South Texas Project
Electric Generating Station

Field-Threaded Anchor Bolts
Thread Deficiency

Final Report

I. Summary

A. A Synopsis of the Incident

During a routine surveillance inspection of the installation of the ECCS accumulator tanks of Unit 2, the anchor bolts were found to have deformed and undersized threads. This condition was evaluated under the guidelines of 10CFR50.55(e) and determined to be a non-reportable incident based upon the results of a test program and analysis. The uniqueness of the thread condition on these specific anchor bolts was investigated, however. This investigation revealed that a large number of anchor bolts had similar thread conditions. The bolts involved had been manufactured at the STPEGS site using bar stock. A nonconformance report (NCR) was issued at the site on June 26, 1978, to document the apparent generic problem with site-manufactured anchor bolts.

In order to properly account for each potentially deficient anchor bolt, an intense, detailed investigation was initiated. The 1,100 anchor bolts of various sizes that had been site-manufactured had their physical location marked on appropriate drawings. These drawings were then reviewed and 628 of the 1,100 anchor bolts were determined to support safety-related equipment. The 628 anchor bolts were then subjected to in situ dimensional measurements. The NRC was informed of the incident and activities to this point via telecon on October 27, 1978.

Based on the evaluation of the site dimensional inspection results, the incident was determined to be non-reportable under the guidelines of 10CFR50.55(e). However, a "pull" test conducted on one anchor bolt as part of a strength verification program indicated utilization of improper material for the anchor bolt. This condition was reported to the NRC on February 8, 1979. A written report was forwarded to the NRC on March 8, 1979, which addressed the anchor bolt improper material deficiency. On June 5, 1979, a second written report was sent to the NRC.

The final report addresses in detail the deficient thread condition of the field-fabricated anchor bolts. Although the original intent was to close out the improper material problem in this final report, additional investigations necessitate deferral of a final report on anchor bolt improper material until January 2, 1980.

B. Postulated Cause of Incident

The cause of the thread deficiency originated from the use of inadequate manufacturing controls and was further complicated by inadequate inspection methods and equipment.

C. A Synopsis of the Corrective Action

A sample of 12 bolts of various sizes and materials that were manufactured under the same processes as the suspect bolts was subjected to laboratory examination. Thread acceptance was checked by several techniques including micrometers, the three wire method, and GO-LO gauges. Thread major diameters were also measured using micrometers. Bolts were sectioned at the threaded portions for profile determination. It was found that the measurements of pitch diameter made at the site consistently produced erroneous data, but that measurements of major diameter were correct. It was also determined that the pitch angle was in accordance with the specification. (Refer to Figure 1 for definitions of terms.) Thus, the tensile areas of all bolts were determined from the measured major diameter. All installed bolts were found to have sufficient tensile area and thread engagement to carry the design loads with an acceptable margin. Therefore, the nonconformance reports were dispositioned: "use-as-is". This disposition was further substantiated by full section load tests on all of the 12 anchor bolt-nut assemblies. All bolts failed in tension at approximately 1.5 to 2 times their specified design load.

D. A Synopsis of Safety Evaluation

Since the anchor bolts were determined to meet or exceed all design criteria based upon load capacity, no safety evaluation was conducted.

II. Description of Incident

A. Component Identification

A large quantity of anchor bolts was manufactured at the STPEGS site by Brown & Root to offset an inadequate supply of vendor supplied anchor bolts. These anchor bolts are used to anchor components to concrete structures throughout the plant. A diagram showing a typical anchor bolt design is shown in Figure 2. The bolt configuration is designed based upon the loading, tensile stress area of the bolt (ANSI Std. B1.1), and the yield strength of the bolt. A design allowable strength of 22 ksi was used for ASTM A36 and 48 ksi was used for ASTM A193 Grade B7. These design allowable strengths are used even though the minimum ASTM yield strengths are 36 ksi and 115 ksi for the A36 and A193 Grade B7 materials, respectively.

B. Source and Extent of Incident

During a routine surveillance inspection, Quality Control discovered an improper fit on the Unit 2 ECCS accumulator tank anchor bolts. Measurement

of the thread dimensions indicated the threads were smaller than had been specified. This condition was determined to be potentially reportable and the NRC was notified. However, testing and analysis demonstrated that an adequate safety margin was maintained.

