Technical Report Documentation Page

1. REPORT No.
CA-DOT-TL-6831-1-76-44

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
An Evaluation Of New Methods For Developing Proper Tensions In High Strength Structural Bolts

5. REPORT DATE
June 1976

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT No.
19601-646831

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, California 95807

13. TYPE OF REPORT & PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT
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The following are conclusions resulting from this study:

Load Indicator Washers. Installation and inspection require skilled personnel and are more time consuming than the other two systems. Bolt tension precision is good (the coefficient of variation, V=6.2% maximum). Corrosion resistance is poor when a standard paint system is used, as such a system does not adequately protect the load indicator washer assembly or bolt shank and base thread region from corrosion. Corrosion resistance of the load indicator washers is improved by coating the washers with a zinc-rich primer prior to installation.

17. KEYWORDS
High strength bolts, tension tests, tension torque, corrosion tests, corrosion resistance

18. No. OF PAGES:
49

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1976-1977/76-44.pdf

20. FILE NAME
76-44.pdf

This page was created to provide searchable keywords and abstract text for older scanned research reports.
November 2005, Division of Research and Innovation

TRANSPORTATION LABORATORY

RESEARCH REPORT

An Evaluation Of New Methods For Developing Proper Tensions In High Strength Structural Bolts

FINAL REPORT

CA-DOT-TL-6831-1-76-44

JUNE 1976

76-44

Caltrans

CALIFORNIA DEPARTMENT OF TRANSPORTATION

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TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
CA-DOT-TL-6831-1-76-44		

4. TITLE AND SUBTITLE	5. REPORT DATE
AN EVALUATION OF NEW METHODS FOR DEVELOPING PROPER TENSIONS IN HIGH STRENGTH STRUCTURAL BOLTS	June 1976
	6. PERFORMING ORGANIZATION CODE
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The following are conclusions resulting from this study:

Load Indicator Washers. Installation and inspection require skilled personnel and are more time consuming than the other two systems. Bolt tension precision is good (the coefficient of variation, V = 6.2% maximum). Corrosion resistance is poor when a standard paint system is used, as such a system does not adequately protect the load indicator washer assembly or bolt shank and base thread region from corrosion. Corrosion resistance of the load indicator washers is improved by coating the washers with a zinc-rich primer prior to installation.

"Hi-Lok" Nuts. Installation is easily done by unskilled personnel without special tools; proper installation can be verified by a quick visual inspection. Bolt tension precision (V = 11.3% and 5.5%) for the two designs tested is better than for high strength hot-dip galvanized nuts and bolts (V = 16.6%). Resistance to corrosion of the 1 mil minimum

Continued

17. KEY WORDS	18. DISTRIBUTION STATEMENT
High strength bolts, tension tests, tension torque, corrosion tests, corrosion resistance.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	49	

DH-TL 1242 (Rev. 3-74)

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16. Abstract (Continued)

zinc electroplating on the "Hi-Lok" nuts tested was less than that of heavy hex nuts hot-dip galvanized in accordance with ASTM Designation: A153. Heat treating and chemical requirements specified for Grades 2H or DH heavy hex nuts (ASTM Specification A194/A563) were not met. "Hi-Lok" nuts tested may be acceptable for use on Type 30 and 31 lighting standard slip base clamping bolts provided that the manufacturer can prove that the fatigue limit of "Hi-Lok" nuts is equivalent to that of Grade 2H or DH nuts or if the nuts comply with ASTM requirements for the Grades 2H or DH nuts.

