A WHITE PAPER
FASTENER STRENGTH ANALYSIS
NUCLEAR SAFETY CONCERN 93-11

BACKGROUND

In early 1993, the systematic dimensional verification of fastener thread form during Receipt Inspection was shifted from the use of Fixed Limit (Go/No-Go) Gages, which are the accepted nuclear industry standard, to the Johnson Indicating Gage process which provided a direct digital readout of thread attributes for comparison with the appropriate criteria. The Johnson Gage system was found to provide improved inspection accuracy through the measurement of specific thread attribute to the ten thousanths of an inch, and increased ease of use when compared with the Go/No-Go gages.

Since its first issuance in 1924, the ANSI Standard for threaded fasteners, B-1.1, has provided dimensional criteria for standardized thread forms. The dimensions and tolerances have been presented to the ten thousandth's of an inch, and have remained constant over the years for the standard thread forms. Early dimensional inspection methodology was unable to assure exact fastener thread conformance to the fine tolerances stated in the standard. Modern fastener industry practice has included the usage of indicating gages for the setup and maintenance of the manufacturing machining processes, with the fixed limit gages providing final dimensional acceptance. In 1978, framework for the use of indicating gages for final dimensional acceptance of threaded fasteners was provided with the issuance of ANSI B-1.3. This standard provided definition of System 21 inspection requirements (which are met with the Go/No-Go gaging), and System 22 inspection requirements (which include the measurement of Pitch Diameter and are met with an indicating gage system).

The nuclear industry is governed by construction standards which routinely provide a margin in the range of 200 to 300% of ultimate strength in bolting materials over the maximum operating service load. Nuclear industry oversight organizations and interest groups routinely provide information on industry equipment failure and trend performance of specific categories of components, such as fasteners. Most recently, the NRC issued Generic Letter 91-17, "Bolting Degradation or Failure in Nuclear Power Plants", which closed Generic Safety Issue 29, on the same subject, based on studies conducted by EPRI, MPC and AIF. In closing this issue, the NRC found no evidence to indicate that failures were directly attributable to dimensionally nonconforming fasteners. These findings combined with the margins inherent in nuclear power plant design made unnecessary the need for additional requirements for bolting inspection. Thus, the Fixed Limit (Go/No-Go) gages remain the industry accepted standard for nuclear power applications.

The usage of the Johnson Gage system at San Onofre Nuclear Generating Station has a twofold purpose, improved inspection productivity and the trending of supplier performance. An independent report by Nuclear Oversight on the usage of the Johnson Gaging system in October, 1993 stated the following advantages over the previous system of inspection:

- Increased accuracy in measurement of thread attributes
- Faster inspection process
- Minimum gage wear
- Less frequent and easier calibration
- Direct readout of thread dimensions precludes dispute with suppliers over accuracy of Go/No-Go gages

The Johnson Gage system at use in the Commercial Grade Item laboratory is connected to a computer database into which results of each inspection are entered. The computer can then process the information and produce a Supplier Quality Index for each supplier. From this information, it can be determined if a specific supplier is providing consistent bolting product, which is a good indicator that the supplier is utilizing statistical process controls. Analysis of the inspection data has allowed Procurement Engineering to recommend consistent high-quality suppliers over the less consistent suppliers.

In December of 1993, the inspection of threaded fasteners with the Johnson gage system was expanded from its use during Quality Control receipt inspection, to the inspection of fasteners which had previously been examined and accepted with Go/No-Go gages.

Return To Stock Inspections

- Bolting which had been issued for plant use, but not used, was subjected to restocking inspection with the Johnson Gage equipment. Inspection revealed several fasteners with dimensionally out-of-tolerance conditions. Two WNCRs were written on 12/8 and 12/13/93 to document the inspection results. The potential existed that out-of-tolerance fasteners had been installed in the plant.

  NOTE: Subsequent review of work documents revealed that the subject items had not been installed in Safety Related systems, but had been used as construction and maintenance aids, and on non-safety related equipment. No plant NCRs were required to be written.

Initiation of Nuclear Safety Concern

- A Nuclear Safety Concern was issued on 12/27/93 stating the potential for out-of-tolerance fasteners to have been installed in the plant.