Discovery of the deficiency in the accumulator tank anchor bolts prompted Quality Control to investigate the condition of all anchor bolts manufactured at the site. Three work orders of site-manufactured anchor bolts were selected at random and their pitch and major diameters measured. As a result of these measurements, it was determined that an unsatisfactory condition existed and an NCR was issued. B&R Construction and Quality Assurance identified the locations, applications, and dimensional measurements of anchor bolts manufactured under site work orders. The bolts were identified and their locations indicated on a set of drawings. From these drawings Engineering identified bolts which were safety-related. Site Quality Control was then furnished a list of work orders from which safety-related bolts were manufactured. The list determined which anchor bolts required thread inspection. Each work order of anchor bolts was individually dispositioned.

C. Date and Means by Which Incident Information was Obtained

The accumulator tank anchor bolt deficiency was identified by NCR on June 20, 1978. This led to the investigation described above and an NCR against all anchor bolts was issued on June 26, 1978.

D. Unusual Circumstances

Fabrication of anchor bolts at the site was not anticipated in the original planning for the South Texas Project. Initially, all anchor bolts were to be procured from vendors. When production delays at the vendors' facilities resulted in too few bolts being delivered at the site to allow work to continue as scheduled, a decision was made to manufacture some bolts at the site. At that time, however, equipment at the site included only some adjustable thread cutting dies and no thread measuring equipment. Requisitions for better thread cutting tools and thread ring gauges were denied on the basis that fabrication of anchor bolts at the site was only a temporary measure. However, the number of anchor bolts manufactured on-site increased rapidly. Eventually, new requests for threading tools and thread ring gauges were made. These requests were approved and the equipment has now been provided at the site.

E. Status of Construction at the Time of the Incident

By the time of the incident, the Site Construction organization had manufactured 1,100 anchor bolts of various sizes and several configurations. Of the 1,100 bolts, 628 have been identified as being used in safety-related applications. A majority of the safety-related bolts had already been installed when the deficiency was identified.

F. Procedures in Effect to Avoid Incident

The anchor bolts in question were manufactured in accordance with the directions included in work orders which referenced drawings which contained the required thread measurements. The threads were inspected using a nut of the proper size and thread form which had been procured from a bolt vendor. This method proved to be inadequate.

III. Corrective Action

The thread configuration of these questionable site-manufactured bolts was determined to be satisfactory. The mechanism for arriving at this position is described below.

A. Site Measurements

The problem was initially identified as an out-of-tolerance condition on threads for embedded anchor bolts for the Unit 2 ECCS accumulator tanks. An investigation of the cause of this condition made a total of 1,100 site-manufactured bolts suspect. A random check of some of these bolts revealed some cases of unsatisfactory conditions or both major and pitch diameter measurements. A set of design drawings was then marked-up by the site personnel showing the location of suspect anchor bolt locations. These drawings were then reviewed by Engineering and those anchor bolt locations where failure could affect safety were identified. The major and pitch diameters of these bolts were then measured and reported to Engineering. A small percentage of the measurements were out-of-tolerance on pitch diameter. An analysis was made of these measurements and enough inconsistency was found to warrant further examination.

B. Laboratory Examination

A total of 12 anchor bolts was delivered from the site to the Brown & Root Materials Engineering Laboratory for examination. These bolts were of various dimensions and materials and had been manufactured by the same process as the suspect bolts. The bolt sizes and materials are identified in Tables I and II.

The first task was to determine the thread dimensions using standard methods and tools. Bolt threads were verified using micrometers, pitch gauges, GO-LO gauges and the three wire method. The bolts were then sectioned through the thread areas and measurements obtained using an optical comparator. The results are shown in Table I. All bolts were within tolerance in major diameter. Five bolts, however, were not within tolerance for the pitch diameter. The measurements were out-of-tolerance less than 0.012 inch. The thread pitch was found to be within tolerance on all bolts. During these tests, it was determined that the site measurements of major diameter could be duplicated but the measurements of pitch diameter could not. The pitch diameter measurements reported by the site were consistently lower than those measured at the laboratory.

