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August 26, 1980

Mr. James G. Keppler
Region III
Office of Inspection and Enforcement
US Nuclear Regulatory Commission
799 Roosevelt Rd.
Glen Ellyn, IL 60137

ULNRC- 379

Dear Mr. Keppler:

FINAL REPORT
NSSS LATERAL SUPPORT ANCHOR BOLT NUTS
CALLAWAY PLANT UNIT 1

In accordance with a telephone request from your Mr. Richard Kiessel to our Mr. Passwater we are enclosing one copy of our final report "Investigation of Nonconforming Threads on 3 1/2 inch Diameter Studs and Nuts for the NSSS Steam Generator Lateral Supports" as transmitted with annotated Bechtel letter BLSE 8508, July 17, 1980.

This information will supplement our final report as transmitted in our letter ULNRC-370, July 31, 1980.

Very truly yours,

John K. Bryan

John K. Bryan

WHZ/jds

cc: R. Kiessel, NRR, w/a
H. M. Wescott, Region III w/a
B. H. Grier, Region I w/a
Victor Stello, Jr., Director Office I&E w/a
K. V. Seyfrit, Region IV w/a
W. A. Hansen, NRC Resident Inspector, Callaway Plant w/a
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SEP 0 9 1980

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JUL 1 8 1980

Group Supv.	Systems	Facilities	Lic. & Env.	Admin./P&C	Site

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JUL 1 7 1980

BLSE 8508 File: C-134A/315
Bechtel Job No. 10466
SNUPPS Project
NSSS Lateral Support Anchor Bolts

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CLF		1	—		✓			
NRC		1	—					
OCA-LPA		1	—					

RETURN COMMENTS TO W. H. ZVANUT - CODE

Ref: 1. BLSE 8368 dated 5/22/80
2. SLBE 80-511 dated 6/5/80
3. ULS-3239 dated 5/13/80

Encl: Final Report - Investigation of Nonconforming Threads on 3-1/2 Inch Diameter Studs and Nuts for the NSSS Steam Generator Lateral Supports

NRC Dear Mr. ~~Petrick~~ L Lu VLNRC 379 8/26/80

Enclosed is the final report on the thread nonconformance of studs and nuts supplied for the NSSS lateral supports.

The conclusion of this report is that the subject studs and nuts provide very adequate safety margins against thread failure at the maximum design load, and had the nonconformance gone undetected there would have been no impact to the health and safety of the public. Therefore, the need to report this nonconformance as a significant deficiency is questionable.

"unnecessary" is what we intended to convey (see previous sent P.H. Divjak 8/5/80

Very truly yours,

Original Signed by
J. Smith
J. H. Smith
Project Engineering Manager

GB:bg

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AUG 8 1980
D. F. SCHNELL

POOR ORIGINAL

FINAL REPORT

INVESTIGATION OF NONCONFORMING THREADS ON 3-1/2 INCH DIAMETER STUDS AND NUTS FOR THE NSSS STEAM GENERATOR LATERAL SUPPORTS

Bechtel Power Corporation

Gaithersburg, Maryland

Prepared by: Gerald Brown
Eugene Thomas

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I STATEMENT OF PROBLEM

The threads on a quantity of 3-1/2 inch diameter studs and nuts supplied under Specification 10466-C-134A for the NSSS steam generator lateral supports have been identified as not conforming to the dimensional requirements of ASA Standard B1.1-1960. The studs are ASTM A 540, Grade 23, Class 4, and the nuts are ASTM A 194, Grade 7. The studs and nuts were manufactured by the Southern Bolt Company, Shreveport, Louisiana.

The nonconformance was initially identified when unsymmetrical thread profiles were observed on several nuts at the Wolf Creek jobsite. Measurements confirmed the threads on these nuts to be out of tolerance. An inspection of nuts at the Callaway jobsite revealed similar conditions. As this investigation continued it was also determined that the threads on some of the companion studs were also outside the tolerance limits of ASA B1.1.

At the time this nonconformance was identified, 188 studs with single nuts had been embedded in concrete at the Callaway jobsite, and 24 studs and nuts had been embedded at the Wolf Creek jobsite. There are 324 studs and 1,108 nuts per site, all of which have been shipped to both jobsites.

