280
	0.6875	0.6781	0.6875	0.6433	0.6469	0.6079	0.6153	0.6267	0.6353	0.6469	0.6515	0.6875	0.6297	0.6383	0.6499	0.6545	0.6905
	0.8125	0.8031	0.8125	0.7683	0.7719	0.7329	0.7403	0.7517	0.7602	0.7719	0.7766	0.8125	0.7547	0.7632	0.7749	0.7796	0.8155
0.8750		0.8656	0.8750	0.8308	0.8344	0.7954	0.8028	0.8142	0.8227	0.8344	0.8391	0.8750	0.8172	0.8257	0.8374	0.8421	0.8780
	0.9375	0.9281	0.9375	0.8932	0.8969	0.8578	0.8653	0.8767	0.8852	0.8969	0.9018	0.9375	0.8797	0.8882	0.8999	0.9048	0.9405
1.0000		0.9906	1.0000	0.9557	0.9594	0.9203	0.9278	0.9392	0.9477	0.9594	0.9643	1.0000	0.9422	0.9507	0.9624	0.9673	1.0030
	1.0625	1.0531	1.0625	1.0182	1.0219	0.9828	0.9903	1.0017	1.0102	1.0219	1.0268	1.0625	1.0047	1.0132	1.0249	1.0298	1.0655
1.1250		1.1156	1.1250	1.0807	1.0844	1.0453	1.0528	1.0642	1.0727	1.0844	1.0893	1.1250	1.0672	1.0757	1.0874	1.0923	1.1280
	1.1875	1.1781	1.1875	1.1431	1.1469	1.1077	1.1153	1.1267	1.1352	1.1469	1.1519	1.1875	1.1297	1.1382	1.1499	1.1549	1.1905
1.2500		1.2406	1.2500	1.2056	1.2094	1.1702	1.1778	1.1892	1.1977	1.2094	1.2144	1.2500	1.1922	1.2007	1.2124	1.2174	1.2530
	1.3125	1.3031	1.3125	1.2681	1.2719	1.2327	1.2403	1.2517	1.2602	1.2719	1.2769	1.3125	1.2547	1.2632	1.2749	1.2799	1.3155
1.3750		1.3656	1.3750	1.3306	1.3344	1.2952	1.3028	1.3142	1.3227	1.3344	1.3394	1.3750	1.3172	1.3257	1.3374	1.3424	1.3780
	1.4375	1.4281	1.4375	1.3930	1.3969	1.3576	1.3653	1.3767	1.3852	1.3969	1.4020	1.4375	1.3797	1.3882	1.3999	1.4050	1.4405
1.5000		1.4906	1.5000	1.4555	1.4594	1.4201	1.4278	1.4392	1.4477	1.4594	1.4645	1.5000	1.4422	1.4507	1.4624	1.4675	1.5030
	1.5625	1.5531	1.5625	1.5180	1.5219	1.4826	1.4903	1.5017	1.5102	1.5219	1.5270	1.5625	1.5047	1.5132	1.5249	1.5300	1.5655
1.6250		1.6156	1.6250	1.5805	1.5844	1.5451	1.5528	1.5642	1.5727	1.5844	1.5895	1.6250	1.5672	1.5757	1.5874	1.5925	1.6280
	1.6875	1.6781	1.6875	1.6429	1.6469	1.6075	1.6153	1.6267	1.6352	1.6469	1.6521	1.6875	1.6297	1.6382	1.6499	1.6551	1.6905
1.7500		1.7406	1.7500	1.7054	1.7094	1.6700	1.6778	1.6892	1.6977	1.7094	1.7146	1.7500	1.6922	1.7007	1.7124	1.7176	1.7530
	1.8125	1.8031	1.8125	1.7679	1.7719	1.7325	1.7403	1.7517	1.7602	1.7719	1.7771	1.8125	1.7547	1.7632	1.7749	1.7801	1.8155
1.8750		1.8656	1.8750	1.8304	1.8344	1.7950	1.8028	1.8142	1.8227	1.8344	1.8396	1.8750	1.8172	1.8257	1.8374	1.8426	1.8780
	1.9375	1.9281	1.9375	1.8929	1.8969	1.8575	1.8653	1.8767	1.8852	1.8969	1.9021	1.9375	1.8797	1.8882	1.8999	1.9051	1.9405
2.0000		1.9906	2.0000	1.9554	1.9594	1.9200	1.9278	1.9392	1.9477	1.9594	1.9646	2.0000	1.9422	1.9507	1.9624	1.9676	2.0030
	2.1250	2.1156	2.1250	2.0804	2.0844	2.0450	2.0528	2.0642	2.0727	2.0844	2.0896	2.1250	2.0672	2.0757	2.0874	2.0926	2.1280
2.2500		2.2406	2.2500	2.2054	2.2094	2.1700	2.1778	2.1892	2.1977	2.2094	2.2146	2.2500	2.1922	2.2007	2.2124	2.2176	2.2530
	2.3750	2.3656	2.3750	2.3303	2.3344	2.2949	2.3028	2.3142	2.3227	2.3344	2.3398	2.3750	2.3172	2.3257	2.3374	2.3428	2.3780

TABLE VI. (Continued) Twelve Thread Series

BASIC SIZE		EXTERNAL THREAD 12 UNJ CLASS 3A ROOT RADIUS 0.0125 MIN 0.0150 MAX						INTERNAL THREAD - 12 UNJ CLASS 3B					INTERNAL THREAD - 12 UNJ CLASS 3BG				
		MAJOR DIAMETER		PITCH DIAMETER		MINOR DIAMETER		MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA	MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA
PRI-MARY	SEC-OND-ARY	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MAX	MIN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	3.3750	3.3636	3.3750	3.3161	3.3209	3.2690	3.2788	3.2939	3.3039	3.3209	3.3272	3.3750	3.2969	3.3069	3.3239	3.3302	3.3780
3.5000		3.4886	3.5000	3.4411	3.4459	3.3940	3.4038	3.4189	3.4289	3.4459	3.4522	3.5000	3.4219	3.4319	3.4489	3.4552	3.5030
	3.6250	3.6136	3.6250	3.5661	3.5709	3.5190	3.5288	3.5439	3.5539	3.5709	3.5772	3.6250	3.5469	3.5569	3.5739	3.5802	3.6280
3.7500		3.7386	3.7500	3.6911	3.6959	3.6440	3.6538	3.6689	3.6789	3.6959	3.7022	3.7500	3.6719	3.6819	3.6989	3.7052	3.7530
	3.8750	3.8636	3.8750	3.8160	3.8209	3.7688	3.7788	3.7939	3.8039	3.8209	3.8273	3.8750	3.7969	3.8069	3.8239	3.8303	3.8780
4.0000		3.9886	4.0000	3.9410	3.9459	3.8938	3.9038	3.9189	3.9289	3.9459	3.9523	4.0000	3.9219	3.9319	3.9489	3.9553	4.0030
	4.1250	4.1136	4.1250	4.0660	4.0709	4.0188	4.0288	4.0439	4.0539	4.0709	4.0773	4.1250	4.0469	4.0569	4.0739	4.0803	4.1280
4.2500		4.2386	4.2500	4.1910	4.1959	4.1438	4.1538	4.1689	4.1789	4.1959	4.2023	4.2500	4.1719	4.1819	4.1989	4.2053	4.2530
	4.3750	4.3636	4.3750	4.3160	4.3209	4.2688	4.2788	4.2939	4.3039	4.3209	4.3273	4.3750	4.2969	4.3069	4.3239	4.3303	4.3780
4.5000		4.4886	4.5000	4.4410	4.4459	4.3938	4.4038	4.4189	4.4289	4.4459	4.4523	4.5000	4.4219	4.4319	4.4489	4.4553	4.5030
	4.6250	4.6136	4.6250	4.5658	4.5709	4.5188	4.5288	4.5439	4.5539	4.5709	4.5775	4.6250	4.5469	4.5569	4.5739	4.5805	4.6280
4.7500		4.7386	4.7500	4.6909	4.6959	4.6438	4.6538	4.6689	4.6789	4.6959	4.7025	4.7500	4.6719	4.6819	4.6989	4.7055	4.7530
	4.8750	4.8636	4.8750	4.8159	4.8209	4.7688	4.7788	4.7939	4.8039	4.8209	4.8275	4.8750	4.7969	4.8069	4.8239	4.8305	4.8780
5.0000		4.9886	5.0000	4.9409	4.9459	4.8938	4.9038	4.9189	4.9289	4.9459	4.9525	5.0000	4.9219	4.9319	4.9489	4.9555	5.0030
	5.1250	5.1136	5.1250	5.0659	5.0709	5.0188	5.0288	5.0439	5.0539	5.0709	5.0775	5.1250	5.0469	5.0569	5.0739	5.0805	5.1280
5.2500		5.2386	5.2500	5.1909	5.1959	5.1438	5.1538	5.1689	5.1789	5.1959	5.2025	5.2500	5.1719	5.1819	5.1989	5.2055	5.2530
	5.3750	5.3636	5.3750	5.3159	5.3209	5.2688	5.2788	5.2939	5.3039	5.3209	5.3275	5.3750	5.2969	5.3069	5.3239	5.3305	5.3780
5.5000		5.4886	5.5000	5.4409	5.4459	5.3938	5.4038	5.4189	5.4289	5.4459	5.4525	5.5000	5.4219	5.4319	5.4489	5.4555	5.5030
	5.6250	5.6136	5.6250	5.5657	5.5709	5.5186	5.5288	5.5439	5.5539	5.5709	5.5776	5.6250	5.5469	5.5569	5.5739	5.5806	5.6280
5.7500		5.7386	5.7500	5.6907	5.6959	5.6436	5.6538	5.6689	5.6789	5.6959	5.7026	5.7500	5.6719	5.6819	5.6989	5.7056	5.7530
	5.8750	5.8636	5.8750	5.8157	5.8209	5.7686	5.7788	5.7939	5.8039	5.8209	5.8276	5.8750	5.7969	5.8069	5.8239	5.8306	5.8780
6.0000		5.9886	6.0000	5.9407	5.9459	5.8936	5.9038	5.9189	5.9289	5.9459	5.9526	6.0000	5.9219	5.9319	5.9489	5.9556	6.0030

TABLE VII (Continued) Sixteen Thread Series

		EXTERNAL THREAD 16 UNJ CLASS 3A ROOT RADIUS 0.0094 MIN 0.0113 MAX						INTERNAL THREAD 16 UNJ CLASS 3B					INTERNAL THREAD 16 UNJ CLASS 3BG				
BASIC SIZE		MAJOR DIAMETER		PITCH DIAMETER		MINOR DIAMETER		MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA	MINOR DIAMETER		PITCH DIAMETER		MAJOR DIA
PRIMARY	SECONDARY	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MAX	MIN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2.5000		2.4906	2.5000	2.4553	2.4594	2.4199	2.4278	2.4392	2.4477	2.4594	2.4648	2.5000	2.4422	2.4507	2.4624	2.4678	2.5030
	2.6250	2.6156	2.6250	2.5803	2.5844	2.5449	2.5528	2.5642	2.5727	2.5844	2.5898	2.6250	2.5672	2.5757	2.5874	2.5928	2.6280
2.7500		2.7406	2.7500	2.7053	2.7094	2.6699	2.6778	2.6892	2.6977	2.7094	2.7148	2.7500	2.6922	2.7007	2.7124	2.7178	2.7530
	2.8750	2.8656	2.8750	2.8302	2.8344	2.7948	2.8028	2.8142	2.8227	2.8344	2.8399	2.8750	2.8172	2.8257	2.8374	2.8429	2.8780
3.0000		2.9906	3.0000	2.9552	2.9594	2.9198	2.9278	2.9392	2.9477	2.9594	2.9649	3.0000	2.9422	2.9507	2.9624	2.9679	3.0030
	3.1250	3.1156	3.1250	3.0802	3.0844	3.0448	3.0528	3.0642	3.0727	3.0844	3.0899	3.1250	3.0672	3.0757	3.0874	3.0929	3.1280
3.2500		3.2406	3.2500	3.2052	3.2094	3.1698	3.1778	3.1892	3.1977	3.2094	3.2149	3.2500	3.1922	3.2007	3.2124	3.2179	3.2530
	3.3750	3.3656	3.3750	3.3301	3.3344	3.2947	3.3028	3.3142	3.3227	3.3344	3.3400	3.3750	3.3172	3.3257	3.3374	3.3430	3.3780
3.5000		3.4906	3.5000	3.4551	3.4594	3.4197	3.4278	3.4392	3.4477	3.4594	3.4650	3.5000	3.4422	3.4507	3.4624	3.4680	3.5030
	3.6250	3.6156	3.6250	3.5801	3.5844	3.5447	3.5528	3.5642	3.5727	3.5844	3.5900	3.6250	3.5672	3.5757	3.5874	3.5930	3.6280
3.7500		3.7406	3.7500	3.7051	3.7094	3.6697	3.6778	3.6892	3.6977	3.7094	3.7150	3.7500	3.6922	3.7007	3.7124	3.7180	3.7530
	3.8750	3.8656	3.8750	3.8300	3.8344	3.7946	3.8028	3.8142	3.8227	3.8344	3.8401	3.8750	3.8172	3.8257	3.8374	3.8431	3.8780
4.0000		2.9906	4.0000	3.9550	3.9594	3.9596	3.9278	3.9392	3.9477	3.9594	3.9651	4.0000	3.9422	3.9507	3.9624	3.9681	4.0030
	4.1250	4.1156	4.1250	4.0800	4.0844	4.0446	4.0528	4.0642	4.0727	4.0844	4.0901	4.1250	4.0672	4.0757	4.0874	4.0931	4.1280
4.2500		4.2406	4.2500	4.2050	4.2094	4.1696	4.1778	4.1892	4.1977	4.2094	4.2151	4.2500	4.1922	4.2007	4.2124	4.2181	4.2530
	4.3750	4.3656	4.3750	4.3300	4.3344	4.2946	4.3028	4.3142	4.3227	4.3344	4.3401	4.3750	4.3172	4.3257	4.3374	4.3431	4.3780
4.5000		4.4906	4.5000	4.4550	4.4594	4.4196	4.4278	4.4392	4.4477	4.4594	4.4651	4.5000	4.4422	4.4507	4.4624	4.4681	4.5030
	4.6250	4.6156	4.6250	4.5799	4.5844	4.5445	4.5528	4.5642	4.5727	4.5844	4.5903	4.6250	4.5672	4.5757	4.5874	4.5933	4.6280
4.7500		4.7406	4.7500	4.7049	4.7094	4.6695	4.6778	4.6892	4.6977	4.7094	4.7153	4.7500	4.6922	4.7007	4.7124	4.7183	4.7530
	4.8750	4.8656	4.8750	4.8299	4.8344	4.7945	4.8028	4.8142	4.8227	4.8344	4.8403	4.8750	4.8172	4.8257	4.8374	4.8433	4.8780
5.0000		4.9906	5.0000	4.9549	4.9594	4.9195	4.9278	4.9392	4.9477	4.9594	4.9653	5.0000	4.9422	4.9507	4.9624	4.9683	5.0030
	5.1250	5.1156	5.1250	5.0795	5.0844	5.0445	5.0528	5.0642	5.0727	5.0844	5.0903	5.1250	5.0672	5.0757	5.0874	5.0933	5.1280
5.2500		5.2406	5.2500	5.2049	5.2094	5.1695	5.1778	5.1892	5.1977	5.2094	5.2153	5.2500	5.1922	5.2007	5.2124	5.2183	5.2530
	5.3750	5.3656	5.3750	5.3299	5.3344	5.2945	5.3028	5.3142	5.3227	5.3344	5.3403	5.3750	5.3172	5.3257	5.3374	5.3433	5.3780
5.5000		5.4906	5.5000	5.4549	5.4594	5.4195	5.4278	5.4392	5.4477	5.4594	5.4653	5.5000	5.4422	5.4507	5.4624	5.4683	5.5030
	5.6250	5.6156	5.6250	5.5797	5.5844	5.5443	5.5528	5.5642	5.5727	5.5844	5.5905	5.6250	5.5672	5.5757	5.5874	5.5935	5.6280
5.7500		5.7406	5.7500	5.7047	5.7094	5.6693	5.6778	5.6892	5.6977	5.7094	5.7155	5.7500	5.6922	5.7007	5.7124	5.7185	5.7530
	5.8750	5.8656	5.8750	5.8297	5.8344	5.7943	5.8028	5.8142	5.8227	5.8344	5.8405	5.8750	5.8172	5.8257	5.8374	5.8435	5.8780
6.0000		5.9906	6.0000	5.9547	5.9594	5.9193	5.9278	5.9392	5.9477	5.9594	5.9655	6.0000	5.9422	5.9507	5.9624	5.9685	6.0030

APPENDIX

ALLOWABLE LEAD AND HALF-ANGLE DEVIATIONS

10. SCOPE

10.1 This appendix contains the formulas for calculating lead and angle deviations and a tabulation of 0.4 of the pitch diameter tolerance and the lead and angle variations equal thereto.

20. Limits of size. With respect to the pitch diameter limits of size, it is intended, except as qualified in section 3, that no portion of the complete thread be permitted to project beyond the envelope defined by the maximum-material limits on the one hand, or beyond that defined by the minimum-material limits on the other, and thus be outside of the tolerance zone specified. Also, the diameter equivalent of the variation of any given element except pitch diameter shall not exceed 0.4 of the pitch diameter tolerance. The full tolerance cannot, therefore, be used on pitch diameter unless deviations in all other thread elements are zero.

20.1 Formulas. Deviations equivalent to 0.4 of the pitch diameter tolerance shall be determined from the following formulas:

a. Diameter equivalents of lead deviations

$$\delta p = \frac{\delta E}{\cot \alpha} = \frac{\delta E}{1.7321}$$

where

δE = Pitch diameter increment due to lead deviation

δp = The maximum pitch deviation between any two of the threads engaged.

α = Basic half angle of thread

b. Diameter equivalent of angle deviations:

$$\tan \delta\alpha = \frac{\delta E}{1.5p}$$

where

$\delta\alpha$ = Error in half angle of thread

δE = Pitch diameter increment due to deviation in half angle

Tabulated values for 0.4 of the pitch diameter tolerance and the lead deviation equivalents are given to 5 significant places and are determined prior to rounding the pitch diameter tolerance to 4 places.

TABLE VIII

ALLOWABLE LEAD AND HALF-ANGLE DEVIATIONS

SIZE	EXTERNAL THREAD				INTERNAL THREAD			
	.4PD TOL IN.	EQUIV LEAD IN.	EQUIV ANGLE Deg	Min	.4PD TOL IN.	EQUIV LEAD IN.	EQUIV ANGLE Deg	Min
.0600 -80	.00052	.00030	1	35	.00068	.00039	2	5
.0730 -64	.00060	.00035	1	28	.00076	.00044	1	51
.0730 -72	.00056	.00032	1	32	.00076	.00044	2	5
.0860 -56	.00064	.00037	1	22	.00084	.00048	1	48
.0860 -64	.00060	.00035	1	28	.00080	.00046	1	57
.0990 -48	.00068	.00039	1	15	.00088	.00051	1	37
.0990 -56	.00064	.00037	1	22	.00084	.00048	1	48
.1120 -40	.00076	.00044	1	10	.00096	.00055	1	28
.1120 -48	.00072	.00042	1	19	.00092	.00053	1	41
.1250 -40	.00076	.00044	1	10	.00100	.00058	1	32
.1250 -44	.00076	.00044	1	17	.00096	.00055	1	37
.1380 -32	.00084	.00048	1	2	.00112	.00065	1	22
.1380 -40	.00080	.00046	1	13	.00100	.00058	1	32
.1640 -32	.00088	.00051	1	5	.00112	.00065	1	22
.1640 -36	.00084	.00048	1	9	.00108	.00062	1	29
.1900 -24	.00100	.00058	0	55	.00128	.00074	1	10
.1900 -32	.00092	.00053	1	7	.00116	.00067	1	25
.2160 -24	.00100	.00058	0	55	.00132	.00076	1	13
.2160 -28	.00096	.00055	1	2	.00124	.00072	1	20
.2160 -32	.00096	.00055	1	10	.00124	.00072	1	31
.2500 -20	.00112	.00065	0	51	.00144	.00083	1	6
.2500 -28	.00100	.00058	1	4	.00128	.00074	1	22
.2500 -32	.00096	.00055	1	10	.00124	.00072	1	31
.3125 -18	.00120	.00069	0	50	.00156	.00090	1	4
.3125 -24	.00108	.00062	0	59	.00144	.00083	1	19
.3125 -32	.00100	.00058	1	13	.00128	.00074	1	34
.3750 -16	.00132	.00076	0	48	.00172	.00099	1	3
.3750 -24	.00116	.00067	1	4	.00148	.00085	1	21
.3750 -32	.00100	.00058	1	13	.00132	.00076	1	37
.4375 -14	.00140	.00081	0	45	.00184	.00106	0	59
.4375 -16	.00140	.00081	0	51	.00180	.00104	1	6
.4375 -20	.00124	.00072	0	57	.00164	.00095	1	15
.4375 -28	.00108	.00062	1	9	.00140	.00081	1	30
.5000 -13	.00148	.00085	0	44	.00192	.00111	0	57
.5000 -16	.00140	.00081	0	51	.00184	.00106	1	7
.5000 -20	.00128	.00074	0	59	.00168	.00097	1	17
.5000 -28	.00112	.00065	1	12	.00144	.00083	1	32
.5625 -12	.00156	.00090	0	43	.00204	.00118	0	56
.5625 -16	.00140	.00081	0	51	.00184	.00106	1	7
.5625 -18	.00136	.00079	0	56	.00176	.00102	1	13

TABLE VIII (Continued)

ALLOWABLE LEAD AND HALF-ANGLE DEVIATIONS

SIZE	EXTERNAL THREAD				INTERNAL THREAD			
	.4PD TOL IN.	EQUIV LEAD IN.	EQUIV ANGLE Deg	Min	.4PD TOL IN.	EQUIV LEAD IN.	EQUIV ANGLE Deg	Min
.5625 -24	.00120	.00069	1	6	.00156	.00090	1	26
.6250 -11	.00164	.00095	0	41	.00216	.00125	0	54
.6250 -12	.00164	.00095	0	45	.00212	.00122	0	58
.6250 -16	.00144	.00083	0	53	.00188	.00109	1	9
.6250 -18	.00140	.00081	0	58	.00180	.00104	1	14
.6250 -24	.00120	.00069	1	6	.00156	.00090	1	26
.6875 -12	.00164	.00095	0	45	.00212	.00122	0	58
.6875 -16	.00144	.00083	0	53	.00188	.00109	1	9
.6875 -24	.00120	.00069	1	6	.00156	.00090	1	26
.7500 -10	.00176	.00102	0	40	.00228	.00132	0	52
.7500 -12	.00164	.00095	0	45	.00216	.00125	0	59
.7500 -16	.00152	.00088	0	56	.00196	.00113	1	12
.7500 -20	.00132	.00076	1	0	.00172	.00099	1	19
.8125 -12	.00168	.00097	0	46	.00216	.00125	0	59
.8125 -16	.00148	.00085	0	54	.00192	.00111	1	10
.8125 -20	.00132	.00076	1	0	.00172	.00099	1	19
.8750 -9	.00188	.00109	0	39	.00244	.00141	0	50
.8750 -12	.00168	.00097	0	46	.00220	.00127	1	0
.8750 -14	.00164	.00095	0	53	.00212	.00122	1	8
.8750 -16	.00148	.00085	0	54	.00192	.00111	1	10
.8750 -20	.00136	.00079	1	2	.00176	.00102	1	21
.9375 -12	.00168	.00097	0	46	.00220	.00127	1	0
.9375 -16	.00148	.00085	0	54	.00192	.00111	1	10
.9375 -20	.00136	.00079	1	2	.00176	.00102	1	21
1.0000 -8	.00204	.00118	0	37	.00264	.00152	0	48
1.0000 -12	.00176	.00102	0	48	.00228	.00132	1	3
1.0000 -16	.00148	.00085	0	54	.00196	.00113	1	12
1.0000 -20	.00136	.00079	1	2	.00176	.00102	1	21
1.0625 -8	.00204	.00118	0	37	.00268	.00155	0	49
1.0625 -12	.00172	.00099	0	47	.00220	.00127	1	0
1.0625 -16	.00152	.00088	0	56	.00196	.00113	1	12
1.0625 -18	.00144	.00083	0	59	.00188	.00109	1	18
1.1250 -7	.00216	.00125	0	35	.00284	.00164	0	46
1.1250 -8	.00208	.00120	0	38	.00268	.00155	0	49
1.1250 -12	.00180	.00104	0	50	.00236	.00136	1	5
1.1250 -16	.00152	.00088	0	56	.00196	.00113	1	12
1.1250 -18	.00144	.00083	0	59	.00188	.00109	1	18
1.1875 -8	.00208	.00120	0	38	.00272	.00157	0	50
1.1875 -12	.00172	.00099	0	47	.00224	.00129	1	2
1.1875 -16	.00152	.00088	0	56	.00196	.00113	1	12

TABLE VIII (Continued)

ALLOWABLE LEAD AND HALF-ANGLE DEVIATIONS

SIZE	EXTERNAL THREAD				INTERNAL THREAD			
	.4PD TOL IN.	EQUIV LEAD IN.	EQUIV ANGLE		.4 PD TOL IN.	EQUIV LEAD IN.	EQUIV ANGLE	
			Deg	Min			Deg	Min
1.1875 -18	.00144	.00083	0	59	.00188	.00109	1	18
1.2500 -7	.00220	.00127	0	35	.00288	.00166	0	46
1.2500 -8	.00212	.00122	0	39	.00276	.00159	0	51
1.2500 -12	.00184	.00106	0	51	.00240	.00139	1	6
1.2500 -16	.00152	.00088	0	56	.00200	.00115	1	13
1.2500 -18	.00144	.00083	0	59	.00188	.00109	1	18
1.3125 -8	.00212	.00122	0	39	.00276	.00159	0	51
1.3125 -12	.00176	.00102	0	48	.00228	.00132	1	3
1.3125 -16	.00152	.00088	0	56	.00200	.00115	1	13
1.3125 -18	.00148	.00085	1	1	.00192	.00111	1	19
1.3750 -6	.00240	.00139	0	33	.00312	.00180	0	43
1.3750 -8	.00216	.00125	0	40	.00280	.00162	0	51
1.3750 -12	.00188	.00109	0	52	.00244	.00141	1	7
1.3750 -16	.00156	.00090	0	57	.00200	.00115	1	13
1.3750 -18	.00148	.00085	1	1	.00192	.00111	1	19
1.4375 -8	.00216	.00125	0	40	.00284	.00164	0	52
1.4375 -12	.00176	.00102	0	48	.00228	.00132	1	3
1.4375 -16	.00156	.00090	0	57	.00204	.00118	1	15
1.4375 -18	.00148	.00085	1	1	.00192	.00111	1	19
1.5000 -6	.00244	.00141	0	34	.00316	.00182	0	43
1.5000 -8	.00220	.00127	0	40	.00284	.00164	0	52
1.5000 -12	.00192	.00111	0	53	.00252	.00145	1	9
1.5000 -16	.00156	.00090	0	57	.00204	.00118	1	15
1.5000 -18	.00148	.00085	1	1	.00192	.00111	1	19
1.5625 -8	.00220	.00127	0	40	.00288	.00166	0	53
1.5625 -12	.00176	.00102	0	48	.00232	.00134	1	4
1.5625 -16	.00156	.00090	0	57	.00204	.00118	1	15
1.5625 -18	.00148	.00085	1	1	.00196	.00113	1	21
1.6250 -8	.00224	.00129	0	41	.00288	.00166	0	53
1.6250 -12	.00176	.00102	0	48	.00232	.00134	1	4
1.6250 -16	.00156	.00090	0	57	.00204	.00118	1	15
1.6250 -18	.00152	.00088	1	3	.00196	.00113	1	21
1.6875 -8	.00224	.00129	0	41	.00292	.00169	0	54
1.6875 -12	.00180	.00104	0	50	.00232	.00134	1	4
1.6875 -16	.00160	.00092	0	59	.00204	.00118	1	15
1.6875 -18	.00152	.00088	1	3	.00196	.00113	1	21
1.7500 -5	.00268	.00155	0	31	.00348	.00201	0	40
1.7500 -8	.00228	.00132	0	42	.00296	.00171	0	54
1.7500 -12	.00180	.00104	0	50	.00232	.00134	1	4
1.7500 -16	.00160	.00092	0	59	.00208	.00120	1	16

TABLE VIII (Continued)

ALLOWABLE LEAD AND HALF-ANGLE DEVIATIONS

SIZE	EXTERNAL THREAD				INTERNAL THREAD			
	.4PD TOL IN.	EQUIV LEAD IN.	EQUIV ANGLE		.4PD TOL IN.	EQUIV LEAD IN.	EQUIV ANGLE	
			Deg	Min			Deg	Min
1.8125 -8	.00228	.00132	0	42	.00296	.00171	0	54
1.8125 -12	.00180	.00104	0	50	.00232	.00134	1	4
1.8125 -16	.00160	.00092	0	59	.00208	.00120	1	16
1.8750 -8	.00228	.00132	0	42	.00300	.00173	0	55
1.8750 -12	.00180	.00104	0	50	.00236	.00136	1	5
1.8750 -16	.00160	.00092	0	59	.00208	.00120	1	16
1.9375 -8	.00232	.00134	0	43	.00300	.00173	0	55
1.9375 -12	.00180	.00104	0	50	.00236	.00136	1	5
1.9375 -16	.00160	.00092	0	59	.00208	.00120	1	16
2.0000-4.5	.00284	.00164	0	29	.00372	.00215	0	38
2.0000 -8	.00232	.00134	0	43	.00304	.00176	0	56
2.0000 -12	.00180	.00104	0	50	.00236	.00136	1	5
2.0000 -16	.00160	.00092	0	59	.00208	.00120	1	16
2.1250 -8	.00236	.00136	0	43	.00308	.00178	0	56
2.1250 -12	.00184	.00106	0	51	.00236	.00136	1	5
2.1250 -16	.00164	.00095	1	0	.00212	.00122	1	18
2.2500-4.5	.00292	.00169	0	30	.00380	.00219	0	39
2.2500 -8	.00240	.00139	0	44	.00312	.00180	0	57
2.2500 -12	.00184	.00106	0	51	.00240	.00139	1	6
2.2500 -16	.00164	.00095	1	0	.00212	.00122	1	18
2.3750 -8	.00240	.00139	0	44	.00316	.00182	0	58
2.3750 -12	.00184	.00106	0	51	.00240	.00139	1	6
2.3750 -16	.00164	.00095	1	0	.00216	.00125	1	19
2.5000 -4	.00312	.00180	0	29	.00404	.00233	0	37
2.5000 -8	.00244	.00141	0	45	.00320	.00185	0	59
2.5000 -12	.00184	.00106	0	51	.00240	.00139	1	6
2.5000 -16	.00164	.00095	1	0	.00216	.00125	1	19
2.6250 -8	.00248	.00143	0	45	.00320	.00185	0	59
2.6250 -12	.00188	.00109	0	52	.00244	.00141	1	7
2.6250 -16	.00168	.00097	1	2	.00216	.00125	1	19
2.7500 -4	.00316	.00182	0	29	.00412	.00238	0	38
2.7500 -8	.00252	.00145	0	46	.00324	.00187	0	59
2.7500 -12	.00188	.00109	0	52	.00244	.00141	1	7
2.7500 -16	.00168	.00097	1	2	.00216	.00125	1	19
2.8750 -8	.00252	.00145	0	46	.00328	.00189	1	0
2.8750 -12	.00188	.00109	0	52	.00244	.00141	1	7
2.8750 -16	.00168	.00097	1	2	.00220	.00127	1	21
3.0000 -4	.00320	.00185	0	29	.00416	.00240	0	38
3.0000 -8	.00256	.00148	0	47	.00332	.00192	1	1
3.0000 -12	.00188	.00109	0	52	.00248	.00143	1	8

TABLE VIII (Continued)

ALLOWABLE LEAD AND HALF-ANGLE DEVIATIONS

SIZE	EXTERNAL THREAD .4PD TOL IN.	EXTERNAL THREAD EQUIV LEAD IN.	EXTERNAL THREAD EQUIV ANGLE Deg	EXTERNAL THREAD EQUIV ANGLE Min	INTERNAL THREAD .4PD TOL IN.	INTERNAL THREAD EQUIV LEAD IN.	INTERNAL THREAD EQUIV ANGLE Deg	INTERNAL THREAD EQUIV ANGLE Min
3.0000 -16	.00168	.00097	1	2	.00220	.00127	1	21
3.1250 -8	.00256	.00148	0	47	.00336	.00194	1	2
3.1250 -12	.00192	.00111	0	53	.00248	.00143	1	8
3.1250 -16	.00172	.00099	1	3	.00220	.00127	1	21
3.2500 -4	.00328	.00189	0	30	.00424	.00245	0	39
3.2500 -8	.00260	.00150	0	48	.00340	.00196	1	2
3.2500 -12	.00192	.00111	0	53	.00248	.00143	1	8
3.2500 -16	.00172	.00099	1	3	.00224	.00129	1	22
3.3750 -8	.00264	.00152	0	48	.00340	.00196	1	2
3.3750 -12	.00192	.00111	0	53	.00252	.00145	1	9
3.3750 -16	.00172	.00099	1	3	.00224	.00129	1	22
3.5000 -4	.00332	.00192	0	30	.00432	.00249	0	40
3.5000 -8	.00264	.00152	0	48	.00344	.00199	1	3
3.5000 -12	.00192	.00111	0	53	.00252	.00145	1	9
3.5000 -16	.00172	.00099	1	3	.00224	.00129	1	22
3.6250 -8	.00268	.00155	0	49	.00348	.00201	1	4
3.6250 -12	.00192	.00111	0	53	.00252	.00145	1	9
3.6250 -16	.00172	.00099	1	3	.00224	.00129	1	22
3.7500 -4	.00336	.00194	0	31	.00436	.00252	0	40
3.7500 -8	.00268	.00155	0	49	.00352	.00203	1	5
3.7500 -12	.00196	.00113	0	54	.00252	.00145	1	9
3.7500 -16	.00176	.00102	1	5	.00228	.00132	1	24
3.8750 -8	.00272	.00157	0	50	.00352	.00203	1	5
3.8750 -12	.00196	.00113	0	54	.00256	.00148	1	10
3.8750 -16	.00176	.00102	1	5	.00228	.00132	1	24
4.0000 -4	.00340	.00196	0	31	.00444	.00256	0	41
4.0000 -8	.00272	.00157	0	50	.00356	.00206	1	5
4.0000 -12	.00196	.00113	0	54	.00256	.00148	1	10
4.0000 -16	.00176	.00102	1	5	.00228	.00132	1	24
4.1250 -8	.00276	.00159	0	51	.00360	.00208	1	6
4.1250 -12	.00196	.00113	0	54	.00256	.00148	1	10
4.1250 -16	.00176	.00102	1	5	.00228	.00132	1	24
4.2500 -8	.00280	.00162	0	51	.00360	.00208	1	6
4.2500 -12	.00196	.00113	0	54	.00256	.00148	1	10
4.2500 -16	.00176	.00102	1	5	.00232	.00134	1	25
4.3750 -8	.00280	.00162	0	51	.00364	.00210	1	7
4.3750 -12	.00200	.00115	0	55	.00256	.00148	1	10
4.3750 -16	.00180	.00104	1	6	.00232	.00134	1	25
4.5000 -8	.00284	.00164	0	52	.00368	.00212	1	7
4.5000 -12	.00200	.00115	0	55	.00260	.00150	1	11

TABLE VIII (Continued)

ALLOWABLE LEAD AND HALF-ANGLE DEVIATIONS

SIZE	EXTERNAL THREAD .4PD TOL IN.	EXTERNAL THREAD EQUIV LEAD IN.	EXTERNAL THREAD EQUIV ANGLE Deg	EXTERNAL THREAD EQUIV ANGLE Min	INTERNAL THREAD .4PD TOL IN.	INTERNAL THREAD EQUIV LEAD IN.	INTERNAL THREAD EQUIV ANGLE Deg	INTERNAL THREAD EQUIV ANGLE Min
4.5000 -16	.00180	.00104	1	6	.00232	.00134	1	25
4.6250 -8	.00284	.00164	0	52	.00368	.00212	1	7
4.6250 -12	.00200	.00115	0	55	.00260	.00150	1	11
4.6250 -16	.00180	.00104	1	6	.00232	.00134	1	25
4.7500 -8	.00288	.00166	0	53	.00372	.00215	1	8
4.7500 -12	.00200	.00115	0	55	.00260	.00150	1	11
4.7500 -16	.00180	.00104	1	6	.00236	.00136	1	27
4.8750 -8	.00288	.00166	0	53	.00376	.00217	1	9
4.8750 -12	.00200	.00115	0	55	.00260	.00150	1	11
4.8750 -16	.00180	.00104	1	6	.00236	.00136	1	27
5.0000 -8	.00292	.00169	0	54	.00376	.00217	1	9
5.0000 -12	.00200	.00115	0	55	.00264	.00152	1	13
5.0000 -16	.00180	.00104	1	6	.00236	.00136	1	27
5.1250 -8	.00292	.00169	0	54	.00380	.00219	1	10
5.1250 -12	.00204	.00118	0	56	.00264	.00152	1	13
5.1250 -16	.00184	.00106	1	7	.00236	.00136	1	27
5.2500 -8	.00292	.00169	0	54	.00380	.00219	1	10
5.2500 -12	.00204	.00118	0	56	.00264	.00152	1	13
5.2500 -16	.00184	.00106	1	7	.00236	.00136	1	27
5.3750 -8	.00296	.00171	0	54	.00384	.00222	1	10
5.3750 -12	.00204	.00118	0	56	.00264	.00152	1	13
5.3750 -16	.00184	.00106	1	7	.00240	.00139	1	28
5.5000 -8	.00296	.00171	0	54	.00388	.00224	1	11
5.5000 -12	.00204	.00118	0	56	.00264	.00152	1	13
5.5000 -16	.00184	.00106	1	7	.00240	.00139	1	28
5.6250 -8	.00300	.00173	0	55	.00388	.00224	1	11
5.6250 -12	.00204	.00118	0	56	.00268	.00155	1	14
5.6250 -16	.00184	.00106	1	7	.00240	.00139	1	28
5.7500 -8	.00300	.00173	0	55	.00392	.00226	1	12
5.7500 -12	.00204	.00118	0	56	.00268	.00155	1	14
5.7500 -16	.00184	.00106	1	7	.00240	.00139	1	28
5.8750 -8	.00304	.00176	0	56	.00392	.00226	1	12
5.8750 -12	.00208	.00120	0	57	.00268	.00155	1	14
5.8750 -16	.00184	.00106	1	7	.00240	.00139	1	28
6.0000 -8	.00304	.00176	0	56	.00396	.00229	1	13
6.0000 -12	.00208	.00120	0	57	.00268	.00155	1	14
6.0000 -16	.00188	.00109	1	8	.00244	.00141	1	29

MIL-F-18240D
25 February 1972
Superseding
MIL-F-18240C(ASG)
17 November 1967

MILITARY SPECIFICATION

FASTENER, EXTERNALLY THREADED, 250°F SELF-LOCKING ELEMENT FOR

This specification is mandatory for use by all Departments and Agencies of the Department of Defense

1. SCOPE

1.1 This specification covers the self-locking element to be used in externally threaded fasteners, such as bolts and screws, to be used in applications where the temperatures will not exceed 250°F.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Military

MIL-H-3982	Hardware (Fasteners and Related Items) Packaging and Packing for Shipment and Storage of

STANDARDS

Military

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes

FSC 5305
FSC 5306

STANDARDS

Military (Cont'd)

MIL-STD-1312	Fastener, Test Methods
MS15891	Fasteners, Threaded Externally, Self-Locking, Aerospace Vehicles and Equipment Design and Usage Limitations for
MS26531	Vibration Test Rig
AN3 thru 20	Bolt, Machine, Aircraft
AN315	Nut, Plain, Airframe
AN121501 thru AN121525	Nut - Plain

(When requesting applicable documents, refer to both title and number. Copies of unclassified documents may be obtained from the Commanding Officer, Naval Publications and Forms Center, 5861 Tabor Avenue, Philadelphia, Pennsylvania 19120. Requests for copies of classified documents should be addressed to the Naval Publications and Forms Center, via the cognizant Government representative.)