Next, the same twelve bolt-nut assemblies were subjected to full section load tests until failure occurred. The load was applied to the bolt-nut assembly and the loads at yield and failure were determined. The results are shown in Table II. In each case, the bolt material failed at ultimate strengths higher than the minimum specified for the material. The margin between the bolt design allowables and their test loads varied by a factor of between 1.5 and 2.

C. Field Examination

The purpose of this exercise was to provide a correlation between the site data and laboratory data. Selected installed anchor bolts were subjected to thread measurements by Materials Engineering personnel. Thread verification was made using GO-LO gauges, thread micrometers, diameter micrometers, three wire gauges, and pitch angle gauges. The results are shown in Table III.

The thread measurements in the field verified those made in the laboratory. They also confirmed that the previous measurements of pitch diameter made by site personnel were in error. This fact was further confirmed when site personnel remeasured the threads for several bolts that had previously been measured and, on the second attempt, obtained satisfactory results. The nonconformance reports for these measurements were revised to show only the major diameter measurements which were then used in the analysis. In general, the majority of the bolts were found to have major diameter measurements that met requirements. Of the bolts that did not, the maximum deviation was less than 0.020 inch.

D. Analysis

Based on measured major diameter and the pitch, the tensile areas were calculated for each work order, each group of bolts and each foundation pad. The analysis has shown that the stressed area of the bolt averaged 5% below the specified tensile area, which is within the allowable design criteria.

E. Repair

None of the installed anchor bolts were rejected because of thread deficiencies; therefore, no repair was required.

IV. Recurrence Control

In order to preclude recurrence of this deficiency, four actions have been taken. These actions are:

A. Purchase of Thread Cutting Tools

The new thread dies have a more accurate cutting tool. The re-

sulting improvement in the precision of thread formation will help to prevent recurrence of this deficiency.

B. Purchase of Thread Ring Gauges

The use of precise inspection tooling will assure a more accurate measurement of thread dimensions. Similar deficiencies can thus be avoided in the future by the detection of out-of-tolerance threads before they are accepted.

C. Preparation and Distribution of Procedure

A procedure has been developed and issued for use which describes the thread-cutting process and gives a detailed explanation of the proper method for inspecting threads.

D. Training Program

A training program has been initiated in which site personnel are instructed in the proper procedure for fabricating and inspecting threads. This includes the proper use of thread ring gauges and pitch micrometers.

V. Safety Analysis

Since anchor bolts were determined to meet or exceed all design criteria based upon capacity, no safety evaluation was conducted.