II INVESTIGATION

An investigation of the thread nonconformance was initiated to determine the capability of the studs and nuts, particularly those previously embedded in concrete, to support the design loads with acceptable margins of safety. The investigation proceeded as follows:

A. Jobsite reinspection of nuts.

B. Tension tests at Lehigh University

C. Jobsite reinspection of studs.

D. Analysis of the maximum design bolt load.

E. Statistical analysis of the load capacity of stud-nut combinations.

A. Reinspection of Nuts

A reinspection of available nuts was made, using a specially prepared cylindrical NO-GO gage, to identify nuts with minor diameters greater than 3.390 inches - the maximum allowable minor diameter per ASA B1.1. Figure 1 shows a cross section of the NO-GO gage used for this inspection. This gage provides the ability to check overall conformance of the thread minor diameter and identifies any ovalation of the minor diameter. Minimum minor diameters were not investigated since nuts with minor diameters smaller than the allowable dimension do not adversely affect the load capacity of the threaded connection.

Subsequently, all nuts identified as nonconforming by the specially prepared NO-GO gage, and a sample quantity of conforming nuts, were measured with dial calipers to obtain precise measurements of the minor diameter. Four measurements per nut were taken - two perpendicular measurements located 2-3 threads from each face of the nut. The following is a summary of the nut reinspection:

1. Callaway

   a. 546 nuts (49% of all the 3-1/2 inch diameter nuts) were reinspected. Minor diameter measurements were obtained on 262 nuts.

   b. 115 nuts (21% of the inspected nuts) are nonconforming with at least one measurement of the minor diameter greater than 3.390 inches. However, only 18 nuts (3% of all the inspected nuts) are out of tolerance by more than 0.010 inches, and only 4 nuts are out of tolerance by more than 0.030 inches. The maximum out of tolerance is 0.076 inches.

2. Wolf Creek

   a. 677 nuts (61% of all the 3-1/2 inch diameter nuts) were reinspected. Minor diameter measurements were obtained on 291 nuts.

   b. 99 nuts (15% of the inspected nuts) are nonconforming with at least one measurement of the minor diameter greater than 3.390 inches. However, only 14 nuts (2% of the inspected nuts) are out of tolerance by more than 0.010 inches, and only 1 nut is out of tolerance by more than 0.025 inches. The maximum out of tolerance is 0.053 inches.

The data collected during the reinspection program are reported in References 2, 3, 4, 5, 7 and 10.

B. Tension Tests

Tension tests were conducted at Lehigh University, Fritz Engineering Laboratory, under the direction of Dr. R. Slutter, on three of the most out-of-tolerance nuts, combined with three randomly selected studs. The tests were performed to gain direct information on the ability of the out-of-tolerance nuts to support the design loads, and also to verify the applicability of the methods in Appendix A of ASA B1.1 to determine the ultimate thread capacity of connections with out-of-tolerance threads.

Dimensional and physical properties of the tested studs and nuts, and the test results, are included in Table 1. The results indicate that the load capacities were directly affected by the amount of thread out of tolerance. All tests failed below the ultimate tensile capacity of the studs; however, even the most out-of-tolerance case exceeded the maximum design load of 334 kips by a factor of 1.49.

In all cases, the capacity of the stud-nut combination was limited by shear failure of the external (stud) thread, as predicted. The test results also indicated that the ultimate loads calculated using the methods in ASA B1.1 are conservative but realistic estimates (within 10%) of the actual failure loads. Therefore it was concluded that the ASA B1.1 methods could be used to accurately predict the load capacities of other out-of-tolerance conditions.

In preparation for the tests, stud pitch diameter measurements were taken. These measurements indicated that the studs were also slightly outside the tolerance limits of ASA B1.1. Consequently, a reinspection of stud threads was initiated.