2.2 Other publications - The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

National Aerospace Standards Committee

NAS 600 thru 602	Screw, Machine, Aircraft, Pan Head, Phillips Recess, Full Threaded, Alloy Steel

NAS 1316	Bolt, Hex Head, Close Tolerance, 160,000 PSI Tensile

(C[illegible] of NAS publications may be obtained from National Standards Association, 1321 14th Street, N.W., Washington, D.C. 20005.)

3. REQUIREMENTS

3.1 Qualification - The self-locking elements incorporated in fasteners furnished under this specification shall be an element design which has been subjected to and which has passed the qualification tests specified herein, and which has been listed on or approved for listing on the applicable Qualified Products Lists.

* In addition, the retention of qualified products list shall be dependent on a periodic verification of continued compliance with the requirements of this specification (see 4.4.3.1).

3.2 Performance - The performance characteristics and dimensions of the bolts and screws, with the self-locking elements incorporated therein, shall conform to the requirements of the applicable drawings, the supplementary specifications, and the additional requirements specified in this specification. (For definition of "supplementary specifications," see 6.5.1.)

3.3 Torque - The bolt or screw, with the self-locking element incorporated therein, shall withstand the torque test specified in 4.6.3.

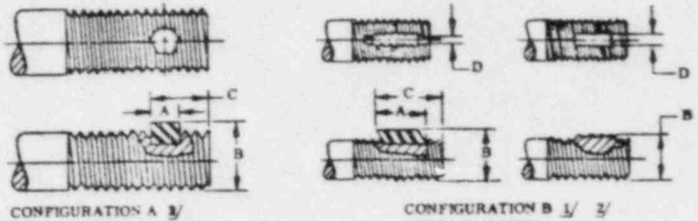
3.4 Vibration - The bolt or screw, with the self-locking element incorporated therein, shall withstand the vibration test specified in 4.6.7.

3.5 Dimensions - The self-locking element shall be within the dimensional limitations of MS15981 and if the element design is to be of a configuration illustrated by figure 1, it shall be dimensionally in accordance with figure 1.

3.6 Workmanship - Workmanship shall be consistent with high-grade commercial practice.

4. QUALITY ASSURANCE PROVISIONS

4.1 General - The sampling, inspection, and test procedures of this specification and the applicable supplementary bolt or screw specifications shall apply.



CONFIGURATION A 3/
SLUG - ROUND OR HEX

CONFIGURATION B 1/ 3/
STRIP OR PATCH

GOVERNMENT DESIGNATION 5/	NOMINAL THREAD SIZE 4/	CONFIGURATION	A		B		C		D	PREVIOUS 3/ GOVERNMENT DESIGNATION
			MAX	MIN	MAX	MIN	MAX	MIN	MIN	
04	4	A B	.106 .250	.053 .099	.115	.105	.161 .285	.121 .195	.025	1, 35, 51 2, 40, 22
06	6	A B	.106 .281	.066 .125	.141	.131	.184 .359	.144 .222	.030	3, 53, 36 4, 41, 23
08	8	A B	.124 .344	.084 .125	.167	.157	.192 .406	.152 .234	.030	5, 6, 52, 34 7, 42, 24
10	10	A B	.124 .344	.084 .125	.193	.183	.208 .406	.150 .234	.030	8, 47, 37 9, 43, 25
40	1/4	A B	.144 .375	.089 .142	.253	.243	.231 .437	.191 .267	.025	10, 38, 39 11, 44, 26
50	5/16	A B	.188 .437	.130 .166	.315	.305	.278 .500	.222 .312	.025	12, 13, 54, 50 14, 45, 27
60	3/8	A B	.188 .500	.168 .166	.378	.368	.284 .563	.230 .312	.035	15, 16, 17, 48 55, 31, 28
70	7/16	A B	.166 .562	.146 .200	.440	.430	.301 .637	.261 .375	.035	18, 19 32, 46, 29
80	1/2	A B 1/	.166 .609	.146 .200	.503	.493	.301 .684	.261 .375	.035	20, 21, 49 33, 30

1/ 1/2 INCH SIZE MAY HAVE TWO LOCKING ELEMENTS 90° APART.
2/ CONFIGURATION OF LOCKING ELEMENT OPTIONAL IF WITHIN DIMENSIONAL LIMITS "A" AND "B"
3/ GOVERNMENT DESIGNATION OF REV. B (5 DEC. 1961) AND AMENDMENT -1 (2 NOV. 1965).
4/ SEE 6.4.1.
5/ SEE 6.4.1.1 AND 6.4.1.2.

FIGURE 1. Elements, self-locking 250°F

4.2 Responsibility for inspection - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any other commercial laboratory acceptable to the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.3 Classification of inspection - The examination and testing of the bolts and screws, incorporating the self-locking element, shall be classified as follows:

(a) Qualification inspection (4.4)
(b) Quality conformance inspection (4.5)

4.4 Qualification inspection

4.4.1 Sampling instructions - The qualification inspection samples shall consist of 60 bolts or screws, as applicable, with the self-locking element incorporated therein, as specified in table I, for each diameter upon which qualification is desired. All nuts necessary for inspections specified herein shall be furnished by the manufacturer. These nuts shall conform to table II. Samples shall be identified as required and forwarded to the activity designated in the letter of authorization from the activity responsible for qualification (see 6.4).

4.4.2 Qualification inspection by the Government will be limited to the bolts or screws shown in table I. Qualification inspection will be authorized only upon presentation of certified test reports to the activity responsible for qualification indicating that the bolts or screws of the diameters to be tested have met or will meet, the requirements of this specification. These test reports shall include actual results of all tests specified by this specification. When these test reports are submitted, a drawing shall be submitted which shows the location, size, material, method of attachment, and protrusion of the self-locking element for each diameter upon which qualification is desired. A manufacturer's designation shall be submitted for the locking element to be used in each diameter of bolt or screw.

Table I. Length and diameter of bolts and screws required for qualification inspection

Basic part No.	Length dash No.	Basic part No.	Length dash No.
NAS 600	12P	AN8	20
NAS 601	12P	AN9	21
NAS 602	12P	AN10	21
AN3	15	AN12	22
AN4	16	AN14	23
AN5	16	NAS 1316	22W
AN6	17	AN18	25
AN7	17	AN20	27

Table II. Dimensions of nuts required for tests (inches)

Thread size	Maximum across flats	Nut thickness ±.010	90-degree csink dia. ±.010
No. 4-40 UNC-3B	0.250	0.203	0.132
No. 6-32 UNC-3B	.312	.250	.168
No. 8-32 UNC-3B	.344	.250	.194
No. 10-32 UNF-3B	.375	.250	.220
1/4 -28 UNF-3B	.437	.281	.281
5/16-24 UNF-3B	.500	.328	.344
3/8 -24 UNF-3B	.562	.328	.406
7/16-20 UNF-3B	.688	.375	.468
1/2 -20 UNF-3B	.750	.375	.531
9/16-18 UNF-3B	.875	.422	.593
5/8 -18 UNF-3B	.937	.468	.656
3/4 -16 UNF-3B	1.062	.625	.781
7/8 -14 UNF-3B	1.250	.656	.906
1 -12 UNF-3B	1.437	.750	1.031
1-1/8 -12 UNF-3B	1.625	.812	1.156
1-1/4 -12 UNF-3B	1.812	.875	1.281

NOTE: For thread size 9/16 and larger, nuts shown on AN315 may be used except for the countersink, which is to be altered to 90 degrees by 0.030 inch over OD of threads. For thread sizes 3/8 through 1, nuts shown on AN121501 through AN121525 may be used.

Material: Steel, cadmium-plated; corrosion-resistant steel, passivated; as required. (See 4.6.3 and 4.6.7.)

4.4.3 **Inspection** - The qualification inspection of the bolts and screws, with the self-locking element incorporated therein, shall consist of all the inspections of this specification.

4.4.3.1 **Retention** - The retention of qualification shall consist of periodic verification to determine compliance of the qualification requirements of the specification. The time and method of periodic verification shall be specified by the activity responsible for the qualified Products List and shall be included in the Notice of Qualification letter.

4.5 **Quality conformance inspection** - The bolt or screw manufacturer shall be responsible for accomplishing the quality conformance inspection specified herein and the quality conformance inspections required under the supplementary bolt or screw specifications. The procuring activity may, at its discretion accept certification of inspections required under the supplementary bolt or screw specifications when the basic bolts or screws are manufactured at a separate facility. When milling or slotting operation is used for insertion of locking element into non-corrosive resistant bolts or screws the complete assembly shall pass the salt spray test as required by the applicable bolt, screw or plating specification.

4.5.1 **Sampling** - For the inspections specified herein, the sample bolts or screws shall be selected at random from each lot as specified below.

4.5.1.1 **Random sample** - A random sample is a specific number of items so selected that each item of the lot from which the sample is drawn has the same chance of being the first item in the sample; after the first item in the sample is drawn, each of the remaining items has the same chance of being the second item in the sample, and so on.

4.5.1.2 **Lot** - A lot shall consist of finished bolts or screws with self-locking elements incorporated which are of the same diameter and length, fabricated by the same process, heat treated in the same manner, and produced as one continuous run or order or part thereof.

4.5.1.3 **For examination of product** - Sample sizes for examination of product shall be in accordance with Inspection Level I of MIL-STD-105. The acceptance and rejection criteria shall be applied for the following Acceptable Quality Levels (AQL's) applying to the corresponding class of characteristics:

Major 2.5 percent
Minor A - 4.0 percent
Minor B - 6.5 percent

4.5.1.3.1 **Classification of defects** - All dimensional characteristics are considered defective when out of tolerance. The classification of defects for self-locking bolts and screws shall be as follows:

Major

101 Locking element missing (see applicable standard).

Minor A

201 Locking element location (see applicable standard).
202 Measurement over locking element (see applicable standard).
203 Burrs and slivers (see applicable standard).

Minor B

301 Identification of product (see applicable standard).

4.5.1.4 **For maximum torque, minimum breakaway torque, and reusability** - Sampling for these tests shall be in accordance with the attribute plan shown in table III. The same sample may be used throughout for these tests. The acceptance and rejection numbers shall apply to these tests taken separately, i.e., a bolt or screw may be classified as defective for maximum torque, minimum breakaway torque, or reusability.

Table III. Attribute Plan

Lot size	Sample size	Acceptance number
Under 10,000	5	0
10,000 through 50,000	10	0
50,001 through 100,000	15	0
Over 100,000	27	1

4.5.2 **Inspections** - The quality conformance inspections of self-locking bolts and screws shall consist of the quality conformance inspections of the applicable supplementary bolt or screw specifications and the following inspections:

Tensile strength	(see 4.6.1.1)
Examination of product	(see 4.6.2)
Maximum torque	(see 4.6.3.1)
Minimum breakaway torque	(see 4.6.3.2)
Reusability	(see 4.6.6)

Also, self-locking bolts and screws shall meet any of the other tests herein specified which are considered necessary by the procuring activity to determine conformance with the requirements of this specification.

4.6 Inspection methods -

4.6.1 General - The bolts or screws shall be tested as specified in the applicable supplementary bolt or screw specification, except as specified in 4.6.1.1.

4.6.1.1 Tensile strength - The tensile test shall be conducted as specified in the applicable supplementary bolt or screw specifications with the added provision that when the tensile test is conducted, the nut shall meet the dimensions of table II and shall engage the threads of bolts and screws that have grip portions, to within one to two thread pitches of the thread runout. Bolts and screws that do not have grip portions shall be engaged by the nut until the bolt or screw protrudes from the top of the nut a distance of two thread pitches, including chamfer, if any. The nuts shall be of such strength as to fail the bolts or screws.

4.6.2 Examination of product - The bolts or screws shall be examined for conformance to the applicable standard, relative to:

Presence of locking element
Location of locking element
Measurement over locking element
Presence of burrs and slivers
Identification of product

4.6.3 Torque - The nuts used for this test shall be as specified in table II and shall assemble freely on the bolt or screw up to the self-locking device. Carbon-steel nuts shall be used with carbon-steel and alloy-steel bolts or screws. Corrosion-resistant steel nuts shall be used with corrosion-resistant steel bolts or screws. Each nut shall be screwed on and off the bolt or screw a total of 15 consecutive installations and removals. Each installation shall consist of either turning the nut until its bearing surface has traveled completely along the thread length of the effective area of the specific element design or at least five complete turns of the nut after the threads of the nut have initially engaged the locking device, whichever provides the greater number of turns. For quality conformance inspection on bolts or screws without sufficient thread length for X min. of MS15981, only a positive indication of torque is required for 15 installations and removals. Each removal shall consist of the same number of complete turns, in the opposite direction, as was required for installation. The torque test shall be run at a rate slow enough to yield a dependable measure of torque, and the temperature rise of the nut being tested shall not exceed 75°F. A new nut and bolt or screw shall be used for each test. For qualification, 10 of the sample bolts or screws supplied shall be used for this test.

4.6.3.1 Maximum torque - Maximum torque shall be the maximum value indicated by the torque device during the 15 installations and removals. This torque value shall not exceed the applicable value shown in table IV.

4.6.3.2 Minimum breakaway torque - Minimum breakaway torque shall be the minimum torque required to start removal of the nut from the installed position. It shall be determined at the start of the first and fifteenth removals. This value shall be not less than the applicable value shown in table IV.

4.6.4 Torque (with heat-conditioned bolts or screws) - The nuts used for this test shall be as specified in table II. The nuts shall be screwed on the bolts or screws until the bearing surface of the nut has traveled completely along the thread length of the effective area of the specific element design or at least 5 complete turns after the threads of the nuts have initially engaged the locking element, whichever provides the greater number of turns. Ten new bolts or screws shall be subjected to this test. These assemblies shall be conditioned at a temperature of 250° ± 10° F for 3 hours. The assemblies shall then be cooled in air to room temperature for not less than 1 hour. The assemblies shall then be tested as specified in 4.6.3. Maximum locking torque readings shall be taken each installation and removal of the nut.

4.6.4.1 Maximum torque - Maximum torque shall be the maximum value indicated by the torque device during the installation and removal. This value shall not exceed 150 percent of the applicable value shown in table IV.

4.6.4.2 Minimum breakaway torque - Minimum breakaway torque shall be the minimum torque required to start removal of the nut from the installed position. It shall be determined at the start of the first removal. This torque value shall be not less than the applicable value shown in table IV.

TABLE IV. Torque
(At room temperature in inch-pounds)

Bolt or screw size	Maximum torque (installation or removal)	Minimum breakaway torque
No. 4-40 UNC-3A	3	0.5
No. 6-32 UNC-3A	6	1.0
No. 8-32 UNC-3A	9	1.5
No. 10-32 UNF-3A	13	2.0
1/4 -28 UNF-3A	30	3.5
5/16 -24 UNF-3A	60	6.5
3/8 -24 UNF-3A	80	9.5
7/16 -20 UNF-3A	100	14.0
1/2 -20 UNF-3A	150	18.0
9/16 -18 UNF-3A	200	24.0
5/8 -18 UNF-3A	300	32.0
3/4 -16 UNF-3A	400	50.0
7/8 -14 UNF-3A	600	70.0
1 -12 UNF-3A	800	92.0
1-1/8 -12 UNF-3A	900	117.0
1-1/4 -12 UNF-3A	1,000	143.0

4.6.5 Minimum breakaway torque at 250°F temperature - Using the same assemblies tested in accordance with 4.6.4, minimum breakaway torque shall be determined on the first removal cycle at temperature while the bolt or screw engagement with the nut is made according to 4.6.3, and after the fastener assembly has been preheated 1 hour at 250° ± 10°F and held at this temperature during the test. This torque value shall be not less than the applicable requirement of table IV.

4.6.6 Reusability - The threads of the bolts or screws and nuts used in the torque tests shall show no distortion or scratches deep enough to reduce the efficiency of the threads. The threads of the bolts or screws and nuts shall remain in a serviceable condition and shall freely permit the installation with the fingers, of a new bolt or screw or nut, as applicable, up to the self-locking device.

* 4.6.7 Vibration - Sample nuts with bolts of the size and quantities specified in Table V shall be vibrated in accordance with MS26531 or MIL-STD-1312, Test 7. An average vibration life, for each lot of eight specimens tested to MS26531, of less than specified in Table V shall be cause for rejection. Vibration life, for each lot of five specimens tested to MIL-STD-1312 Test 7 of less than 30,000 cycles shall be cause for rejection. The vibration test may be waived at the option of the activity responsible for qualification for bolts larger than the 1/2-inch thread size, provided the bolt of 1/2-inch thread size with the same type and design of locking element has satisfactorily passed the vibration test. The vibration test is not required for elements for screw-thread sizes below 10-32.

* 4.6.7.1 Preparation for vibration test to MS26531

* 4.6.7.1.1 Method - The nuts shall be screwed on the bolts or screws that pass through the drilled holes in the arbor and sleeve of the test rig, as shown on sheet 5 of MS26531. The nuts shall not be tightened against the sleeve but shall be screwed on until the end of the bolt or screw extends through the nut a minimum length of two thread pitches and a maximum length of three thread pitches. The bolts or screws shall be free to rotate in the arbor and sleeve. The locking element of the bolt or screw shall be the only factor which restrains the nut from turning on the bolt or screw. The thrust load on the test arbor, including the weight of the electrical power unit, shall be 65 pounds. Reference lines shall be scribed, or other suitable markings shall be made, on both the nuts and the bolts or screws for the purpose of determining whether or not the nut turns on the bolt or screw during the vibration test.

* 4.6.7.1.2 The tests shall be conducted in periods of running and periods of rest to permit the electrical power unit to cool. A fan or blower shall be set to direct a current of air on the test rig, in order that 20-minute runs with 10-minute rest intervals shall not develop temperatures greater than 105°F in the test specimen.

(a) The fan or blower shall be turned off after each 20-minute running period is complete, and shall remain off until the temperature readings are taken.

(b) A rotation of greater than 30 degrees for a nut shall be considered a failure of that element, and the end of the run period in which the element failed shall be recorded as its vibration life.

5.3 Marking - In addition to any special marking required by the contract or order. the unit packages and shipping containers shall be marked in accordance with MIL-H-3982.

6. NOTES

6.1 Intended use - The self-locking elements covered by this specification are intended to be incorporated in external screw threads to provide resistance to turning due to vibration. These elements are to be used in applications where maximum temperature does not exceed 250° F. When these elements are incorporated in external threads and are used in compliance with MS15981. all the configurations of figure 1 are interchangeable. It is intended that in specifying elements in conformance with this specification the locking element shall be specified in accordance with MS15981 (i.e., a configuration should not be specified). A configuration should be specified only for nonstandard parts where. because of part design or application requirements. only one configuration can be used.

6.2 Ordering data - Procurement documents should specify:

- (a) Title, number, and date of this specification.
- (b) Part number in accordance with the applicable standard (see 3.5).
- (c) Applicable level of preservation, packaging, and packing (see 5.1 and 5.2).

6.3 Use of standard and nonstandard self-locking externally threaded fasteners. - For definition of these terms, see 6.5.2 and 6.5.3)

6.3.1 Standard self-locking externally threaded fasteners.- The release for use of standard self-locking externally threaded fasteners is governed by the requirements of the weapon system or equipment general or detail specification.

6.3.2 Nonstandard self-locking externally threaded fasteners - Self-locking externally threaded fasteners, formed by incorporation of self-locking elements listed on QPL-18240 with fasteners that are in accordance with specifications and standards approved by the weapon system or equipment specification and, as assemblies, are in accordance with the acceptance tests and requirements of this specification, will be considered to have been released by the procuring activity for use for specific applications at the time the procuring activity has received notice of the specific applications and complete descriptions of the items being specified. This release for use does not constitute waiver of the other applicable requirements of the weapon system or equipment specification. The use of other nonstandard self-locking externally threaded fasteners will require prior release for use.

6.4 Qualification - With respect to products incorporating element designs requiring qualification, awards will be made only for such products incorporating elements, the design of which, prior to the time set for opening of bids, has been tested and approved for inclusion in the applicable Qualified Products List, whether or not such element designs have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the locking element designs that they propose to incorporate in bolts or screws to be offered to the Federal Government tested for qualification, in order that they may be eligible to be awarded contracts or orders for products incorporating element designs covered by this specification. The activity responsible for the Qualified Products List is the Naval Air Systems Command, Attn: AIR-52021, Washington, D. C. 20360. However, information pertaining to qualification of products may be obtained form the Naval Air Development Center, Aero Materials Department (MAEM), Johnsville, Warminster, Pennsylvania 18974.

6.4.1 Qualification approval for locking element designs are based on testing and evaluation of element designs incorporated in 3A coarse threads for sizes smaller than No. 10 and on 3A fine threads for size No. 10 and larger. Element designs listed in figure 1 are approved for incorporation in 2A or 3A fine threads for sizes smaller than No. 10 and in 2A and 3A coarse threads for sizes No. 10 and larger if the requirements for quality conformance inspection (4.5) are met and are within the dimensional limitations of MS15981.

6.4.1.1 Qualification inspection and evaluation of configuration "A" (see figure 1) locking element designs were based on the protrusion of the element being in accordance with figure 1, dimension "B". Configuration "A" designs with protrusion of "B +0.007", and that are otherwise the same as those listed, also have qualification approval.

6.4.1.2 To identify the additional element design with the greater protrusion the additional +0.007 protrusion must be specified on the standard or drawing for the part; for nonstandard parts that require a specific configuration add a "P" to the Government designation.

Example: Locking element MIL-F-18240 Government designation of 40P, 1/4 thread with configuration "A" 0.010-inch protrusion, self-locking element.

It should be noted that fasteners with 0.003-inch and 0.010-inch protrusion elements are not universally interchangeable. A fastener with 0.003-inch protrusion can be substituted for a fastener with 0.010-inch protrusion, if all other interchangeable factors are substantive.

* 6.4.2 For qualification, vibration requirements as specified in MIL-F-18240 prior to Revision D can be used until 31 December 1973.

6.5 Definitions -

6.5.1 Supplementary specification(s) - In this specification "Supplementary specification(s)" refers to the bolt or screw specification(s) that contain the requirements for the bolt or screw, with the exception of the requirements for the locking element, which are covered by this specification. These supplementary specifications, as well as this specification, are to be listed as the procurement specifications on the self-locking bolt or screw drawings.

6.5.2 Standard self-locking externally threaded fastener(s) - In this specification a "standard self-locking externally threaded fastener" refers to bolts or screws that incorporate self-locking elements conforming to this specification, and locking elements specified in accordance with MS15981, and are completely described as assemblies by specifications and standards released for weapon design and construction by weapon system equipment specifications.

6.5.3 Nonstandard self-locking externally threaded fastener(s) - In this specification a "nonstandard self-locking externally threaded fastener" refers to all bolts and screws incorporated with self-locking elements, except standard self-locking externally threaded fasteners.

6.6 Marginal indicia - The margins of this specification are marked to indicate where changes, deletions, or additions to the previous issue have been made. This is done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations. Bidders and contractors are cautioned to evaluate the requirements of this document based on the entire content as written, irrespective of the marginal notations and relationship to the last previous issue.

* Custodians:
Navy - AS
Air Force - 11
Army - AV
Reviewer activities:
Navy - AS
Air Force - 11, 82
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MILITARY SPECIFICATION

NUT, SELF-LOCKING, 250° F, 450° F, AND 800° F, 125 KSI FTU, 60 KSI FTU, AND 30 KSI FTU

This specification is mandatory for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 This specification covers self-locking nuts (see 6.4) and self-locking plate nuts for use where temperatures will not exceed 250° F, 450° F, and 800° F, and will develop the ultimate tensile strength of 125, 60, and 30 ksi (1,000 pounds per square inch) F_{tu} (ultimate tensile stress) bolts, as applicable.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effebt on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Federal

QQ-P-416	Plating, Cadmium (Electrodeposited)
TT-E-751	Ethyl Acetate, Technical
TT-I-735	Isopropyl Alcohol
TT-M-261	Methyl-Ethyl-Ketone (for Use in Organic Coatings)
TT-N-97	Naphtha, Aromatic
GGG-W-636	Wrenches (Box, Open End, and Combination)

Military

MIL-H-3982	Hardware (Fasteners and Related Items) Packaging and Packing for Shipment and Storage of
MIL-S-5002	Surface Treatments and Metallic Coatings for Metal Surfaces of Weapons Systems
MIL-C-5541	Chemical Films and Chemical Film Materials for Aluminum and Aluminum Alloys
MIL-B-6812	Bolts, Aircraft
MIL-I-6866	Inspection, Penetrant Method of
MIL-I-6868	Inspection Process, Magnetic Particle
MIL-F-7179	Finishes and Coatings: General Specification for Protection of Aircraft and Aircraft Parts

FSC 5310

MIL-S-7502	Sealing Compound, Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion, Accelerator Required
MIL-S-7742	Screw Threads, Standard, Optimum Selected Series: General Specification for
MIL-A-8625	Anodic Coatings, for Aluminum and Aluminum Alloys
MIL-S-8802	Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High-Adhesion
MIL-S-8879	Screw Threads, Controlled Radius Root with Increased Minor Diameter, General Specification for
MIL-I-17214	Indicator, Permeability, Low-Mu (Go-No-Go)

STANDARDS

Federal

FED. TEST METHOD STD. NO. 151 Metals: Test Methods

Military

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-410	Qualification of Inspection Personnel (Magnetic Particle and Penetrant)
MIL-STD-753	Corrosion-Resistant Steel Parts: Sampling, Inspection and Testing for Surface Passivation
MIL-STD-1312	Fasteners, Test Methods
MS26531	Vibration Test Rig
AN3 thru AN20	Bolt - Machine, Aircraft
AN503	Screw - Machine, Drilled Fillister Head, Coarse Thread
AN960	Washer, Flat

(Copies of specifications, standards, drawings, and publications required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. - The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal, shall apply.

United States of America Standards Institute

USA B46.1-1962 Surface Texture (Surface Roughness, Waviness and Lay)

(Application for copies should be addressed to the United States of America Standards Institute, 10 East 40th Street, New York, New York 10016.)

Society of Automotive Engineers

AMS2410 Silver Plating, Nickel Strike - High Bake

(Copies of SAE publications may be obtained from the Society of Automotive Engineers, Inc., Two Pennsylvania Plaza, New York, New York 10001.)

National Aerospace Standard

NAS220-21 Screws - Brazier Head, Phillips Recess

(Application for copies of NAS publications should be addressed to the Aerospace Industries, Association of America, Inc., 1725 DeSales Street N.W., Washington, D.C. 20036.)

3. REQUIREMENTS

3.1 Qualification. - The nuts furnished under this specification shall be products which are qualified for listing on the applicable Qualified Products List at the time set for opening of bids (see 4.3 and 6.3).

3.2 Materials. -

3.2.1 250° F nuts. - The threaded and load-carrying elements of the 250° F nuts shall be fabricated from noncorrosion-resistant steel, corrosion-resistant steel, aluminum alloy, or copper-base alloy in accordance with the coding on the applicable MS or other approved standard. Aluminum alloy may be used which will conform to the specification requirements. When using noncorrosion-resistant steel, neither the sulfur nor phosphorus content shall exceed 0.050 percent by weight for thread sizes No. 8 and above when the nut is heat treated to Rockwell C36 or greater.

3.2.2 450° F nuts. - The threaded and load-carrying elements of the 450° nuts shall be fabricated from noncorrosion-resistant steel or corrosion-resistant steel. The sulfur content or the phosphorus content of noncorrosion-resistant steel shall not exceed 0.050 percent by weight for thread sizes No. 8 and above when the nut is heat treated to Rockwell C36 or greater.

3.2.3 800° F nuts. - The 800° F nuts shall be fabricated from corrosion-resistant steel.

3.3 Design. - Nut design shall conform to that shown on the applicable standard.

3.4 Construction. - The lock nut shall be a self-contained unit, including the self-locking device. The locking device shall not operate by means of separate movement from the installation and shall not depend upon pressure on the bearing surface for locking action.

3.4.1 Bearing surface. - The bearing surface shall be normal to the axis of the pitch diameter of the threads within the values shown on figure 1. The surface roughness of the bearing surface shall not exceed 125 mircoinches in accordance with USA B46.1-1962.

3.4.2 Threads. - The threads shall be as specified on the applicable standard. Threads used on the locking device may be displaced or deformed in any manner which provides self-locking nuts conforming to this specification. The nut, without lubricant, shall allow the "go" gage to enter a minimum of one-half turn before engagement of the locking element. When the application of a lubricant prevents the use of standard gages, the nuts shall permit a minimum free rotational bolt thread engagement of three-fourths turn before engagement of the locking element.

3.4.3 Plate nut rivet-bolt hole spacing. - Plate nut rivet-bolt hole spacing shall be in accordance with the applicable standard.

3.5 Plating or surface treatment. -

3.5.1 Noncorrosion-resistant steel. - Nuts fabricated from noncorrosion-resistant steel shall be cadmium plated in accordance with the applicable standard.

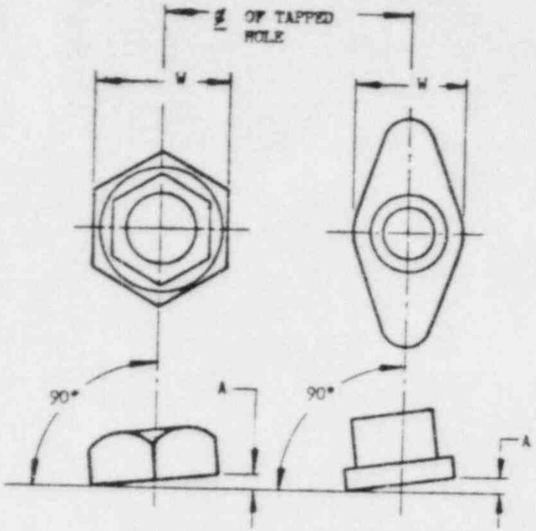
3.5.2 800° F corrosion-resistant steel nuts. - The threads of 800° F corrosion-resistant steel nuts shall be silver plated in accordance with AMS2410. Application of such finish to the exterior surface of nut or nut retaining cage may be omitted. No plating finish shall be applied in the area of the projection weld nibs of projection weld plate nuts.

3.5.2.1 250° F and 450° F corrosion-resistant steel nuts. - The 250° F and 450° F corrosion-resistant steel nuts shall be cleaned in accordance with the cleaning surface requirements of MIL-S-5002 and tested in accordance with 4.5.1.3.

3.5.3 Copper-base alloy. - Nuts fabricated from copper-base alloy shall be cadmium plated in accordance with the applicable standard.

3.5.3.1 Marking of copper-base alloy nuts. - Copper-base alloy nuts shall be provided with a means of identification. This designation shall be specified on the applicable standard.

3.5.4 Aluminum alloy. - Nuts fabricated from aluminum alloy shall be anodized in accordance with MIL-A-8625 or chemically surface treated in accordance with MIL-C-5541. No protective finish need be applied to clad aluminum-plate nut retainers or gang channels. For identification purposes, the threaded element of the high-strength aluminum-alloy nuts, through 1/4-28 size of the regular type and through No. 10 size of the shear type, shall be dyed blue. In case the threaded elements of these nuts are not exposed, the exposed portion of the nuts shall be dyed blue.



W WIDTH OR BASE RING BEARING SURFACE DIAMETER (TO NEAREST 1/16 INCH)	A MAXIMUM (INCH)
LESS THAN 3/16	0.004
3/16, 1/4	.005
5/16, 3/8	.006
7/16, 1/2	.007
9/16, 5/8	.008
11/16, 3/4	.009
13/16, 7/8	.010
15/16, 1	.011
1-1/16, 1-1/8	.012
1-3/16, 1-1/4	.013
1-5/16, 1-3/8	.014
1-7/16, 1-1/2	.015
1-9/16, 1-5/8	.016
1-11/16, 1-3/4	.017
1-13/16	.018

FIGURE 1. Dimensions for measuring relationship of bearing surface with respect to the axis of the pitch diameter of the thread.

3.6 Lubrication. - The nut may be provided with coating which will prevent nut-bolt seizure, provided the coating has passed the applicable tests of 4.5.8. The Qualified Products List shall identify the lubricant and shall classify it as either dry film or soluble film. The lubricant shall not be changed without requalification of the nut.

3.6.1 Dry film lubricant (lubricant that is not removed by test 4.5.8.6). - Dry film lubricant shall pass the tests specified in 4.5.8.1, 4.5.8.2, 4.5.8.3, 4.5.8.4, and 4.5.8.5. The test specified in 4.5.8.6 shall be used for determining if the lubricant is a dry film type.

3.6.2 Soluble lubricant (lubricant that is removed by test 4.5.8.6). - Soluble lubricants shall pass the test specified in 4.5.8.1, 4.5.8.2, 4.5.8.5, and 4.5.8.6

3.7 Axial tensile strength. - Unless otherwise specified, the nuts shall have a minimum axial tensile strength as specified in table I when tested as specified in 4.5.2.