"Tension Set" Fasteners. Installation is easily done by unskilled personnel with a special tool and inspection of proper installation is visual. Bolt tension precision is good (V = 7.0% for the 7/8 in. diameter bolts tested). The corrosion resistance is similar to uncoated nuts and bolts conforming to either ASTM Specification A325 or A490.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES AND ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

June 1976

TL No. 646831

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research report titled:

AN EVALUATION OF NEW METHODS FOR
DEVELOPING PROPER TENSIONS IN HIGH
STRENGTH STRUCTURAL BOLTS

Study made by . . . . . Structural Materials Branch

Under the Supervision of . . . . . E. F. Nordlin

Principal Investigator . . . . . J. R. Stoker

Co-Investigators . . . . . J. P. Dusel, Jr.
R. F. Prodoehl
D. H. Andersen

Report Prepared by . . . . . R. F. Prodoehl

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

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ACKNOWLEDGEMENTS

The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Appreciation is due Walter Richards, Assistant Steel Inspector, Vincent Bartley, Highway Engineering Technician, and Kerry Wilson, Photographer for their assistance in gathering data, conducting tests, and taking pictures for this project.

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I. INTRODUCTION

The need for developing a quick, reliable method of acquiring a given bolt tension in structural bolts has long been recognized by engineers, manufacturers and contractors. Presently there is a problem in obtaining and verifying proper bolt tensions in bolted structural connections. The problem results from interpreting the term "snug tight" when using the turn-of-nut method, and relying on the consistency of the torque-tension relationship of a nut and bolt fastening system regardless of differences in bolt and nut thread dimensions and lubricants when using the torque wrench method for tensioning bolts. In response to the demand for improved techniques for obtaining accurate tensile forces in bolts, manufacturers have developed and introduced new devices to overcome some of the previous problems.

A. General Description of Devices Tested

The three devices that were evaluated in this project are the load indicator washer, the "Hi-Lok" nut, and the "Tension Set" fastening system. These devices are briefly described below and proprietary literature on each system is included in the Appendix.

1. Load Indicator Washers. These are special hardened washers which have bumps or protrusions on one side and are used in conjunction with A325 or A490 high strength bolts to insure accurate tension in bolts. Applications, specifications, and alleged features of the load indicator washer are shown in Figures 12 and 13. As can be noted from Figure 12, the load indicator washers used with A325 bolts have 5 protrusions whereas the washers used with A490 bolts have 6 protrusions. The load indicator washer is generally placed under the bolt head with the protrusions bearing against

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the head. If the bolt head will not be accessible, the washer is placed at the nut end with the protrusions bearing against a supplemental hardened flat washer located between the nut and the load indicator washer. The protrusions are compressed as the bolt tension increases. The proper tension is reached when the average gap created by the protrusions has been reduced to 0.015 in. or less when used under the bolt head or to 0.010 in. when used under a hardened flat washer. The gap is measured by a feeler gage. The washers are supplied by Bethlehem Steel Corporation in black finish only.

2. "Hi-Lok" Nuts. These nuts are specially designed, barrel zinc electroplated, hex headed nuts which have a machined groove around the midsection of each nut that provides a reduced nut wall thickness of close tolerance. Figures 15 and 16 show alleged features and illustrated installation procedures of "Hi-Lok" nuts. The "Hi-Lok" nut may be substituted for a standard nut in a typical bolt installation. As the special nut is turned and the proper torque (also bolt tension) is reached, the upper portion of the nut will shear off at the machined groove. A refined version of the commonly used torque-tension relationship has been utilized in the successful development of this type of nut for the aircraft industry. Prerequisites for the success of this system are consistency in the lubricants used, mechanical properties of the steel used for the manufacture of the nuts, dimensions of nut threads, and closely controlled groove depths around the nut midsection.

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3. "Tension Set" Fasteners. The success of this fastening system also depends on a constant torque-tension relationship between the nut and bolt. The "Tension Set" fastening system features, as well as the various installation stages, are shown in Figures 17 and 18. Three features are unique in this bolting system:

a. The dome shaped bolt head which does not have a hexagonal configuration and cannot be gripped.

b. A spline drive which protrudes from the end of the bolt opposite the head.

c. The fasteners may be tightened from only one side of a structural joint.