Specific Bin Inspections

- In response to specific information from the Submitter, samples of eight warehouse stock bins were inspected with Johnson Gage instruments, revealing dimensionally out-of-tolerance fasteners in three of the bins. WNCRs were written to document the observed conditions. The original two WNCRs (above) combined with the discovery of this additional out-of-tolerance stock in the Warehouse validated an additional element of the NSC that more out-of-tolerance fasteners may exist in Warehouse stores.

Warehouse Sample Inspection

In order to obtain a statistical representation of the range of thread dimensional conditions which existed in the Warehouse fastener stock, a representative sample of fasteners was obtained and inspected.

- A Sample Plan was devised which utilized the existing Commercial Grade Item Lab sampling procedure, which was designed to provide a 95% confidence level of acceptable items. A computer listing of all fastener Material Codes, including item descriptions, was obtained from responsible Warehouse personnel. Obvious items which were not subject to the concern were eliminated from the listing (washers, metal screws, set screws). To further define the test sample, bolting smaller than 1/2 inch diameter was omitted. Additionally, items which had been previously examined with Johnson Gaging were eliminated from the listing. This left 286 fastener Mat Codes subject to sample inspection.

  From the Procedure SO123-XXXII-2.5, "Sampling Program for Assessing, Estimating, and Reporting Commercial Grade Item Quality" a sample size of 32 Mat Codes was chosen from Table 2. It should be noted that 32 is the maximum sample size with very minor statistical improvement in confidence level from any larger sample sizes. Given that 32 sample mat Codes needed to be chosen from the 286, it was decided that every ninth Mat Code from the listing would provide an adequate assurance of randomness. The fasteners had been sorted by item name alphabetically. Every ninth Mat Code would then provide various samples of each item type. If a Mat Code item proved uninspectable due to unavailability of Johnson Gage segments, the next Mat Code, of the 286, would be chosen. The bins associated with the 32 Mat Codes were provided in their entirety to qualified Receiving Quality Control Inspectors. Random samples were obtained from each Mat Code in accordance with procedure SO123-XXXII-2.5 and samples were examined with the Johnson Gages.

- Sample Data was obtained and evaluated. The 32 sample Mat Codes contained 1542 items, of which 356 were inspected using the Johnson Gaging system. A total of 96 items were found to be out-of-tolerance when compared to the requirements of ANSI B-1.1. This represents a 26% failure rate. The out-of-tolerance items were also checked with Go/No-Go gages. All but one of the out-of-tolerance items were found to be acceptable when checked with Go/No-Go gages. Many of the out-of-tolerance readings were only out by a few 10,000ths and several were reported to be slightly out of round, with the worst deviation being the recorded value. Also noted in the review of the data were repeat readings of the same item which showed some minor deviations which were not averaged, the largest out-of-tolerance reading was reported and subsequently used in this analysis.

The results of the warehouse sample inspection revealed that over 99% of the inspected fasteners passed the System 21 requirements. This level of acceptance is the best that can be expected given the statistical nature of receipt inspection techniques. The fact that only one item failed inspection, of all inspected, validates previous receipt inspection processes as effective in meeting the nuclear industry standard. This evaluation is therefore centered in the band of improved accuracy afforded by the indicating gages measuring specific System 22 parameters.

FASTENER STRENGTH ANALYSIS

- A "Worst Case" condition was determined for internally threaded fasteners (nuts) and for externally threaded fasteners (bolts/studs/allthread). The Worst Case conditions were analyzed for the amount of reduction in thread strength which would result from the measured out-of-tolerance conditions. The readings for fastener Pitch Diameter were significant because Pitch Diameter relates directly to thread shear area. Fastener strength is affected by the thread shear area and the shear strength of the fastener material. Therefore, a reduction in fastener Pitch Diameter could affect the strength capacity of the threaded joint.