C. Reinspection of Studs

A reinspection of available studs was performed at the Callaway and Wolf Creek jobsites. Typically, four measurements of the pitch diameter (two perpendicular measurements at two locations) were obtained for each stud end using a pitch micrometer. The following is a summary of the stud reinspection program:

1. Callaway

   a. 98 stud ends (15% of the 648 stud ends, i.e., 324 studs with each end threaded) were reinspected.

   b. 45 stud ends (46% of the inspected stud ends) are nonconforming with at least one measurement of the pitch diameter less than 3.407 inches. (Note that the minimum allowable pitch diameter per ASA B1.1 is 3.4074 inches; however, since the pitch micrometer used for inspection was only accurate to 0.001 inches, 3.407 inches has been used as the acceptance standard.) The maximum out of tolerance is 0.021 inches. Only 4 stud ends (4% of the inspected stud ends) are out of tolerance by more than 0.010 inches.

2. Wolf Creek

   a. 136 stud ends (21% of the stud ends) were reinspected.

   b. 67 stud ends (49% of the inspected stud ends) are nonconforming with at least one measurement of the pitch diameter less than 3.407 inches. Only 3 stud ends (2% of the inspected stud ends) are more than 0.010 inches out of tolerance. The maximum out of tolerance is 0.029 inches.

The data collected during the reinspection program are reported in References 3, 4, 5 and 8.

D. Analysis of Maximum Design Bolt Load

Westinghouse Electric Corporation, the responsible designer for the NSSS supports, performed two analyses of the NSSS steam generator lateral supports for the SNUPPS Project (the original bolt design was based on Westinghouse generic envelope loads). The first analysis considered all bolts in each lateral support capable of carrying load. The results of this analysis indicated the maximum bolt load is 334 kips. Subsequently, a second analysis was performed assuming that the bolt with the highest load in each support was not capable of carrying load. These results indicated the maximum bolt load in the effective bolts to be 375 kips.

E. Statistical Analysis

An analysis of the thread shear capacities of the subject studs and nuts, using accepted statistical methods as outlined in Appendix A, was undertaken. The analysis was performed to determine, with an acceptable level of confidence, the minimum expected thread shear capacity of the stud-nut combinations at each jobsite.

The thread shear capacities were determined using the mimimum allowable tensile stress of 135 ksi (ASTM A 540) and a minimum shear stress of 67.5 ksi (ASA B1.1 Appendix A). A confidence level of 99.99 percent was used for this analysis.

Separate analyses were completed for both the Callaway and Wolf Creek jobsites based on the inspection data collected at the respective sites. The results of these analyses indicate that, with 99.99 percent level of confidence, the minimum expected thread shear capacities for stud-nut combinations are 912 kips at the Callaway jobsite and 968 kips at the Wolf Creek jobsite. Comparing these capacities with the maximum design load of 334 kips, a considerable margin of safety is evident.

III CORRECTIVE ACTION

The inspection criteria imposed by the governing specification (10466-C-134A) requires the use of GO/NO-GO gages. Plug gages were used to inspect nuts and ring gages were used to inspect studs. All gages were properly calibrated. The manufacturer's procedures require 100% inspection using these gages.

Although the reinspection data identified a substantial number of non-conformances, many of these nonconformances are very minor. The measurement technique used for the reinspection (i.e., specially-prepared plug gages and dial calipers on nuts and a screw thread micrometer on the studs, all applied to measure several specific diameters) is undoubtedly more precise in identifying minor thread nonconformances than the production GO/NO-GO gage system. This precision accounts for the detection of many minor deviations. This is not to suggest that the production gaging system is insufficient to provide an adequate screw thread system for the purpose intended. The GO/NO-GO gaging system is the primary technique included in ASA B1.1 for production inspection and has been used in the screw thread industry as standard practice for many years. A more sophisticated system, which quantified the out of tolerance, was used during the reinspection to allow a rigorous evaluation of the nonconformances.

All the nonconformances, however, cannot be attributed to the production inspection gaging system. It is apparent that the most out-of-tolerance studs and nuts escaped the manufacturer's intended inspection program without detection. Additionally, the manufacturer, in reviewing his

production records, noted a machining error and a reading error in establishing the proper tolerances for flats on some 3-1/2 inch diameter nuts. The nuts were reworked before final threading to correct these errors, but the rework created a condition that could have contributed to the final threading being out of tolerance.

The manufacturer indicates that he has taken several actions, since these nuts and studs were shipped, to preclude a future reoccurence of this problem. These include:

1. The primary nut manufacturing method has been improved by the use of NC (numerical control) type lathes and lathes tooled to drill using indexable inserts instead of conventional drills.