Around the base of this special spline drive end is a circumferencial break-neck groove. Installation of these fasteners requires the use of a special tool with a mating socket which grips the spline end of the bolt while it turns the nut at the same time. When the bolt is permanently installed and proper torque is reached, the spline end shears off at the break-neck groove.

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II. CONCLUSIONS AND RECOMMENDATIONS

A. Load Indicator Washers

They provide more precise, consistent means of obtaining bolt tension (coefficient of variation, V = 6.2% maximum) than a torque wrench or turn-of-nut method applied to high strength nuts and bolts conforming to ASTM standards.

With the A490 bolt, the load indicator washer must be placed under the bolt head, only. With the A325 bolt it may be placed under the head or under a hardened washer at the nut.

Installation and inspection require skilled personnel and are very time consuming. Many precautions are necessary to assure a satisfactory installation.

A standard full paint system as required by the California Department of Transportation will not seal the gaps around the periphery of the load indicator washers. As a result of the unsealed gaps around the periphery of the washers, the corrosion resistance of the uncoated load indicator washers is poor and the adjacent shank and thread regions of the bolts may corrode significantly.

Corrosion of the load indicator washers is inhibited greatly when the washers are coated with a zinc-rich primer prior to installation.

Positive sealing of the gaps around the periphery of load indicator washers should be considered in all cases to prevent corrosion of the washer protrusions and corrosion of the shank and thread region of the high strength bolts which may otherwise be subject to stress corrosion or hydrogen embrittlement.

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B. "Hi-Lok" Nuts

Installation is easily done by unskilled personnel without special tools. Proper installation can be verified by a quick visual inspection. Precision of bolt tension (V = 11.3% and 5.5% for the two designs tested) is better than for ASTM high strength hot-dip galvanized nuts and bolts (V = 16.6%).

It is to be noted that the "Hi-Lok" nuts evaluated in this study were designed to be used with the clamping bolts for slip bases for lighting standards wherein the applied tension is limited to 36,000 psi maximum. Thus the clamping force is considerably less than for a normal structural friction joint. "Hi-Lok" nuts designed for greater clamping forces may result in different and perhaps improved precision of bolt tension.

Resistance to corrosion of "Hi-Lok" nuts with a 1 mil minimum electroplated zinc coating is less than for Grade 2H nuts with a standard hot-dip galvanized coating (2.1 mils minimum). An electroplated zinc coating meeting the ASTM Specification A164 for Type GS coating with a minimum thickness of .0010 inches of zinc will be acceptable for nuts on clamping bolts used on slip bases for lighting standards.

As the "Hi-Lok" nuts tested in this research project do not meet ASTM requirements for Grade 2H or DH nuts (A194/A563) including hardness, proof load, and chemical requirements or heat treatment procedures, they are not satisfactory for use as a substitute for either Grade 2H or DH nuts.

"Hi-Lok" nuts are recommended for use on clamping bolts for slip bases on lighting standards only if the manufacturer can show that "Hi-Lok" nuts have a fatigue life equivalent to Grade 2H or DH nuts and can present acceptable specifications for such nuts, or if "Hi-Lok" nuts are made to comply with ASTM requirements for Grade 2H or DH nuts.

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C. "Tension Set" Fasteners

Installation is easily done by unskilled personnel - a special installation tool is required. Inspection of proper installation is quick and visual. Precision of bolt tensions measured resulted in a coefficient of variation, V, of 7.0% for the 7/8 in. diameter black bolts and nuts.

Corrosion resistance is similar to an uncoated bolt and nut system conforming to either ASTM Specification A325 or A490.

The "Tension Set" fastener is considered as an acceptable alternate to bolts and nuts conforming to either ASTM Specification A325 or A490.

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III. TESTING PROGRAM AND RESULTS

The three bolt tensioning systems were evaluated for ease of installation and inspection, precision and accuracy of tension acquired, and corrosion resistance. So that the precision of various data might be compared, the coefficient of variation, V, (a ratio of the standard deviation to the mean) is used to express the dispersion of results on a percentage basis. The testing and results are described below:

A. Ease of Installation

Many specimens of each device were installed while testing for precision of bolt tension and thus the ease of installation was evaluated.