3.8 Torque. -

3.8.1 Wrench torque. - Hexagon steel nuts shall withstand the wrench torques specified in table II when tested as specified in 4.5.3.1, without any permanent deformation which may interfere with the use of a box or open end wrench conforming to GGG-W-636. Wrench torques for aluminum-alloy nuts shall be a percentage of the values of table II equal to the ratio of their axial tensile strengths, as specified in table I, to that of steel nuts. Values for copper-alloy nuts shall be 50 percent of the values specified in table II.

3.8.2 Locking torque. - Locking torque tests shall be performed in accordance with the applicable paragraphs of section 4 covering locking torque.

3.8.2.1 Permanent set. - The nuts shall not exceed the maximum locking torque nor be less than the minimum breakaway torque specified in table III when tested as specified in 4.5.3.2.1.

3.8.2.2 Durability. - New nuts and bolts or screws, as applicable, shall be used for each of the tests 1, 2, 4, and 6 specified in table IV, and new bolts or screws, as applicable, shall be used for each of the tests 3, 5, and 7, specified in table IV when these tests are required.

3.8.2.2.1 Maximum locking torque. - The torque for any installation or removal shall not exceed the percentages for each tests as listed in table IV for allowable maximum torque when tested as specified in 4.5.3.2.2.1. The tabulated maximum torque values to which these percentages apply are listed in table III. All nuts shall be subjected to test No. 1 in table IV. In addition, nuts shall be subjected to tests 2, 4, or 6 which apply in accordance with their maximum usage temperature as listed under nut types in table IV.

Table II. Wrench torque

Fine thread series			Coarse thread series		
Thread size	Inch-pounds		Thread size	Inch-pounds	
	Regular nuts	Shear nuts		Regular nuts	Shear nuts
1/ ~~No. 8-36~~	~~23~~	~~14~~	No. 2-56	4	
No. 10-32	46	29	No. 4-40	8	
			No. 6-32	15	
			No. 8-32	23	14
			2/ No. 10-24	40	22
1/4-28	115	69	2/ 1/4-20	85	
5/16-24	260	160	2/ 5/16-18	185	
3/8-24	450	275	3/8-16	325	
7/16-20	965	575	2/ 7/16-14	550	
1/2-20	1,265	760	2/ 1/2-13	1,000	
9/16-18	1,840	1,100	2/ 9/16-12	1,265	
5/8-18	2,750	1,600	2/ 5/8-11	1,725	
3/4-16	5,750	3,450	2/ 3/4-10	2,875	
7/8-14	8,050	4,830	2/ 7/8-9	5,300	
1-12	10,990	6,822			
1/ ~~1-14~~	~~11,300~~	~~6,900~~	2/ 1-8	8,750	
1-1/8-12	14,850	10,350	1/ ~~1-1/8-8~~	~~13,000~~	
1-1/4-12	22,500	17,250	1/ ~~1-1/4-8~~	~~19,000~~	

1/ Inactive for design.
2/ Inactive for design for military aircraft.

Table I. Axial tensile strength in pounds

Fine thread series					Coarse thread series				
Thread size	Regular nuts 1/		Shear nuts 2/		Thread size	Regular nuts 1/		Shear nuts 2/	
	Steel	Al alloy	Steel	Al alloy		Steel	Al alloy	Steel	Al alloy
					2-56	440	4/ 440	230	4/ 230
					4-40	750	4/ 750	375	4/ 375
					6-32	1,130	4/ 1,130	560	4/ 560
3/ ~~8-36~~	~~1,840~~	~~920~~	~~920~~	~~460~~	8-32	1,720	4/ 1,720	860	4/ 860
10-32	2,460	4/ 2,460	1,230	4/ 1,230			5/ ~~860~~		5/ ~~430~~
		5/ ~~1,230~~		5/ ~~615~~	6/ 10-24	2,010	1,000		
1/4-28	4,580	4/ 4,580	2,290	1,140	6/ 1/4-20	3,760	1,860		
		5/ ~~2,290~~		5/ ~~1,140~~					
5/16-24	7,390	3,620	3,700	1,830	6/ 5/16-18	6,360	3,150		
3/8-24	11,450	5,680	5,720	2,840	6/ 3/8-16	9,540	4,730		
7/16-20	15,450	7,680	7,720	3,830	6/ 7/16-14	13,140	6,520		
1/2-20	21,110	10,470	10,550	5,240	6/ 1/2-13	17,730	8,800		
9/16-18	26,810	13,300	13,400	6,650	6/ 9/16-12	22,890	11,360		
5/8-18	34,130	16,930	17,060	8,460	6/ 5/8-11	28,530	14,150		
3/4-16	50,020	24,810	25,010	12,400	6/ 3/4-10	42,770	21,220		
7/8-14	68,440	33,950	34,220	[illegible]	6/ 7/8-9	60,330	29,920		
3/ ~~1-14~~	~~92,180~~	~~44,700~~	~~46,000~~	~~22,000~~	6/ 1-8	79,280	39,330		
1-12	90,000	44,640	45,000	22,320					
1-1/8-12	116,700	57,880	58,350	28,940	3/ ~~1-1/8-8~~	~~104,000~~	~~51,850~~		
1-1/4-12	147,940	73,380	73,970	36,690	3/ ~~1-1/4-8~~	~~133,300~~	~~66,200~~		

1/ There are no axial tensile strength requirements on copper-base alloy nuts.

2/ The "regular nut" values shall be used unless the standard specifies that the values for shear nuts are applicable.

3/ Inactive for design.

4/ These are the axial tensile strength values for the high strength aluminum-alloy nuts identified by a blue dye.

5/ These are the axial tensile strength values for the low-strength aluminum-alloy nuts. These nuts are inactive for design.

6/ Inactive for design for military aircraft. For application other than military aircraft, see 6.1.2.

Table III. Locking torque at room ambient temperature
(In inch-pounds)

Fine thread series			Coarse thread series		
Thread size	Maximum locking torque, installation or removal	Minimum breakaway torque	Thread size	Maximum locking torque, installation or removal	Minimum breakaway torque
1/ ~~4-48~~	~~5~~		2/ 2-56	2.5	
1/ ~~6-40~~	~~10~~	~~1.0~~	2/ 4-40	5	
1/ ~~8-36~~	~~15~~	~~1.5~~	1/ ~~5-40~~	~~5~~	~~1.0~~
10-32	18	2.0	6-32	10	1.0
			8-32	15	1.5
1/4-28	30	3.5	3/ 10-24	18	2.0
5/16-24	60	6.5	3/ 1/4-20	30	4.5
3/8-24	80	9.5	3/ 5/16-18	60	7.5
7/16-20	100	14.0	3/ 3/8-16	80	12.0
1/2-20	150	18.0	3/ 7/16-14	100	16.5
9/16-18	200	24.0	3/ 1/2-13	150	24.0
5/8-18	300	32.0	3/ 9/16-12	200	30.0
3/4-16	400	50.0	3/ 5/8-11	300	40.0
7/8-14	600	70.0	3/ 3/4-10	400	60.0
1-12	800	90.0	3/ 7/8-9	600	82.0
1/ ~~1-14~~	~~800~~	~~90.0~~	3/ 1-8	800	110.0
1-1/8-12	900	117.0	1/ ~~1-1/8-8~~	~~900~~	~~137.0~~
1-1/4-12	1,000	143.0	1/ ~~1-1/4-8~~	~~1,000~~	~~165.0~~

1/ Inactive for design.
2/ Must have some indication of torque.
3/ Inactive for design for military aircraft.

Table IV. Durability tests

Test No. and test paragraph	Nut types	Percent allowable maximum torque of table III	Baking procedure 1/	Test temperature
1 4.5.3.2.2.1.1	All nuts	100	None	Room ambient
2 4.5.3.2.2.1.2	250° F nuts	150	Bake 3 hours at 250° F then cool to room ambient temperature	Room ambient
3 4.5.3.2.2.1.2		150		Preheat 1 hour at 250° F and test at this temperature
4 4.5.3.2.2.1.1	450° F nuts	200	Bake 6 hours at 450° F then cool to room ambient temperature	Room ambient
5 4.5.3.2.2.2		150		Preheat 1 hour at 450° F and test at this temperature
6 4.5.3.2.2.1.1	800° F nuts	200	Bake 6 hours at 800° F then cool to room ambient temperature	Room ambient
7 4.5.3.2.2.2		150		Preheat 1 hour at 800° F and test at this temperature

1/ Nuts requiring baking shall be preassembled on bolts or screws, as applicable, with at least a length of 2 thread pitches (including chamfer) extending beyond the nut.

3.8.2.2.2 Minimum breakaway torque. - Breakaway torque shall not fall below the values listed in table III for the minimum breakaway torque when tested as specified in 4.5.3.2.2.2. All nuts shall be subjected to test No. 1 specified in table IV. In addition, nuts shall be subjected to those tests 2 through 7 which may apply in accordance with their maximum usage temperature as listed under "Nut types" of table IV. For tests 3, 5, and 7 listed in table IV, nuts used in tests 2, 4, or 6, as applicable, shall be assembled on bolts with at least a length of two thread pitches (including chamfer) extending beyond the nuts, and preheated as specified.

3.8.2.2.3 Reusability. - All nuts and bolts or screws used in the durability tests shall be inspected for injury to the threads as specified in 4.5.3.2.2.3.

3.8.3 Torque out. - Torque out values for floating and retained nonfloating type plate nuts and gang channel nuts, with no axial load on the seat of the nut, shall be not less than the values listed in table V, when tested as specified in 4.5.3.3. This test is not applicable to other types of plate nuts than those listed above or to hexagon nuts.

Table V. Torque out

Thread size	Torque (inch-pounds)
No. 2	10
No. 4	20
1/ ~~No. 5~~	~~25~~
No. 6	30
No. 8	45
No. 10	60
1/4	100
5/16	160
3/8	240
7/16	350

1/ Inactive for new design.

3.9 Push out. - Push out values for the floating and nonfloating type plate nuts and gang channel nuts shall be not le-- than the values listed in table VI when tested as specified in 4.5.4.

Table VI. Push out

Thread size	Pounds
No. 2	20
No. 4	40
1/ ~~No. 5~~	~~50~~
No. 6	60
No. 8	80
No. 10	100
1/4 and over	125

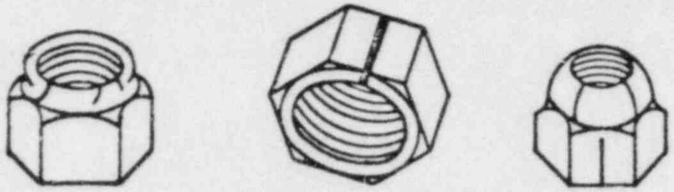
1/ Inactive for new design

3.10 Vibration. - Self-locking nuts shall withstand the vibration test specified in 4.5.5.

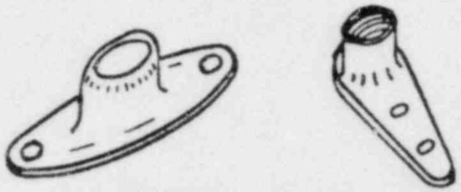
3.11 Discontinuities. - Discontinuities in steel nuts, as specified on figure 2, shall not exceed the depths shown in table VII when tested as specified in 4.5.7. Care must be exercised not to confuse cracks with discontinuities. A crack is defined as a clean crystalline break passing through the grain or grain boundary without the inclusion of foreign elements. Cracks are not permitted in any location

Table VII. Limits of depths on laps, seams, and inclusion of finished nuts

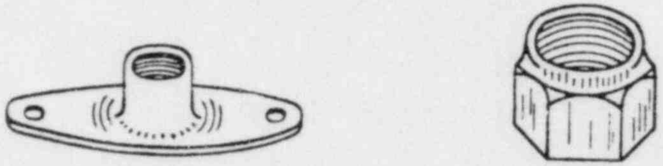
Thread size of nut	5/16 and under	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1	1-1/8	1 1/4
Hexagon and plate nuts made from sheet metal	0.005	0.006	0.007	0.009	0.011	0.012	0.014	0.017			
Hexagon and plate nuts made from bar or wire	.010	.011	.012	.014	.016	.017	.019	.022	.025	.028	.031



(SEAM EXTENDS INTO WASHER FACE AND SIDE)
FORGED NUT



ACCEPTABLE, PROVIDED DISCONTINUITIES ARE WITHIN THE LIMITS OF TABLE VII.



TOOL MARKS AND DRAW MARKS ON SELF-LOCKING NUTS AS A RESULT OF NORMAL MACHINING OR HEADING OPERATIONS SHALL NOT BE CAUSE FOR REJECTION.

ACCEPTABLE

FIGURE 2. (Sheet 1 of 3) Acceptable and rejectable defects of self-locking nuts as revealed by magnetic particle or fluorescent penetrant inspection

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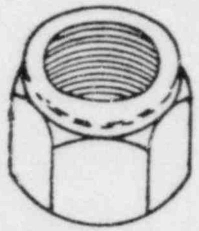
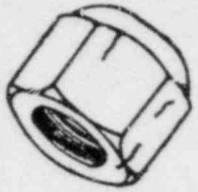
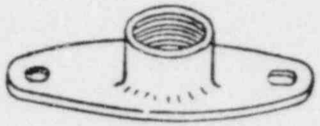
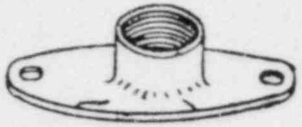


NUT HAVING SHALLOW TOOL MARKS

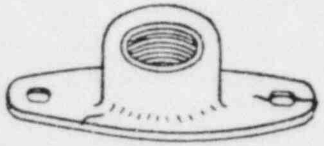


NUT FABRICATED FROM BAR STOCK WHICH HAS SEAMS, LAPS, OR INCLUSIONS WHICH INTERSECT AN EDGE





NUT HAVING LAPS, SEAMS, OR INCLUSIONS



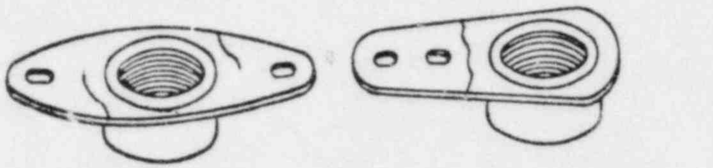
NUT HAVING SEAMS, LAPS, OR INCLUSIONS

ACCEPTABLE, PROVIDED DISCONTINUITIES ARE WITHIN THE LIMITS OF TABLE VII.

FIGURE 2. (Sheet 2 of 3) Acceptable and rejectable defects of self-locking nuts as revealed by magnetic particle or fluorescent penetrant inspection

NUT HAVING SEAMS, LAPS, OR INCLUSIONS WHICH INTERSECT AN EDGE IN LINE WITH BEAM SLOTS PASSING THROUGH THE CENTER OF THE HEX FLATS

ACCEPTABLE, PROVIDED DISCONTINUITIES DO NOT EXCEED ONE-HALF THE LIMITS OF TABLE VII



NUTS HAVING LAPS OR SEAMS DUE TO THE FORMING OF THE METAL IN EXCESS OF THE LIMITS SPECIFIED IN TABLE VII

REJECTABLE

FIGURE 2. (Sheet 3 of 3) Acceptable and rejectable defects of self-locking nuts as revealed by magnetic particle or fluorescent penetrant inspection

3.12 Stress embrittlement. - The noncorrosion-resistant steel nuts shall satisfactorily pass the stress embrittlement tests specified in 4.5.9.

3.13 Magnetic permeability. - The magnetic permeability of the corrosion-resistant steel nuts shall be less than 2.0 (air=1.0) for a field strength of H=200 oersteds.

3.14 Workmanship. - Workmanship shall be consistent with the type of product, finish, and the class of thread fit specified. Sharp edges shall be broken; hanging burrs and slivers which might become dislodged under usage shall be removed.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Classification of inspections. - The inspection and testing of nuts shall be classified as follows:

(a) Qualification inspection (4.3)
(b) Quality conformance inspection (4.4)

4.3 Qualification inspection. -

4.3.1 Sampling instructions. - The qualification test samples shall consist of 100 nuts or plate nuts for each size upon which qualification is desired. All bolts, screws, and mandrels necessary for tests specified herein shall be furnished by the manufacturer. Complete descriptive and processing data shall be submitted as to the lubricating material used on the nuts. Samples shall be identified as required and forwarded to the activity responsible for qualification, designated in the letter of authorization from that activity (see 6.3).

4.3.2 Tests. - The qualification tests of self-locking nuts shall consist of all examinations and tests of this specification as specified under 4.5.

4.3.3 Certified test report. - The manufacturer shall furnish a certified test report showing that the manufacturer's product satisfactorily conforms to this specification. The test report shall include, as a minimum, actual results of the tests specified herein. When this report is submitted, it shall be accompanied by a dated drawing which completely describes the manufacturer's product by specifying all dimensions and tolerances, composition of materials selected, coating or plating applied, forming process (machined, stamped, forged, or drawn), and the heat treatment. The manufacturer's part number for each size shall be included on the above specified drawing (see 6.3).

4.4 Quality conformance inspection. - Quality conformance inspection shall consist of the sampling tests specified in 4.4.2.

4.4.1 Selection of samples. - Sample nuts shall be selected at random from each lot as specified herein.

4.4.1.1 Lot. - A lot shall consist of finished nuts which are of the same type and diameter fabricated by the same process, heat treated in the same manner, and produced as one continuous run or order or part thereof.

4.4.1.2 Sampling plan A. - Sampling sizes for examination of product (threads, finish, and dimensions) shall be in accordance with MIL-STD-105, Inspection level I. The acceptance and rejection criteria shall be applied for the following Acceptable Quality Levels (AQL'S) applying to the corresponding class characteristics:

Major A - 1.0 percent
Major B - 2.5 percent
Minor - 4.0 percent

4.4.1.2.1 Classification of defects. - The classification of defects for self-locking nuts shall be as follows:

Major A:
  Locking element missing
Major B:
  101 Thread fit
  102 Locking element deformed
  103 Bearing surface squareness
  104 Surface finish, plating or surface treatment
  105 Rivet hole location and alignment (plate nuts only)
Minor:
  201 Height of nut
  202 Dimension across hex flat (hexagon nuts only)
  203 Loose or hanging burrs
  204 Height of hex wrenching surface (hexagon nuts only)
  205 All other dimensional characteristics not covered above

4.4.1.3 Sampling plan B. - For the Axial strength test (4.5.2), the sample shall be selected in accordance with table VIII or table IX, as specified herein.

Table VIII. Variables plan

Lot size	Sample size
Under 10,000	5
10,000 to 50,000	7
50,001 to 100,000	10
Over 100,000	15

Each sample shall conform to the requirements that $\overline{X}-0.40R$ exceed the minimum strength requirements of table I

Where: $\overline{X}$ = sample average tensile strength
R = sample range, i.e., largest tensile strength minus smallest tensile strength

In the event that the sample fails the above variables plan test and no one item of the sample falls below the minimum requirement, a new sample shall be taken according to the attribute plan below.

Table IX. Attribute plan

Lot size	Sample size	Acceptance number
Under 10,000	5	0
10,000 to 50,000	10	0
50,001 to 100,000	15	0
Over 100,000	27	1

4.4.1.3.1 Axial strength (alternate sampling plan). - The attribute plan shown in table IX may be used at the outset in lieu of the variables plan.

4.4.1.4 Sampling plan C. - For the locking torque, the torque out, and push out tests (4.5.3.2, 4.5.3.3, and 4.5.4, respectively), sampling shall be in accordance with the attribute plan shown in table IX. The acceptance or rejection numbers shall apply to all of the individual tests for the locking torque, torque out, and push out tests taken separately; i.e., a nut shall be classified defective if it fails to conform to any requirements of any one of these tests.

4.4.1.5 Sampling plan D. - For the discontinuities test (4.5.7), sampling shall be at random in accordance with MIL-STD-105. The acceptance and rejection numbers for an AQL of 1 percent defective shall be applied to those nuts which are judged defective or in nonconformance with the requirements of figure 2 and table VII after microexamination in accordance with 4.5.7. Multipiece nuts, such as gang channels and floating nuts, shall be inspected prior to assembly. These requirements shall not apply to nuts less than 1/4 inch in thread diameter.

4.4.2 Tests. - The quality conformance tests of self-locking nuts shall consist of the following tests:

(a) Examination of product (4.5.1)
(b) Axial tensile strength (4.5.2)
(c) Locking torque (table IV)
  (Except tests 2 and 3 of table IV for 250° F nuts;
  except tests [illegible] and [illegible] of table IV [illegible]° F nuts;
  except tests 6 and 7 of table IV for 800° F nuts) (4.5.3.2)

(d) Torque out (4.5.3.3)
(e) Push out (not applicable to right-angle plate nuts) (4.5.4)
(f) Discontinuities (4.5.7)
(g) 48-hour stress embrittlement test (4.5.9)

4.5 Inspection methods. -

4.5.1 Examination of product. - The nuts shall be examined for conformance to this specification and applicable approved standards with respect to material, workmanship, dimensions, design and construction, and finish.

4.5.1.1 Bearing surface. - Bearing surface values shall be measured by means of a table squareness gage, with a seating surface diameter equal to W (see figure 1), in conjunction with a feeler gage, with a class 3A threaded member at engagement in the locking device, and turned finger tight.

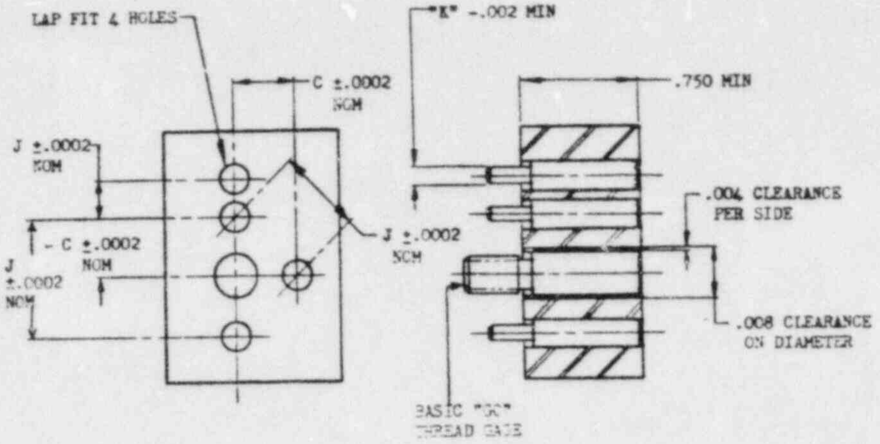
4.5.1.2 Plate nut rivet-bolt hole spacing. - Plate nut rivet-bolt hole spacing may be determined by the means of a functional alignment gage in accordance with figure 3.

4.5.1.3 250° F and 450° F corrosion-resistant steel nuts. - The corrosion-resistant steel nuts shall be tested for surface cleanliness in accordance with Method 101 of MIL-STD-753.

4.5.2 Axial tensile strength. - Bolts of minimum grip length equal to twice the bolt diameter on which the nuts assemble freely up to the self-locking element with the fingers may be used for this test. The bolt and nut assembly shall be tested with at least a length of two thread pitches (including chamfer) of the bolt extending through the nut. Such bolts shall be heat treated to an ultimate tensile strength of 160,000 pounds per square inch (psi) minimum and shall have class 3A threads in accordance with MIL-S-7742 or MIL-S-8879. All bolts shall be clean. The bolt hole in the bearing plate shall have a free fit not in excess of 0.01 inch greater than the diameter of the bolt. Thickness of the bearing plate shall not be less than the diameter of the bolt used in the test. In the case of floating nuts, the hole in the test plate should be large enough to simulate the float. Axial tensile load for 100-degree countersunk nuts shall be met when tested on a fixture with a configuration conforming to the bearing contour of the nut assembly.

4.5.2.1 Qualification. - Not less than six sample nuts shall be subjected to the axial strength test. The nuts shall be assembled on the bolts. Three of the 450° F nuts shall be baked on the bolt for 6 hours at 450° F. Three of the 800° F (corrosion-resistant steel) nuts shall be baked on the bolt for 6 hours at 800° F. The 250° nuts need not be baked prior to this test. All the nuts shall then be tested at room temperature. The tests shall be carried to destruction.

4.5.2.2 Quality conformance. - The nuts shall be assembled on the bolts and subjected to the axial strength test. The testing shall be done at room temperature. The tests shall be carried to destruction when the variables sampling plan (4.4.1.3) is used. The tests need not be carried to destruction when the attribute sampling plan (4.4.1.3.1) is used.



MS OR AN TOLERANCE ON DIMENSION "J" BETWEEN RIVET HOLES = ±.002, GAGE PINS BEING .002 BELOW MIN "K" DIA CHECK PARTS TO .002 FUNCTIONALLY.

MS TOLERANCE ON DIMENSION "C" BETWEEN RIVET AND TAPPED HOLE = THE CENTER OF TAPPED HOLE SHALL NOT DEVIATE IN ANY DIRECTION FROM THE CENTER OF PLATE NUT AS DETERMINED BY THE RIVET HOLES BY MORE THAN .005.

THE CENTER HOLE IN THE GAGE HAVING .004 CLEARANCE PER SIDE AND THE RIVET HOLE PINS HAVING .001 CLEARANCE PER SIDE CHECKS THE RELATIONSHIP TO A TOTAL OF .005 PER SIDE FUNCTIONALLY.

DIMENSIONS IN INCHES.

FIGURE 3. Plate nut functional alignment gage

4.5.3 Torque. -

4.5.3.1 Wrench torque (hexagon nuts only). - Steel bolts identical to those used in the axial strength test (4.5.2) on which the nuts assemble freely up to the self-locking element with the fingers may be used for this test. Such bolts shall have class 3A threads in accordance with MIL-S-7742. Three of the nuts submitted for qualification shall be subjected to this test. The regular nuts shall be tightened against a steel bushing with a box wrench to the torque values for regular nuts specified in table II. The regular nuts shall also be tightened against a steel bushing with an open end wrench to the torque values specified in table II for shear nuts for sizes through 5/8 inch. Shear nuts shall be tightened to the values specified for shear nuts by a box wrench. The open end wrench and box wrench shall be type I, class 1, and type IV conforming to GGG-W-636. Deformation which interferes with the proper application and removal of the nut with the wrench is sufficient cause for rejection.

4.5.3.2 Locking torque. - The locking torque tests shall be run with no axial load on the nut at a rate slow enough to obtain a dependable measure of torque. The temperature rise of the nut under test shall not exceed 75° F above room ambient temperature.

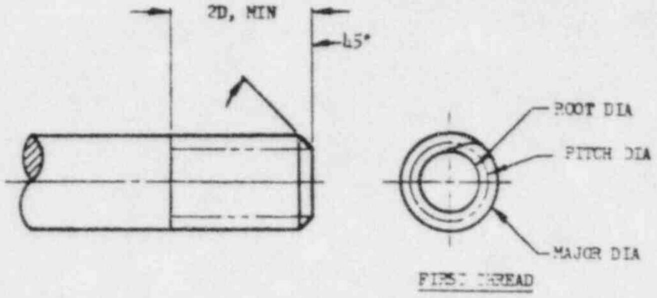
4.5.3.2.1 Permanent set. - Permanent set shall be evaluated by subjecting the nut, at room ambient temperature, to one complete installation and removal cycle on a bolt or screw, as applicable, and then repeating the test cycle with the same clean nut on a minimum pitch mandrel, in accordance with 4.5.3.2.1.1. Three of the nuts submitted shall be subjected to this test. The bolts or screws for this test shall conform to MIL-B-6812 for sizes No. 10 and above, and to AN503 for sizes under No. 10, except that the pitch diameter of the bolt or screw shall be established at 75 percent, +0.0000 - 0.0004, of the tolerance range of class 3A above the minimum pitch diameter, subject to check with functional pitch diameter tri-roll gages.

4.5.3.2.1.1 Mandrel for permanent set test. - The mandrel shall conform to figure 4. Threads shall conform to table X. It shall be checked with pitch diameter tri-roll gages.

4.5.3.2.2 Durability. - For qualification, 20 nuts shall be subjected to this test. Failure of any nut to pass the requirements of this test shall be cause for rejection.

4.5.3.2.2.1 Maximum locking torque, class 3A bolts or screws. -

4.5.3.2.2.1.1 Tests 1, 4, and 6 of table IV. - For these tests, the nuts shall be engaged or disengaged on a clean bolt or screw, as applicable, as specified in 4.5.3.2.2.1.3 for 15 full installation and removal cycles without any axial load on the nut. A bolt shall be considered fully installed when a length of two thread pitches (including chamfer) extend beyond the locking device of the nut, and the removal cycle shall be considered completed when the locking device is disengaged. Maximum locking torque readings shall be taken on the first, seventh, and fifteenth cycles.



DETAILS:

MATERIAL: STEEL.

HARDNESS: HEAT TREATED TO ROCKWELL C60 to 64.

THREADS: THE THREAD FORM SHALL CONFORM TO THAT SHOWN IN MIL-S-7742. THE THREADS SHALL BE RIGHT HAND. THE THREAD DIMENSIONS SHALL BE AS SHOWN IN TABLE X.

SURFACE ROUGHNESS: 20 MICROINCHES MAXIMUM IN ACCORDANCE WITH USA B46.1 - 1962

THE MANDREL END SHALL HAVE A 45-DEGREE CHAMFER EXTENDING BELOW THE ROOT DIAMETER. THE RESULTING SHARP FEATHER EDGE OF THE INCOMPLETE THREAD SHALL BE REMOVED BY STONING.

NOTE: LUBRICANT SHALL BE USED ONLY WHEN THE MANDREL IS USED WITH CORROSION-RESISTING STEEL NUTS.

FIGURE 4. Mandrel

4.5.3.2.2.1.2 Tests 2 and 3 of table IV. - For these tests, the nuts shall be tested as specified in 4.5.3.2.2.1.1, immediately preceding, except that the nut shall be engaged or disengaged, as applicable, for only one full installation and removal cycle. Maximum locking torque readings shall be taken on installation and removal of the nut.

4.5.3.2.2.1.3 Bolt or screws for maximum locking torque and minimum breakaway torque tests. - For the maximum locking torque and minimum breakaway torque tests, screws conforming to AN503 shall be used on nuts under number 10 size, and bolts conforming to MIL-B-6812 shall be used on nuts number 10 size and larger. The pitch diameter after plating on these screws or bolts shall be class 3A. All screws or bolts used shall allow the nut to be assembled freely with the fingers up to the locking element. Each new nut shall conform to these dimensional requirements at the beginning of each test. Cadmium-plated, noncorrosion-resistant steel screws or bolts shall be used for testing noncorrosion-resistant steel nuts, copper-base alloy nuts, and high-strength aluminum-alloy nuts, sizes No. 8-32, No. 10-32, and 1/4-28, identified by a blue dye. Aluminum-alloy bolts or screws shall be used for the testing of the other aluminum-alloy nuts. Corrosion-resistant steel bolts shall be used for testing corrosion-resistant steel nuts.

4.5.3.2.2.2 Minimum breakaway torque. - During the last installation and removal cycle in the test specified in 4.5.3.2.2.1, the same nut shall be checked for minimum breakaway torque. Minimum breakaway torque shall be determined during the last removal cycle (1st or 15th, as applicable) between the limits of a minimum of one, and a maximum of two threads of the bolt or screw, as applicable, extending beyond the nut. In addition to the above, tests 3, 5, and 7 of table IV, as applicable, to the maximum usage temperature, shall be conducted by checking the minimum breakaway torque on the first removal cycle only.

4.5.3.2.2.3 Reusability. - At the conclusion of the minimum breakaway torque tests, the nuts and bolts or screws used in this test shall be examined for damage to the threads. Noticeable distortion or scratches deep enough to reduce the efficiency of the threads shall be cause for rejection. The threads on the bolt or screw, as applicable, shall remain in serviceable condition and permit the installation of a new nut freely with the fingers up to the self-locking element.

4.5.3.3 Torque out. - In table V, the torque out values of floating and nonfloating-type plat nuts and gang channel nuts listed shall apply to nuts when tested with no axial load on the seat of the nut. The nut or nut assembly shall conform to the values specified without cracking the retainer and without becoming malformed sufficiently to preclude the application of the same torque in the opposite direction. The nuts to be subjected to this test shall be riveted to a steel plate of a thickness equal to or greater than the maximum thread diameter. The bolt hole in the plate shall be located concentric with the nominal position of the threads in the nut within 0.010-inch full indicator reading. The diameter of the torque stud or device shall have a maximum diametral clearance of 0.010 inch in the test plate. The torque stud or device shall be provided with a shoulder to seat against the base of the nut or shall incorporate a suitable bushing to accomplish this. Reverse loading may be accomplished by the addition of a check nut.

Table X. Thread dimensions for maximum stud and minimum mandrel for permanent set test

Size	Maximum 3A stud		Minimum 3A mandrel		Tolerance in lead (per inch)	Tolerance on half angle of thread (in minutes)
	Pitch diameter		+0.0000	-0.0004		
	Maximum	Minimum	Major diameter	Pitch diameter		
2-56	0.0740	0.0736	0.0819	0.0728	±0.0002	±20
4-40	.0953	.0949	.1069	.0939	±0.0002	±20
6-32	.1171	.1167	.1320	.1156	±.0003	±15
8-32	.1431	.1427	.1580	.1415	±.0003	±15
1/ 10-24	.1623	.1619	.1828	.1604	±.0003	±15
10-32	.1691	.1687	.1840	.1674	±.0003	±15
1/ 1/4-20	.2168	.2164	.2419	.2147	±.0003	±15
1/4-28	.2261	.2257	.2435	.2243	±.0003	±15
1/ 5/16-18	.2757	.2753	.3038	.2734	±.0003	±10
5/16-24	.2847	.2843	.3053	.2827	±.0003	±15
1/ 3/8-16	.3336	.3332	.3656	.3311	±.0003	±10
3/8-24	.3471	.3467	.3678	.3450	±.0003	±15
1/ 7/16-14	.3902	.3898	.4272	.3876	±.0003	±10
7/16-20	.4042	.4038	.4294	.4019	±.0003	±15
1/ 1/2-13	.4491	.4487	.4891	.4463	±.0003	±10
1/2-20	.4667	.4663	.4919	.4643	±.0003	±15
1/ 9/16-12	.5074	.5070	.5511	.5045	±.0003	±10
9/16-18	.5255	.5251	.5538	.5230	±.0003	±10
1/ 5/8-11	.5650	.5646	.6129	.5619	±.0003	±10
5/8-18	.5880	.5876	.6163	.5854	±.0003	±10
1/ 3/4-10	.6839	.6835	.7371	.6806	±.0003	±10
3/4-16	.7084	.7080	.7406	.7056	±.0003	±10
1/ 7/8-9	.8016	.8012	.8611	.7981	±.0003	±10
7/8-14	.8275	.8271	.8647	.8245	±.0003	±10
1/ 1-8	.9175	.9171	.9850	.9137	±.0004	±5
2/ ~~1-14~~	~~.9525~~	~~.9521~~	~~.9897~~	~~.9494~~	~~±.0003~~	~~±10~~
1-12	.9448	.9444	.9886	.9415	±.0003	±10
1-1/8-12	1.0697	1.0693	1.1136	1.0664	±.0003	±10
1-1/4-12	1.1947	1.1943	1.2386	1.1913	±.0003	±10

1/ Inactive for design for military aircraft.
2/ Inactive for design.

4.5.4 Push out. - The minimum load required to push out the nut from the retainer of any type plate nut and gang channel nut or to effect a permanent deformation axial with the threaded element of 0.030 inch, measured at the thread centerline between the test plate and the base of the nut, shall be not less than the values specified in table VI. The nuts shall be prepared for this test in the manner specified in 4.5.3.3, except that the push-out stud or device shall be provided with a hemispherical end of a diameter equal to the thread diameter plus 1/32 inch, minimum, instead of the shoulder or bushing.

4.5.5 Vibration. - Sample nuts with bolts of the size and quantities specified in table XI shall be vibrated in accordance with MS26531 or test 7 of MIL-STD-1312. An average vibration life, for each lot of eight specimens tested to MS26531, of less than specified in table XI shall be cause for rejection. Vibration life, for each lot of five specimens tested in accordance with MIL-STD-1312, test 7, at less than 30,000 cycles shall be cause for rejection.