2. A more comprehensive training program has been implemented for all manufacturing operators.

3. The qualifications of QC inspectors have been upgraded.

All material has been shipped to the Callaway (Unit 1) and Wolf Creek jobsites. Bechtel will schedule an audit of the manufacturer's facility prior to shipment of materials for additional SNUPPS units.

IV EVALUATION AND CONCLUSION

The results of the investigation indicate that an extremely high level of confidence exists that all stud-nut combinations at the Callaway and Wolf Creek jobsites can adequately support the maximum design load. The 912 kip minimum expected thread shear capacity provides a safety factor of 2.75 against a thread shear failure at the maximum design load of 334 kips. This is considerably greater than the minimum safety factor of 1.51 provided by fully-loaded 3-1/2 inch diameter bolts conforming to the dimensional requirements of ASA B1.1. Although a number of threads do not conform to the dimensional requirements of ASA B1.1, the studs and nuts can satisfactorily support the design loads. Had the nonconformance gone undetected there would have been no impact to the health and safety of the public. Several other factors which have not been included in this report provide additional support for this conclusion. They are:

1. Of the 648 stud ends with nuts, the 460 exposed stud ends have double nuts. The second nut acts as a jam nut, but also provides additional load capacity to the threaded connection.

2. The Westinghouse analysis indicates that even if the highest-loaded bolt in each support should fail, the remaining bolts can support the design loads with acceptable margins of safety.

3. Only those nuts measured with the dial calipers (for precise measurement of the minor diameter) were included in the statistical analysis. Therefore, all nonconforming nuts and only a portion of the conforming nuts were considered in the analysis. Thus, the reported analysis is conservative. Had all the conforming nuts been included, the calculated minimum expected thread shear capacity would have been higher.

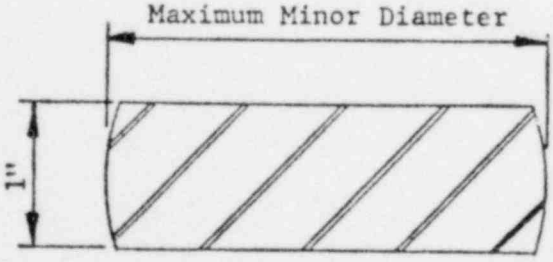
TABLE 1

DATA FROM TENSION TESTS AT LEHIGH UNIVERSITY

	Test 1	Test 2	Test 3
Nut (ASTM A 194, Grade 7)	R-108	R-29	D92
Maximum Minor Diameter (inches)	3.462	3.433	3.420
Stud (ASTM A 540)	A1	B2	C2
Yield Stress, minimum specified (ksi)	120	120	120
Yield Stress, actual (ksi)	127.5	127.5	127.5
Tensile Stress, minimum specified (ksi)	135	135	135
Tensile Stress, actual (ksi)	147.5	147.5	147.5
Maximum Pitch Diameter (inches)	3.392	3.405	3.400
Stud-Nut Combination			
Failure Load (kips)	498	1,140	1,240
Calculated Failure Load (kips)	496	1,032	1,131
Percent Difference	0.4	9	9

FIGURE 1

CROSS SECTION OF SPECIAL NO-GO GAGE



REFERENCES

1. ASA B1.1-1960, Unified Screw Threads, American National Standards Institute, New York, New York.

2. Letter DLUC-4944, Daniel International Corporation to Union Electric Company, February 1, 1980.

3. Letter DLUC-5279, Daniel International Corporation to Union Electric Company, April 21, 1980.

4. Letter CLK-2089, Daniel International Corporation to Kansas Gas and Electric Company, May 9, 1980.

5. Wolf Creek Nonconformance Report 1SN-1548-C.

6. Wolf Creek Nonconformance Report 1SN-2246-C.

7. Callaway Nonconformance Report 2SN-1909-C

8. Callaway Nonconformance Report 2SN-1915-C.

9. Ang, Alfredo H-S. and Tang, Wilson H., Probability Concepts in Engineering Planning and Design, John Wiley and Sons, Inc., New York, New York, 1975.