The following formulas were utilized in the development of the Fastener Strength Analysis (From ANSI B-1.1):

$$\text{Shear Strength of Threads} = 0.5\ \mathrm{St}\ (\mathrm{ASn} \text{ or } \mathrm{Ass})$$

Where: St = Ultimate Tensile Strength of Fastener Material
Asn = Minimum Thread Shear Area for Internal Threads
Ass = Minimum Thread Shear Area for External Threads

$$\mathrm{Asn} = \mathrm{Pi}\ (1/P)\ (\mathrm{LE})\ (\mathrm{Dmin})\ [\ 1/(2(1/P)) + 0.57735(\mathrm{Dmin} - \mathrm{D2max})]$$

and

$$\mathrm{Ass} = \mathrm{Pi}\ (1/P)\ (\mathrm{LE})\ (\mathrm{D1max})\ [\ 1/(2(1/P)) + 0.57735(\mathrm{D2min} - \mathrm{D1max})]$$

Where: Pi = 3.14159
1/P = Number of Threads per Inch
LE = Length of Engagement
Dmin = Minimum Major Diameter of External Thread
D1max = Maximum Minor Diameter of Internal Thread
D2max = Maximum Pitch Diameter of Internal Thread
D2min = Minimum Pitch Diameter of External Thread

Worst Case External Threads:

Item Description: All Thread Stud, 5/8" dia - 11 threads/inch by 36" length

Material Code: 305-05606 RSO#: 2063-93 Supplier: NOVA Inc.

Material Specification: ASME SA193 Grade B7 Heat Code: 8099572

Thread Functional Size Inspection was performed Satisfactorily

Thread Pitch Diameter Inspection was shown to be Out Of Tolerance.

Pitch Diameter Reading: 0.5554 inches

Pitch Diameter Range: 0.5644 (max) to 0.5589 (min) inches. (ANSI B-1.1)

Amount Out-of-Tolerance: 0.0035 inches (Class 2A)

Ultimate Material Strength (St) = 125,000 psi (min) (ASME Section III)

Calculated Length of Thread Engagement (LE) = 1 Diameter = 0.625 inches

THREAD STRENGTH CALCULATIONS FOR WORST CASE EXTERNAL THREAD CONDITION UTILIZING THE ABOVE EQUATIONS AND DATA:

A) Maximum Material Conditions for both Internal and External Threads

Ass = 3.14159 * 11 * .625 * .527 * [1/(2*11) + .57735(.5644 - .5270)]
= 0.7632 square inches

Thread Strength = 0.5 * 0.7632 * 125,000 = 47,700 pounds (min)

B) Minimum Material Conditions for both Internal and External Threads
(ANSI B-1.1)

Ass = 3.14159 * 11 * .625 * .546 * [1/(2*11) + .57735(.5589 - .5460)]
= 0.6239 square inches

Thread Strength = 0.5 * 0.6239 * 125,000 = 38,992 pounds (min)

C) Out of Tolerance Conditions from Worst Case Data:

Ass = 3.14159 * 11 * .625 * .546 * [1/(2*11) + .57735(.5554 - .5460)]
= 0.6000 square inches

Thread Strength = 0.5 * 0.6000 * 125,000 = 37,502 pounds (min)

It should be noted that the Worst Case External Thread condition represents only a 2.2% reduction in thread strength from the "B" case above, which represents the industry standard calculation of thread strength based on the requirements of ANSI B-1.1. An ideal thread condition calculation is presented in case "A" above which assumes that both the internal and external threads are at the maximum material limit. Comparing "A" and "B" above provide the strength reduction over the band from the maximum tolerance to minimum tolerance numbers for both the internal and external threads, indicating a 19.2% reduction in strength across this band. The Worst Case External Thread conditions are shown to have thread strength 21.4% lower than the ideal thread condition from case "A".

EXTERNAL THREAD CALCULATION SUMMARY:

CONDITIONS	DIFFERENCE IN THREAD STRENGTH
Case A, Maximum Material both Int and Ext	
	} 19.2%
Case B, Minimum Material both Int and Ext	
	} 2.2%
Case C, Worst Case Out-of-Tolerance	

ASME CODE SERVICE APPLICATIONS:

The Worst Case out-of-tolerance thread conditions are shown to create reduced thread shear areas thereby reducing the shear strength of the threads. Maximum stress levels for bolting materials are specified in Section III of the ASME Code. Design stress levels are required to be lower than these maximum levels for each specified material. Shear stresses increase across the reduced shear areas when design loading is applied to a fastener with out-of-tolerance threads. The Worst Case out-of-tolerance condition must be evaluated to determine if the increased shear stresses created by the reduced thread shear area falls within the maximum allowed by the ASME Code.