Table XI. Vibration requirements

<table>
<tr><th rowspan="3">Nut Size</th><th rowspan="3">Bolt Size</th><th colspan="3">MS26531</th><th colspan="3">MIL-STD-1312, test 7</th></tr>
<tr><th colspan="2">Bolts and nuts required (min. of each)</th><th rowspan="2">Average Vibration life (hours)</th><th colspan="2">Bolts and nuts required (min. of each)</th><th rowspan="2">Assembly torque after bake (in. - lb.)</th></tr>
<tr><th>250°F</th><th>450 & 800°F</th><th>250°F</th><th>450 & 800°F</th></tr>
<tr><td>10-32</td><td>AN3-15A</td><td>8</td><td>16</td><td>0.6</td><td>5</td><td>10</td><td>36</td></tr>
<tr><td>1/4-28</td><td>AN4-16A</td><td>8</td><td>16</td><td>1.0</td><td>5</td><td>10</td><td>60</td></tr>
<tr><td>5/16-24</td><td>AN5-16A</td><td>8</td><td>16</td><td>3.5</td><td>5</td><td>10</td><td>120</td></tr>
<tr><td>3/8-24</td><td>AN6-17A</td><td>8</td><td>16</td><td>6.0</td><td>5</td><td>10</td><td>160</td></tr>
<tr><td>7/16-20</td><td>AN7-17A</td><td>8</td><td>16</td><td>8.0</td><td>5</td><td>10</td><td>200</td></tr>
<tr><td>1/2-20</td><td>AN8-20A</td><td>8</td><td>16</td><td>9.5</td><td>5</td><td>10</td><td>300</td></tr>
</table>

4.5.5.1 Vibration tests on nuts larger than 1/2-inch size are waived, provided that 1/2-inch nuts and smaller of the same type and design of locking device have satisfactorily passed the vibration test.

4.5.5.2 Preparation for vibration test to MS26531. -

4.5.5.2.1 Baking of test specimens. - Half of the 450° F and 800° F nuts shall be assembled on the appropriate AN bolts and baked for 6 hours at 450° F and 800° F, respectively. The baked specimens shall be allowed to cool slowly in air to room ambient temperature before being vibrated. It is not necessary to bake the 250° F nuts for this test.

4.5.5.2.2 Lug removal of plate nuts. - One-piece plate nuts shall have their attaching lugs so trimmed that they are equal to the width of the part and provide symmetry about their threaded axes. On multipiece plate nuts, fixed or floating type, only the threaded element shall be tested, provided the locking device is integral therewith. Such threaded locking element shall be made symmetrical as above noted. If the threaded element and locking device are not integral, the lugs of the attaching retainer shall be trimmed as above to provide the closest possible symmetry. The trimmed assembly shall then be tested.

4.5.5.3 Method. - The test nuts shall be screwed on the aircraft bolts which pass through the drilled holes in the arbor and sleeve of the test rig as shown on sheet 5 of MS26531. The nuts shall not be tightened against the sleeve, but shall be screwed on until the end of the bolt extends through the nut. The bolts shall be free to rotate in the arbor and sleeve. The locking device of the nut shall be the only factor which restrains the nut from turning on the bolt. The thrust load on the test arbor, including the weight of the electrical power unit, shall be 65 pounds. Reference lines shall be scribed, or other suitable markings shall be made on both the nuts and the bolts for the purpose of determining if the nut turns on the bolt during the vibration test.

4.5.5.3.1 The tests shall be conducted in periods of running and periods of rest to permit the electrical power unit to cool. A fan or blower shall be set to direct a current of air on the test rig in order that 20-minute runs with 10-minute rest intervals shall not develop temperatures greater than [illegible]° F in the test specimens when conducted as follows:

(a) The fan or blower shall be turned off after each 20-minute running period is complete, and shall remain off until the temperature readings are taken.

(b) The vibration test shall be conducted for a period equal to the average vibration life specified in table XI. If a rotation of greater than 30 degrees either side of the scribe line is observed on two or more nuts, the test may be extended to a total of 1-1/2 times the specified average vibration life requirement. A rotation of greater than 30 degrees for a nut shall be considered a failure of that nut, and the end of the run period in which the nut failed shall be recorded as the nut's vibration life. The average vibration life shall be defined as the arithmetical mean of the vibration life of the eight nuts being evaluated. During the average life run, if only one nut has a rotation greater than 30 degrees and the other seven nuts have a rotation of 30 degrees or less, the nut design shall have passed the test.

4.5.5.3.2 The nuts shall be considered to have failed to pass the vibration test under the following conditions:

(a) If any structural failure, such as broken segments, locking inserts falling out, and significantly cracked nuts, occurs during the test, provided failure is not the result of failure of the bolt.

(b) If any nut can be freely turned completely on or off the bolt with the fingers after any 20-minute run during and after the completion of the average vibration time.

(c) If any nut comes completely off the bolt during the average vibration time.

(d) If a test lot fails to develop an average vibration life equal to or greater than the average vibration life specified in table XI.

4.5.5.4 Preparation for vibration test to MIL-STD-1312, test 7. -

4.5.5.4.1 Accelerated vibration. - The nuts shall be assembled in accordance with figure 1, of MIL-STD-1312, test 7, with bolts and torque values as specified in table XI. The nuts shall then be removed and reinstalled to this torque four additional times before being vibrated.

4.5.5.4.2 Baking of test specimens. - Half of the 450 and 800° F nuts shall be assembled on the appropriate bolts and baked for six hours at 450 and 800° F, respectively. The baked specimens shall be allowed to cool slowly in air to room temperature. The nuts shall then be removed and reinstalled to torque values specified in table XI for four additional times before being vibrated. It is not necessary to bake the 250° F nuts for this test.

4.5.5.5 Method. - Use MIL-STD-1312, test 7 procedure.

4.5.5.5.1 Determination shall be made throughout the test to guarantee that assembly is traversing the entire length of the slots in the test fixture. The test shall be run for 30,000 cycles except that it shall be stopped prior to the completion of the 30,000 cycles in the event a nut becomes disassembled from the bolt. The nut samples shall be examined under 10X magnification for cracks.

4.5.5.5.2 The nuts shall be considered to have failed to pass the vibration test under the following conditions:

(a) If any structural failure, such as broken segments, locking inserts falling out, or cracks occurring in the nuts during the test, provided failure is not the result of failure of the bolt.

(b) If any nut comes completely off the bolt or can be turned completely on or off the bolt with the fingers during or after completion of 30,000 cycles.

(c) If relative rotation between any nut and bolt exceeds 360 degrees.

4.5.6 Stress corrosion. - For purposes of qualification, samples of the sizes No. 2-56 through and including 1/4-28 high strength aluminum alloy nuts shall be subjected to the following test. Five of the nuts of the size being qualified shall be assembled on cadmium plated steel bolts or screws, as applicable, against cadmium plated steel bushings. The torque used in assembly shall be:

(a) 4 inch-pounds for the No. 2-56 size.
(b) 8 inch-pounds for the No. 4-40 size.
(c) 15 inch-pounds for the No. 6-32 size.
(d) 20 inch-pounds for the No. 8-32 size.
(e) 40 inch-pounds for the No. 10-32 size.
(f) 100 inch-pounds for the No. 1/4-23 size.

The assembly shall then be submerged in a solution consisting of 53 grams of sodium chloride and 50 grams of sodium chromate per liter of solution for a period of 2 weeks at room temperature (75° F). At the conclusion of the time period, the nuts shall be examined and any cracks visible to the unaided eye shall be automatic cause for rejection. If no cracks are visible, one sample of each size from the above tests shall be sectioned, polished, and subjected to metallurgical examination. Any cracks shown by this examination shall cause rejection of the lot.

4.5.7 Discontinuities. - The presence of discontinuities in nuts, such as laps, seams, and inclusions, shall be determined by one of the following methods of inspection, unless visual inspection discloses discontinuities which would preclude the necessity for these inspection means. The presence of cracks in nuts is cause for rejection. Other indications as noted on figure 2 shall not be cause for rejection, provided the are within the acceptable limits of table VII. If, in the opinion of the Government inspector, the indications are cause for rejection, representative samples shall be taken from those nuts showing indications which shall be further examined by microexamination to determine whether the indicated discontinuities are in accordance with the limits specified herein. In general, discontinuities within the acceptable limits of table VII shall not be cause for rejection.

4.5.7.1 Inspection method for noncorrosion-resistant steel nuts. - Magnetic particle inspection shall be performed in accordance with MIL-I-6868. Such inspection shall, in general, be performed by the self-locking nut manufacturer on finished nuts, of thread sizes 1/4 inch and larger, but in any case subsequent to any processing operations which could adversely affect the part. The nuts shall be magnetically inspectioned circularly only. The magnetizing field shall be normal to the longitudinal axis of the nut. Nuts shall not be dyed as an indication of magnetic particle inspection specified by the sampling requirements of this specification. Personnel conducting magnetic particle inspection shall be qualified in accordance with MIL-STD-410.

4.5.7.2 Inspection method for corrosion-resistant steel nuts. - Fluorescent penetrant inspection shall be performed in accordance with MIL-I-6866. Such inspection shall, in general, be performed on finished nuts, of thread sizes 1/4 inch and larger, but in any case subsequent to any processing operations which could adversely affect the part. Nuts shall not be dyed as an indication of fluorescent penetrant inspection specified by the sampling requirements of this specification. Personnel conducting fluorescent penetrant inspection shall be qualified in accordance with MIL-STD-410.

4.5.8 Suitability of lubricant coatings. -

4.5.8.1 Effect of the coating on the ability of cadmium plating to prevent galvanic corrosion. - Lubricant coated and unlubricant coated "Scratch panels," made of the same material as the finished fastener product, and cadmium plated in accordance with QQ-P-416, shall be scratched through to the basis metal. The unlubricated panel shall be cadmium plated in accordance with type II, class 3 of QQ-P-416. These panels shall be subjected to a 96-hour salt spray test in accordance with Method 811 of Fed. Test Method Std. No. 151. After exposure, no significant difference in corrosion shall be found when a comparison is made between the panels with the lubricant and the unlubricated panels.

4.5.8.2 Effect of the coating on structural materials in contact with the fastener. - Corrosion test specimens will be panels with four test fasteners per panel. Two fasteners of each specimen panel shall be cadmium plated in accordance with type II, class 3 of QQ-P-416 without lubricant coating, and the other two fasteners shall be plated in accordance with type II, class 3 of QQ-P-416 and shall be lubricant coated. Duplicate specimen sets of the following alloys and finishes shall be subjected to a 96-hour salt spray test in accordance with Method 811 of Fed. Test Method Std. No. 151:

(a) Bare 7075-T6 and 2024-T6 aluminum-alloy surfaces treated in accordance with MIL-C-5541 and anodized in accordance with MIL-A-8625
(b) Clad 7075-T6 and 2024-T6 aluminum alloy
(c) Titanium alloy
(d) Corrosion-resistant steel
(e) Magnesium alloy wherein the fasteners are insulated from the magnesium in accordance with MIL-F-7179

After exposure, the specimens shall be disassembled and no significant difference in corrosion shall be found on either the fasteners or panel faying surface when a comparison is made between the fasteners with lubricant and fasteners without lubricant.

4.5.8.3 Behavior of coating with paint. - Corrosion test specimens shall be of aluminum alloy similar to those specified in 4.5.8.2 and painted, including the fasteners, with wash primer zinc-chromate primer system in accordance with MIL-F-7179. These specimens shall be subjected to a 96-hour salt spray test in accordance with Method 811 of Fed. Test Method Std. No. 151. After exposure, no significant difference in corrosion, blistering, or loss of adhesion of the paint shall be found when a comparison is made between the fasteners with lubricant and fasteners without lubricant.

4.5.8.4 Effect of coating on sealing materials. - Corrosion test specimens shall be of aluminum alloy similar to those specified in 4.5.8.2, except that MIL-S-8802 and MIL-S-7502 fuel tank sealant material shall be applied to the fasteners. A specimen panel shall be prepared for each sealant material. Before the application of the sealant material, the fasteners and panels shall be cleaned by scrubbing and rinsing with solvent formulated in accordance with table XII. After rinsing, and while still wet, the specimens shall be wiped dry with clean, nonoily wiping cloths or tissue. These specimens shall be subjected to a 96-hour salt spray test in accordance with Method 811 of Fed. Test Method Std. No. 151. After exposure, no significant difference in loss of adhesion or degradation of sealant material shall be found when a comparison is made between the fasteners with lubricant and fasteners without lubricant.

Table XII. Formulation of cleaner

Ingredient	Specification	Percent by volume
Aromatic petroleum naphtha	TT-N-97, type I, grade B	50
Ethyl acetate	TT-E-751	20
Methyl-ethyl-ketone	TT-M-261	20
Isopropyl alcohol	TT-I-735	10

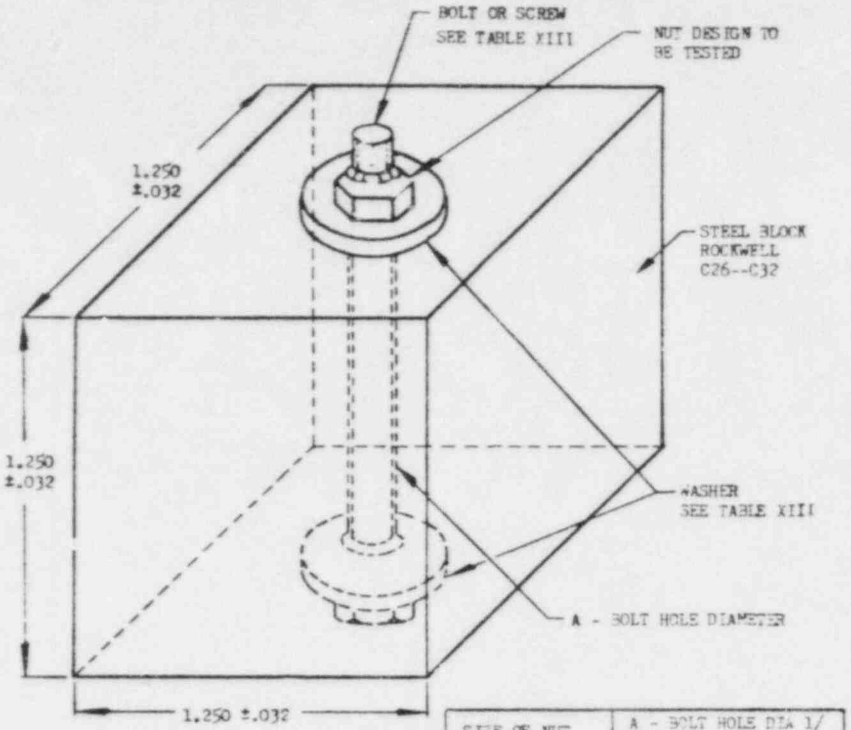
4.5.8.5 Effect of coating on stress corrosion resistance of fasteners. - The lubricated threaded fastener shall be scratched through to the basis metal. Torque shall be applied against the aluminum-alloy panels to induce 90,000 psi in mating bolt. The assembly shall be salt-spray tested for 96 hours in accordance with Method 811 of Fed. Test Method Std. No. 151. After exposure, the lubricated fastener shall not have any cracks which can be determined by visual inspection under 10 diameters magnification.

4.5.8.6 Soluble lubricant removability. - Soluble lubricant coated panels, made of the same material and containing the same finish as the fastener product, shall be submerged for 10 minutes ±1 minute in the cleaner specified in table XII. The panel shall then be wiped dry with clean, nonoily wiping cloths or tissue. Failure of all lubricant to be removed from the panel by the above process shall be cause for rejection of the fastener product.

4.5.9 Stress embrittlement. - Nut products that are heat treated to over Rockwell C46, or equivalent, shall be subjected to a stress embrittlement test.

4.5.9.1 48-hour stress embrittlement test. - A minimum of 10 nuts, or not more than 10 percent, shall be selected from each lot and assembled with suitable bolts or screws and washers in a drilled steel bushing-type member heat treated to Rockwell C26-C32. (See figure 5 and table XIII.) The assembly shall be stored at room temperature for 48 hours. After 48 hours, the nuts shall be visually examined for cracks and the minimum breakaway torque shall be determined. Nuts with lower breakaway torque than the minimum requirements of table III shall be sectioned and examined under 10X magnification. The presence of cracks shall be cause for rejection of the lot.

4.5.9.2 168-hour embrittlement test. - A minimum of 10 nuts or not more than 10 percent shall be selected from each lot and assembled with suitable bolts or screws and washers in a drilled steel bushing-type member heat treated to Rockwell C26-C32 (see figure 5 and table XIII). The assembly shall be stored at room ambient temperature for 168 hours. After 168 hours, the nuts shall be visually examined for cracks and the minimum breakaway torque shall be determined. Nuts with lower breakaway torque than the minimum requirements of table III shall be sectioned and examined under 10X magnification. The presence of cracks shall be cause for rejection of the lot.



D = MAX MAJOR DIA OF BOLT THREAD

SIZE OF NUT TO BE TESTED	A - BOLT HOLE DIA 1/	
	MAXIMUM	MINIMUM
4-40	--	--
6-32	--	--
8-32	.188	.173
10-32	.213	.198
1/4-28	.273	.258
5/16-24	.338	.323
3/8-24	.399	.384
7/16-20	.463	.448

1/ THERE ARE NO STRESS EMBRITTLEMENT TESTS ON THE NO. 4 AND NO. 6 NUTS

FIGURE 6. Stress embrittlement test fixture

Table XIII. Stress embrittlement test specimen assembly and torque values

Nut design to be tested	Bolt or screw	Washer	Torque (inch-lb)
2-56	1/	1/	
4-40	1/	1/	
6-32	1/	1/	
8-32	NAS220-21	AN960-8L	23
10-32	AN3-15A	AN960-10L	45
1/4-28	AN4-16A	AN960-416L	115
5/16-24	AN5-16A	AN960-516L	260
3/8-24	AN6-17A	AN960-616L	450
7/16-20	AN7-17A	AN960-716L	965

1/ There are no stress embrittlement tests on the No. 2, No. 4, and No. 6 nuts.

4.5.10 Magnetic permeability. - The magnetic permeability shall be determined by the use of an indicator in accordance with MIL-I-17214, or equivalent. This test shall be performed on the same samples which were used in the axial strength test (4.5.2).

4.6 Packaging, packing, and marking. - Preparation for delivery shall be examined for conformance to section 5.

5. PREPARATION FOR DELIVERY

5.1 Preservation, packaging, packing, and marking. - Self-locking nuts shall be preserved, packaged, packed, and marked for shipment in accordance with MIL-H-3932. Preservation and packaging shall be level A or C as specified in the contract or order (see 6.2). Packing shall be level A, B, or C, as specified in the contract or order (see 6.2).

6. NOTES

6.1 Intended use. - The nuts and plate nuts conforming to this specification are intended for use in applications where the maximum temperatures do not exceed the following values:

Copper-base alloy nuts - 250° F.
Aluminum-alloy nuts - 250° F.
Noncorrosion-resisting steel - 250° F or 450° F. 1/
Corrosion-resisting steel - 250° F, 450° F, or 800° F.

1/ The noncorrosion-resisting steel nuts covered by this specification are for use at two different temperatures as shown on the complementary MS.

6.1.1 The specifying, by reference to this specification, of self-locking nut designs for use in the design and construction of military aerospace vehicles will be limited to those nut designs with thread size and pitch combinations noted as approved for design in table I or listed as approved for design in standards approved by the specific aerospace vehicles specifications and are also listed on QPL-25027. 1/ Design and usage limitations shall conform to MS33588.

1/ Nut designs listed on QPL-25027 which are qualified and classified as 550° or 500° F nuts, under previous revisions of this specification are universally interchangeable with nut design classified as 450° F nuts.

6.1.2 The specifying, by reference to this specification, of self-locking nut design for applications other than military aerospace vehicles may include those nut designs with fine thread pitches for sizes under No. 10 and coarse thread pitches for sizes No. 10 and larger if there is a nut design listed on QPL-25027 for the thread size, and there are no exceptions taken to the locking element dimensions, locking element material, and locking torque of the design qualified. For applications other than military aerospace vehicles, these nut designs are considered qualified. If any provision of the specific equipment specification conflicts with this provision, the equipment specification will govern.

6.1.3 Standard and nonstandard nut designs that are approved for use in design and construction of aerospace vehicles; that are specified by reference by this specification; and that have all descriptive factors that affect universal interchangeability the same, except for the type of plating in accordance with QQ-P-416, are considered to have the following interchangeability relationship:

( ) Those nuts with type II plating can be used to replace those nuts with type I plating in all applications.

(b) Those nuts with type I plating cannot be used in place of those nuts with type II plating. In applications for dry film lubricated nuts, the type and class are optional, if the nuts meet the salt spray requirements for type II of QQ-P-416.

6.2 Ordering data. - Procurement documents should specify the following:

(a) Title, number, and date of this specification.
(b) MS Part No. (see section 3).
(c) Applicable levels of packaging and packing (see 5.1).

6.3 Qualification. - With respect to products requiring qualification, awards will be made only for products which are at the time set for opening of bids, qualified for inclusion in the applicable Qualified Products List, whether or not such products have actually been so listed by that date. The attention of the suppliers is called to this requirement, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification in order that they may be eligible to be awarded contracts or orders for the products covered by this specification. The activity responsible for the Qualified Products List is the Naval Air Systems Command, Navy Department, Washington, D.C., 20360; however, information pertaining to qualification of products may be obtained from the Naval Air Engineering Center, Philadelphia, Pennsylvania, 19112.

6.3.1 Qualification tests will be authorised only upon presentation of certified test reports indicating that the nuts conform to or will conform to this specification (see 4.3.3) and the applicable MS or a standard approved by the activity responsible for qualification.

6.4 Definitions. - In this specification the word "nuts", unless qualified by hexagon or plate, refers to both hexagon nuts and plate nuts. When only hexagon nuts or only plate nuts are being referred to, it will be so indicated in the specification.

Custodians:
Army - WC
Navy - AS
Air Force - 11

Reviewer activities:
Army - MI, AV, WC
Navy - AS, SH
Air Force - 82, 85

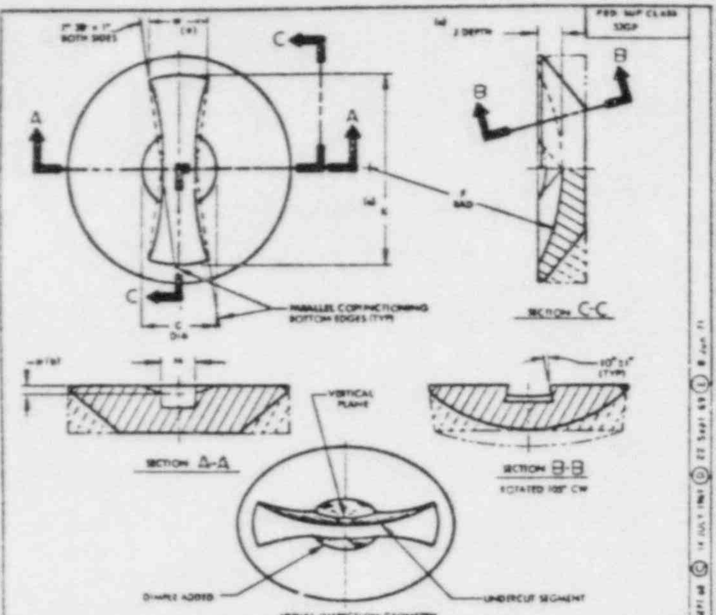
User activities:
Army - GL, MU, WC
Air Force - 82

Preparing activity:
Navy - AS

Project No. 5310-0627

[illegible] RNMENT PRINTING OFFICE: [illegible]-393-[illegible] 5307

FED SUP CLASS 53GP



RECESS DIMENSIONS

RECESS NO.	C DIA	F RAD ± .005	W WIDTH MAX	W WIDTH MIN	P REF	RECESS NO.	C DIA	F RAD ± .005	W WIDTH MAX	W WIDTH MIN	P REF
0	[illegible]	.113	.034	.030	[illegible]	12	.597/.613	1.250	.223	.218	.042
1	.101/.111	.163	.054	.050	.013	14	.702/.718	1.400	.253	.248	.050
2	.127/.137	.187	.066	.062	.015	16	.802/.818	1.600	.283	.279	.056
3	.146/.156	.281	.066	.062	.014	18	.897/.913	1.800	.320	.314	.060
4	.196/.206	.437	.078	.074	.015	20	.992/1.008	2.000	.356	.350	.068
5	.246/.256	.500	.084	.080	.020	22	1.107/1.123	2.250	.391	.384	.076
6	.296/.306	.625	.100	.096	.022	24	1.210/1.230	2.400	.427	.420	.084
7	.346/.356	.687	.118	.113	.027	26	1.310/1.330	2.600	.462	.455	.090
8	.396/.406	.750	.148	.143	.031	28	1.415/1.430	2.800	.496	.488	.096
9	.446/.456	.875	.168	.162	.033	30	1.515/1.533	3.000	.530	.522	.102
10	.499/.511	1.000	.188	.183	.036	32	1.615/1.633	3.250	.566	.558	.108

(a) THE SPECIFIC PART STANDARD OR DRAWING WHICH SPECIFIES THE HI-TORQUE RECESS BY REFERENCING THIS STANDARD SHALL SPECIFY TOLERANCED VALUES FOR DIMENSION [illegible] AND REFERENCE VALUES FOR [illegible] AND [illegible].

(b) DIMENSION "P" IS THE THEORETICAL INTERSECTION OF THE DEPRESSION AND FASTENER CENTERLINE.

(c) DIMPLE NOT REQUIRED FOR THIS SIZE.

Ⓔ UNLESS OTHERWISE SPECIFIED ON THE PART DRAWING, FASTENERS WITHOUT DIMPLE MAY BE FURNISHED UNTIL 31 JUNE 1972.

DIMENSIONS IN INCHES

THIS IS A DESIGN STANDARD, NOT TO BE USED AS A PART NUMBER.

Ⓔ FOR CHANGES SEE SHEET 1

P.A. USAF-11 Other Cust: Army - MI Navy - AS	TITLE RECESS - HI-TORQUE, DIMENSIONS OF RECESS, GAGE, AND DRIVER FOR	MILITARY STANDARD MS33750
PROCUREMENT SPECIFICATION NONE	SUPERSEDES: NAS 1392	SHEET 1 OF 2

APPROVED 14 NOV 62 REVISED Ⓐ 14 APRIL 1962 Ⓑ 22 SEPT 64 Ⓒ 14 JULY 1967 Ⓓ 22 Sept 69 Ⓔ 8 Jun 71

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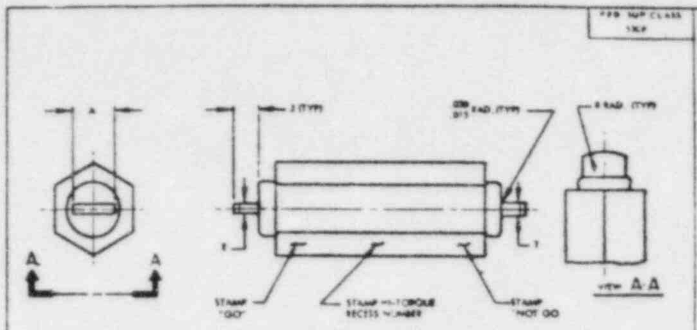
DD FORM 672-1

FED SUP CLASS 53GP



HI-TORQUE RECESS WIDTH GAGE DIMENSIONS

RECESS NO.	A ± .005	E +.0000 -.0002	J MIN	K ± .003	T +.0002 -.0000	A G D HANDLE SIZE
0	.088	.0300	.125	.030	.0340	00
1	.144	.0500		.050	.0540	
2	.219	.0620		[illegible]	.0660	0
3	.250			[illegible]		
4	.375	.0740		[illegible]	.0780	
5	.406	.0800		.443	.0840	
6	.500	.0960	.172	[illegible]	.1000	1
7	.562	.1130		[illegible]	.1180	
8	.690	.1430		[illegible]	.1460	
9	.687	.1620		[illegible]	.1680	
10	.812	.1830	.250	[illegible]	.1880	
12	.937	.2180		[illegible]	.2230	2
14	1.062	.2480	.312	[illegible]	.2530	
16	1.250	.2790		[illegible]	.2830	
18	1.500	.3140	.375	[illegible]	.3230	3
20		.3500		[illegible]	.3560	
22		.3840		[illegible]	.3910	
24		.4200	.437	[illegible]	.4270	
26		.4550		[illegible]	.4620	
28		.4880		[illegible]	.4960	
30		.5220	.500	[illegible]	.5300	
32		.5580		[illegible]	.5660	

P.A. USAF-11 Other Cust: Army - MI Navy - AS	RECESS - HI-TORQUE, DIMENSIONS OF RECESS, GAGE, AND DRIVER FOR	MILITARY STANDARD MS33750
PROCUREMENT SPECIFICATION		SHEET 2 OF 2

APPROVED 14 NOV 62

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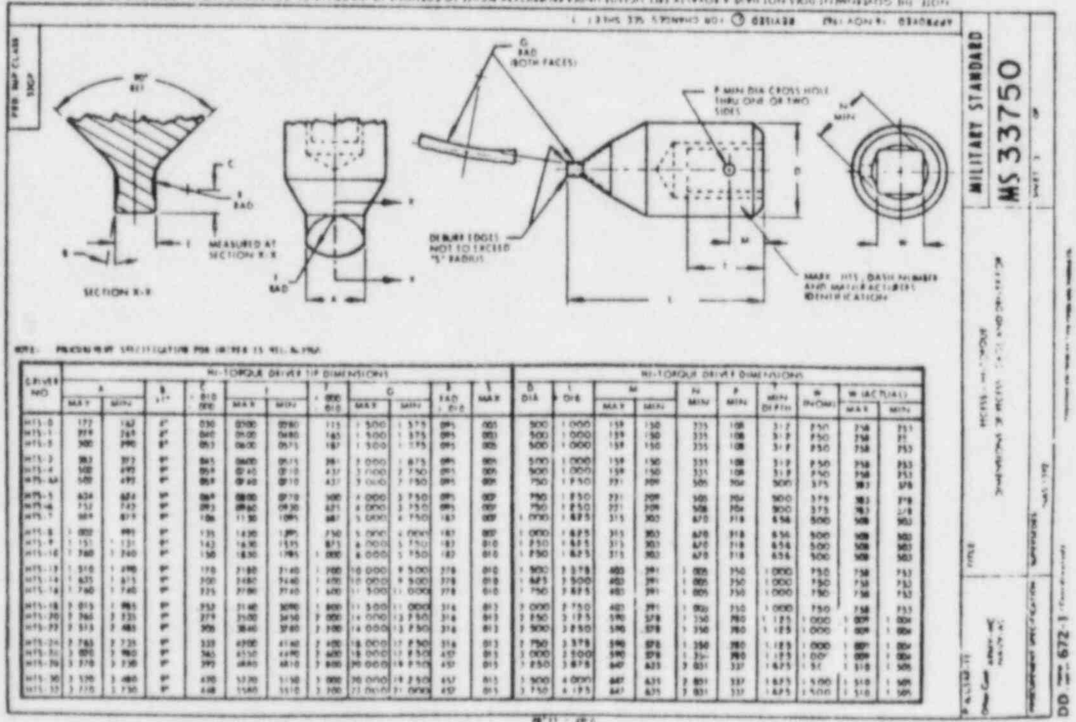
DD FORM 672-1



APPROVED 16 NOV 1962 REVISED Ⓒ FOR CHANGES SEE SHEET 1.

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Review activities: Army - MC, AT, ME; Navy - AS; Air Force - 11, 82

DD FORM 672-1

U.S. GOVERNMENT PRINTING OFFICE

MIL-STD-105D
29 April 1963

SUPERSEDING
MIL-STD-105C
18 July 1961

MILITARY STANDARD

SAMPLING PROCEDURES AND TABLES FOR INSPECTION BY ATTRIBUTES

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

ORIGINAL COPY

NOT TO BE REMOVED
FROM FILE

CONTENTS

TABLES

* * *

SAMPLING PROCEDURES AND TABLES FOR INSPECTION BY ATTRIBUTES

1. SCOPE

1.1 PURPOSE. This publication establishes sampling plans and procedures for inspection by attributes. When specified by the responsible authority, this publication shall be referenced in the specification, contract, inspection instructions, or other documents and the provisions set forth herein shall govern. The "responsible authority" shall be designated in one of the above documents.

1.2 APPLICATION. Sampling plans designated in this publication are applicable, but not limited, to inspection of the following:

a. End items.

b. Components and raw materials.

c. Operations.

d. Materials in process.

e. Supplies in storage.

f. Maintenance operations.

g. Data or records.

h. Administrative procedures.

These plans are intended primarily to be used for a continuing series of lots or batches. The plans may also be used for the inspection of isolated lots or batches, but, in this latter case, the user is cautioned to consult the operating characteristic curves to find a plan which will yield the desired protection (see 11.6).

1.3 INSPECTION. Inspection is the process of measuring, examining, testing, or otherwise comparing the unit of product (see 1.5) with the requirements.

1.4 INSPECTION BY ATTRIBUTES. Inspection by attributes is inspection whereby either the unit of product is classified simply as defective or nondefective, or the number of defects in the unit of product is counted, with respect to a given requirement or set of requirements.

1.5 UNIT OF PRODUCT. The unit of product is the thing inspected in order to determine its classification as defective or nondefective or to count the number of defects. It may be a single article, a pair, a set, a length, an area, an operation, a volume, a component of an end product, or the end product itself. The unit of product may or may not be the same as the unit of purchase, supply, production, or shipment.

2. CLASSIFICATION OF DEFECTS AND DEFECTIVES

2.1 METHOD OF CLASSIFYING DEFECTS. A classification of defects is the enumeration of possible defects of the unit of product classified according to their seriousness. A defect is any nonconformance of the unit of product with specified requirements. Defects will normally be grouped into one or more of the following classes; however, defects may be grouped into other classes, or into subclasses within these classes.

2.1.1 CRITICAL DEFECT. A critical defect is a defect that judgment and experience indicate is likely to result in hazardous or unsafe conditions for individuals using, maintaining, or depending upon the product; or a defect that judgment and experience indicate is likely to prevent performance of the tactical function of a major end item such as a ship, aircraft, tank, missile or space vehicle. NOTE: For a special provision relating to critical defects, see 6.3.

2.1.2 MAJOR DEFECT. A major defect is a defect, other than critical, that is likely to result in failure, or to reduce materially the usability of the unit of product for its intended purpose.

2.1.3 MINOR DEFECT. A minor defect is a defect that is not likely to reduce materially the usability of the unit of product for its intended purpose, or is a departure from established standards having little bearing on the effective use or operation of the unit.

2.2 METHOD OF CLASSIFYING DEFECTIVES. A defective is a unit of product which contains one or more defects. Defectives will usually be classified as follows:

2.2.1 CRITICAL DEFECTIVE. A critical defective contains one or more critical defects and may also contain major and or minor defects. NOTE: For a special provision relating to critical defectives, see 6.3.

2.2.2 MAJOR DEFECTIVE. A major defective contains one or more major defects, and may also contain minor defects but contains no critical defect.

2.2.3 MINOR DEFECTIVE. A minor defective contains one or more minor defects but contains no critical or major defect.

3. PERCENT DEFECTIVE AND DEFECTS PER HUNDRED UNITS

3.1 EXPRESSION OF NONCONFORMANCE. The extent of nonconformance of product shall be expressed either in terms of percent defective or in terms of defects per hundred units.

3.2 PERCENT DEFECTIVE. The percent defective of any given quantity of units of product is one hunderd times the number of defective units of product contained therein divided by the total number of units of product, i.e.:

$$\text{Percent defective} = \frac{\text{Number of defectives}}{\text{Number of units inspected}} \times 100$$

3.3 DEFECTS PER HUNDRED UNITS. The number of defects per hundred units of any given quantity of units of product is one hundred times the number of defects contained therein (one or more defects being possible in any unit of product) divided by the total number of units of product, i.e.:

$$\text{Defects per hundred units} = \frac{\text{Number of defects}}{\text{Number of units inspected}} \times 100$$

4. ACCEPTABLE QUALITY LEVEL (AQL)

4.1 USE. The AQL, together with the Sample Size Code Letter, is used for indexing the sampling plans provided herein.

4.2 DEFINITION. The AQL is the maximum percent defective (or the maximum number of defects per hundred units) that, for purposes of sampling inspection, can be considered satisfactory as a process average (see 11.2).

4.3 NOTE ON THE MEANING OF AQL. When a consumer designates some specific value of AQL for a certain defect or group of defects, he indicates to the supplier that his (the consumer's) acceptance sampling plan will accept the great majority of the lots or batches that the supplier submits, provided the process average level of percent defective (or defects per hundred units) in these lots or batches be no greater than the designated value of AQL. Thus, the AQL is a designated value of percent defective (or defects per hundred units) that the consumer indicates will be accepted most of the time by the acceptance sampling procedure to be used. The sampling plans provided herein are so arranged that the probability of acceptance at the designated AQL value depends upon the sample size, being generally higher for large samples than for small ones, for a given AQL. The AQL alone does not describe the protection to the consumer for individual lots or batches but more directly relates to what might be expected from a series of lots or batches, provided the steps indicated in this publication are taken. It is necessary to refer to the operating characteristic curve of the plan, to determine what protection the consumer will have.