10. Callaway Nonconformance Report 2SN-2172-C.

11. Slutter, Roger G., Tension Tests of 3-1/2" Diameter Nuts for the SNUPPS Project - Bechtel Job Number 10466, Lehigh University, Fritz Engineering Laboratory, Bethlehem, PA.

12. Letter SNP-3250, Westinghouse Electric Corporation to Bechtel Power Corporation, March 31, 1980.

13. Letter SNP-3341, Westinghouse Electric Corporation to Bechtel Power Corporation, May 15, 1980.

APPENDIX A

METHOD OF STATISTICAL ANALYSIS

The thread shear capacity for the stud-nut combinations is a function of two thread variables: the minor diameter of the nuts and the pitch diameter of the studs. A first-order approximation (Reference 9, pages 198 and 199) of the mean value and standard deviation of the thread shear capacities was obtained using the available measurements of the pitch and minor diameters. The minimum expected thread shear capacity was then calculated. The analysis proceeded as follows:

1. Calculate the mean value ($\bar{E}$) and the standard deviation (Se) of the pitch diameters.

2. Calculate the mean value ($\bar{K}$) and the standard deviation (Sk) of the minor diameter.

3. Calculate the mean value ($\bar{P}$) of the thread shear capacity of the stud-nut combinations, where $P = f(E,K)$, and P = P evaluated at the mean values of the pitch diameter ($\bar{E}$) and the minor diameter ($\bar{K}$). (Ref. 9, Eq. 4.43)

4. Calculate the variance (Vp) of the thread shear capacity (P), where

   $$Vp = \left(\frac{\partial P}{\partial E}\right)^2 (Se)^2 + \left(\frac{\partial P}{\partial K}\right)^2 (Sk)^2 \qquad \text{(Ref. 9, Eq. 4.44)}$$

5. Calculate the standard deviation (Sp) of the thread shear capacity, where $Sp = \sqrt{Vp}$

6. Calculate, at 99.99 percent confidence, the minimum thread shear capacity (Pm) of all stud-nut combinations, where

   $$Pm = \bar{P} - 3.72(Sp) \qquad \text{(Ref. 9, Eq. 3.28)}$$

APPENDIX B

DISCUSSION OF OTHER SIZE STUDS AND NUTS

Southern Bolt Company has provided studs and nuts in sizes ranging from 1-1/2 inches to 3-1/2 inches to the SNUPPS Project for anchoring the NSSS supports. Although the thread nonconformance had only been identified with the 3-1/2 inch diameter nuts, a limited reinspection of other size nuts was undertaken. A summary of that reinspection is included in Table B.1.

The results of the reinspection of nuts indicates that a few of the nuts are out of tolerance. However, the majority of the nonconforming nuts are only slightly out of tolerance (less than 0.004 inches). An analysis of thread shear capacities indicates that even the most out-of-tolerance nut can develop the yield capacity of studs at their limits of thread tolerance.

A reinspection of other size studs was not undertaken based on 1) a review of the out of tolerance of the 3-1/2 diameter studs, 2) a comparison of the out-of-tolerance data for the 3-1/2 inch diameter nuts with the data for the other size nuts, 3) the analysis of the 3-1/2 inch diameter stud-nut combinations and 4) an evaluation of the load capacity of the other size nuts.

A review of all the data and analyses indicates that all studs and nuts supplied by the Southern Bolt Company can support the maximum design loads with adequate margins of safety.

TABLE B.1

Nut Diameter (inches)	1-1/2	1-3/4	2	2-1/4	2-1/2	3
Number of Nuts per Site	32	96	358	48	128	560
Callaway						
No. of Nuts Reinspected	8	21	20	28	31	50
No. of Nonconforming Nuts	1	1	2	3	6	0
Maximum Out of Tolerance (inches)	0.001	0.004	0.002	0.010	0.011	-
Wolf Creek						
No. of Nuts Reinspected	4	0	50	48	69	50
No. of Nonconforming Nuts	1	-	0	5	5	0
Maximum Out of Tolerance (inches)	0.001	-	-	0.031*	0.015	-

Note: There is a total of 1,222 nuts required for 640 stud ends. 480 stud ends have double nuts.

* One stud only; the second most out-of-tolerance nut is 0.008 inches out of tolerance.