For the Worst Case out-of-tolerance external thread conditions:

From ASME Section III, Appendix I, Table I-1.3 (Class 1) and I-7.3 (Class 2 & 3) for SA193 B7 Bolting:

Design Stress Intensity Value Sm = 35 Ksi for Class 1 applications

Allowable Stress Value S = 25 Ksi for Class 2 and 3 applications

From ASME Section III, NB 3230 states that stresses for design conditions be limited to Sm. However, service conditions including preload in bolts may be higher than Sm but that average stresses shall not exceed Two times Sm listed in Table I-1.3. These requirements may also be applied to Class 2 and 3 bolting.

Applied to the Worst Case 5/8"-11 Stud, the maximum allowable preload would be:

ASME Section III Class 1:

2 * 35 Ksi * 0.226 square inches tensile stress area = 15,820 pounds

ASME Section III Class 2 and 3:

2 * 25 Ksi * 0.226 square inches tensile stress area = 11,300 pounds

When compared to the ultimate Thread Strength for the Worst Case out-of-tolerance conditions calculated above (37,502 pounds), a margin of 2.37 to one above the maximum Code allowables is concluded.

When the maximum Code allowable load under Design conditions is applied to the reduced thread shear area which was calculated for the Worst Case out-of-tolerance conditions:

ASME Section III Class 1:

Maximum allowable shear stress per ASME Code (NB-3227.2) is 0.6 Sm:

0.6Sm = 0.6 * 26,800 psi = 16,080 psi @ 700 degrees F

Maximum Design Load is limited to Sm times tensile stress area:

35 ksi * 0.226 square inches tensile area = 7910 pounds

Shear stress is the Maximum Design Load divided by the shear area

7910 / 0.600 square inches shear area = 13,173 psi

Therefore the calculated shear stress is less than the maximum allowable shear stress specified in ASME Section III.

Similarly for ASME Section III Class 2 and 3:

Maximum allowable shear stress per ASME Code (NC-3216.3(b)) is 0.6 S:

0.6 S = 0.6 * 25,000 psi = 15,000 @ 700 degrees F

25 ksi * .226 square inches tensile area = 5650 pounds Max Design Load

Shear Stress = 5650 pounds / 0.600 square inches = 9417 psi

Therefore, the calculated shear stress is less than the maximum allowable shear stress specified in ASME Section III.

Worst Case Internal Threads:

Item Description: Heavy Hex Nut 1/2" - 13 Threads per Inch

Material Code: 305-04211 RSO#: 2583-92 Supplier: NOVA / Texas Bolt

Material Specification: ASME SA194 Grade 2H Heat Code: 1D3716

Thread Functional Size Inspection was shown to be Out-of-Tolerance

Functional Size Reading: 0.4572 inches

Functional Size Range: 0.4565 (max) to 0.4500 (min) inches (ANSI B-1.1)

Amount Out-of-Tolerance: 0.0007 inches

Thread Pitch Diameter Inspection was shown to be Out Of Tolerance.

Pitch Diameter Reading: 0.4642 inches

Pitch Diameter Range: 0.4565 (max) to 0.4500 (min) inches. (ANSI B-1.1)

Amount Out-of-Tolerance: 0.0077 inches (Class 2A)

Ultimate Material Strength (St) = 175,000 psi (min) (ASME Section II)

Calculated Length of Thread Engagement (LE) = 1 Diameter = 0.500 inches

THREAD STRENGTH CALCULATIONS FOR WORST CASE INTERNAL THREAD CONDITION UTILIZING THE ABOVE EQUATIONS AND DATA:

A) Maximum Material Conditions for both Internal and External Threads

Asn = 3.14159 * 13 * .500 * .4985 * [1/(2*13) + .57735(.4985 - .4500)]
= 0.6765 square inches

Thread Strength = 0.5 * 0.6765 * 175,000 = 59,198 pounds (min)

B) Minimum Material Conditions for both Internal and External Threads (ANSI B-1.1)