4.4 LIMITATION. The designation of an AQL shall not imply that the supplier has the right to supply knowingly any defective unit of product.

4.5 SPECIFYING AQLs. The AQL to be used will be designated in the contract or by the responsible authority. Different AQLs may be designated for groups of defects considered collectively, or for individual defects. An AQL for a group of defects may be designated in addition to AQLs for individual defects, or subgroups, within that group. AQL values of 10.0 or less may be expressed either in percent defective or in defects per hundred units; those over 10.0 shall be expressed in defects per hundred units only.

4.6 PREFERRED AQLs. The values of AQLs given in these tables are known as preferred AQLs. If, for any product, an AQL be designated other than a preferred AQL, these tables are not applicable.

5. SUBMISSION OF PRODUCT

5.1 LOT OR BATCH. The term lot or batch shall mean "inspection lot" or "inspection batch," i.e., a collection of units of product from which a sample is to be drawn and inspected to determine conformance with the acceptability criteria, and may differ from a collection of units designated as a lot or batch for other purposes (e.g., production, shipment, etc.).

5.2 FORMATION OF LOTS OR BATCHES. The product shall be assembled into identifiable lots, sublots, batches, or in such other manner as may be prescribed (see 5.4). Each lot or batch shall, as far as is practicable, consist of units of product of a single type, grade, class, size, and composition, manufactured under essentially the same conditions, and at essentially the same time.

5.3 LOT OR BATCH SIZE. The lot or batch size is the number of units of product in a lot or batch.

5.4 PRESENTATION OF LOTS OR BATCHES. The formation of the lots or batches, lot or batch size, and the manner in which each lot or batch is to be presented and identified by the supplier shall be designated or approved by the responsible authority. As necessary, the supplier shall provide adequate and suitable storage space for each lot or batch, equipment needed for proper identification and presentation, and personnel for all handling of product required for drawing of samples.

6. ACCEPTANCE AND REJECTION

6.1 ACCEPTABILITY OF LOTS OR BATCHES. Acceptability of a lot or batch will be determined by the use of a sampling plan or plans associated with the designated AQL or AQLs.

6.2 DEFECTIVE UNITS. The right is reserved to reject any unit of product found defective during inspection whether that unit of product forms part of a sample or not, and whether the lot or batch as a whole is accepted or rejected. Rejected units may be repaired or corrected and resubmitted for inspection with the approval of, and in the manner specified by, the responsible authority.

6.3 SPECIAL RESERVATION FOR CRITICAL DEFECTS. The supplier may be required at the discretion of the responsible authority to inspect every unit of the lot or batch for critical defects. The right is reserved to inspect every unit submitted by the supplier for critical defects, and to reject the lot or batch immediately, when a critical defect is found. The right is reserved also to sample, for critical defects, every lot or batch submitted by the supplier and to reject any lot or batch if a sample drawn therefrom is found to contain one or more critical defects.

6.4 RESUBMITTED LOTS OR BATCHES. Lots or batches found unacceptable shall be resubmitted for reinspection only after all units are re-examined or retested and all defective units are removed or defects corrected. The responsible authority shall determine whether normal or tightened inspection shall be used, and whether reinspection shall include all types or classes of defects or f~~o~~r only the particular types or classes of defects which caused initial rejection.

7. DRAWING OF SAMPLES

7.1 SAMPLE. A sample consists of one or more units of product drawn from a lot or batch, the units of the sample being selected at random without regard to their quality. The number of units of product in the sample is the sample size.

7.2 REPRESENTATIVE SAMPLING. When appropriate, the number of units in the sample shall be selected in proportion to the size of sublots or subbatches, or parts of the lot or batch, identified by some rational criterion.

7. DRAWING OF SAMPLES (Continued)

When representative sampling is used, the units from each part of the lot or batch shall be selected at random.

7.3 TIME OF SAMPLING. Samples may be drawn after all the units comprising the lot or batch have been assembled, or samples may be drawn during assembly of the lot or batch.

7.4 DOUBLE OR MULTIPLE SAMPLING. When double or multiple sampling is to be used, each sample shall be selected over the entire lot or batch.

8. NORMAL, TIGHTENED AND REDUCED INSPECTION

8.1 INITIATION OF INSPECTION. Normal inspection will be used at the start of inspection unless otherwise directed by the responsible authority.

8.2 CONTINUATION OF INSPECTION. Normal, tightened or reduced inspection shall continue unchanged for each class of defects or defectives on successive lots or BATCHES batchs except where the switching procedures given below require a change. ~~The switching procedures given below require a change.~~ The switching procedures shall be applied to each class of defects or defectives independently.

8.3 SWITCHING PROCEDURES.

8.3.1 NORMAL TO TIGHTENED. When normal inspection is in effect, tightened inspection shall be instituted when 2 out of 5 consecutive lots or batches have been rejected on original inspection (i.e., ignoring resubmitted lots or batches for this procedure).

8.3.2 TIGHTENED TO NORMAL. When tightened inspection is in effect, normal inspection shall be instituted when 5 consecutive lots or batches have been considered acceptable on original inspection.

8.3.3 NORMAL TO REDUCED. When normal inspection is in effect, reduced inspection shall be instituted providing that all of the following conditions are satisfied:

a. The preceding 10 lots or batches (or more, as indicated by the note to Table VIII) have been on normal inspection and none has been rejected on original inspection; and

b. The total number of defectives (or defects) in the samples from the preceding 10 lots or batches (or such other number as was used for condition "a" above) is equal to or less than the applicable number given in Table VIII. If double or multiple sampling is in use, all samples inspected should be included, not "first" samples only; and

c. Production is at a steady rate; and

d. Reduced inspection is considered desirable by the responsible authority.

8.3.4 REDUCED TO NORMAL. When reduced inspection is in effect, normal inspection shall be instituted if any of the following occur on original inspection:

a. A lot or batch is rejected; or

b. A lot or batch is considered acceptable under the procedures of 10.1.4; or

c. Production becomes irregular or delayed; or

d. Other conditions warrant that normal inspection shall be instituted.

8.4 DISCONTINUATION OF INSPECTION. In the event that 10 consecutive lots or batches remain on tightened inspection (or such other number as may be designated by the responsible authority), inspection under the provisions of this document should be discontinued pending action to improve the quality of submitted material.

9. SAMPLING PLANS

9.1 SAMPLING PLAN. A sampling plan indicates the number of units of product from each lot or batch which are to be inspected (sample size or series of sample sizes) and the criteria for determining the acceptability of the lot or batch (acceptance and rejection numbers).

9.2 INSPECTION LEVEL. The inspection level determines the relationship between the lot or batch size and the sample size. The inspection level to be used for any particular requirement will be prescribed by the responsible authority. Three inspection levels: I, II, and III, are given in Table I for general use. Unless otherwise specified, Inspection Level II will be used. However, Inspection Level I may be specified when less discrimination is needed, or Level III may be specified for greater discrimination. Four additional special levels: S–1, S–2, S–3 and S–4, are given in the same table and may be used where relatively small sample sizes are necessary and large sampling risks can or must be tolerated.

NOTE: In the designation of inspection levels S–1 to S–4, care must be exercised to avoid AQLs inconsistent with these inspection levels.

9.3 CODE LETTERS. Sample sizes are designated by code letters. Table I shall be used to find the applicable code letter for the particular lot or batch size and the prescribed inspection level.

9.4 OBTAINING SAMPLING PLAN. The AQL and the code letter shall be used to obtain the sampling plan from Tables II, III or IV. When no sampling plan is available for a given combination of AQL and code letter, the tables direct the user to a different letter. The sample size to be used is given by the new code letter not by the original letter. If this procedure leads to different sample sizes for different classes of defects, the code letter corresponding to the largest sample size derived may be used for all classes of defects when designated or approved by the responsible authority. As an alternative to a single sampling plan with an acceptance number of 0, the plan with an acceptance number of 1 with its correspondingly larger sample size for a designated AQL (where available), may be used when designated or approved by the responsible authority.

9.5 TYPES OF SAMPLING PLANS. Three types of sampling plans: Single, Double and Multiple, are given in Tables II, III and IV, respectively. When several types of plans are available for a given AQL and code letter, any one may be used. A decision as to type of plan, either single, double, or multiple, when available for a given AQL and code letter, will usually be based upon the comparison between the administrative difficulty and the average sample sizes of the available plans. The average sample size of multiple plans is less than for double (except in the case corresponding to single acceptance number 1) and both of these are always less than a single sample size. Usually the administrative difficulty for single sampling and the cost per unit of the sample are less than for double or multiple.

10. DETERMINATION OF ACCEPTABILITY

10.1 PERCENT DEFECTIVE INSPECTION. To determine acceptability of a lot or batch under percent defective inspection, the applicable sampling plan shall be used in accordance with 10.1.1, 10.1.2, 10.1.3, and 10.1.4, and 10.1.5.

10.1.1 SINGLE SAMPLING PLAN. The number of sample units inspected shall be equal to the sample size given by the plan. If the number of defectives found in the sample is equal to or less than the acceptance number, the lot or batch shall be considered acceptable. If the number of defectives is equal to or greater than the rejection number, the lot or batch shall be rejected.

10.1.2 DOUBLE SAMPLING PLAN. The number of sample units inspected shall be equal to the first sample size given by the plan. If the number of defectives found in the first sample is equal to or less than the first acceptance number, the lot or batch shall be considered acceptable. If the number of defectives found in the first sample is equal to or greater than the first rejection number, the lot or batch shall be rejected. If the number of defectives found in the first sample is between the first acceptance and rejection numbers, a second sample of the size given by the plan shall be inspected. The number of defectives found in the first and second samples shall be accumulated. If the cumulative number of defectives is equal to or less than the second acceptance number, the lot or batch shall be considered acceptable. If the cumulative number of defectives is equal to or greater than the second rejection number, the lot or batch shall be rejected.

10.1.3 MULTIPLE SAMPLE PLAN. Under multiple sampling, the procedure shall be similar to that specified in 10.1.2, except that the number of successive samples required to reach a decision may be more than two.

10.1.4 SPECIAL PROCEDURE FOR REDUCED INSPECTION. Under reduced inspection, the sampling procedure may terminate without either acceptance or rejection criteria having been met. In these circumstances, the lot or batch will be considered acceptable, but normal inspection will be reinstated starting with the next lot or batch (see 8.3.4 (b)).

10.2 DEFECTS PER HUNDRED UNITS INSPECTION. To determine the acceptability of a lot or batch under Defects per Hundred Units inspection, the procedure specified for Percent Defective inspection above shall be used, except that the word "defects" shall be substituted for "defectives."

11. SUPPLEMENTARY INFORMATION

11.1 OPERATING CHARACTERISTIC CURVES. The operating characteristic curves for normal inspection, shown in Table X (pages 30–62), indicate the percentage of lots or batches which may be expected to be accepted under the various sampling plans for a given process quality. The curves shown are for single sampling; curves for double and multiple sampling are matched as closely as practicable. The O. C. curves shown for AQLs greater than 10.0 are based on the Poisson distribution and are applicable for defects per hundred units inspection; those for AQLs of 10.0 or less and sample sizes of 80 or less are based on the binomial distribution and are applicable for percent defective inspection; those for AQLs of 10.0 or less and sample sizes larger than 80 are based on the Poisson distribution and are applicable either for defects per hundred units inspection, or for percent defective inspection (the Poisson distribution being an adequate approximation to the binomial distribution under these conditions). Tabulated values, corresponding to selected values of probabilities of acceptance (P_a, in percent) are given for each of the curves shown, and, in addition, for tightened inspection, and for defects per hundred units for AQLs of 10.0 or less and sample sizes of 80 or less.

11.2 PROCESS AVERAGE. The process average is the average percent defective or average number of defects per hundred units (whichever is applicable) of product submitted by the supplier for original inspection. Original inspection is the first inspection of a particular quantity of product as distinguished from the inspection of product which has been resubmitted after prior rejection.

11.3 AVERAGE OUTGOING QUALITY (AOQ). The AOQ is the average quality of outgoing product including all accepted lots or batches, plus all rejected lots or batches after the rejected lots or batches have been effectively 100 percent inspected and all defectives replaced by nondefectives.

11.4 AVERAGE OUTGOING QUALITY LIMIT (AOQL). The AOQL is the maximum of the AOQs for all possible incoming qualities for a given acceptance sampling plan. AOQL values are given in Table V-A for each of the single sampling plans for normal inspection and in Table V-B for each of the single sampling plans for tightened inspection.

11.5 AVERAGE SAMPLE SIZE CURVES. Average sample size curves for double and multiple sampling are in Table IX. These show the average sample sizes which may be expected to occur under the various sampling plans for a given process quality. The curves assume no curtailment of inspection and are approximate to the extent that they are based upon the Poisson distribution, and that the sample sizes for double and multiple sampling are assumed to be 0.631n and 0.25n respectively, where n is the equivalent single sample size.

11.6 LIMITING QUALITY PROTECTION. The sampling plans and associated procedures given in this publication were designed for use where the units of product are produced in a continuing series of lots or batches over a period of time. However, if the lot or batch is of an isolated nature, it is desirable to limit the selection of sampling plans to those, associated with a designated AQL value, that provide not less than a specified limiting quality protection. Sampling plans for this purpose can be selected by choosing a Limiting Quality (LQ) and a consumer's risk to be associated with it. Tables VI and VII give values of LQ for the commonly used consumer's risks of 10 percent and 5 percent respectively. If a different value of consumer's risk is required, the O.C. curves and their tabulated values may be used. The concept of LQ may also be useful in specifying the AQL and Inspection Levels for a series of lots or batches, thus fixing minimum sample size where there is some reason for avoiding (with more than a given consumer's risk) more than a limiting proportion of defectives (or defects) in any single lot or batch.

TABLE I—Sample size code letters

(See 9.2 and 9.3)

Lot or batch size	Special inspection levels				General inspection levels		
	S-1	S-2	S-3	S-4	I	II	III
2 to 8	A	A	A	A	A	A	B
9 to 15	A	A	A	A	A	B	C
16 to 25	A	A	B	B	B	C	D
26 to 50	A	B	B	C	C	D	E
51 to 90	B	B	C	C	C	E	F
91 to 150	B	B	C	D	D	F	G
151 to 280	B	C	D	E	E	G	H
281 to 500	B	C	D	E	F	H	J
501 to 1200	C	C	E	F	G	J	K
1201 to 3200	C	D	E	G	H	K	L
3201 to 10000	C	D	F	G	J	L	M
10001 to 35000	C	D	F	H	K	M	N
35001 to 150000	D	E	G	J	L	N	P
150001 to 500000	D	E	G	J	M	P	Q
500001 and over	D	E	H	K	N	Q	R

NOTE.

SMALL SAMPLE INSPECTION LEVELS
OF MIL-STD-105C
CONVERT TO THESE SPECIAL INSP. LEVELS

L-1 AND L-2 — — — — S-1
L-3 AND L-4 — — — — S-2
L-5 AND L-6 — — — — S-3
L-7 AND L-8 — — — — S-4

CODE LETTERS

SINGLE NORMAL

TABLE II-A—Single sampling plans for normal inspection (Master table)

(See 9.4 and 9.5)

Sample size code letter	Sample size	Acceptable Quality Levels (normal inspection)																																																			
		0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A	2	↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		0	1	↓		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	30	31
B	3																											0	1	↑				1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	30	31	44	45
C	5																									0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	30	31	44	45	↑	
D	8																							0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	30	31	44	45	↑			
E	13																					0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	30	31	44	45	↑					
F	20																			0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑		↑		↑							
G	32																	0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑													
H	50															0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑															
J	80													0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑																	
K	125											0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑																			
L	200									0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑																					
M	315							0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑																							
N	500					0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑																									
P	800			0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑																											
Q	1250	0	1	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑																													
R	2000	↑				1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑																															

↓ = Use first sampling plan below arrow. If sample size equals, or exceeds, lot or batch size, do 100 percent inspection.

↑ = Use first sampling plan above arrow.

Ac = Acceptance number.

Re = Rejection number.

TABLE II-B—Single sampling plans for tightened inspection (Master table)

(See 9.4 and 9.5)

Sample size code letter	Sample size	Acceptable Quality Levels (tightened inspection)																																																			
		0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A	2	↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		1	2	2	3	3	4	5	6	8	9	12	13	18	19	27	28
B	3																													0	1					1	2	2	3	3	4	5	6	8	9	12	13	18	19	27	28	41	42
C	5																											0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	27	28	41	42	↑	
D	8																									0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	27	28	41	42	↑			
E	13																							0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	27	28	41	42	↑					
F	20																					0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑		↑		↑							
G	32																			0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑													
H	50																	0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑															
J	80															0	1	↓				1	2	2	3	3	4	5	6	3	9	12	13	18	19	↑																	
K	125													0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑																			
L	200											0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑																					
M	315									0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑																							
N	500							0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑																									
P	800					0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑																											
Q	1250			0	1	↓				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑																													
R	2000	0	1	↑				1	2	2	3	3	4	5	6	8	9	12	13	18	19	↑																															
S	3150					1	2																																														

↓ = Use first sampling plan below arrow. If sample size equals or exceeds lot or batch size, do 100 percent inspection.

↑ = Use first sampling plan above arrow.

Ac = Acceptance number.

Re = Rejection number.

SINGLE REDUCED

TABLE II-C—Single sampling plans for reduced inspection (Master table)

(See 9.4 and 9.5)

Sample size code letter	Sample size	Acceptable Quality Levels (reduced inspection)†																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	0 1	⇩	⇩	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	2														0 1	⇧		6 2	1 3	2 4	3 5	5 6	7 8	10 11	14 15	21 22	30 31
C	2													0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	14 17	21 24	⇧
D	3												0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	14 17	21 24	⇧	
E	5											0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	14 17	21 24	⇧		
F	8										0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧	⇧	⇧			
G	13									0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧						
H	20								0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧							
J	32							0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧								
K	50						0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧									
L	80					0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧										
M	125				0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧											
N	200			0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧												
P	315		0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧													
Q	500	0 1	⇧	⇩	0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧														
R	800	⇧		0 2	1 3	1 4	2 5	3 6	5 8	7 10	10 13	⇧															

⇩ = Use first sampling plan below arrow. If sample size equals or exceeds lot or batch size, do 100 percent inspection.
⇧ = Use first sampling plan above arrow.
Ac = Acceptance number.
Re = Rejection number.
† = If the acceptance number has been exceeded, but the rejection number has not been reached, accept the lot, but reinstate normal inspection (see 10.1.4).

TABLE III-A—Double sampling plans for normal inspection (Master table)

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																															
				0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A				↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		*		↓		↓		*		*		*		*		*		*		*		*		*	
B	First	2	2																											*		↑				0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	17	22	25	31
	Second	2	4																																	1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27	37	38	56	57
C	First	3	3																									*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	17	22	25	31	↑	
	Second	3	6																															1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27	37	38	56	57		
D	First	5	5																							*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	17	22	25	31	↑			
	Second	5	10																													1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27	37	38	56	57				
E	First	8	8																					*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	17	22	25	31	↑					
	Second	8	16																											1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27	37	38	56	57						
F	First	13	13																			*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑		↑		↑							
	Second	13	26																									1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27												
G	First	20	20																	*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑													
	Second	20	40																							1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27														
H	First	32	32															*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑															
	Second	32	64																					1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																
J	First	50	50													*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑																	
	Second	50	100																			1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																		
K	First	80	80											*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑																			
	Second	80	160																	1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																				
L	First	125	125									*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑																					
	Second	125	250															1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																						
M	First	200	200							*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑																							
	Second	200	400													1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																								
N	First	315	315					*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑																									
	Second	315	630											1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																										
P	First	500	500			*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑																											
	Second	500	1000											1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																												
Q	First	800	800	*		↑		↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑																													
	Second	800	1600							1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																																
R	First	1250	1250	↑				0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑																															
	Second	1250	2500					1	2	3	4	4	5	6	7	8	9	12	13	18	19	26	27																																

↓ = Use first sampling plan below arrow. If sample size equals or exceeds lot or batch size, do 100 percent inspection.

↑ = Use first sampling plan above arrow.

Ac = Acceptance number

Re = Rejection number

* = Use corresponding single sampling plan (or alternatively, use double sampling plan below, where available).

TABLE III-B — Double sampling plans for tightened inspection (Master table)

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (tightened inspection)																									
				0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
				Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A				⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	⇩	*	*	*	*	*	*	*	*
B	First Second	2 2	2 4															*			0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	15 20 34 35	23 29 52 53
C	First Second	3 3	3 6														*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	15 20 34 35	23 29 52 53	⇧
D	First Second	5 5	5 10													*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	15 20 34 35	23 29 52 53	⇧	
E	First Second	8 8	8 16												*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	15 20 34 35	23 29 52 53	⇧		
F	First Second	13 13	13 26											*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧	⇧	⇧			
G	First Second	20 20	20 40										*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧						
H	First Second	32 32	32 64									*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧							
J	First Second	50 50	50 100								*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧								
K	First Second	80 80	80 160							*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧									
L	First Second	125 125	125 250						*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧										
M	First Second	200 200	200 400					*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧											
N	First Second	315 315	315 630				*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧												
P	First Second	500 500	500 1000			*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧													
Q	First Second	800 800	800 1600		*	⇩		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧														
R	First Second	1250 1250	1250 2500	*	⇧		0 2 1 2	0 3 3 4	1 4 4 5	2 5 6 7	3 7 11 12	6 10 15 16	9 14 23 24	⇧															
S	First Second	2000 2000	2000 4000			0 2 1 2																							

⇩ = Use first sampling plan below arrow. If sample size equals or exceeds lot or batch size, do 100 percent inspection.

⇧ = Use first sampling plan above arrow.

Ac = Acceptance number

Re = Rejection number

* = Use corresponding single sampling plan (or alternatively, use double sampling plan below, where available).

TABLE III-C—Double sampling plans for reduced inspection (Master table)

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (reduced inspection)†																																																			
				0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A				↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		•		↓		↓		•		•		•		•		•		•		•		•		•	
B				↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		•		↑		↓		•		•		•		•		•		•		•		•		•		•	
C				↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		•		↑		↓		•		•		•		•		•		•		•		•		•		•		↑	
D	First Second	2 2	2 4	↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	7 18	12 22	11 26	17 30	↑		↑	
E	First Second	3 3	3 6	↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	7 18	12 22	11 26	17 30	↑		↑		↑	
F	First Second	5 5	5 10	↓		↓		↓		↓		↓		↓		↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑	
G	First Second	8 8	8 16	↓		↓		↓		↓		↓		↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑	
H	First Second	13 13	13 26	↓		↓		↓		↓		↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑	
J	First Second	20 20	20 40	↓		↓		↓		↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑		↑	
K	First Second	32 32	32 64	↓		↓		↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑		↑		↑	
L	First Second	50 50	50 100	↓		↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑	
M	First Second	80 80	80 160	↓		↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑	
N	First Second	125 125	125 250	↓		↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑	
P	First Second	200 200	200 400	↓		•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑	
Q	First Second	315 315	315 630	•		↑		↓		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑	
R	First Second	500 500	500 1000	↑		↑		0 0	2 2	0 0	3 4	0 1	4 5	0 3	4 6	1 4	5 7	2 6	7 9	3 8	8 12	5 12	10 16	↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑		↑	

↓ = Use first sampling plan below arrow. If sample size equals or exceeds lot or batch size, do 100 percent inspection.
↑ = Use first sampling plan above arrow.
Ac = Acceptance number.
Re = Rejection number.
• = Use corresponding single sampling plan (or alternatively, use double sampling plan below, when available.)
† = If, after the second sample, the acceptance number has been exceeded, but the rejection number has not been reached, accept the lot, but reinstate normal inspection (see 10.14).

DOUBLE
REDUCED

MULTIPLE
NORMAL

TABLE IV-A—*Multiple sampling plans for normal inspection (Master table)*

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																																			
				0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A				⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		*		⇩		⇩		*		*		*		*		*		*		*		*		*	
B																														*		⇧				++		++		++		++		++		++		++		++		++		++	
C																												*		⇧		⇩		++		++		++		++		++		++		++		++		++		++		⇧	
D	First	2	2																							*		⇧		⇩		•	2	•	2	•	3	•	4	0	4	0	5	1	7	2	9	4	12	6	16	⇧			
	Second	2	4																													•	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14	11	19	17	27				
	Third	2	6																													0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19	19	27	29	39				
	Fourth	2	8																													0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25	27	34	40	49				
	Fifth	2	10																													1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29	36	40	53	58				
	Sixth	2	12																													1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33	45	47	65	68				
	Seventh	2	14																													2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38	53	54	77	78				
E	First	3	3																					*		⇧		⇩		•	2	•	2	•	3	•	4	0	4	0	5	1	7	2	9	4	12	6	16	⇧					
	Second	3	6																											•	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14	11	19	17	27						
	Third	3	9																											0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19	19	27	29	39						
	Fourth	3	12																											0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25	27	34	40	49						
	Fifth	3	15																											1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29	36	40	53	58						
	Sixth	3	18																											1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33	45	47	65	68						
	Seventh	3	21																											2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38	53	54	77	78						
F	First	5	5																			*		⇧		⇩		•	2	•	2	•	3	•	4	0	4	0	5	1	7	2	9	⇧		⇧		⇧							
	Second	5	10																									•	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14												
	Third	5	15																									0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19												
	Fourth	5	20																									0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25												
	Fifth	5	25																									1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29												
	Sixth	5	30																									1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33												
	Seventh	5	35																									2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38												
G	First	8	8																	*		⇧		⇩		•	2	•	2	•	3	•	4	0	4	0	5	1	7	2	9	⇧													
	Second	8	16																							•	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14														
	Third	8	24																							0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19														
	Fourth	8	32																							0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25														
	Fifth	8	40																							1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29														
	Sixth	8	48																							1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33														
	Seventh	8	56																							2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38														
H	First	13	13															*		⇧		⇩		•	2	•	2	•	3	•	4	0	4	0	5	1	7	2	9	⇧															
	Second	13	26																					•	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																
	Third	13	39																					0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																
	Fourth	13	52																					0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																
	Fifth	13	65																					1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																
	Sixth	13	78																					1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																
	Seventh	13	91																					2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																
J	First	20	20													*		⇧		⇩		•	2	•	2	•	3	•	4	0	4	0	5	1	7	2	9	⇧																	
	Second	20	40																			•	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																		
	Third	20	60																			0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																		
	Fourth	20	80																			0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																		
	Fifth	20	100																			1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																		
	Sixth	20	120																			1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																		
	Seventh	20	140																			2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																		

⇩ = Use first sampling plan below arrow (refer to continuation of table on following page, when necessary). If sample size equals or exceeds lot or batch size, do 100 percent inspection.
⇧ = Use first sampling plan above arrow.
Ac = Acceptance number.
Re = Rejection number.
* = Use corresponding single sampling plan (or alternatively, use multiple sampling plan below, where available).
++ = Use corresponding double sampling plan (or alternatively, use multiple sampling plan below, where available).
• = Acceptance not permitted at this sample size.

TABLE IV-A — Multiple sampling plans for normal inspection (Master table)
(Continued)

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																																			
				0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
K	First	32	32	↓		↓		↓		↓		↓				↑		↓		*	2	*	2	*	3	*	4	0	4	0	5	1	7	2	9	↑		↑		↑		↑		↑		↑		↑		↑		↑		↑	
	Second	32	64																	*	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																				
	Third	32	96																	0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																				
	Fourth	32	128																	0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																				
	Fifth	32	160																	1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																				
	Sixth	32	192																	1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																				
	Seventh	32	224																	2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																				
L	First	50	50									*		↑		↓		*	2	*	2	*	3	*	4	0	4	0	5	1	7	2	9	↑																					
	Second	50	100															*	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																						
	Third	50	150															0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																						
	Fourth	50	200															0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																						
	Fifth	50	250															1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																						
	Sixth	50	300															1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																						
	Seventh	50	350															2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																						
M	First	80	80							*		↑		↓		*	2	*	2	*	3	*	4	0	4	0	5	1	7	2	9	↑																							
	Second	80	160													*	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																								
	Third	80	240													0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																								
	Fourth	80	320													0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																								
	Fifth	80	400													1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																								
	Sixth	80	480													1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																								
	Seventh	80	560													2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																								
N	First	125	125					*		↑		↓		*	2	*	2	*	3	*	4	0	4	0	5	1	7	2	9	↑																									
	Second	125	250											*	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																										
	Third	125	375											0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																										
	Fourth	125	500											0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																										
	Fifth	125	625											1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																										
	Sixth	125	750											1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																										
	Seventh	125	875											2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																										
P	First	200	200			*		↑		↓		*	2	*	2	*	3	*	4	0	4	0	5	1	7	2	9	↑																											
	Second	200	400									*	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																												
	Third	200	600									0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																												
	Fourth	200	800									0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																												
	Fifth	200	1000									1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																												
	Sixth	200	1200									1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																												
	Seventh	200	1400									2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																												
Q	First	315	315	*		↑		↓		*	2	*	2	*	3	*	4	0	4	0	5	1	7	2	9	↑																													
	Second	315	630							*	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																														
	Third	315	945							0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																														
	Fourth	315	1260							0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																														
	Fifth	315	1575							1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																														
	Sixth	315	1890							1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																														
	Seventh	315	2205							2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																														
R	First	500	500	↑				*	2	*	2	*	3	*	4	0	4	0	5	1	7	2	9	↑																															
	Second	500	1000					*	2	0	3	0	3	1	5	1	6	3	8	4	10	7	14																																
	Third	500	1500					0	2	0	3	1	4	2	6	3	8	6	10	8	13	13	19																																
	Fourth	500	2000					0	3	1	4	2	5	3	7	5	10	8	13	12	17	19	25																																
	Fifth	500	2500					1	3	2	4	3	6	5	8	7	11	11	15	17	20	25	29																																
	Sixth	500	3000					1	3	3	5	4	6	7	9	10	12	14	17	21	23	31	33																																
	Seventh	500	3500					2	3	4	5	6	7	9	10	13	14	18	19	25	26	37	38																																

↓ = Use first sampling plan below arrow. If sample size equals or exceeds lot or batch size, do 100 percent inspection.
↑ = Use first sampling plan above arrow (refer to preceding page, when necessary).
Ac = Acceptance number.
Re = Rejection number.
* = Use corresponding single sampling plan (or alternatively, use multiple plan below, where available).
* = Acceptance not permitted at this sample size.

TABLE IV-B — Multiple sampling plans for tightened inspection (Master table)

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (tightened inspection)																																																			
				0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A				⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		*		*		*		*		*		*		*		*	
B																																*						++		++		++		++		++		++		++		++		++	
C																														*		⇩				++		++		++		++		++		++		++		++		++		⇧	
	First	2	2																									*		⇩				#	2	#	2	#	3	#	4	0	4	0	6	1	8	3	10	6	15	⇧			
	Second	2	4																															#	2	0	3	0	3	1	5	2	7	3	9	6	12	10	17	16	25				
	Third	2	6																															0	2	0	3	1	4	2	6	4	9	7	12	11	17	17	24	26	36				
	Fourth	2	8																															0	3	1	4	2	5	3	7	6	11	10	15	16	22	24	31	37	46				
	Fifth	2	10																															1	3	2	4	3	6	5	8	9	12	14	17	22	25	32	37	49	55				
	Sixth	2	12																															1	3	3	5	4	6	7	9	12	14	18	20	27	29	40	43	61	64				
	Seventh	2	14																															2	3	4	5	6	7	9	10	14	15	21	22	32	33	48	49	72	73				
E	First	3	3																							*		⇩				#	2	#	2	#	3	#	4	0	4	0	6	1	8	3	10	6	15	⇧					
	Second	3	6																													#	2	0	3	0	3	1	5	2	7	3	9	6	12	10	17	16	25						
	Third	3	9																													0	2	0	3	1	4	2	6	4	9	7	12	11	17	17	24	26	36						
	Fourth	3	12																													0	3	1	4	2	5	3	7	6	11	10	15	16	22	24	31	37	46						
	Fifth	3	15																													1	3	2	4	3	6	5	8	9	12	14	17	22	25	32	37	49	55						
	Sixth	3	18																													1	3	3	5	4	6	7	9	12	14	18	20	27	29	40	43	61	64						
	Seventh	3	21																													2	3	4	5	6	7	9	10	14	15	21	22	32	33	48	49	72	73						
F	First	5	5																					*		⇩				#	2	#	2	#	3	#	4	0	4	0	6	1	8	⇧		⇧		⇧							
	Second	5	10																											#	2	0	3	0	3	1	5	2	7	3	9	6	12												
	Third	5	15																											0	2	0	3	1	4	2	6	4	9	7	12	11	17												
	Fourth	5	20																											0	3	1	4	2	5	3	7	6	11	10	15	16	22												
	Fifth	5	25																											1	3	2	4	3	6	5	8	9	12	14	17	22	25												
	Sixth	5	30																											1	3	3	5	4	6	7	9	12	14	18	20	27	29												
	Seventh	5	35																											2	3	4	5	6	7	9	10	14	15	21	22	32	33												
G	First	8	8																			*		⇩				#	2	#	2	#	3	#	4	0	4	0	6	1	8	⇧													
	Second	8	16																									#	2	0	3	0	3	1	5	2	7	3	9	6	12														
	Third	8	24																									0	2	0	3	1	4	2	6	4	9	7	12	11	17														
	Fourth	8	32																									0	3	1	4	2	5	3	7	6	11	10	15	16	22														
	Fifth	8	40																									1	3	2	4	3	6	5	8	9	12	14	17	22	25														
	Sixth	8	48																									1	3	3	5	4	6	7	9	12	14	18	20	27	29														
	Seventh	8	56																									2	3	4	5	6	7	9	10	14	15	21	22	32	33														
H	First	13	13																	*		⇩				#	2	#	2	#	3	#	4	0	4	0	6	1	8	⇧															
	Second	13	26																							#	2	0	3	0	3	1	5	2	7	3	9	6	12																
	Third	13	39																							0	2	0	3	1	4	2	6	4	9	7	12	11	17																
	Fourth	13	52																							0	3	1	4	2	5	3	7	6	11	10	15	16	22																
	Fifth	13	65																							1	3	2	4	3	6	5	8	9	12	14	17	22	25																
	Sixth	13	78																							1	3	3	5	4	6	7	9	12	14	18	20	27	29																
	Seventh	13	91																							2	3	4	5	6	7	9	10	14	15	21	22	32	33																
J	First	20	20															*		⇩				#	2	#	2	#	3	#	4	0	4	0	6	1	8	⇧																	
	Second	20	40																					#	2	0	3	0	3	1	5	2	7	3	9	6	12																		
	Third	20	60																					0	2	0	3	1	4	2	6	4	9	7	12	11	17																		
	Fourth	20	80																					0	3	1	4	2	5	3	7	6	11	10	15	16	22																		
	Fifth	20	100																					1	3	2	4	3	6	5	8	9	12	14	17	22	25																		
	Sixth	20	120																					1	3	3	5	4	6	7	9	12	14	18	20	27	29																		
	Seventh	20	140																					2	3	4	5	6	7	9	10	14	15	21	22	32	33																		

⇩ = Use first sampling plan below arrow (refer to continuation of table on following page, when necessary). If sample size equals or exceeds lot or batch size, do 100 percent inspection.
⇧ = Use first sampling plan above arrow.
Ac = Acceptance number.
Re = Rejection number.
* = Use corresponding single sampling plan (or alternatively, use multiple sampling plan below, where available).
++ = Use corresponding double sampling plan (or alternatively, use multiple sampling plan below, where available).
\# = Acceptance not permitted at this sample size.