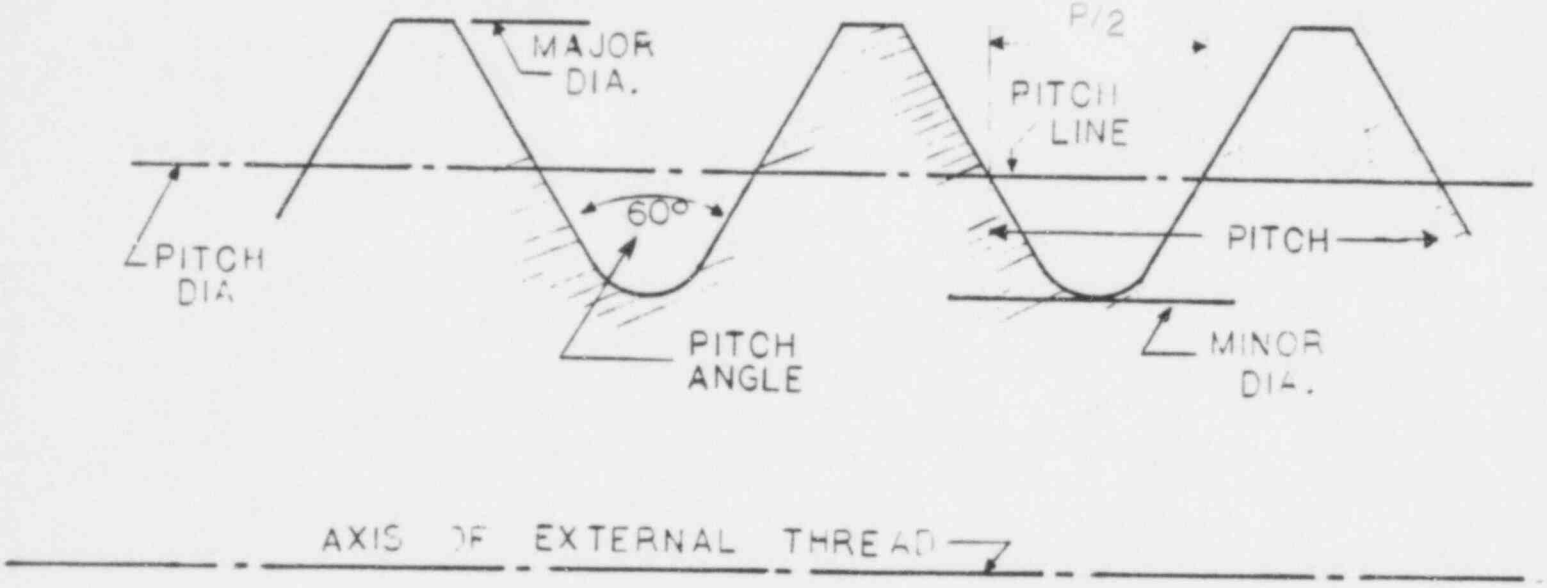

FIG.1: EXTERNAL SCREW THREAD DESIGN FORM

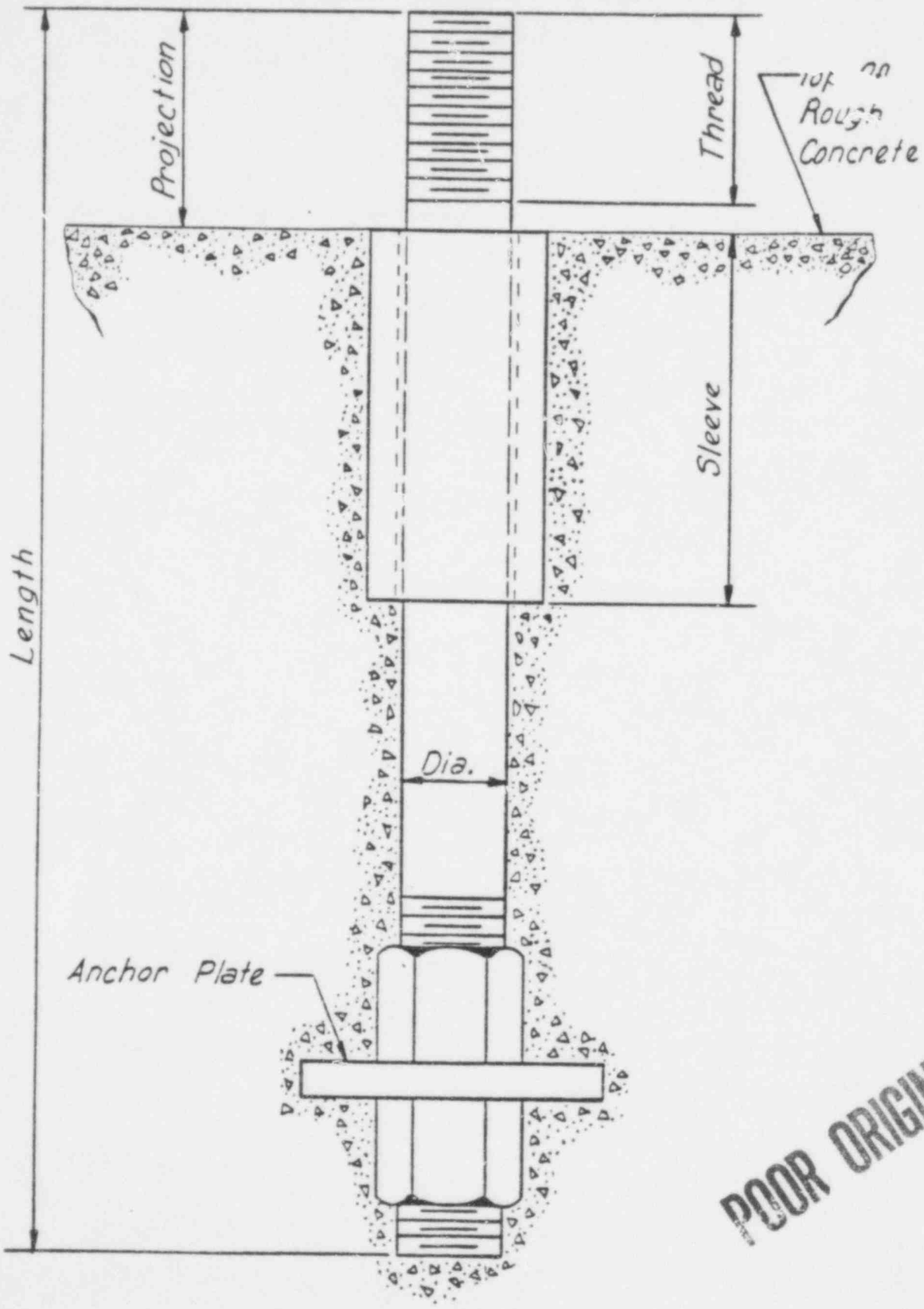

FIG. 2: TYPICAL EMBEDDED ANCHOR BOLT DETAIL

TABLE I

ANCHOR BOLT THREAD DIMENSION DETERMINATION

SAMPLE NUMBER	MEASUREMENT LOCATION	METHOD USED	MEASURED DIMENSION (IN.)	ANSI B1.1 REQUIREMENTS CLASS 2A (IN.)
1	OD	Micrometer	.736-.744	.7353-.7482
(.75 In.)	Pitch Dia.	Micrometer	.679-.680	.6773-.6832
	Pitch Dia.	3 Wire (.055In.)	.681-.682	.6773-.6832
	Minor Dia.	Opt. Comp.	.6155	.6255
	Pitch	Pitch Gage	10 TPI (1)	10 TPI
2	OD	Micrometer	.742-.745	.7353-.7482
(.75 In.)	Pitch Dia.	Micrometer	.680	.6773-.6832
	Pitch Dia.	3 Wire (.055In.)	.680-.681	.6773-.6832
	Minor Dia.	Opt. Comp.	.6167	.6255
	Pitch	Pitch Gage	10 TPI	10 TPI
3	OD	Micrometer	.867-.868	.8592-.8731
(.875 In.)	Pitch Dia.	Micrometer	.796-.797	.7946-.8009
	Pitch Dia.	3 Wire (.063In.)	.795-.797	.7946-.8009
	Minor Dia.	Opt. Comp.	.7236	.7368