Ass = 3.14159 * 13 * .500 * .4876 * [1/(2*13) + .57735(.4876 - .4565)]
= 0.5618 square inches

Thread Strength = 0.5 * 0.5618 * 175,000 = 49,158 pounds (min)

C) Out of Tolerance Conditions from Worst Case Data:

Ass = 3.14159 * 13 * .500 * .4876 * [1/(2*13) + .57735(.4876 - .4642)]
= 0.5174 square inches
Thread Strength = 0.5 * 0.5174 * 175,000 = 45,270 pounds (min)

It should be noted that the Worst Case Internal Thread conditions represent only a 6.5% reduction in thread strength from the "B" case above, which represents the calculation of thread strength based on the requirements of ANSI B-1.1. An ideal thread calculation is presented in case "A" above which assumes that both the internal and external threads are at the maximum material limit. The Worst Case Internal Thread conditions are shown to have thread strength 23.5% lower than the ideal thread condition from case "A".

INTERNAL THREAD CALCULATION SUMMARY:

CONDITIONS	DIFFERENCE IN THREAD STRENGTH
Case A, Maximum Material both Int and Ext	
	} 17%
Case B, Minimum Material both Int and Ext	
	} 6.5%
Case C, Worst Case Out-of-Tolerance	

EVALUATION OF SERVICE APPLICATIONS:

Inherent in the design of threaded fasteners is a strength bias favoring the internally threaded components. The thread stripping areas for internal threads are 1.3 to 1.5 times those for external threads. A typical bolted joint will fail in tension at the root of the external threads. The reduced thread shear area calculated above for the Worst Case out-of-tolerance internal threads would still exceed the maximum material shear area for corresponding external threads.

Worst Case Internal Thread Shear Area = 0.5174 square inches

Maximum Material External Thread Shear Area = 0.4150 square inches

Therefore, even with the reduced shear area resulting from out-of-tolerance conditions, the Worst Case out-of-tolerance nut would still be stronger than the corresponding bolt or stud at the maximum material (max P.D.) conditions.

GENERIC APPLICABILITY OF DATA

The warehouse sample data was obtained by utilizing the Sampling Program for Assessing, Estimating and Reporting Commercial Grade Item Quality contained in SO123-XXXII-2.5. This program is designed to provide a 95% confidence level of zero out-of-tolerance items per lot/batch with a user risk of 5%. To obtain this level of confidence, the program requires that samples be taken in accordance with a referenced table of sample sizes, and that if one out-of-tolerance item is found, that the entire lot/batch be rejected.

In applying this program to the specific task of sampling the warehouse fasteners, the program was followed as stated in the procedures, except that the data was not analyzed for rejection of lots/batches. The data was analyzed to determine the Worst Case statistical condition and assess its acceptability for plant service. This task was driven by the necessary assumption that conditions found in the warehouse would be typical of those found in the plant.

Following the statistical logic that provides a 95% confidence level to lots/batches found acceptable using this sampling program, it can be shown that the same confidence level can be applied to the band of readings found during this specific warehouse sample. **In short, the sampling plan is designed to provide a 95% confidence level that there are no greater out-of-tolerance conditions in the warehouse stock, than those identified in this sample.**

SERVICE APPLICATION ANALYSIS

Calculations have shown that the Worst Case out-of-tolerance conditions can be generalized across all sizes of internal and external threaded fasteners. Expressing the out-of-tolerance conditions as a percentage of nominal fastener diameter will produce a relatively constant percentage reduction in thread strength for an equivalent Worst Case condition across all sizes of fasteners. Analysis of the most severe service conditions at SONGS were reviewed. High Temperature ASME Section III Class 1 service requirements were researched and fastener loading for these applications were found to be below the applicable ASME Code allowances. Given that the fastener strength reduction calculated from the Worst Case out-of-tolerance conditions (above) left the thread strength with a 2.37 to 1 margin over ASME Code stress allowables, it can be concluded that the Worst Case conditions observed during the sample of Warehouse stock, generalized across all sizes and materials, contain adequate strength margin for service in the most severe service conditions at SONGS.