TABLE IV-B — Multiple sampling plans for tightened inspection (Master table)
(Continued)

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (tightened inspection)																									
				0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
				Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
K	First	32	32	↓	↓	↓	↓	↓	↓	•	↓	↓	* 2	* 2	* 3	* 4	0 4	0 6	1 8	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	32	64										* 2	0 3	0 3	1 5	2 7	3 9	6 12										
	Third	32	96										0 2	0 3	1 4	2 6	4 9	7 12	11 17										
	Fourth	32	128										0 3	1 4	2 5	3 7	6 11	10 15	16 22										
	Fifth	32	160										1 3	2 4	3 6	5 8	9 12	14 17	22 25										
	Sixth	32	192										1 3	3 5	4 6	7 9	12 14	18 20	27 29										
	Seventh	32	224										2 3	4 5	6 7	9 10	14 15	21 22	32 33										
L	First	50	50						•	↓		* 2	* 2	* 3	* 4	0 4	0 6	1 8	↑										
	Second	50	100									* 2	0 3	0 3	1 5	2 7	3 9	6 12											
	Third	50	150									0 2	0 3	1 4	2 6	4 9	7 12	11 17											
	Fourth	50	200									0 3	1 4	2 5	3 7	6 11	10 15	16 22											
	Fifth	50	250									1 3	2 4	3 6	5 8	9 12	14 17	22 25											
	Sixth	50	300									1 3	3 5	4 6	7 9	12 14	18 20	27 29											
	Seventh	50	350									2 3	4 5	6 7	9 10	14 15	21 22	32 33											
M	First	80	80					•	↓		* 2	* 2	* 3	* 4	0 4	0 6	1 8	↑											
	Second	80	160								* 2	0 3	0 3	1 5	2 7	3 9	6 12												
	Third	80	240								0 2	0 3	1 4	2 6	4 9	7 12	11 17												
	Fourth	80	320								0 3	1 4	2 5	3 7	6 11	10 15	16 22												
	Fifth	80	400								1 3	2 4	3 6	5 8	9 12	14 17	22 25												
	Sixth	80	480								1 3	3 5	4 6	7 9	12 14	18 20	27 29												
	Seventh	80	560								2 3	4 5	6 7	9 10	14 15	21 22	32 33												
N	First	125	125				•	↓		* 2	* 2	* 3	* 4	0 4	0 6	1 8	↑												
	Second	125	250							* 2	0 3	0 3	1 5	2 7	3 9	6 12													
	Third	125	375							0 2	0 3	1 4	2 6	4 9	7 12	11 17													
	Fourth	125	500							0 3	1 4	2 5	3 7	6 11	10 15	16 22													
	Fifth	125	625							1 3	2 4	3 6	5 8	9 12	14 17	22 25													
	Sixth	125	750							1 3	3 5	4 6	7 9	12 14	18 20	27 29													
	Seventh	125	875							2 3	4 5	6 7	9 10	14 15	21 22	32 33													
P	First	200	200			•	↓		* 2	* 2	* 3	* 4	0 4	0 6	1 8	↑													
	Second	200	400						* 2	0 3	0 3	1 5	2 7	3 9	6 12														
	Third	200	600						0 2	0 3	1 4	2 6	4 9	7 12	11 17														
	Fourth	200	800						0 3	1 4	2 5	3 7	6 11	10 15	16 22														
	Fifth	200	1000						1 3	2 4	3 6	5 8	9 12	14 17	22 25														
	Sixth	200	1200						1 3	3 5	4 6	7 9	12 14	18 20	27 29														
	Seventh	200	1400						2 3	4 5	6 7	9 10	14 15	21 22	32 33														
Q	First	315	315		•	↓		* 2	* 2	* 3	* 4	0 4	0 6	1 8	↑														
	Second	315	630					* 2	0 3	0 3	1 5	2 7	3 9	6 12															
	Third	315	945					0 2	0 3	1 4	2 6	4 9	7 12	11 17															
	Fourth	315	1260					0 3	1 4	2 5	3 7	6 11	10 15	16 22															
	Fifth	315	1575					1 3	2 4	3 6	5 8	9 12	14 17	22 25															
	Sixth	315	1890					1 3	3 5	4 6	7 9	12 14	18 20	27 29															
	Seventh	315	2205					2 3	4 5	6 7	9 10	14 15	21 22	32 33															
R	First	500	500	•	↑		* 2	* 2	* 3	* 4	0 4	0 6	1 8	↑															
	Second	500	1000				* 2	0 3	0 3	1 5	2 7	3 9	6 12																
	Third	500	1500				0 2	0 3	1 4	2 6	4 9	7 12	11 17																
	Fourth	500	2000				0 3	1 4	2 5	3 7	6 11	10 15	16 22																
	Fifth	500	2500				1 3	2 4	3 6	5 8	9 12	14 17	22 25																
	Sixth	500	3000				1 3	3 5	4 6	7 9	12 14	18 20	27 29																
	Seventh	500	3500				2 3	4 5	6 7	9 10	14 15	21 22	32 33																
S	First	800	800			* 2																							
	Second	800	1600			* 2																							
	Third	800	2400			0 2																							
	Fourth	800	3200			0 3																							
	Fifth	800	4000			1 3																							
	Sixth	800	4800			1 3																							
	Seventh	800	5600			2 3																							

↓ = Use first sampling plan below arrow. If sample size equals or exceeds lot or batch size, do 100 percent inspection.
↑ = Use first sampling plan above arrow (refer to preceding page, when necessary).
Ac = Acceptance number
Re = Rejection number
• = Use corresponding single sampling plan (or alternatively, use multiple sampling plan below, where available).
* = Acceptance not permitted at this sample size.

TABLE IV-C—Multiple sampling plans for reduced inspection (Master table)

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (reduced inspection) †																			
				0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A				⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩		⇩	
B																							
C																							
D																							
E																							
F	First	2	2																			•	
	Second	2	4																				
	Third	2	6																				
	Fourth	2	8																				
	Fifth	2	10																				
	Sixth	2	12																				
	Seventh	2	14																				
G	First	3	3																	•		⇧	
	Second	3	6																				
	Third	3	9																				
	Fourth	3	12																				
	Fifth	3	15																				
	Sixth	3	18																				
	Seventh	3	21																				
H	First	5	5															•		⇧		⇩	
	Second	5	10																				
	Third	5	15																				
	Fourth	5	20																				
	Fifth	5	25																				
	Sixth	5	30																				
	Seventh	5	35																				
J	First	8	8													•		⇧		⇩		*	2
	Second	8	16																			*	2
	Third	8	24																			0	2
	Fourth	8	32																			0	3
	Fifth	8	40																			0	3
	Sixth	8	48																			0	3
	Seventh	8	56																			1	3
K	First	13	13											•		⇧		⇩		*	2	*	2
	Second	13	26																	*	2	*	3
	Third	13	39																	0	2	0	3
	Fourth	13	52																	0	3	0	4
	Fifth	13	65																	0	3	0	4
	Sixth	13	78																	0	3	1	5
	Seventh	13	91																	1	3	1	5

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (reduced inspection) †																															
				1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A				⇩		⇩		⇩		⇩		•		⇩		⇩		•		•		•		•		•		•		•		•		•	
B										•		⇧				•		•		•		•		•		•		•		•		•		•	
C								•		⇧		⇩		•		•		•		•		•		•		•		•		•		•		⇧	
D						•		⇧		⇩		↔		↔		↔		↔		↔		↔		↔		↔		↔		↔		⇧			
E				•		⇧		⇩		↔		↔		↔		↔		↔		↔		↔		↔		↔		↔		⇧					
F	First	2	2	⇧		⇩		*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧		⇧		⇧							
	Second	2	4					*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9												
	Third	2	6					0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12												
	Fourth	2	8					0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15												
	Fifth	2	10					0	3	0	4	1	6	2	7	3	8	5	11	7	13	11	17												
	Sixth	2	12					0	3	1	5	1	6	3	7	4	9	7	12	10	15	14	20												
	Seventh	2	14					1	3	1	5	2	7	4	8	6	10	9	14	13	17	18	22												
G	First	3	3	⇩		*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧													
	Second	3	6			*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9														
	Third	3	9			0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12														
	Fourth	3	12			0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15														
	Fifth	3	15			0	3	0	4	1	6	2	7	3	8	5	11	7	13	11	17														
	Sixth	3	18			0	3	1	5	1	6	3	7	4	9	7	12	10	15	14	20														
	Seventh	3	21			1	3	1	5	2	7	4	8	6	10	9	14	13	17	18	22														
H	First	5	5	*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧															
	Second	5	10	*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9																
	Third	5	15	0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12																
	Fourth	5	20	0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15																
	Fifth	5	25	0	3	0	4	1	6	2	7	3	8	5	11	7	13	11	17																
	Sixth	5	30	0	3	1	5	1	6	3	7	4	9	7	12	10	15	14	20																
	Seventh	5	35	1	3	1	5	2	7	4	8	6	10	9	14	13	17	18	22																
J	First	8	8	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧																	
	Second	8	16	*	3	*	3	0	4	0	5	1	6	1	7	3	9																		
	Third	8	24	0	3	0	4	0	5	1	6	2	8	3	9	6	12																		
	Fourth	8	32	0	4	0	5	1	6	2	7	3	10	5	12	8	15																		
	Fifth	8	40	0	4	1	6	2	7	3	8	5	11	7	13	11	17																		
	Sixth	8	48	1	5	1	6	3	7	4	9	7	12	10	15	14	20																		
	Seventh	8	56	1	5	2	7	4	8	6	10	9	14	13	17	18	22																		
K	First	13	13	*	3	*	3	*	4	*	4	0	5	0	6	⇧																			
	Second	13	26	*	3	0	4	0	5	1	6	1	7	3	9																				
	Third	13	39	0	4	0	5	1	6	2	8	3	9	6	12																				
	Fourth	13	52	0	5	1	6	2	7	3	10	5	12	8	15																				
	Fifth	13	65	1	6	2	7	3	8	5	11	7	13	11	17																				
	Sixth	13	78	1	6	3	7	4	9	7	12	10	15	14	20																				
	Seventh	13	91	2	7	4	8	6	10	9	14	13	17	18	22																				

⇩ = Use first sampling plan below arrow (refer to continuation of table on following page, when necessary). If sample size equals, or exceeds lot or batch size, do 100 percent inspection.
⇧ = Use first sampling plan above arrow.
Ac = Acceptance number
Re = Rejection number
• = Use corresponding single sampling plan (or alternatively, use multiple sampling plan below, where available).
↔ = Use corresponding double sampling plan (or alternatively, use multiple sampling plan below, where available).
* = Acceptance not permitted at this sample size.
† = If, after the final sample, the acceptance number has been exceeded, but the rejection number has not been reached, accept the lot but reinstate normal inspection (see 10.1.4).

TABLE IV-C — *Multiple sampling plans for reduced inspection (Master table)*
(Continued)

(See 9.4 and 9.5)

Sample size code letter	Sample	Sample size	Cumulative sample size	Acceptable Quality Levels (reduced inspection)†																																																			
				0.010		0.015		0.025		0.040		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10		15		25		40		65		100		150		250		400		650		1000	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
L	First	20	20	⇩		⇩		⇩		⇩		*		⇧		⇩		*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧		⇧		⇧		⇧		⇧		⇧		⇧		⇧		⇧		⇧		⇧	
	Second	20	40															*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9																						
	Third	20	60															0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12																						
	Fourth	20	80															0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15																						
	Fifth	20	100															0	3	0	4	1	6	2	7	3	8	5	11	7	13	11	17																						
	Sixth	20	120															0	3	1	5	1	6	3	7	4	9	7	12	10	15	14	20																						
	Seventh	20	140															1	3	1	5	2	7	4	8	6	10	9	14	13	17	18	22																						
M	First	32	32							*		⇧		⇩		*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧																							
	Second	32	64													*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9																								
	Third	32	96													0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12																								
	Fourth	32	128													0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15																								
	Fifth	32	160													0	3	0	4	1	6	2	7	3	8	5	11	7	13	11	17																								
	Sixth	32	192													0	3	1	5	1	6	3	7	4	9	7	12	10	15	14	20																								
	Seventh	32	224													1	3	1	5	2	7	4	8	6	10	9	14	13	17	18	22																								
N	First	50	50					*		⇧		⇩		*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧																									
	Second	50	100											*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9																										
	Third	50	150											0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12																										
	Fourth	50	200											0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15																										
	Fifth	50	250											0	3	0	4	1	6	2	7	3	8	5	11	7	13	11	17																										
	Sixth	50	300											0	3	1	5	1	6	3	7	4	9	7	12	10	15	14	20																										
	Seventh	50	350											1	3	1	5	2	7	4	8	6	10	9	14	13	17	18	22																										
P	First	80	80			*		⇧		⇩		*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧																											
	Second	80	160									*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9																												
	Third	80	240									0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12																												
	Fourth	80	320									0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15																												
	Fifth	80	400									0	3	0	4	1	6	2	7	[illegible]	8	5	11	7	13	11	17																												
	Sixth	80	480									0	3	1	5	1	6	3	7	[illegible]	9	7	12	10	15	14	20																												
	Seventh	80	560									1	3	1	5	2	7	4	8	6	[illegible]	9	14	13	17	18	22																												
Q	First	125	125	*		⇧		⇩		*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧																													
	Second	125	250							*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9																														
	Third	125	375							0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12																														
	Fourth	125	500							0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15																														
	Fifth	125	625							0	3	0	4	1	6	2	7	3	8	5	11	7	13	11	17																														
	Sixth	125	750							0	3	1	5	1	6	3	7	4	9	7	12	10	15	14	20																														
	Seventh	125	875							1	3	1	5	2	7	4	8	6	10	9	14	13	17	18	22																														
R	First	200	200	⇧				*	2	*	2	*	3	*	3	*	4	*	4	0	5	0	6	⇧																															
	Second	200	400					*	2	*	3	*	3	0	4	0	5	1	6	1	7	3	9																																
	Third	200	600					0	2	0	3	0	4	0	5	1	6	2	8	3	9	6	12																																
	Fourth	200	800					0	3	0	4	0	5	1	6	2	7	3	10	5	12	8	15																																
	Fifth	200	1000					0	3	0	4	1	6	2	7	3	8	5	11	7	13	11	17																																
	Sixth	200	1200					0	3	1	5	1	6	3	7	4	9	7	12	10	15	14	20																																
	Seventh	200	1400					1	3	1	5	2	7	4	8	6	10	9	14	13	17	18	22																																

⇩ = Use first sampling plan below arrow. If sample size equals, or exceeds, lot or batch size, do 100 percent inspection.

⇧ = Use first sampling plan above arrow (refer to preceding page when necessary).

Ac = Acceptance number

Re = Rejection number

* = Acceptance not permitted at this sample size.

† = If, after the final sample, the acceptance number has been exceeded, but the rejection number has not been reached, accept the lot, but reinstate normal inspection (see 10.1.4).

AOQL
NORMAL

TABLE V-A—*Average Outgoing Quality Limit Factors for Normal Inspection (Single sampling)*

(See 11.4)

Code Letter	Sample Size	Acceptable Quality Level																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
A	2															18			42	69	97	160	220	330	470	730	1100
B	3														12			28	46	65	110	150	220	310	490	720	1100
C	5													7.4			17	27	39	63	90	130	190	290	430	660	
D	8												4.6			11	17	24	40	56	82	120	180	270	410		
E	13											2.8			6.5	11	15	24	34	50	72	110	170	250			
F	20										1.8			4.2	6.9	9.7	16	22	33	47	73						
G	32									1.2			2.6	4.3	6.1	9.9	14	21	29	46							
H	50								0.74			1.7	2.7	3.9	6.3	9.0	13	19	29								
J	80							0.46			1.1	1.7	2.4	4.0	5.6	8.2	12	18									
K	125						0.29			0.67	1.1	1.6	2.5	3.6	5.2	7.5	12										
L	200					0.18			0.42	0.69	0.97	1.6	2.2	3.3	4.7	7.3											
M	315				0.12			0.27	0.44	0.62	1.00	1.4	2.1	3.0	4.7												
N	500			0.074			0.17	0.27	0.39	0.63	0.90	1.3	1.9	2.9													
P	800		0.046			0.11	0.17	0.24	0.40	0.56	0.82	1.2	1.8														
Q	1250	0.029			0.067	0.11	0.16	0.25	0.36	0.52	0.75	1.2															
R	2000			0.042	0.069	0.097	0.16	0.22	0.33	0.47	0.73																

Note: For the exact AOQL, the above values must be multiplied by $\left(1 - \frac{\text{Sample size}}{\text{Lot or Batch size}}\right)$ (see 11.4)

TABLE V-B—Average Outgoing Quality Limit Factors for Tightened Inspection (Single sampling)

(See 11.4)

Code letter	Sample size	Acceptable Quality Level																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
A	2																			42	69	97	160	260	400	620	970
B	3															12			28	46	65	110	170	270	410	650	1100
C	5														7.4			17	27	39	63	100	160	250	390	610	
D	8													4.6			11	17	24	40	64	99	160	240	380		
E	13												2.8			6.5	11	15	24	40	61	95	150	240			
F	20											1.8			4.2	6.9	9.7	16	26	40	62						
G	32										1.2			2.6	4.3	6.1	9.9	16	25	39							
H	50									0.74			1.7	2.7	3.9	6.3	10	16	25								
J	80								0.46			1.1	1.7	2.4	4.0	6.4	9.9	16									
K	125							0.29			0.67	1.1	1.6	2.5	4.1	6.4	9.9										
L	200						[illegible]			0.42	0.69	0.97	1.6	2.6	4.0	6.2											
M	315					0.12			0.27	0.44	0.62	1.0	1.6	2.5	3.9												
N	500				0.074			0.17	0.27	0.39	0.63	1.0	1.6	2.5													
P	800			0.046			0.11	0.17	0.24	0.40	0.64	0.99	1.6														
Q	1250		0.029			0.067	0.11	0.16	0.25	0.41	0.64	0.99															
R	2000	0.018			0.042	0.069	0.097	0.16	0.26	0.40	0.62																
S	3150			0.027																							

Note: For the exact AOQL, the above values must be multiplied by $\left(1 - \frac{\text{Sample size}}{\text{Lot or Batch size}}\right)$ (see 11.4)

AOQL
TIGHTENED

LQ (DEFECTIVES)
10.0%

TABLE VI-A—Limiting Quality (in percent defective) for which P_a = 10 Percent (for Normal Inspection, Single sampling)

(See 11.6)

Code letter	Sample size	Acceptable Quality Level															
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10
A	2															68	
B	3														54		
C	5													37			58
D	8												25			41	54
E	13											16			27	36	44
F	20										11			18	25	30	42
G	32									6.9			12	16	20	27	34
H	50								4.5			7.6	10	13	18	22	29
J	80							2.8			4.8	6.5	8.2	11	14	19	24
K	125						1.8			3.1	4.3	5.4	7.4	9.4	12	16	23
L	200					1.2			2.0	2.7	3.3	4.6	5.9	7.7	10	14	
M	315				0.73			1.2	1.7	2.1	2.9	3.7	4.9	6.4	9.0		
N	500			0.46			0.78	1.1	1.3	1.9	2.4	3.1	4.0	5.6			
P	800		0.29			0.49	0.67	0.84	1.2	1.5	1.9	2.5	3.5				
Q	1250	0.18			0.31	0.43	0.53	0.74	0.94	1.2	1.6	2.3					
R	2000			0.20	0.27	0.33	0.46	0.59	0.77	1.0	1.4						

TABLE VI-B—*Limiting Quality (in defects per hundred units) for which* P_a *= 10 Percent*
(for Normal Inspection, Single sampling)

(See 11.6)

Code letter	Sample size	Acceptable Quality Level																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
A	2															120			200	270	330	460	590	770	1000	1400	1900
B	3														77			130	180	220	310	390	510	670	940	1300	1800
C	5													46			78	110	130	190	240	310	400	560	770	1100	
D	8												29			49	67	84	120	150	190	250	350	480	670		
E	13											18			30	41	51	71	91	120	160	220	300	410			
F	20										12			20	27	33	46	59	77	100	140						
G	32									7.2			12	17	21	29	37	48	63	88							
H	50								4.6			7.8	11	13	19	24	31	40	56								
J	80							2.9			4.9	6.7	8.4	12	15	19	25	35									
K	125						1.8			3.1	4.3	5.4	7.4	9.4	12	16	23										
L	200					1.2			2.0	2.7	3.3	4.6	5.9	7.7	10	14											
M	315				0.73			1.2	1.7	2.1	2.9	3.7	4.9	6.4	9.0												
N	500			0.46			0.78	1.1	1.3	1.9	2.4	3.1	4.0	5.6													
P	800		0.29			0.49	0.67	0.84	1.2	1.5	1.9	2.5	3.5														
Q	1250	0.18			0.31	0.43	0.53	0.74	0.94	1.2	1.6	2.3															
R	2000			0.20	0.27	0.33	0.46	0.59	0.77	1.0	1.4																

LQ (DEFECTS)
10%

LQ (DEFECTIVES)
5.0%

TABLE VII-A—Limiting Quality (in percent defective) for which P_a = 5 Percent (for Normal Inspection, Single sampling)

(See 11.6)

Code letter	Sample size	Acceptable Quality Level															
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10
A	2															78	
B	3														63		
C	5													45			66
D	8												31			47	60
E	13											21			32	41	50
F	20										14			22	28	34	46
G	32									8.9			14	18	23	30	37
H	50								5.8			9.1	12	15	20	25	32
J	80							3.7			5.8	7.7	9.4	13	16	20	25
K	125						2.4			3.8	5.0	6.2	8.4	11	14	18	24
L	200					1.5			2.4	3.2	3.9	5.3	6.6	8.5	11	15	
M	315				0.95			1.5	2.0	2.5	3.3	4.2	5.4	7.0	9.6		
N	500			0.60			0.95	1.3	1.6	2.1	2.6	3.4	4.4	6.1			
P	800		0.38			0.59	0.79	0.97	1.3	1.6	2.1	2.7	3.8				
Q	1250	0.24			0.38	0.50	0.62	0.84	1.1	1.4	1.8	2.4					
R	2000			0.24	0.32	0.39	0.53	0.66	0.85	1.1	1.5						

TABLE VII-B—Limiting Quality (in defects per hundred units) for which P_a = 5 Percent (for Normal Inspection, Single sampling)

(See 11.6)

Code letter	Sample size	Acceptable Quality Level																									
		0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
A	2															150			240	320	390	530	660	850	1100	1500	2000
B	3														100			160	210	260	350	440	570	730	1000	1400	1900
C	5													60			95	130	160	210	260	340	440	610	810	1100	
D	8												38			59	79	97	130	160	210	270	380	510	710		
E	13											23			37	48	60	81	100	130	170	230	310	440			
F	20										15			24	32	39	53	66	85	110	150						
G	32									9.4			15	20	24	33	41	53	68	95							
H	50								6.0			9.5	13	16	21	26	34	44	61								
J	80							3.8			5.9	7.9	9.7	13	16	21	27	38									
K	125						2.4			3.8	5.0	6.2	8.4	11	14	18	24										
L	200					1.5			2.4	3.2	3.9	5.3	6.6	8.5	11	15											
M	315				0.95			1.5	2.0	2.5	3.3	4.2	5.4	7.0	9.6												
N	500			0.60			0.95	1.3	1.6	2.1	2.6	3.4	4.4	6.1													
P	800		0.38			0.59	0.79	0.97	1.3	1.6	2.1	2.7	3.8														
Q	1250	0.24			0.38	0.50	0.62	0.84	1.1	1.4	1.8	2.4															
R	2000			0.24	0.32	0.39	0.53	0.66	0.85	1.1	1.5																

LQ (DEFECTS)
5%

LIMIT
NUMBERS

TABLE VIII — Limit Numbers for Reduced Inspection

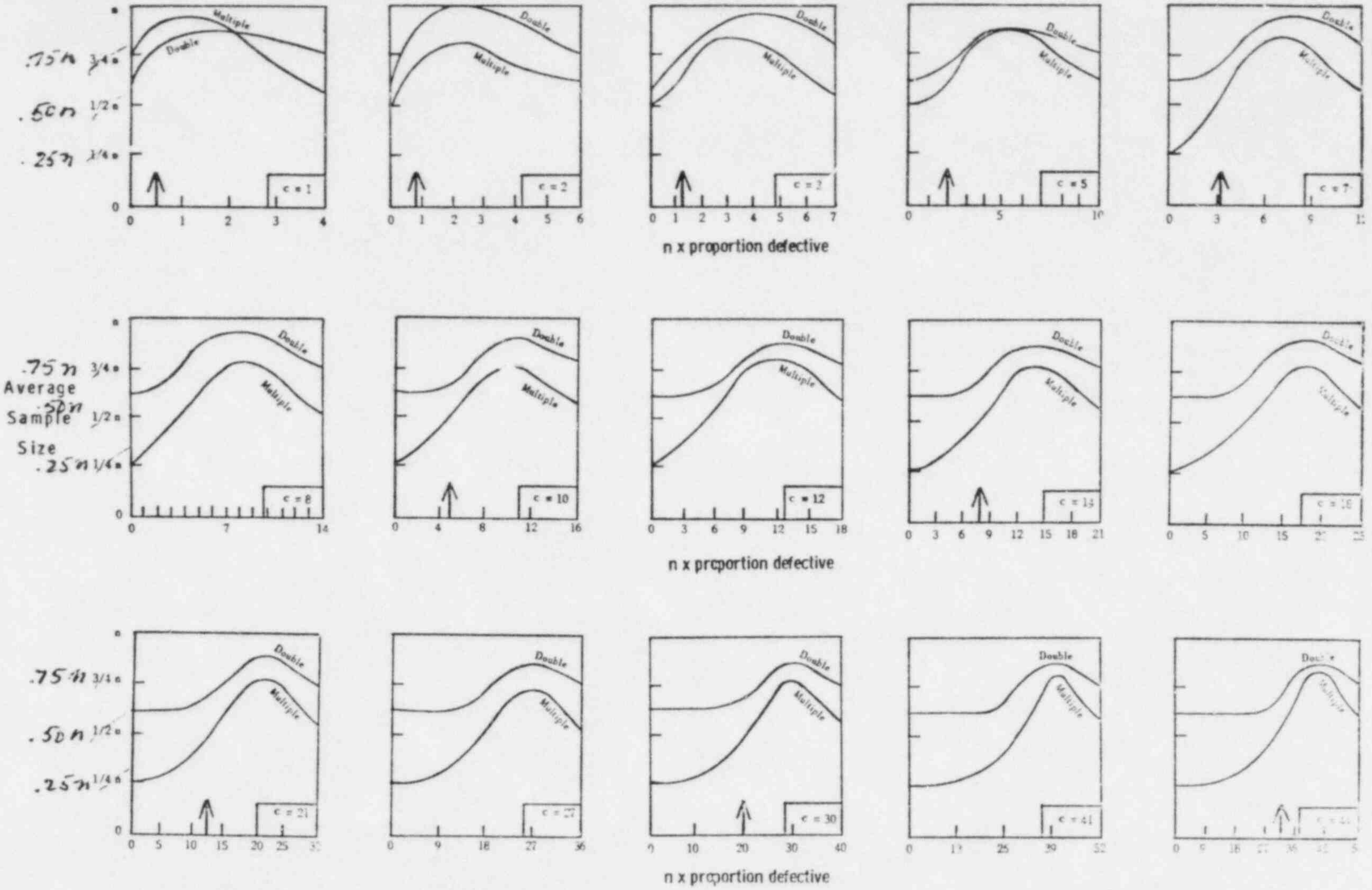
(See 8.3.3)

Number of sample units from last 10 lots or batches	Acceptable Quality Level																									
	0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
20 - 29	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	2	4	8	14	22	40	68	115	181
30 - 49	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	1	3	7	13	22	36	63	105	178	277
50 - 79	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	2	3	7	14	25	40	63	110	181	301	
80 - 129	*	*	*	*	*	*	*	*	*	*	*	*	0	0	2	4	7	14	24	42	68	105	181	297		
130 - 199	*	*	*	*	*	*	*	*	*	*	*	0	0	2	4	7	13	25	42	72	115	177	301	490		
200 - 319	*	*	*	*	*	*	*	*	*	*	0	0	2	4	8	14	22	40	68	115	181	277	471			
320 - 499	*	*	*	*	*	*	*	*	*	0	0	1	4	8	14	24	39	68	113	189						
500 - 799	*	*	*	*	*	*	*	*	0	0	2	3	7	14	25	40	63	110	181							
800 - 1249	*	*	*	*	*	*	*	0	0	2	4	7	14	24	42	68	105	181								
1250 - 1999	*	*	*	*	*	*	0	0	2	4	7	13	24	40	69	110	169									
2000 - 3149	*	*	*	*	*	0	0	2	4	8	14	22	40	68	115	181										
3150 - 4999	*	*	*	*	0	0	1	4	8	14	24	38	67	111	186											
5000 - 7999	*	*	*	0	0	2	3	7	14	25	40	63	110	181												
8000 - 12499	*	*	0	0	2	4	7	14	24	42	68	105	181													
12500 - 19999	*	0	0	2	4	7	13	24	40	69	110	169														
20000 - 31499	0	0	2	4	8	14	22	40	68	115	181															
31500 - 49999	0	1	4	8	14	24	38	67	111	186																
50000 & Over	2	3	7	14	25	40	63	110	181	301																

* Denotes that the number of sample units from the last ten lots or batches is not sufficient for reduced inspection for this AQL. In this instance more than ten lots or batches may be used for the calculation, provided that the lots or batches used are the most recent ones in sequence, that they have all been on normal inspection, and that none has been rejected while on original inspection.

TABLE IX — *Average sample size curves for double and multiple sampling (normal and tightened inspection)*

(See 11.5)



n = Equivalent single sample size

c = Single sample acceptance number

↑ = AQL for normal inspection

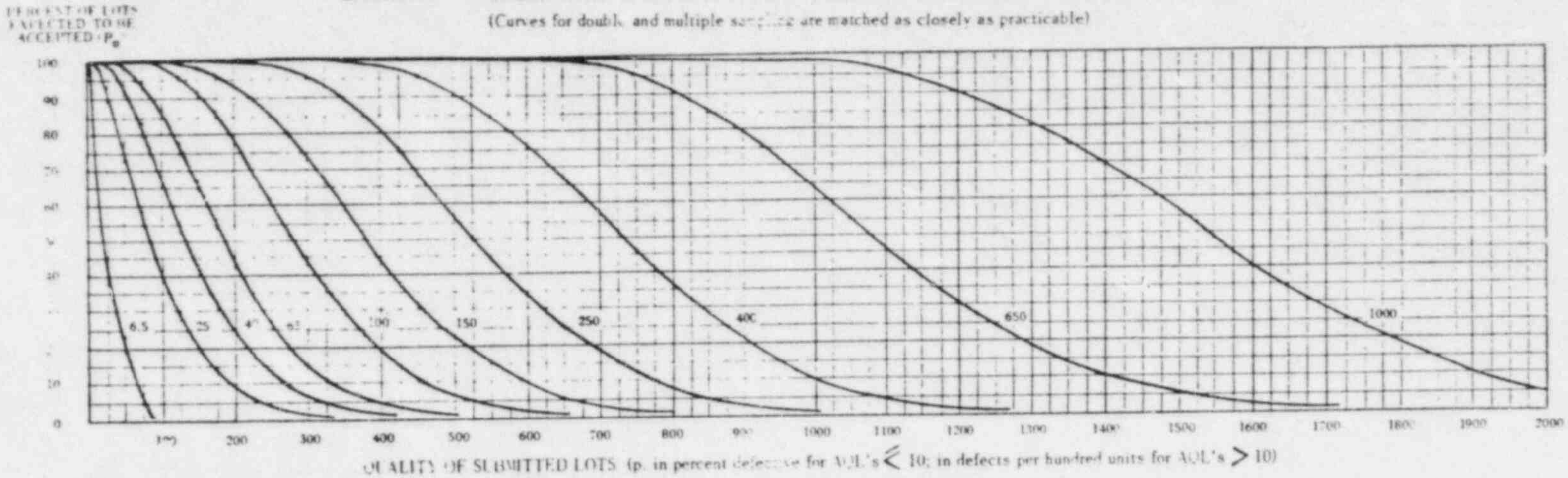
AVERAGE SAMPLE SIZE

A

TABLE X-A—Tables for sample size code letter: A

CHART A - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-A-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)														
	6.5	6.5	25	40	65	100	150	╳	250	╳	400	╳	650	╳	1000
	p (in percent defective)	p (in defects per hundred units)													
99.0	0.501	0.50	7.45	21.8	41.2	89.2	145	175	239	305	374	517	629	859	977
95.0	2.53	2.56	17.8	40.9	68.3	131	199	235	308	385	462	622	745	995	1122
90.0	5.13	5.25	26.6	55.1	87.3	158	233	272	351	432	515	684	812	1073	1206
75.0	13.4	14.4	48.1	86.8	127	211	298	342	431	521	612	795	934	1314	1354
50.0	29.3	34.7	83.9	134	184	284	383	433	533	633	733	933	1083	1383	1533
25.0	50.0	69.3	135	196	256	371	481	540	651	761	870	1087	1248	1568	1728
10.0	68.4	115	195	266	334	464	589	650	770	889	1006	1238	1409	1748	1916
5.0	77.6	150	237	315	388	526	657	722	848	972	1094	1334	1512	1862	2035
1.0	90.0	230	332	420	502	655	800	870	1007	1141	1272	1529	1718	2088	2270
	╳	╳	40	65	100	150	╳	250	╳	400	╳	650	╳	1000	╳
	Acceptable Quality Levels (tightened inspection)														

Note: Binomial distribution used for percent defective computations; Poisson for defects per hundred units.

TABLE X-A-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: A

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																				Cumulative sample size
		Less than 6.5		6.5		☒		10		15		25		40		65		100		150		☒		250		☒		400		☒		650		☒		1000		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	2	▽		0	1	Use Letter D		Use Letter C		Use Letter B		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	27	28	30	31	2
Double		▽		*								(*)		(*)		(*)		(*)		(*)		(*)		(*)		(*)		(*)		(*)		(*)		(*)		(*)		
Multiple		▽		*								*		*		*		*		*		*		*		*		*		*		*		*		*		
		Less than 10		☒		10		15		25		40		65		100		150		☒		250		☒		400		☒		650		☒		1000		☒		
		Acceptable Quality Levels (tightened inspection)																																				

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number

Re = Rejection number

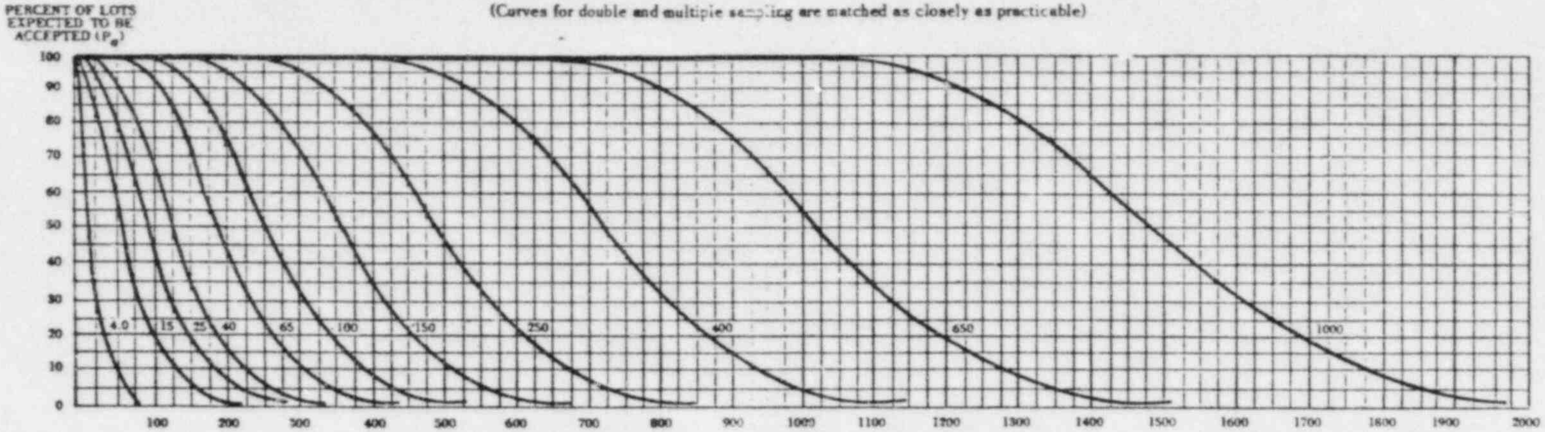
* = Use single sampling plan above (or alternatively use lette D).

(*) = Use single sampling (or alternatively use letter B).

TABLE X-B—Tables for sample size code letter: B

CHART B - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-B-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

Pa	Acceptable Quality Levels (normal inspection)																
	4.0	4.0	15	25	40	65	100	✕	150	✕	250	✕	400	✕	650	✕	1000
	p (in percent defective)	p (in defects per hundred units)															
99.0	0.33	0.34	4.97	14.5	27.4	59.5	96.9	117	159	203	249	345	419	573	651	947	1029
95.0	1.70	1.71	11.8	27.3	45.5	87.1	133	157	206	256	308	415	496	663	748	1065	1152
90.0	3.45	3.50	17.7	36.7	58.2	105	155	181	234	288	343	456	541	716	804	1131	1222
75.0	9.14	9.60	32.0	57.6	84.5	141	199	228	287	347	408	530	623	809	903	1249	1344
50.0	20.6	23.1	55.9	89.1	122	189	256	289	356	422	489	622	722	922	1022	1389	1489
25.0	37.0	46.2	89.8	131	170	247	323	360	434	507	580	724	832	1046	1152	1539	1644
10.0	53.6	76.8	130	177	223	309	392	433	514	593	671	825	939	1165	1277	1683	1793
5.0	63.2	99.9	158	210	258	350	438	481	565	648	730	890	1008	1241	1356	1773	1886
1.0	78.4	154	221	280	335	437	533	580	672	761	848	1019	1145	1392	1513	1951	2069
	6.5	6.5	25	40	65	100	✕	150	✕	250	✕	400	✕	650	✕	1000	✕
	Acceptable Quality Levels (tightened inspection)																

Note: Binomial distribution used for percent defective computations; Poisson for defects per hundred units.