	Pitch	Pitch Gage	9 TPI	9 TPI
4	OD	Micrometer	.868-.869	.8592-.8731
(.875 In.)	Pitch Dia.	Micrometer	.797-.798	.7946-.8009
	Pitch Dia.	3 Wire (.063In.)	.797-.798	.7946-.8009
	Minor Dia.	Opt. Comp.	.7228	.7368
	Pitch	Pitch Gage	9 TPI	9 TPI
5	OD	Micrometer	.993-.995	.9830-.9980
(1.000 In.)	Pitch Dia.	Micrometer	.912-.913	.9100-.9168
	Pitch Dia.	3 Wire (.072In.)	.914-.915	.9100-.9168
	Minor Dia.	Opt. Comp.	.8283	.8446
	Pitch	Pitch Gage	8 TPI	8 TPI
6	OD	Micrometer	.994-.995	.9830-.9980
(1.000 In.)	Pitch Dia.	Micrometer	.902-.912*	.9100-.9168
	Pitch Dia.	3 Wire (.072In.)	.902-.915*	.9100-.9168
	Minor Dia.	Opt. Comp.	.8303	.8446
	Pitch	Pitch Gage	8 TPI	8 TPI
7	OD	Micrometer	1.234-1.236	1.2329-1.2479
(1.250 In.)	Pitch Dia.	Micrometer	1.159-1.160	1.1597-1.1667
	Pitch Dia.	3 Wire (.072In.)	1.159-1.162	1.1597-1.1667
	Minor Dia.	Opt. Comp.	1.0804	1.0945
	Pitch	Pitch Gage	8 TPI	8 TPI

TABLE I
(Continued)