POTENTIAL FOR FASTENER LOOSENING

Vibrating environments, material relaxation and material fatigue are conditions which may result in the loosening and failure of fasteners. The potential for vibration and material relaxation and fatigue of bolted connections is routinely assessed in the design of equipment and components for operating service conditions. The following discussion assesses the affect of the measured out-of-tolerance conditions on vibration, material relaxation and fatigue.

VIBRATION:

Vibration has been shown, under certain conditions, to cause the loosening of threaded fasteners. The vibration can overcome the friction forces which act between the faces of the mating interface of a bolted joint and also the friction forces at the face of the nut and/or bolt. If these friction forces, which can be typically 80 - 90% of the torque loading, are overcome or negated by the effects of vibration, the energy stored in the fastener will be released and the bolt will return to its original length with the inclined plane of the bolt threads pushing the inclined plane of the nut threads out of the way. Vibration is theorized to negate the friction forces by creating a rapid series of small relative motions between the thread mating faces in a direction perpendicular to the friction forces. Vibration loosening is agreed to occur more commonly in fasteners loaded in shear, especially those with vibration forces acting perpendicular to the axis of the fastener. Fasteners loaded in tension are much less susceptible to the effects of vibration. In a bolted joint susceptible to vibration, after loss of sufficient preload, the friction forces will be reduced sufficiently to allow the nut to back off.

Higher initial preload can mitigate the effects of vibration. A higher preload will increase the friction forces between the thread faces making them less susceptible to the small relative motions which negate the friction forces. In many cases a sufficiently high preload can create a completely vibration resistant bolted joint. In other cases, more direct physical means must be considered to prevent relative motion between the nut and bolt:

- Utilize locking devices or other form of action to prevent relative motion between the nut and bolt

- Mechanically prevent slippage between bolted joint surfaces loaded in shear to prevent slip between bolt and joint surfaces.

- Utilize fine thread bolting to reduce the helix angle of threads and thereby reduce the back-off torque caused by the preload.

The consideration of vibration as a potential cause of fastener loosening is performed during the design of individual components for SONGS. Vendor manuals routinely specify the torque values for bolting, and these values are incorporated into maintenance procedures. These values conform to those specified by ASME Code for bolt preloads and have been evaluated by the vendor as satisfactory for the service application. The adequacy of these values is also verified by hydrotest of the component and system, which is usually conducted at 1.5 times the Design pressure. If fastener loosening, as evidenced by leaking joints, is discovered during operation or maintenance, programs are in place to require engineering evaluation of the conditions, and for the specification of corrective measures to prevent recurrence. Corrective measures may include the increase of fastener preload or any of the options listed above, as long as they are appropriately documented on design documents and procedures are updated.

In the consideration of the susceptibility of the Worst Case out-of-tolerance fastener condition identified during the warehouse sample inspection to the effects of vibration, it should be recognized that the thread mating area would be slightly reduced. The reduced thread mating area would be subject to slightly higher forces across this area, for a given preload, which would then be less susceptible to the effects of vibration. It was shown above that even with the reduced shear area from the Worst Case out-of-tolerance condition, the threads maintained a significant margin of strength above Code maximum allowable stresses and would therefore accommodate any preload increase required for specific system or component considerations.

MATERIAL RELAXATION:

Short Term Relaxation can create a reduction in preload. The most common cause of short term relaxation is thread embedment. The loss of preload occurs when tiny high spots on thread surfaces are overcome by pressure from clamping forces. Plastic deformation of the high spots occurs until enough of the total thread surface is loaded to prevent further deformation. Embedment is more common on new parts than on used ones due to the smoothing of thread surfaces that occurs as fasteners are torqued. Critical SONGS bolting applications require torquing of fasteners. Embedment loss of preload was identified through the SONGS Root Cause Program and a successful anti-embedment process was incorporated in applicable procedures as a corrective measure. Fasteners in the Worst Case out-of-tolerance condition would be less susceptible to embedment loss of preload due to the slightly reduced area of thread mating surfaces which would create higher contact forces during torquing. These slightly higher forces would reduce the effects of embedment, for a given torque force, by more effectively smoothing away the slight irregularities which cause the embedment.