1. Load Indicator Washers. They must be installed by skilled personnel and the following installation procedures must be followed: First, it is imperative that the washer be installed under a hardened surface that does not turn while tightening; second, the average washer tab gap must be measured accurately; and third, the nut on the bolt must be tightened to achieve the specified gap.

Installation is time consuming because of the need to make accurate gap measurements necessary for consistent bolt tensions. Measuring an average gap is more difficult than it first appears because the gap can vary significantly from one side of the washer to the other. An extreme case of this occurred while tightening Bolt 1 (Table 2 in Appendix) to a target gap of .010 in. as the gap was .022 in. on one side of the washer and completely closed on the opposite side. This apparently resulted from the nut face not being parallel to the face of the bolt head. To a lesser degree this variance of gap developed with other tests as reported in Tables 1, 2, 3, and 4.

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Also, the joint must be tightened in proper sequence working from the most rigid part of the joint outward. This tightening sequence is required because the protrusions of the load indicator washer are stressed beyond their elastic limit when tensioning a bolt. Thus, the washer may indicate the proper tension in the bolt when in fact tension in the bolt may have been reduced in the process of bolting the remainder of the joint.

2. "Hi-Lok" Nuts. They can be installed by an unskilled worker with a standard wrench or socket and are easily checked (visually) for proper tightening. The sheared off outer portion of the nut is the indication that the design bolt tension was achieved.

3. "Tension Set" Fasteners. These may be quickly installed by an unskilled worker and the fasteners are held and tightened from only one side of a joint. A special lightweight electrical tool is required, but no calibration is necessary and a universal socket is available for installation in tight locations. Inspection is visual, with the sheared off "pigtail" indicating that the proper bolt tension was achieved.

4. General. Although it is imperative when installing bolts using load indicator washers to tighten the joint in proper sequence and in stages working from the most rigid part of the joint outward, this procedure is also recommended for any fastening system used for structural friction joints. In order to take advantage of the inspection value offered by the design break-off torque features of the "Tension Set" fastener or the "Hi-Lok" nut, proper installation procedure of fasteners utilizing these designs should also be followed. Otherwise the pre-load in the fastener could relax after other fasteners are tightened and after the pigtail on the "Tension Set" fastener or the outer portion of the "Hi-Lok" nut has sheared off. Thus a false clamping force would be achieved without further re-torquing.

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B. Precision and Accuracy of Bolt Tension

Several load indicator washers and "Tension Set" bolts were tested in a Norbar Bolt Load Meter and the resulting clamping tensions were recorded. The "Hi-Lok" nuts were tested in jigs on a 60,000 lb Baldwin Testing Machine where the lower tension values obtained on bolts using the "Hi-Lok" nuts could be more accurately read. The Norbar Bolt Load Meter was not considered sufficiently accurate for measuring the loads on the bolts utilizing the "Hi-Lok" nuts that were designed for lighting standard slip base clamping bolts.

1. Load Indicator Washers. Load indicator washers were tested both under the bolt head and under a hardened washer at the nut end of the bolt. With the load indicator washer under the bolt head, the nut was turned, tightening the bolt until an approximate average gap of .015 in. was obtained. Three A325 and three A490 load indicator washers were tested in this manner and the results are shown in Table 1. For the small number of samples tested, the bolt tension precisions were very good and coefficient of variation of V = 3.3% and 2.4% were calculated for the A325 and A490 bolts respectively. The average bolt tensions were close to the specified minimum bolt preloads required.