SAMPLE NUMBER	MEASUREMENT LOCATION	METHOD USED	MEASURED DIMENSION (IN.)	ANSI B1.1 REQUIREMENTS CLASS 2A (IN.)
8	OD	Micrometer	1.234-1.236	1.2329-1.2479
(1.250 In.)	Pitch Dia.	Micrometer	1.158	1.1597-1.1667
	Pitch Dia.	3 Wire (.072In.)	1.159-1.160	1.1597-1.1667
	Minor Dia.	Opt. Comp.	1.0856	1.0945
	Pitch	Pitch Gage	8 TPI	8 TPI
9	OD	Micrometer	1.479-1.482	1.4828-1.4978
(1.500 In.)	Pitch Dia.	Micrometer	1.402-1.405*	1.4093-1.4166
	Pitch Dia.	3 Wire (.072In.)	1.403-1.405*	1.4093-1.4166
	Minor Dia.	Opt. Comp.	1.3234	1.3444
	Pitch	Pitch Gage	8 TPI	8 TPI
10	OD	Micrometer	1.489-1.494	1.4828-1.4978
(1.500 In.)	Pitch Dia.	Micrometer	1.405-1.416*	1.4093-1.4166
	Pitch Dia.	3 Wire (.072In.)	1.402-1.416*	1.4093-1.4166
	Minor Dia.	Opt. Comp.	1.3101	1.3444
	Pitch	Pitch Gage	8 TPI	8 TPI
11	OD	Micrometer	1.483-1.488	1.4828-1.4978
(1.500 In.)	Pitch Dia.	Micrometer	1.402-1.412*	1.4093-1.4166
	Pitch Dia.	3 Wire (.072In.)	1.400-1.413*	1.4093-1.4130
	Minor Dia.	Opt. Comp.	1.3288	1.3444
	Pitch	Pitch Gage	8 TPI	8 TPI
12	OD	Micrometer	1.476-1.486	1.4828-1.4978
(1.500 In.)	Pitch Dia.	Micrometer	1.391-1.407*	1.4093-1.4166
	Pitch Dia.	3 Wire (.072In.)	1.393-1.409*	1.4093-1.4130
	Minor Dia.	Opt. Comp.	1.3221	1.3444
	Pitch	Pitch Gage	8 TPI	8 TPI

* These five Pitch diameter dimensions deviate fro : ANSI specification.

Note: TPI - Threads Per Inch

TABLE II

FULL SECTION LOAD TEST RESULTS

SAMPLE NUMBER	ASTM MATL. SPEC.	NOMINAL SIZE (IN.)	THREADS PER INCH	BOLT AREA(1) (SQ.IN.)	APPROX.LOAD AT YIELD (2)(LB.)	LOAD AT FAILURE(lb)	UTS (PSI)
1.	A36	.750	10	.3344	14400	22930	68570
2.	A193B7	.750	10	.3344	-	48220	144198
3.	A36	.875	9	.4617	20960	32870	71193
4.	A193B7	.875	9	.4617	55700	64600	139917
5.	A193B7	1.000	8	.6058	-	83900	138494
6.	A36	1.000	8	.6058	24770	42410	70006
7.	A36	1.250	8	.9998	42200	66100	66113
8.	A193B7	1.250	8	.9998	117700	135500	135527
9.	A36	1.500	8	1.4920	69000	112600	75469
10.	A36	1.500	8	1.4920	70500	112400	75335
11.	A36	1.500	8	1.4920	69100	113700	76206
12.	A36	1.500	8	1.4920	70100	112300	75268

NOTES:

(1) The stressed area A_s of a bolt is computed from

$$A_s = .7854\ (D - \frac{.9743}{N})^2$$

where D is the nominal bolt diameter and N represents the thread per inch.

(2) Load at yield determined by the halt of the pointer method.