Long Term Relaxation can also create a reduction in preload. This creep or stress relaxation involves the slow shedding of load by a fastener under constant deflection (strain). This process is encouraged by high temperatures. The effects of this relaxation vary for different materials and temperatures and must be considered during the original design of nuclear equipment and systems. The Worst Case out-of-tolerance condition identified in the warehouse sample inspection would not create a condition to further any fasteners susceptibility to this phenomenon. The Worst Case minor reduction in thread shear area did not decrease the fasteners thread shear area below the point where thread shear strength would be less than fastener tensile strength. Therefore the dominant effects of any relaxation would occur across the tensile area, or body, of the fastener. It should also be noted that the effects of creep and stress relaxation occur largely at temperatures above one half of the material melting temperature (Tm expressed in degrees Kelvin). The highest fastener material temperatures at SONGS are conservatively shown to be less than this value.

MATERIAL FATIGUE

The ASME Code provides requirements for the evaluation of the suitability of bolting and bolting materials for cyclic service, including stress limits and design fatigue curves. Minor reductions in thread shear area would have no impact on the fatigue failure of fasteners. Bolting stresses are concentrated at the root of the thread and any cracking propagating from fatigue, even if initiated in the thread material would be expected to propagate through the thread root and across the plane of the minimum tensile area. Samples of stock from lots containing the Worst Case internal and external threaded fasteners were dimensionally examined by independent laboratories. The tensile root stress area for the Worst Case fastener was found to be independent of measured pitch diameter and major diameter readings. A sample of the Worst Case externally threaded stock was machined and destructively tested to verify material properties stated on the supplier Certified Material Test Report. A tensile pull test of a section of this threaded stock was then performed, and tensile area was calculated from the results. The tensile area was found to be essentially unchanged from the design value and correlated well with the areas calculated from dimensional readings. This testing verified that the tensile areas of Worst Case fasteners remain essentially unchanged and therefore the stresses within the fastener would be unaffected by the measured out-of-tolerance thread conditions exhibited during sample inspection. The Worst Case out-of-tolerance condition identified in the warehouse sample inspection would not create a condition to further fastener susceptibility to fatigue failure.

SYSTEM LEAKAGE MONITORING

It should be noted that SONGS systems are continuously monitored for evidence of leakage through routine operator rounds and monitoring of primary system inventory balance. Effective programs exist to correct any identified leakage and ensure corrective actions. The SONGS Root Cause program has been effective in identifying causes and recommending corrective actions for bolting failures including the recommendation of alternate materials, preload and anti-embedment processes. A search of SONGS maintenance and nonconformance databases identified no conditions of bolting failure due to out-of-tolerance threadform. For the Worst Case conditions analyzed above, adequate margin would remain in the strength of the threads to accommodate any preload adjustments required for specific service conditions, within Code specified maximum allowables.

CONCLUSION

The inspection of a statistical sample of warehouse fastener stock with Johnson Gage equipment has identified dimensionally out-of-tolerance conditions in sample items which were shown to be 99% acceptable when inspected with the industry accepted standard of final thread dimensional inspection, Go/No-Go Gages. The out-of-tolerance conditions were analyzed for impact on ultimate thread strength. It was shown that when compared to the ultimate thread strength for the Worst Case out-of-tolerance conditions a minimum margin of safety of 2.37 to one above the maximum fastener preload remains. It can also be concluded that the increased shear stress created by the reduced thread shear area of the Worst Case thread condition are less than the ASME Code stress allowables for the Section III Class 1, 2 and 3 Design conditions. The effects of vibration, material relaxation and fatigue were assessed to compare the susceptibility for the Worst Case out-of-tolerance conditions identified during the warehouse sample inspections to facilitate fastener loosening or failure from these most common recognized failure modes. No increase in susceptibility was found during this evaluation. The methodology utilized in obtaining the statistical sample has provided for a 95% confidence level that there are no greater out-of-tolerance conditions in the warehouse stock, than those seen in this sample. It was also shown that the Worst Case conditions observed during the sample of Warehouse stock, generalized across all sizes and materials, contain adequate strength margin for service in the most severe conditions at SONGS and that adequate thread area remains to develop the full bolt load without thread stripping and will accommodate any preload adjustments required for specific service conditions.

This paper has been independently reviewed and results concurred with by Roger Reedy, of Reedy Associates, Chairman, ASME Section III.

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