TABLE X-B-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: B

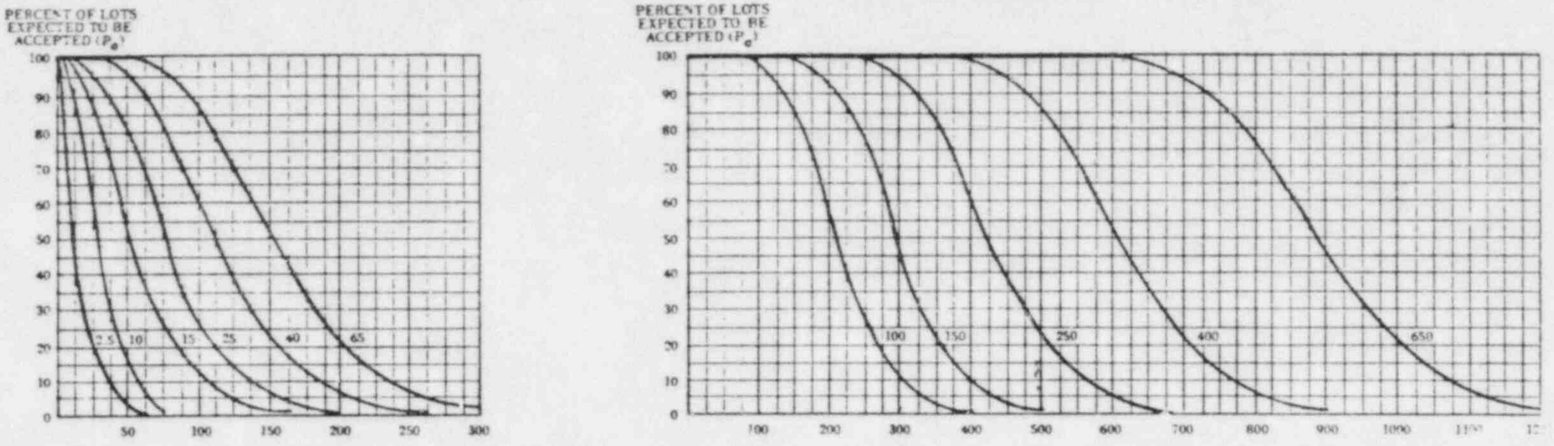
Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																								Cumulative sample size
		Less than 4.0		4.0		6.5		X		10		15		25		40		65		100		X		150		X		250		X		400		X		650		X		1000		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	3	▽		0	1							1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	27	28	30	31	41	42	44	45	3
Double	2	▽		•		Use Letter A		Use Letter D		Use Letter C		0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	15	20	17	22	23	29	25	31	2
	4											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27	34	35	37	38	52	53	56	57	4
Multiple		▽		•								++		++		++		++		++		++		++		++		++		++		++		++		++		++		++		
		Less than 6.5		6.5		X		10		15		25		40		65		100		X		150		X		250		X		400		X		550		X		1000		X		
		Acceptable Quality Levels (tightened inspection)																																								

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.
Ac = Acceptance number
Re = Rejection number
• = Use single sampling plan above (or alternatively use letter E).
++ = Use double sampling plan above (or alternatively use letter D).

TABLE X-C — Tables for sample size code letter: C

CHART C - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's $\leq$ 10; in defects per hundred units for AQL's $>$ 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-C-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)																	
	2.5	10	2.5	10	15	25	40	65	╳	100	╳	150	╳	250	╳	400	╳	650
	p (in percent defective)		p (in defects per hundred units)															
99.0	0.20	3.28	0.20	2.89	8.72	16.5	35.7	58.1	70.1	95.4	122	150	207	251	344	39	568	618
95.0	1.02	7.63	1.03	7.10	16.4	27.3	52.3	79.6	93.9	123	154	185	249	298	398	449	639	691
90.0	2.09	11.2	2.10	10.6	22.0	34.9	63.0	93.1	109	140	173	206	273	325	429	482	679	733
75.0	5.59	19.4	5.76	19.2	34.5	50.7	84.4	119	137	172	208	245	318	374	485	542	749	806
50.0	12.9	31.4	13.9	33.6	53.5	73.4	113	153	173	213	253	293	373	433	553	613	833	893
25.0	24.2	45.4	27.7	53.9	78.4	102	148	194	216	260	304	348	435	499	627	691	923	987
10.0	36.9	58.4	46.1	77.8	106	134	186	235	260	308	356	403	495	564	699	766	1010	1076
5.0	45.1	65.8	59.9	94.9	126	155	210	263	289	339	389	438	534	605	745	814	1064	1131
1.0	60.2	77.8	92.1	133	168	201	262	320	348	403	456	509	612	687	835	908	1171	1241
	4.0	╳	4.0	15	25	40	65	╳	100	╳	150	╳	250	╳	400	╳	650	╳
	Acceptable Quality Levels (tightened inspection)																	

Note: Binomial distribution used for percent defective computations; Poisson for defects per hundred units.

TABLE X-C-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: C

Type of sampling plan	Cumulative sample size	Less than 2.5		2.5		4.0		X		6.5		10		15		25		40		65		X		100		X		150		X		250		X		400		X		650		1000		Cumulative sample size
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	5	▽		0	1	Use Letter B		Use Letter E		Use Letter D		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	27	28	30	31	41	42	44	45	Use Letter B		5
Double	3	▽		*								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	15	20	17	22	23	29	25	31			3
	6											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27	34	35	37	38	52	53	56	57			6
Multiple		▽		*								++		++		++		++		++		++		++		++		++		++		++		++		++		++		++				
		Less than 4.0		4.0		X		6.5		10		15		25		40		65		X		100		X		150		X		250		X		400		X		650		X		1000		

Acceptable Quality Levels (tightened inspection)

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number.

Re = Rejection number.

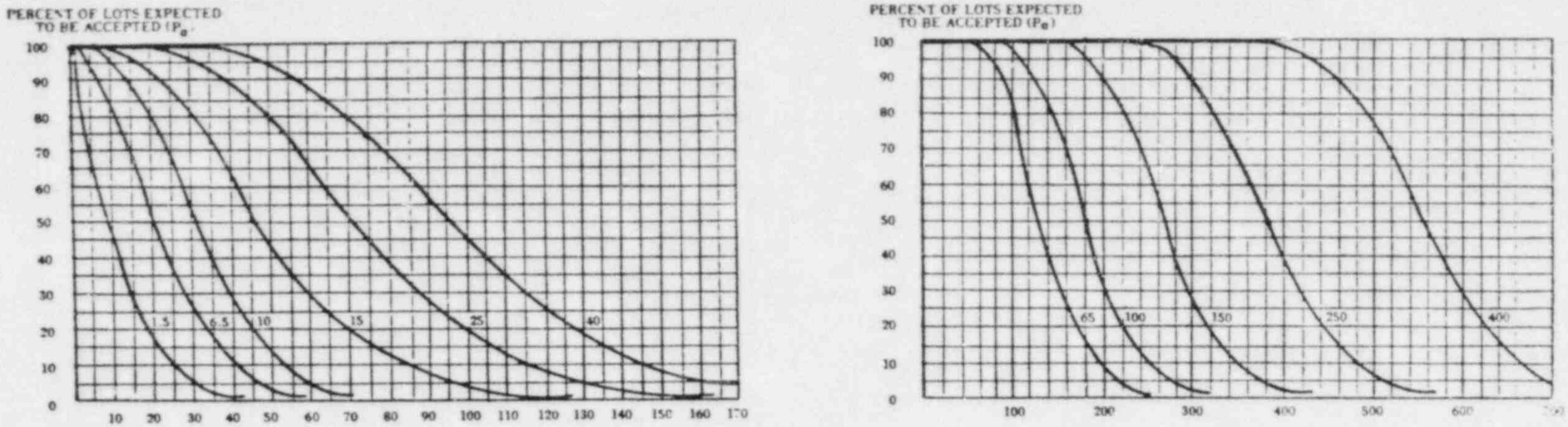
* = Use single sampling plan above (or alternatively use letter F).

++ = Use double sampling plan above (or alternatively use letter D).

TABLE X-D—Tables for sample size code letter: D

CHART D - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-D-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)																		
	1.5	6.5	10	1.5	6.5	10	15	25	40	╳	65	╳	100	╳	150	╳	250	╳	400
	p (in percent defective)			p (in defects per hundred units)															
99.0	0.13	2.00	6.00	0.13	1.86	5.45	10.3	22.3	36.3	43.8	59.6	76.2	93.5	129	157	215	244	355	366
95.0	0.64	2.64	11.1	0.64	4.44	10.2	17.1	32.7	49.8	58.7	77.1	96.1	116	156	186	249	281	399	432
90.0	1.31	6.88	14.7	1.31	6.65	13.8	21.8	39.4	58.2	67.9	87.8	108	129	171	203	268	301	424	459
75.0	3.53	12.1	22.1	3.60	12.0	21.6	31.7	52.7	74.5	85.5	108	130	153	199	234	303	339	468	504
50.0	8.30	20.1	32.1	8.66	21.0	33.4	45.9	70.9	95.9	108	133	158	183	233	271	346	383	521	559
25.0	15.9	30.3	43.3	17.3	33.7	49.0	63.9	92.8	121	135	163	190	218	272	312	392	432	577	617
10.0	25.0	40.6	53.9	28.8	48.6	66.5	83.5	116	147	162	193	222	252	309	352	437	478	631	672
5.0	31.2	47.1	59.9	37.5	59.3	78.7	96.9	131	164	180	212	243	274	334	378	465	509	665	707
1.0	43.8	58.8	70.7	57.6	83.0	105	126	164	200	218	252	285	318	382	429	522	568	732	774
	2.5	10	╳	2.5	10	15	25	40	╳	65	╳	100	╳	150	╳	250	╳	400	╳
	Acceptable Quality Levels (tightened inspection)																		

NOTE: BINOMINAL DISTRIBUTION USED FOR PERCENT DEFECTIVE COMPUTATIONS, POISSON FOR DEFECTS PER HUNDRED UNITS

TABLE X-D-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: D

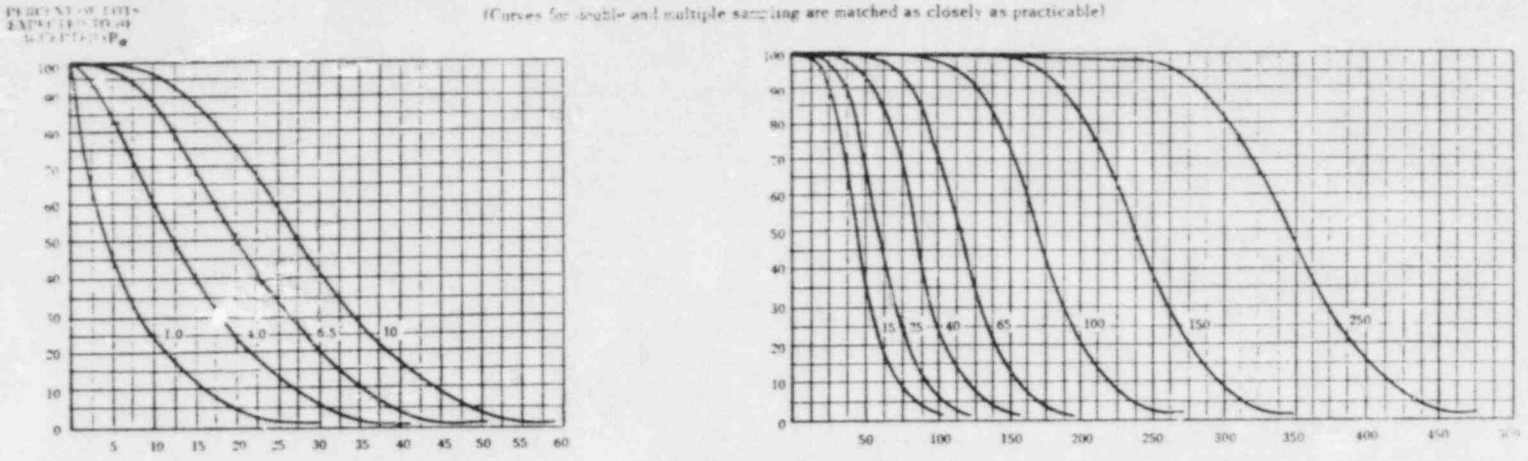
Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																										Cumulative sample size
		Less than 1.5		1.5		2.5		╳		4.0		6.5		10		15		25		40		╳		65		╳		100		╳		150		╳		250		╳		400		Higher than 400		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	8	▽		0	1	Use Letter C		Use Letter F		Use Letter E		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	27	28	30	31	41	42	44	45	△		8
Double	5	▽		•								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	15	20	17	22	23	29	25	31	△		5
	10											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27	34	35	37	38	52	53	56	57			10
Multiple	2	▽		•								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	3	10	4	12	6	15	6	16	△		2
	4											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14	10	17	11	19	16	25	17	27			4
	6											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19	17	24	19	27	26	36	29	39			6
	8											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25	24	31	27	34	37	46	40	49			8
	10											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29	32	37	36	40	49	55	53	58			10
	12											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33	40	43	45	47	61	64	65	68			12
	14											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38	48	49	53	54	72	73	77	78			14
		Less than 2.5		2.5		╳		4.0		6.5		10		15		25		40		╳		65		╳		100		╳		150		╳		250		╳		400		╳		Higher than 400		
		Acceptable Quality Levels (tightened inspection)																																										

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.
▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.
Ac = Acceptance number
Re = Rejection number
• = Use single sampling plan above (or alternatively use letter G).
= Acceptance not permitted at this sample size.

TABLE X-E—Tables for sample size code letter: E

CHART E - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-E-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)																			
	1.0	4.0	6.5	10	1.0	4.0	6.5	10	15	25	×	40	×	65	×	100	×	150	×	250
	p (in percent defective)				p (in defects per hundred units)															
99.0	0.077	1.19	3.63	7.00	0.078	1.15	3.35	6.33	13.7	22.4	27.0	36.7	46.9	57.5	79.6	96.7	132	150	219	238
95.0	0.394	2.81	6.63	11.3	0.395	2.73	6.29	10.5	20.1	30.6	36.1	47.5	59.2	71.1	95.7	115	153	173	246	266
90.0	0.807	4.16	8.80	14.2	0.808	4.09	8.48	13.4	24.2	35.8	41.8	54.0	66.5	79.2	105	125	165	185	261	282
75.0	2.19	7.41	13.4	19.9	2.22	7.39	13.3	19.5	32.5	45.8	52.6	66.3	80.2	94.1	122	144	187	208	288	310
50.0	5.19	12.6	20.0	27.5	5.33	12.9	20.6	28.2	43.6	59.0	66.7	82.1	97.5	113	144	168	213	236	321	344
25.0	10.1	19.4	28.0	36.2	10.7	20.7	30.2	39.3	57.1	74.5	83.1	100	117	134	167	192	241	266	355	379
10.0	16.2	26.8	36.0	44.4	17.7	29.9	40.9	51.4	71.3	90.5	100	119	137	155	190	217	269	295	388	414
5.0	20.6	31.6	41.0	49.5	23.0	36.5	48.4	59.6	80.9	101	111	130	150	168	205	233	286	313	409	435
1.0	29.8	41.5	50.6	58.7	35.4	51.1	64.7	77.3	101	123	134	155	176	196	235	264	321	349	450	477
	1.5	6.5	10	×	1.5	6.5	10	15	25	×	40	×	65	×	100	×	150	×	250	×
	Acceptable Quality Levels (tightened inspection)																			

Note: Binomial distribution used for percent defective computations; Poisson for defects per hundred units

TABLE X-E-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: E

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																										Cumulative sample size
		Less than 1.0		1.0		1.5		X		2.5		4.0		6.5		10		15		25		X		40		X		65		X		100		X		150		X		250		Higher than 250		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	13	▽		0	1	Use Letter D		Use Letter G		Use Letter F		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	27	28	30	31	41	42	44	45	△		13
Double	8	▽		*								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	15	20	17	22	23	29	25	31	△		8
	16											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27	34	35	37	38	52	53	56	57			16
Multiple	3	▽		*								[illegible]	[illegible]	[illegible]	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	3	10	4	12	6	15	6	16	△		3
	6											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14	10	17	11	19	16	25	17	27			6
	9											0	[illegible]	[illegible]	[illegible]	[illegible]	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19	17	24	19	27	26	36	29	39			9
	12											0	3	1	[illegible]	[illegible]	[illegible]	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25	24	31	27	34	37	46	40	49			12
	15											1	3	2	[illegible]	[illegible]	[illegible]	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29	32	37	36	40	49	55	53	58			15
	18											1	3	3	5	[illegible]	[illegible]	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33	40	43	45	47	61	64	65	68			18
	21											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38	48	49	53	54	72	73	77	78			21
		Less than 1.5		1.5		X		2.5		4.0		6.5		10		15		25		X		40		X		65		X		100		X		150		X		250		X		Higher then 250		
		Acceptable Quality Levels (tightened inspection)																																										

△ = Use next preceding sample size-code letter for which acceptance and rejection numbers are available.

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number.

Re = Rejection number.

* = Use single sampling plan above (or alternatively use letter H).

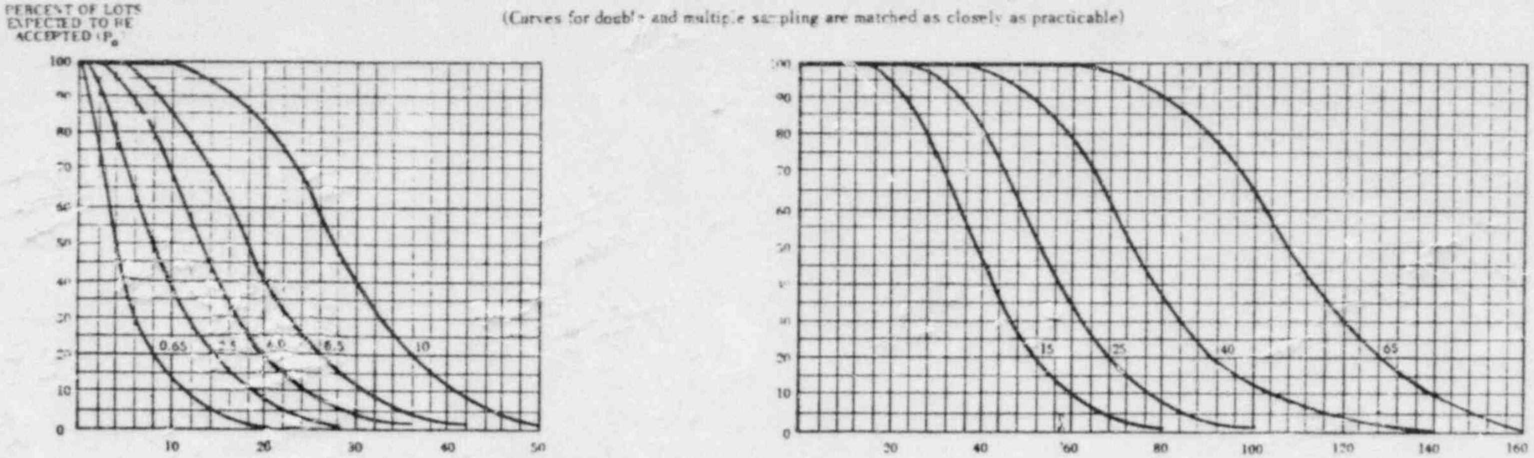
\# = Acceptance not permitted at this sample size.

E

TABLE X-F — Tables for sample size code letter: F

CHART F - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-F-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)																
	0.65	2.5	4.0	6.5	10	0.65	2.5	4.0	6.5	10	15	☒	25	☒	40	☒	65
	p (in percent defective)					p (in defects per hundred units)											
99.0	0.050	0.75	2.25	4.31	9.75	0.051	0.75	2.18	4.12	8.92	14.5	17.5	23.9	30.5	37.4	51.7	62.9
95.0	0.256	1.80	4.22	7.13	14.0	0.257	1.78	4.09	6.83	13.1	19.9	23.5	30.8	38.5	46.2	62.2	74.5
90.0	0.525	2.69	5.64	9.03	16.6	0.527	2.66	5.51	8.73	15.8	23.3	27.2	35.1	43.2	51.5	68.4	81.2
75.0	1.43	4.81	8.70	12.8	21.6	1.44	4.81	8.68	12.7	21.1	29.8	34.2	43.1	52.1	61.2	79.5	93.4
50.0	3.41	8.25	13.1	18.1	27.9	3.47	8.39	13.4	18.4	28.4	38.3	43.3	53.3	63.3	73.3	93.3	108
25.0	6.70	12.9	18.7	24.2	34.8	6.93	13.5	19.6	25.5	37.1	48.4	54.0	65.1	76.1	87.0	109	125
10.0	10.9	18.1	24.5	30.4	41.5	11.5	19.5	26.6	33.4	46.4	58.9	65.0	77.0	88.9	101	124	141
5.0	13.9	21.6	28.3	34.4	45.6	15.0	23.7	31.5	38.8	52.6	65.7	72.2	84.8	97.2	109	133	151
1.0	20.6	28.9	35.6	42.0	53.4	23.0	33.2	42.0	50.2	65.5	80.0	87.6	101	114	127	153	172
	1.0	4.0	6.5	10	☒	1.0	4.0	6.5	10	15	☒	25	☒	40	☒	65	☒
	Acceptable Quality Levels (tightened inspection)																

Note: Binomial distribution used for percent defective computations; Poisson for defects per hundred units.

TABLE X-F-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: F

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		Less than 0.65		0.65		1.0		╳		1.5		2.5		4.0		6.5		10		15		╳		25		╳		40		╳		65		Higher than 65		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	20	∇		0	1	Use Letter E		Use Letter H		Use Letter G		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		20
Double	13	∇		*								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		13
	26											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			26
Multiple	5	∇		*								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		5
	10											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			10
	15											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			15
	20											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			20
	25											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			25
	30											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			30
	35											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			35
		Less than 1.0		1.0		╳		1.5		2.5		4.0		6.5		10		15		╳		25		╳		40		╳		65		╳		Higher than 65		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.

∇ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number

Re = Rejection number

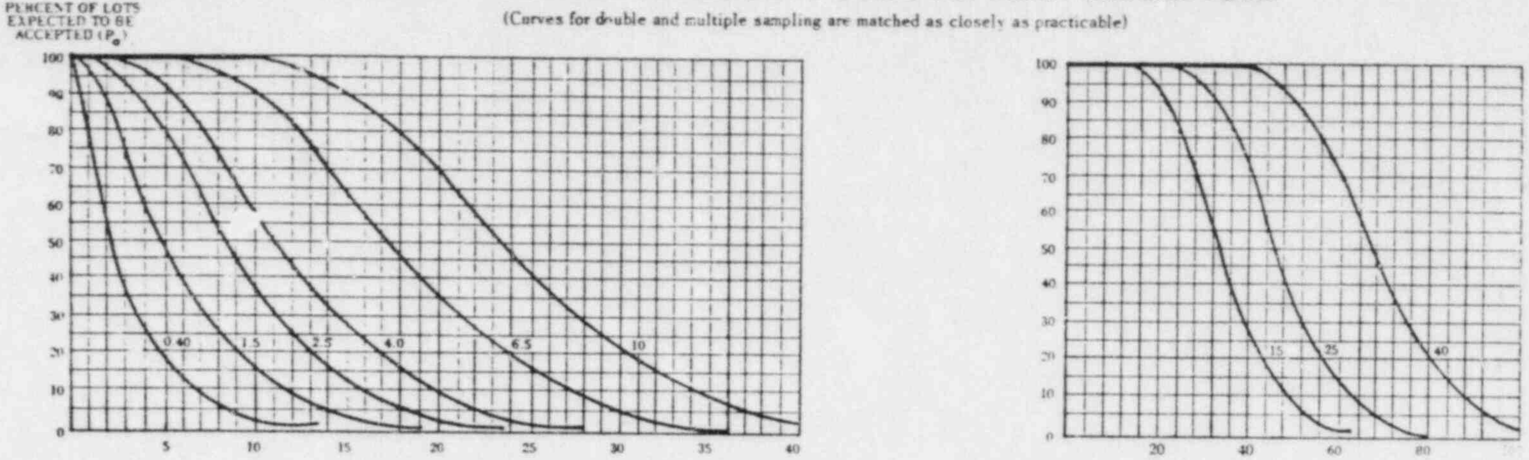
* = Use single sampling plan above (or alternatively use letter J).

\# = Acceptance not permitted at this sample size.

TABLE X-G—Tables for sample size code letter: G

CHART G - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-G-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)																	
	0.40	1.5	2.5	4.0	6.5	10	0.40	1.5	2.5	4.0	6.5	10	×	15	×	25	×	40
	p (in percent defective)						p (in defects per hundred units)											
99.0	0.032	0.475	1.38	2.63	5.94	9.75	0.032	0.466	1.36	2.57	5.57	9.08	11.0	14.9	19.1	23.4	32.3	39.3
95.0	0.161	1.13	2.59	4.39	8.50	13.1	0.160	1.10	2.55	4.26	8.16	12.4	14.7	19.3	24.0	28.9	38.9	46.5
90.0	0.329	1.67	3.50	5.56	10.2	15.1	0.328	1.66	3.44	5.45	9.85	14.6	17.0	21.9	27.0	32.2	42.7	50.8
75.0	0.895	3.01	5.42	7.98	13.4	19.0	0.900	3.00	5.39	7.92	13.2	18.6	21.4	26.9	32.6	38.2	49.7	58.4
50.0	2.14	5.19	8.27	11.4	17.5	23.7	2.16	5.24	8.35	11.5	17.7	24.0	27.1	33.3	39.6	45.8	58.3	67.7
25.0	4.23	8.19	11.9	15.4	22.3	29.0	4.33	8.41	12.3	16.0	23.2	30.3	33.8	40.7	47.6	54.4	67.9	78.0
10.0	6.94	11.6	15.8	19.7	27.1	34.1	7.19	12.2	16.6	20.9	29.0	36.8	40.6	48.1	55.6	62.9	77.4	88.1
5.0	8.94	14.0	18.4	22.5	30.1	37.2	9.36	14.8	19.7	24.2	32.9	41.1	45.1	53.0	60.8	68.4	83.4	94.5
1.0	13.5	19.0	23.7	28.0	35.9	43.3	14.4	20.7	26.3	31.4	41.0	50.0	54.4	63.0	71.3	79.5	95.6	107
	0.65	2.5	4.0	6.5	10	×	0.65	2.5	4.0	6.5	10	×	15	×	25	×	40	×
	Acceptable Quality Levels (tightened inspection)																	

Note: Binomial distribution used for percent defective computations; Poisson for defects per hundred units

TABLE X-G-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: G

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		Less than 0.40		0.40		0.65		╳		1.0		1.5		2.5		4.0		6.5		10		╳		15		╳		25		╳		40		Higher than 40		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	32	▽		0	1	Use Letter F		Use Letter J		Use Letter H		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		32
Double	20	▽		•								0	2	0	3	1	4	2	5	3	7	3	7	5	9		10	7	11	9	14	11	16	△		20
	40											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			40
Multiple	8	▽		•								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		8
	16											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			16
	24											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			24
	32											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			32
	40											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			40
	48											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			48
	56											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			56
		Less than 0.65		0.65		╳		1.0		1.5		2.5		4.0		6.5		10		╳		15		╳		25		╳		40		╳		Higher than 40		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number.

Re = Rejection number.

* = Use single sampling plan above (or alternatively use letter K).

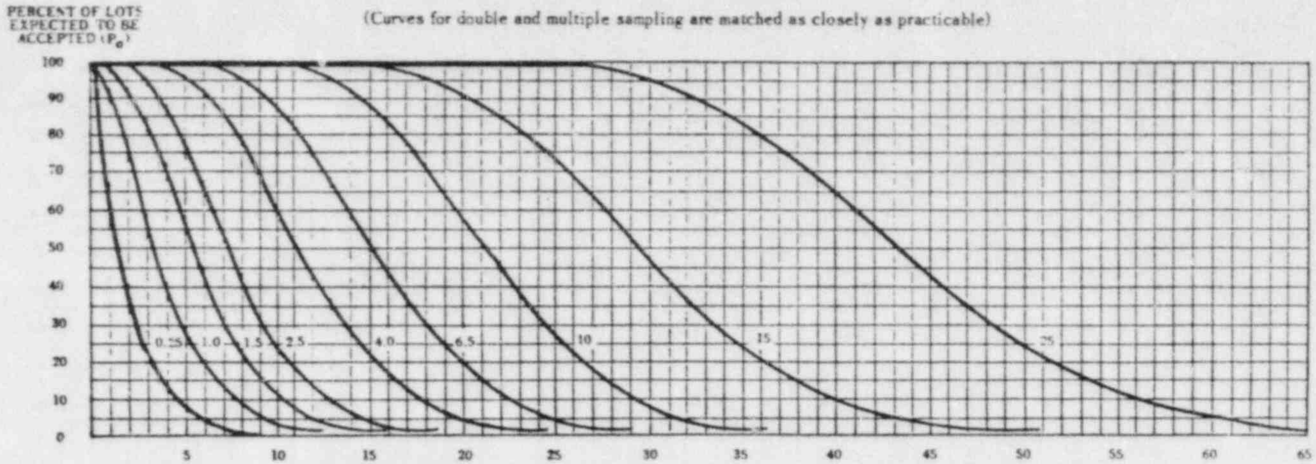
\# = Acceptance not permitted at this sample size.

G

TABLE X-H—Tables for sample size code letter: H

CHART H - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ⩽ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-H-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)																			
	0.25	1.0	1.5	2.5	4.0	6.5	×	10	0.25	1.0	1.5	2.5	4.0	6.5	×	10	×	15	×	25
	p (in percent defective)								p (in defects per hundred units)											
99.0	0.020	0.306	0.868	1.69	3.66	6.06	7.41	11.1	0.020	0.298	0.872	1.65	3.57	5.81	7.01	9.54	12.2	15.0	20.7	25.1
95.0	0.103	0.712	1.66	2.77	5.34	8.20	9.74	12.9	0.103	0.710	1.64	2.73	5.23	7.96	9.39	12.3	15.4	18.5	24.9	29.8
90.0	0.210	1.07	2.23	3.54	6.42	9.53	11.2	14.5	0.210	1.06	2.20	3.49	6.30	9.31	10.9	14.0	17.3	20.6	27.3	32.5
75.0	0.574	1.92	3.46	5.09	8.51	12.0	13.8	17.5	0.576	1.92	3.45	5.07	8.44	11.9	13.7	17.2	20.8	24.5	31.8	37.4
50.0	1.38	3.33	5.31	7.30	11.2	15.2	17.2	21.2	1.39	3.36	5.35	7.34	11.3	15.3	17.3	21.6	25.3	29.3	37.3	43.3
25.0	2.74	5.30	7.70	10.0	14.5	18.8	21.0	25.2	2.77	5.39	7.84	10.2	14.8	19.4	21.6	26.0	30.4	34.8	43.5	49.9
10.0	4.50	7.56	10.3	12.9	17.8	22.4	24.7	29.1	4.61	7.78	10.6	13.4	18.6	23.5	26.0	30.8	35.6	40.3	49.5	56.4
5.0	5.82	9.13	12.1	14.8	19.9	24.7	27.0	31.6	5.99	9.49	12.6	15.5	21.0	26.3	28.9	33.9	38.9	43.8	53.4	60.5
1.0	8.80	12.5	15.9	18.8	24.3	29.2	31.7	36.3	9.21	13.3	16.8	20.1	26.2	32.0	34.8	40.3	45.6	50.9	61.1	68.7
	0.40	1.5	2.5	4.0	6.5	×	10	×	0.40	1.5	2.5	4.0	6.5	×	10	×	15	×	25	×
	Acceptable Quality Levels (tightened inspection)																			

Note: Binomial distribution used for percent defective computations; Poisson for defects per hundred units.

TABLE X-H-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: H

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		Less than 0.25		0.25		0.40		✕		0.65		1.0		1.5		2.5		4.0		6.5		✕		10		✕		15		✕		25		Higher than 25		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	50	▽		0	1	Use Letter G		Use Letter K		Use Letter J		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		50
Double	32	▽		*								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		32
	64											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			64
Multiple	13	▽		*								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		13
	26											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			26
	39											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			39
	52											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			52
	65											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			65
	78											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			78
	91											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			91
		Less than 0.40		0.40		✕		0.65		1.0		1.5		2.5		4.0		6.5		✕		10		✕		15		✕		25		✕		Higher than 25		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number

Re = Rejection number

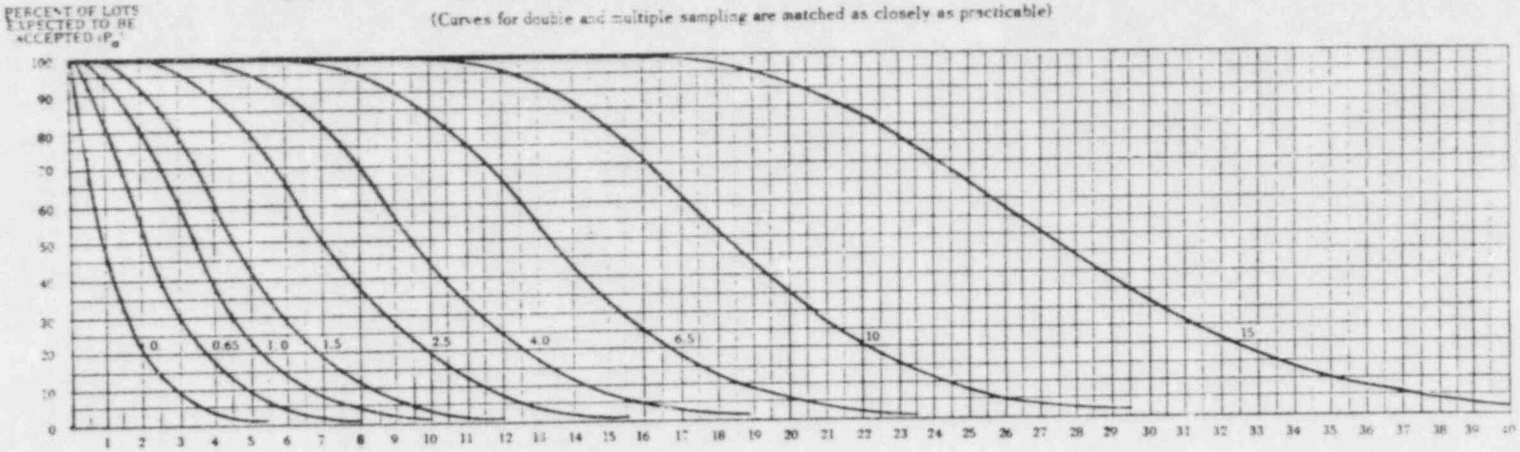
* = Use single sampling plan above (or alternatively use letter L).

\# = Acceptance not permitted at this sample size.