TABLE III
FIELD MEASUREMENTS

WORK ORDER	MEASUREMENT	METHOD USED	MEASURED DIMENSION
836			
#1 (1.375)	O.D.	Micrometer	1.359-1.362
	Pitch Dia.	3 Wire (.072)	1.286
	Pitch Dia.	Micrometer	1.282-1.285
	Pitch	Pitch Gage	8 TPI
#2(1.500)	O.D.	Micrometer	1.475-1.481
	Pitch Dia.	3 Wire (.072)	1.403
	Pitch Dia.	Micrometer	1.402-1.415
	Pitch	Pitch Gage	8 TPI
#3 (1.500)	O.D.	Micrometer	1.475-1.476
	Pitch Dia.	3 Wire (.072)	1.396
	Pitch Dia.	Micrometer	1.393-1.396
	Pitch	Pitch Gage	8 TPI
1257			
#1 (1.000)	O.D.	Micrometer	.976-.986
	Pitch Dia.	3 Wire (.072)	.908
	Pitch Dia.	Micrometer	.906-.916
	Pitch	Pitch Gage	8 TPI
#2 (1.000)	O.D.	Micrometer	.969-.985
	Pitch Dia.	3 Wire (.072)	.908
	Pitch Dia.	Micrometer	.906-.914
	Pitch	Pitch Gage	8 TPI
#3 (1.000)	O.D.	Micrometer	.981-.990
	Pitch Dia.	3 Wire (.072)	.911
	Pitch Dia.	Micrometer	.903-.909
	Pitch	Pitch Gage	8 TPI
1219			
#1 (1.375)	O.D.	Micrometer	1.375-1.378
	Pitch Dia.	3 Wire (.072)	1.290
	Pitch Dia.	Micrometer	1.290-1.298
	Pitch	Pitch Gage	8 TPI

TABLE III
(Continued)

WORK ORDER	MEASUREMENT	METHOD USED	MEASURED DIMENSION
#2 (1.375)	O.D.	Micrometer	1.310-1.379
	Pitch Dia.	3 Wire (.072)	1.285
	Pitch Dia.	Micrometer	1.283-1.287
	Pitch	Pitch Gage	8 TPI
#3 (1.375)	O.D.	Micrometer	1.359-1.371
	Pitch Dia.	3 Wire (.072)	1.284
	Pitch Dia.	Micrometer	1.283-1.286
	Pitch	Pitch Gage	8 TPI
1110			
#1 (1.500)	O.D.	Micrometer	1.486-1.490
	Pitch Dia.	3 Wire (.072)	1.411
	Pitch Dia.	Micrometer	1.408-1.410
	Pitch	Pitch Gage	8 TPI
#2 (1.500)	O.D.	Micrometer	1.486-1.488
	Pitch Dia.	3 Wire (.072)	1.412
	Pitch Dia.	Micrometer	1.408-1.409
	Pitch	Pitch Gage	8 TPI
#3 (1.500)	O.D.	Micrometer	1.488-1.492
	Pitch Dia.	3 Wire (.072)	1.413
	Pitch Dia.	Micrometer	1.410-1.411
	Pitch	Pitch Gage	8 TPI
1373			
#1 (.875)	O.D.	Micrometer	.859-.862
	Pitch Dia.	3 Wire (.072)	.789
	Pitch Dia.	Micrometer	.787-.788
	Pitch	Pitch Gage	9 TPI
#2 (.875)	O.D.	Micrometer	.855-.862
	Pitch Dia.	3 Wire (.072)	.790
	Pitch Dia.	Micrometer	.787-.788
	Pitch	Pitch Gage	9 TPI
#3 (.875)	O.D.	Micrometer	.861-.862
	Pitch Dia.	3 Wire (.072)	.789
	Pitch Dia.	Micrometer	.787-.789
	Pitch	Pitch Gage	9 TPI

TABLE III
(Continued)

WORK ORDER	MEASUREMENT	METHOD USED	MEASURED DIMENSION
1342			
#1 (1.500)	O.D.	Micrometer	1.478-1.496
	Pitch Dia.	3 Wire (.072)	1.419
	Pitch Dia.	Micrometer	1.412-1.413
	Pitch	Pitch Gage	8 TPI
#2 (1.500)	O.D.	Micrometer	1.489-1.497
	Pitch Dia.	3 Wire (.072)	1.445
	Pitch Dia.	Micrometer	1.412-1.431
	Pitch	Pitch Gage	8 TPI
#3 (1.500)	O.D.	Micrometer	1.486-1.491
	Pitch Dia.	3 Wire (.072)	1.414
	Pitch Dia.	Micrometer	1.410-1.411
	Pitch	Pitch Gage	8 TPI