TABLE X-J—Tables for sample size code letter: J

CHART J - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤10; in defects per hundred units for AQL's >10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-J-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

	Acceptable Quality Levels (normal inspection)																					
Pa	0.15	0.65	1.0	1.5	2.5	4.0	X	6.5	X	10	0.15	0.65	1.0	1.5	2.5	4.0	X	6.5	X	10	X	15
	p (in percent defective)										p (in defects per hundred units)											
99.0	0.013	0.188	0.550	1.05	2.30	3.72	4.50	6.13	7.88	9.75	0.013	0.186	0.545	1.03	2.23	3.63	4.38	5.96	7.62	9.35	12.9	15.7
95.0	0.064	0.444	1.03	1.73	3.32	5.06	5.98	7.91	9.89	11.9	0.064	0.444	1.02	1.71	3.27	4.98	5.87	7.71	9.61	11.6	15.6	18.6
90.0	0.132	0.666	1.38	2.20	3.98	5.91	6.91	8.95	11.0	13.2	0.131	0.665	1.38	2.18	3.94	5.82	6.79	8.78	10.8	12.9	17.1	20.3
75.0	0.359	1.202	2.16	3.18	5.30	7.50	8.62	10.9	13.2	15.5	0.360	1.20	2.16	3.17	5.27	7.45	8.55	10.8	13.0	15.3	19.9	23.4
50.0	0.863	2.09	3.33	4.57	7.06	9.55	10.8	13.3	15.8	18.3	0.866	2.10	3.34	4.59	7.09	9.59	10.8	13.3	15.8	18.3	23.3	27.1
25.0	1.72	3.33	4.84	6.31	9.14	11.9	13.3	16.0	18.6	21.3	1.73	3.37	4.90	6.39	9.28	12.1	13.5	16.3	19.0	21.8	27.2	31.2
10.0	2.84	4.78	6.52	8.16	11.3	14.2	15.7	18.6	21.4	24.2	2.88	4.86	6.65	8.35	11.6	14.7	16.2	19.3	22.2	25.2	30.9	35.2
5.0	3.68	5.80	7.66	9.39	12.7	15.8	17.3	20.3	23.2	26.0	3.75	5.93	7.87	9.69	13.1	16.4	18.0	21.2	24.3	27.4	33.4	37.8
1.0	5.59	8.00	10.1	12.0	15.6	18.9	20.5	23.6	26.5	29.5	5.76	8.30	10.5	12.6	16.4	20.0	21.8	25.2	28.5	31.8	38.2	42.9
	0.25	1.0	1.5	2.5	4.0	X	6.5	X	10	X	0.25	1.0	1.5	2.5	4.0	X	6.5	X	10	X	15	X
	Acceptable Quality Levels (tightened inspection)																					

~~Note: All values given in above table based on Poisson distribution as an approximation to the Binomial.~~

NOTE: BINOMINAL DISTRIBUTION USED FOR PERCENT DEFECTIVE COMPUTATIONS. POISSON FOR DEFECTS PER HUNDRED UNITS

TABLE X-J-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: J

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		Less than 0.15		0.15		0.25		╳		0.40		0.65		1.0		1.5		2.5		4.0		╳		6.5		╳		10		╳		15		Higher than 15		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	80	▽		0	1	Use Letter H		Use Letter L		Use Letter K		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		80
Double	50	▽		*								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		50
	100											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			100
Multiple	20	▽		*								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		20
	40											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			40
	60											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			60
	80											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			80
	100											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			100
	120											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			120
	140											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			140
		Less than 0.25		0.25		╳		0.40		0.65		1.0		1.5		2.5		4.0		╳		6.5		╳		10		╳		15		╳		Higher than 15		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number

Re = Rejection number

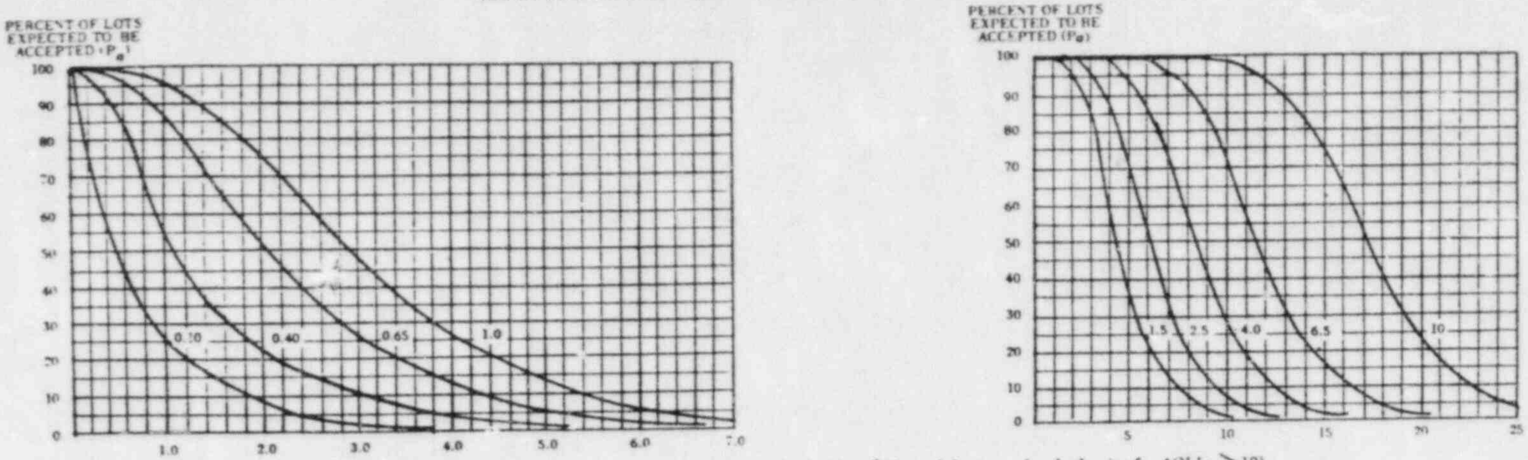
* = Use single sampling plan above (or alternatively use letter M)

\# = Acceptance not permitted at this sample size.

TABLE X-K—Tables for sample size code letter: K

CHART K - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ⩽ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-K-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)											
	0.10	0.40	0.65	1.0	1.5	2.5	✕	4.0	✕	6.5	✕	10
	p (in percent defective or defects per hundred units)											
99.0	0.0081	0.119	0.349	0.658	1.43	2.33	2.81	3.82	4.88	5.98	8.28	10.1
95.0	0.0410	0.284	0.654	1.09	2.09	3.19	3.76	4.94	6.15	7.40	9.95	11.9
90.0	0.0840	0.426	0.882	1.40	2.52	3.73	4.35	5.62	6.92	8.24	10.9	13.0
75.0	0.230	0.769	1.382 ~~0.382~~	2.03	3.38	4.77	5.47	6.90	8.34	9.79	12.7	14.9
50.0	0.554	1.34	2.14	2.94	4.54	6.14	6.94	8.53	10.1	11.7	14.9	17.3
25.0	1.11	2.15	3.14	4.09	5.94	7.75	8.64	10.4	12.2	13.9	17.4	20.0
10.0	1.84	3.11	4.26	5.35	7.42	9.42	10.4	12.3	14.2	16.1	19.8	22.5
5.0	2.40	3.80	5.04	6.20	8.41	10.5	11.5	13.6	15.6	17.5	21.4	24.2
1.0	3.68	5.31	6.73	8.04	10.5	12.8	18.3	16.1	18.3	20.4	24.5	27.5
	0.15	0.65	1.0	1.5	2.5	✕	4.0	✕	6.5	✕	10	✕
	Acceptable Quality Levels (tightened inspection)											

Note: All values given in above table based on Poisson distribution as an approximation to the Binomial.

TABLE X-K-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: K

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		Less than 0.10		0.10		0.15		✕		0.25		0.40		0.65		1.0		1.5		2.5		✕		4.0		✕		6.5		✕		10		Higher than 10		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	125	▽		0	1	Use Letter J		Use Letter M		Use Letter L		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		125
Double	80	▽		•								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		80
	160											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			160
Multiple	32	▽		•								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		32
	64											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			64
	96											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			96
	128											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			128
	160											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			160
	192											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			192
	224											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			224
		Less than 0.15		0.15		✕		0.25		0.40		0.65		1.0		1.5		2.5		✕		4.0		✕		6.5		✕		10		✕		Higher than 10		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number

Re = Rejection number

• = Use single sampling plan above (or alternatively use letter N).

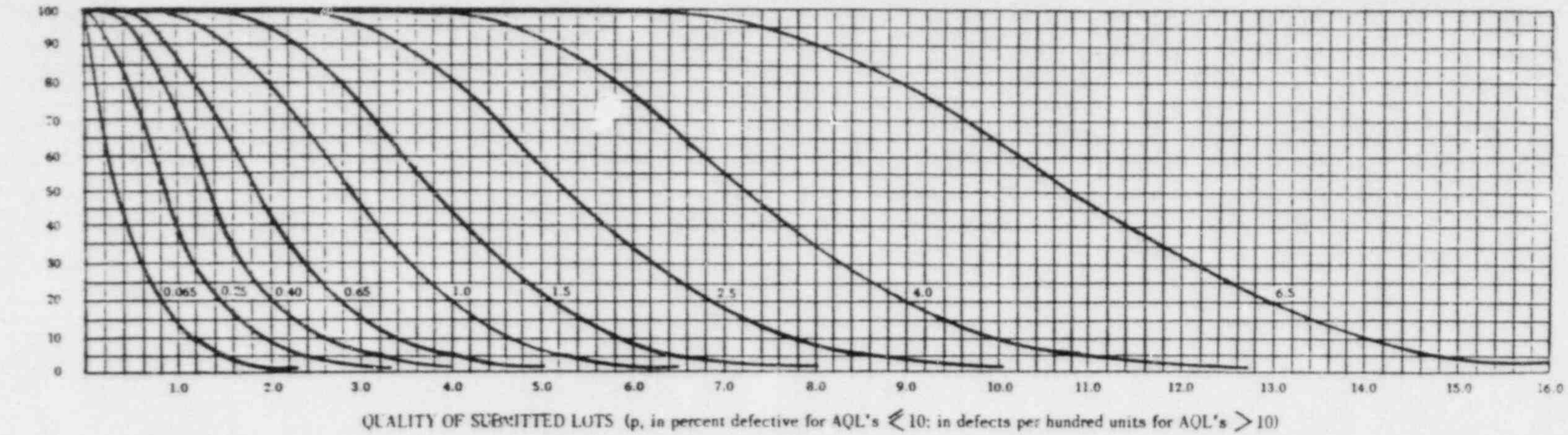
= Acceptance not permitted at this sample size.

K

TABLE X-L—Tables for sample size code letter: L

CHART L - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-L-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)											
	0.065	0.25	0.40	0.65	1.0	1.5	✕	2.5	✕	4.0	✕	6.5
	p (in percent defective or defects per hundred units)											
99.0	0.0051	0.075	0.218	0.412	0.893	1.45	1.75	2.39	3.05	3.74	5.17	6.29
95.0	0.0256	0.178	0.409	0.683	1.31	1.99	2.35	3.09	3.85	4.62	6.22	7.45
90.0	0.0525	0.266	0.551	0.873	1.58	2.33	2.72	3.51	4.32	5.15	6.84	8.12
75.0	0.144	0.481	0.864	1.27	2.11	2.98	3.42	4.31	5.21	6.12	7.95	9.34
50.0	0.347	0.839	1.34	1.84	2.84	3.84	4.33	5.33	6.33	7.33	9.33	10.8
25.0	0.693	1.35	1.96	2.56	3.71	4.84	5.40	6.51	7.61	8.70	10.9	12.5
10.0	1.15	1.95	2.66	3.34	4.64	5.89	6.50	7.79	8.89	10.1	12.4	14.1
5.0	1.50	2.37	3.15	3.88	5.26	6.57	7.22	8.48	9.72	10.9	13.3	15.1
1.0	2.30	3.32	4.20	5.02	6.55	8.00	8.70	10.1	11.4	12.7	15.3	17.2
	0.10	0.40	0.65	1.0	1.5	✕	2.5	✕	4.0	✕	6.5	✕
	Acceptable Quality Levels (tightened inspection)											

Note: All values given in above table based on Poisson distribution as an approximation to the Binomial.

TABLE X-L-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: L

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		Less than 0.065		0.065		0.10		✕		0.15		0.25		0.40		0.65		1.0		1.5		✕		2.5		✕		4.0		✕		6.5		Higher than 6.5		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	200	▽		0	1	Use Letter K		Use Letter N		Use Letter M		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		200
Double	125	▽		*								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		125
	250											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			250
Multiple	50	▽		*								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		50
	100											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			100
	150											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			150
	200											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			200
	250											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			250
	300											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			300
	350											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			350
		Less than 0.10		0.10		✕		0.15		0.25		0.40		0.65		1.0		1.5		✕		2.5		✕		4.0		✕		6.5		✕		Higher than 6.5		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number

Re = Rejection number

* = Use single sampling plan above (or alternatively use letter P).

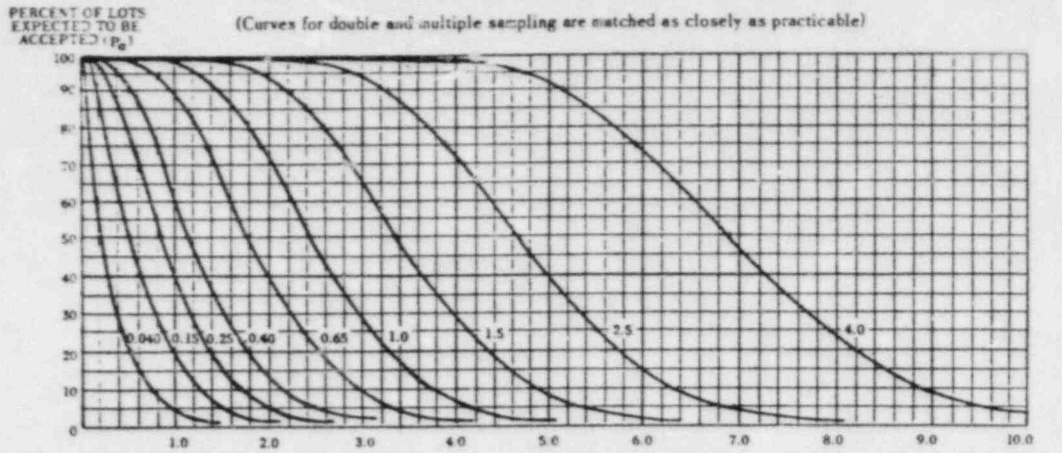
\# = Acceptance not permitted at this sample size.

M

TABLE X-M—Tables for sample size code letter: M

CHART M - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-M-1 - TABULATED VALUES FOR OPERATING CHARACTERSTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)											
	0.040	0.15	0.25	0.40	0.65	1.0	✕	1.5	✕	2.5	✕	4.0
	p (in percent defective or in ~~defects~~ DEFECTS per hundred units)											
99.0	0.0032	0.047	0.138	0.261	0.566	0.922	1.11	1.51	1.94	2.38	3.28	3.99
95.0	0.0163	0.112	0.259	0.433	0.829	1.26	1.49	1.96	2.44	2.94	3.95	4.73
90.0	0.0333	0.168	0.349	0.533	1.00	1.48	1.72	2.23	2.75	3.27	4.34	5.16
75.0	0.0914	0.305	0.580	0.804	1.34	1.89	2.17	2.74	3.31	3.89	5.05	5.93
50.0	0.220	0.532	0.848	1.17	1.80	2.43	2.75	3.39	4.02	4.66	5.93	6.88
25.0	0.440	0.854	1.24	1.62	2.36	3.07	3.43	4.1[illegible]	4.83	5.52	6.90	7.92
10.0	0.731	1.23	1.69	2.12	2.94	3.74	4.13	4.89	5.65	6.39	7.86	8.95
5.0	0.951	1.51	2.00	2.46	3.34	4.17	4.58	5.38	6.17	6.95	8.47	9.60
1.0	1.46	2.11	2.67	3.19	4.16	5.08	5.53	6.40	7.25	8.08	9.71	10.9
	0.065	0.25	0.40	0.65	1.0	✕	1.5	✕	2.5	✕	4.0	✕
	Acceptable Quality Levels (tightened inspection)											

Note: All values given in above table based on Poisson distribution as an approximation to the Binomial

TABLE X-M-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: M

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		Less than 0.040		0.040		0.065		✕		0.10		0.15		0.25		0.40		0.65		1.0		✕		1.5		✕		2.5		✕		4.0		Higher than 4.0		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	315	▽		0	1	Use Letter L		Use Letter P		Use Letter N		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		315
Double	200	▽		*								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		200
	400											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			400
Multiple	80	▽		*								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		80
	160											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			160
	240											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			240
	320											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			320
	400											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			400
	480											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			480
	560											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			560
		Less than 0.065		0.065		✕		0.10		0.15		0.25		0.40		0.65		1.0		✕		1.5		✕		2.5		✕		4.0		✕		Higher than 4.0		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number.

Re = Rejection number.

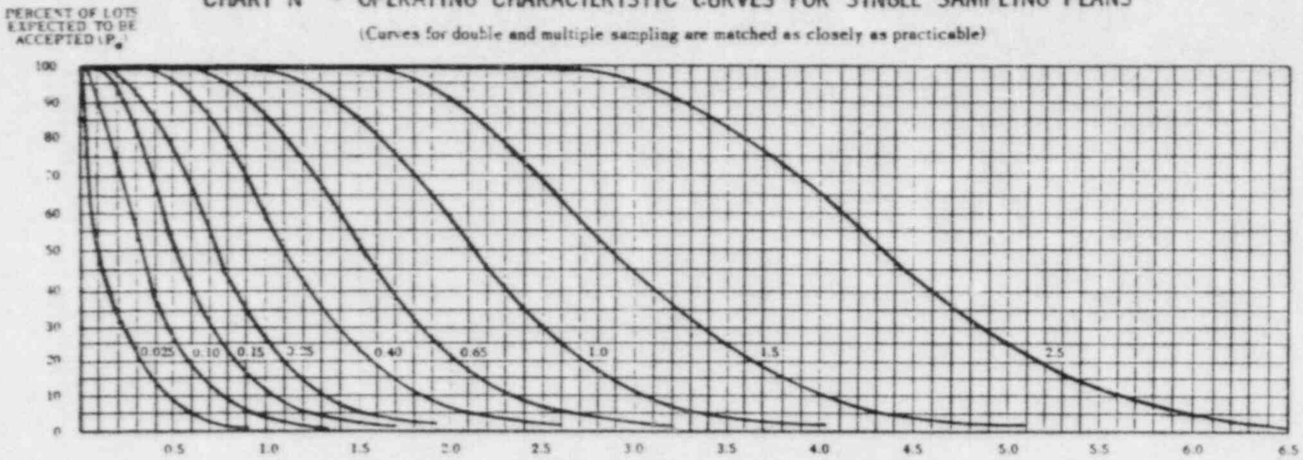
* = Use single sampling plan above (or alternatively use letter Q).

\# = Acceptance not permitted at this sample size.

TABLE X-N—Tables for sample size code letter: N

CHART N - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



QUALITY OF SUBMITTED LOTS (p, in percent defective for AQL's ≤ 10; in defects per hundred units for AQL's > 10)

Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-N-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)											
	0.025	0.10	0.15	0.25	0.40	0.65	✕	1.0	✕	1.5	✕	2.5
	p (in percent defective or in defects per hundred units)											
99.0	0.0020	0.030	0.087	0.165	0.357	0.581	0.701	0.954	1.22	1.50	2.07	2.51
95.0	0.0103	0.071	0.164	0.273	0.523	0.796	0.939	1.23	1.54	1.85	2.49	2.98
90.0	0.0210	0.106	0.220	0.349	0.630	0.931	1.09	1.40	1.73	2.06	2.73	3.25
75.0	0.0576	0.192	0.345	0.507	0.844	1.19	1.37	1.72	2.08	2.45	3.18	3.74
50.0	0.139	0.336	0.535	0.734	1.13	1.53	1.73	2.13	2.53	2.93	3.73	4.33
25.0	0.277	0.539	0.784	1.02	1.48	1.94	2.16	2.60	3.04	3.48	4.35	4.99
10.0	0.461	0.778	1.06	1.34	1.86	2.35	2.60	3.08	3.56	4.03	4.95	5.64
5.0	0.599	0.949	1.26	1.55	2.10	2.63	2.89	3.39	3.89	4.38	5.34	6.05
1.0	0.921	1.328	1.68	2.01	2.62	3.20	3.48	4.03	4.56	5.09	6.12	6.87
	0.040	0.15	0.25	0.40	0.65	✕	1.0	✕	1.5	✕	2.5	✕
	Acceptable Quality Levels (tightened inspection)											

Note: All values given in above table based on [illegible] distribution as an approximation to the Binomial

Poisson

TABLE X-N-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: N

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		Less than 0.025		0.025		0.040		✕		0.065		0.10		0.15		0.25		0.40		0.65		✕		1.0		✕		1.5		✕		2.5		Higher than 2.5		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	500	▽		0	1	Use Letter M		Use Letter Q		Use Letter P		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		500
Double	315	▽		•								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		315
	630											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			630
Multiple	125	▽		•								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		125
	250											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			250
	375											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			375
	500											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			500
	625											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			625
	750											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			750
	875											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			875
		Less than 0.040		0.040		✕		0.065		0.10		0.15		0.25		0.40		0.65		✕		1.0		✕		1.5		✕		2.5		✕		Higher than 2.5		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.

▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.

Ac = Acceptance number

Re = Rejection number

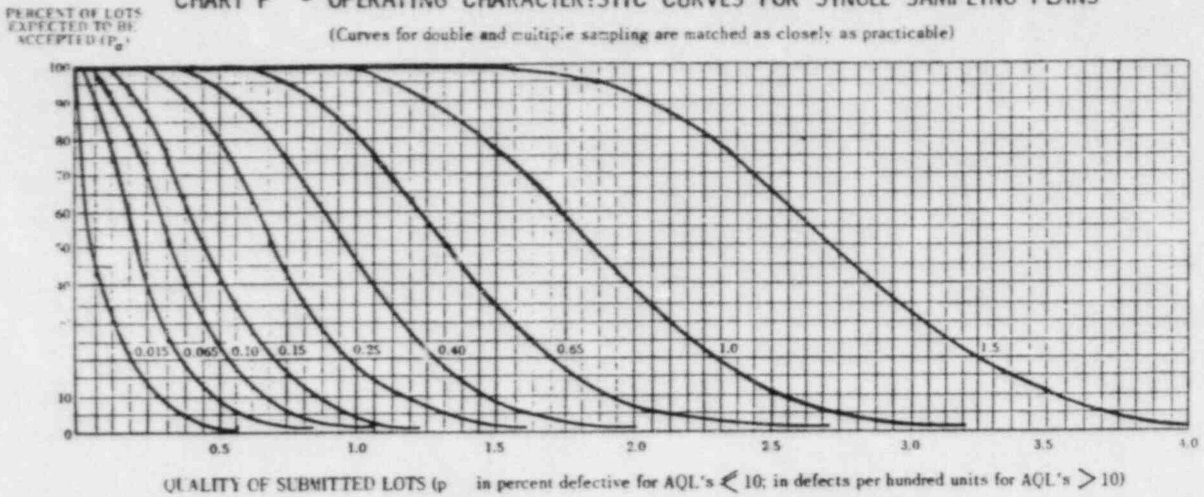
• = Use single sampling plan above (or alternatively use letter R).

= Acceptance not permitted at this sample size.

TABLE X-P—*Tables for sample size code letter: P*

CHART P - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-P-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)											
	0.015	0.065	0.10	0.15	0.25	0.40	✕	0.65	✕	1.0	✕	1.5
	p(in percent defective or defects per hundred units)											
99.0	0.0013	0.0186	0.055	0.103	0.223	0.363	0.438	0.596	0.762	0.935	1.29	1.57
95.0	0.0064	0.0444	0.102	0.171	0.327	0.498	0.587	0.771	0.961	1.16	1.56	1.86
90.0	0.0131	0.0665	0.138	0.218	0.394	0.582	0.679	0.878	1.08	1.29	1.71	2.03
75.0	0.0360	0.120	0.216	0.317	0.527	0.745	0.855	1.08	1.30	1.53	1.99	2.34
50.0	0.0866	0.210	0.334	0.459	0.709	0.959	1.08	1.33	1.58	1.83	2.33	2.71
25.0	0.173	0.337	0.490	0.639	0.928	1.21	1.35	1.63	1.90	2.18	2.72	3.12
10.0	0.288	0.486	0.665	0.835	1.16	1.47	1.62	1.93	2.22	2.52	3.09	3.52
5.0	0.375	0.593	0.787	0.969	1.31	1.64	1.80	2.12	2.43	2.74	3.34	3.78
1.0	0.576	0.830	1.05	1.26	1.64	2.00	2.18	2.52	2.85	3.18	3.82	4.29
	0.025	0.10	0.15	0.25	0.40	✕	0.65	✕	1.0	✕	1.5	✕
	Acceptable Quality Levels (tightened inspection)											

Note: All values given in above table based on Poisson distribution as an approximation to the Binomial

Poisson

TABLE X-P-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: P

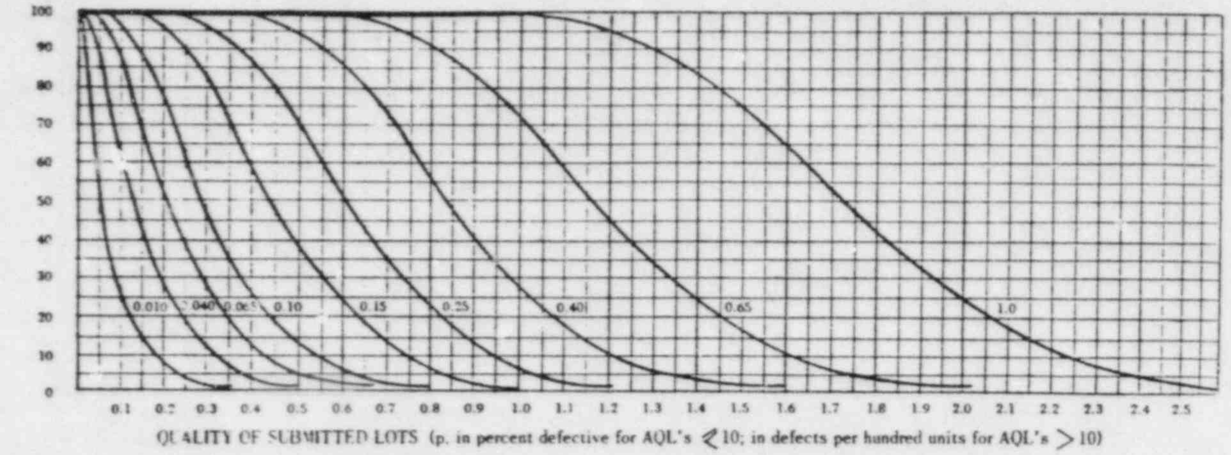
Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		0.010		0.015		0.025		✕		0.040		0.065		0.10		0.15		0.25		0.40		✕		0.65		✕		1.0		✕		1.5		Higher than 1.5		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	800	▽		0	1	Use Letter N		Use Letter R		Use Letter Q		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		800
Double	500	▽		*								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		500
	1000											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			1000
Multiple	200	▽		*								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		200
	400											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			400
	600											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			600
	800											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			800
	1000											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			1000
	1200											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			1200
	1400											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			1400
		Less than 0.025		0.025		✕		0.040		0.065		0.10		0.15		0.25		0.40		✕		0.65		✕		1.0		✕		1.5		✕		Higher than 1.5		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.
▽ = Use next subsequent sample size code letter for which acceptance and rejection numbers are available.
Ac = Acceptance number.
Re = Rejection number.
* = Use single sampling plan above.
\# = Acceptance not permitted at this sample size.

TABLE X-Q—Tables for sample size code letter: Q

CHART Q - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection

TABLE X-Q-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

P_a	Acceptable Quality Levels (normal inspection)											
	0.010	0.040	0.065	0.10	0.15	0.25	╳	0.40	╳	0.65	╳	1.0
	p (in percent defective or defects per hundred units											
99.0	0.00081	0.0119	0.0349	0.0656	0.143	0.232	0.281	0.382	0.488	0.598	0.828	1.01
95.0	0.00410	0.0284	0.0654	0.109	0.209	0.318	0.376	0.494	0.615	0.740	0.995	1.19
90.0	0.00840	0.0426	0.0882	0.140	0.252	0.372	0.435	0.562	0.692	0.824	1.09	1.30
75.0	0.0230	0.0769	0.138	0.203	0.338	0.476	0.547	0.690	0.834	0.979	1.27	1.49
50.0	0.0554	0.134	0.214	0.294	0.454	0.614	0.694	0.853	1.01	1.17	1.49	1.73
25.0	0.111	0.215	0.314	0.409	0.594	0.775	0.864	1.04	1.22	1.39	1.74	2.00
10.0	0.184	0.310	0.425	0.534	0.742	0.942	1.04	1.23	1.42	1.61	1.98	2.25
5.0	0.240	0.380	0.504	0.620	0.841	1.05	1.15	1.36	1.56	1.75	2.14	2.42
1.0	0.368	0.531	0.672	0.804	1.05	1.28	1.83	1.61	1.83	2.04	2.45	2.75
	0.015	0.065	0.10	0.15	0.25	╳	0.40	╳	0.65	╳	1.0	╳
	Acceptable Quality Levels (tightened inspection)											

Note: All values given in above table based on Poisson distribution as an approximation to the Binomial

TABLE X-Q-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: Q

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																		Cumulative sample size
		╳		0.010		0.015		╳		0.025		0.040		0.065		0.10		0.15		0.25		╳		0.40		╳		0.65		╳		1.0		Higher than 1.0		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	1250	Use Letter R		0	1	Use Letter P		Use Letter S		Use Letter R		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		1250
Double	800			•								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		800
	1600											1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			1600
Multiple	315			•								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		315
	630											#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			630
	945											0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			945
	1260											0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			1260
	1575											1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			1575
	1890											1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			1890
	2205											2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			2205
		0.010		0.015		╳		0.025		0.040		0.065		0.10		0.15		0.25		╳		0.40		╳		0.65		╳		1.0		╳		Higher than 1.0		
		Acceptable Quality Levels (tightened inspection)																																		

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available

Ac = Acceptance number

Re = Rejection number

• = Use single sampling plan above.

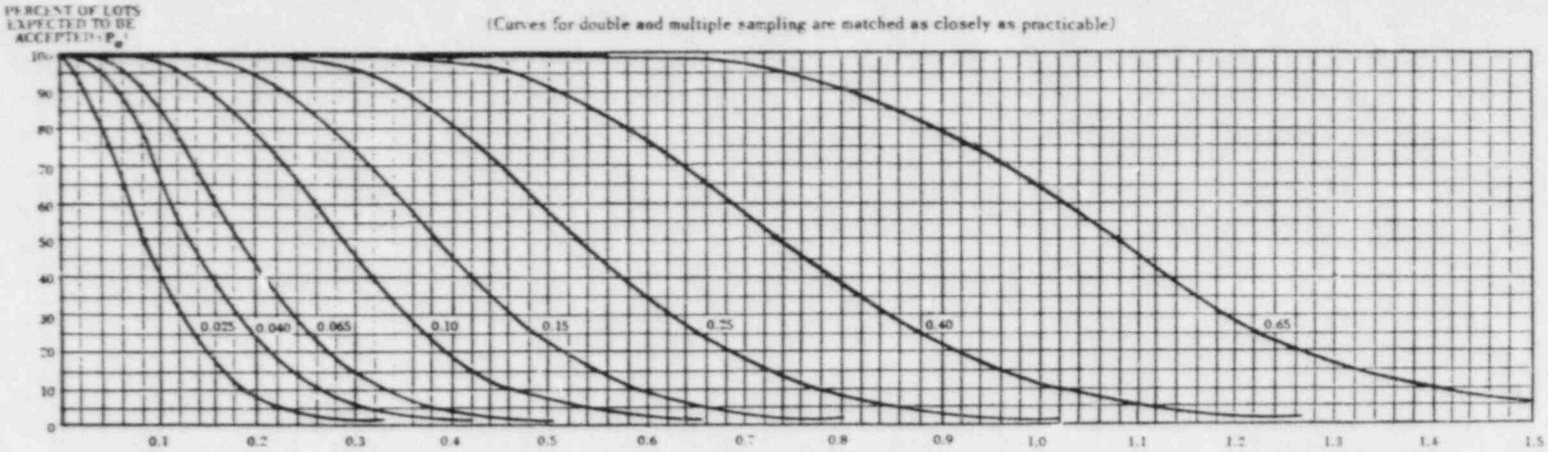
= Acceptance not permitted at this sample size.

Q

TABLE X-R—Tables for sample size code letter: R

CHART R - OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are matched as closely as practicable)



Note: Figures on curves are Acceptable Quality Levels (AQL's) for normal inspection.

TABLE X-R-1 - TABULATED VALUES FOR OPERATING CHARACTERISTIC CURVES FOR SINGLE SAMPLING PLANS

	Acceptable Quality Levels (normal inspection)										
P_a	0.025	0.040	0.065	0.10	0.15	✕	0.25	✕	0.40	✕	0.65
	p (in percent defective or defects per hundred units)										
99.0	0.0074	0.0218	0.0412	0.0892	0.145	0.175	0.239	0.305	0.374	0.517	0.629
95.0	0.0176	0.0409	0.0683	0.131	0.199	0.235	0.309	0.385	0.462	0.622	0.745
90.0	0.0266	0.0551	0.0873	0.158	0.233	0.272	0.351	0.432	0.515	0.684	0.812
75.0	0.0481	0.0868	0.127	0.211	0.298	0.342	0.431	0.521	0.612	0.795	0.934
50.0	0.0839	0.134	0.184	0.284	0.384	0.433	0.533	0.633	0.733	0.933	1.08
25.0	0.135	0.196	0.256	0.371	0.484	0.540	0.651	0.761	0.870	1.09	1.25
10.0	0.195	0.266	0.334	0.464	0.589	0.650	0.770	0.889	1.01	1.24	1.41
5.0	0.237	0.315	0.388	0.526	0.657	0.722	0.848	0.972	1.09	1.33	1.51
1.0	0.332	0.420	0.502	0.655	0.800	0.870	1.02	1.14	1.27	1.53	1.72
	0.040	0.065	0.10	0.15	✕	0.25	✕	0.40	✕	0.65	✕
	Acceptable Quality Levels (tightened inspection)										

Note: All values given in above table based on Poisson distribution as an approximation to the Binomial

TABLE X-R-2 - SAMPLING PLANS FOR SAMPLE SIZE CODE LETTER: R

Type of sampling plan	Cumulative sample size	Acceptable Quality Levels (normal inspection)																																Cumulative sample size
		╳		0.010		0.015		╳		0.025		0.040		0.065		0.10		0.15		╳		0.25		╳		0.40		╳		0.65		Higher than 0.65		
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	
Single	2000	0	1	Use Letter Q		Use Letter P		Use Letter S		1	2	2	3	3	4	5	6	7	8	8	9	10	11	12	13	14	15	18	19	21	22	△		2000
Double	1250	•								0	2	0	3	1	4	2	5	3	7	3	7	5	9	6	10	7	11	9	14	11	16	△		1250
	2500									1	2	3	4	4	5	6	7	8	9	11	12	12	13	15	16	18	19	23	24	26	27			2500
Multiple	500	•								#	2	#	2	#	3	#	4	0	4	0	4	0	5	0	6	1	7	1	8	2	9	△		500
	1000									#	2	0	3	0	3	1	5	1	6	2	7	3	8	3	9	4	10	6	12	7	14			1000
	1500									0	2	0	3	1	4	2	6	3	8	4	9	6	10	7	12	8	13	11	17	13	19			1500
	2000									0	3	1	4	2	5	3	7	5	10	6	11	8	13	10	15	12	17	16	22	19	25			2000
	2500									1	3	2	4	3	6	5	8	7	11	9	12	11	15	14	17	17	20	22	25	25	29			2500
	3000									1	3	3	5	4	6	7	9	10	12	12	14	14	17	18	20	21	23	27	29	31	33			3000
	3500									2	3	4	5	6	7	9	10	13	14	14	15	18	19	21	22	25	26	32	33	37	38			3500
		0.010		0.015		╳		0.025		0.040		0.065		0.10		0.15		╳		0.25		╳		0.40		╳		0.65		╳		Higher than 0.65		
		Acceptable Quality Levels (tightened inspection)																																

△ = Use next preceding sample size code letter for which acceptance and rejection numbers are available.
Ac = Acceptance number.
Re = Rejection number.
• = Use single sampling plan above.
= Acceptance not permitted at this sample size.

R

S

TABLE X-S—Tables for sample size code letter: S

Type of sampling plan	Cumulative sample size	Acceptable Quality Level (normal inspection)	
		×	
		Ac	Re
Single	3150	1	2
Double	2000	0	2
	4000	1	2
Multiple	800	#	2
	1600	#	2
	2400	0	2
	3200	0	3
	4000	1	3
	4800	1	3
	5600	2	3
		0.025	
		Acceptable Quality Level (tightened inspection)	

Ac = Acceptance number
Re = Rejection number
# = Acceptance not permitted at this sample size.

Index of terms with special meanings

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(6-83)

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Technical

12b PERIOD COVERED (Inclusive dates)

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14 ABSTRACT (200 words or less)

An investigation of bolting practices specific to the nuclear industry was performed. The report covered a large spectrum of topics e.g. bolts embedded in concrete, specifications, inspection of bolting, both at receipt and inservice. Plots of preload versus yield strength for different bolting materials in different environments are presented as well as information relative to the stress corrosion cracking resistance of the more recent reactor internals bolting materials A286 and Inconel X-750. Part of the report contains input by Standard Pressed Steel Inc. (a bolting consultant) relative to bolting standards, cottering methods and potential areas for bolting improvement.

15a KEY WORDS AND DOCUMENT ANALYSIS

15b DESCRIPTORS

Bolts
Fasteners
Stress Corrosion Cracking
X-750
A286

16 AVAILABILITY STATEMENT
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