The second set of tests was conducted with the load indicator washer at the nut end of the bolt under a hardened washer; the nut was turned, tightening the bolt. The specified average gap for the nut end assembly is .010 in., but as a check to see how critical the proper gap is, the bolt tension was measured at approximate average gaps of (1) .015 in., (2) .010 in., and (3) when the gap was completely closed at some point around the load indicator washer. Five A325 and three A490 load indicator washers were installed at the nut end and were tested as described; the results are shown in Table 2 and Table 3.

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At the specified average gap of .010 in. when used with a hardened washer, the load indicator washers resulted in good precision of bolt tension (V = 4.5%) and the average tension was 6% over the specified minimum of 39,000 lbs for the 7/8 in. diameter A325 bolts used.

The tests using the A490 load indicator washers yielded unsatisfactory results, as in each case the hardened washer which was bearing against the load indicator washer protrusions, turned. This caused gouging of the hardened washer and the gap width thus was not a proper indication of bolt tension, as seen by the low tension values in Table 3. Thus, placing the load indicator washer at the nut end and tightening by turning the nut is apparently not an acceptable installation procedure for the A490 bolt based on the tests performed under this study.

The California Department of Transportation standard specifications state that for use with high strength galvanized fasteners on sign structures, load indicator washers shall be coated by dipping a 1:1 solution of zinc-rich primer and thinner. An average gap, using the coated load indicator, of .007 in. is specified. Three A325 load indicator washers which had been coated according to specifications were placed under the bolt heads of three A325 galvanized bolts and tightened to the approximate specified gap of .007 in. The recorded bolt tensions, as shown in Table 4, indicate that sufficient bolt tension is obtained using the coated load indicator washer with galvanized fasteners when tightened to an average load indicator washer gap of .007 in.

Although not available from the manufacturer, three load indicator washers that had been hot-dip galvanized specifically for this study were tested. The results were unsatisfactory as the gap measurement is unreliable due to the uneven galvanized surface and the tabs being pushed into the galvanizing on the mating surfaces.

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2. "Hi-Lok" Nuts. The "Hi-Lok" nuts used in these tests were made specially for the clamping bolts on the slip bases of lighting standards which utilize 7/8 in. diameter A325 bolts. Initially, two different lots of nuts were thoroughly tested. The first lot of nuts had a torque-off groove outside diameter of .943 in. and these nuts were designed to break off between 80 and 90 ft-lbs (former slip base clamping bolt torque specifications: 84 ft-lbs front bolts) with a target preload of 11,000 lbs. The second lot had an outside torque-off groove diameter of .954 in. and the nuts were designed to break off between 105 and 115 ft-lbs (former slip base clamping bolt torque specification: 110 ft-lbs rear bolt) with a target preload of 15,000 lbs. These first two lots of nuts were tightened with a torque wrench and meter on 7/8 in. diameter by 4-1/2 in. A325 galvanized bolts. At nut break-off, the bolt tension and torque were recorded as shown in Table 5. The precision of bolt tension was judged by comparing coefficients of variation, V, of 11.3% and 5.5% for the .943 in. and .954 in. groove diameters respectively. These coefficients of variation are better than those for hot-dip galvanized bolts and Grade 2H nuts, which were tested previously for slip base applications and found to have coefficient of variation, V, of 16.6% at 120 ft-lbs of torque (see Table 6). The better precision can be attributed to consistent use of cetyl alcohol lubricant and the nut threads not being retapped. The larger coefficient of variation (V = 11.3%) found for "Hi-Lok" nuts having the smaller groove diameter (.943) most likely is a result of variations in the machined groove diameter causing a larger variation in the shear surface area.

A third lot of "Hi-Lok" nuts was manufactured to meet the final slip base clamping bolt preload requirement of 17,200 lbs (150 ft-lbs torque). However, as current ASTM specifications for high strength bolts and nuts regarding nut hardness, minimum proof load and chemical requirements, and heat treatment procedures were not

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met, no further tests using these nuts were conducted. Compliance tests will be conducted in the future if the manufacturer produces a nut which is equivalent to or meets ASTM requirements for Grade 2H or DH nuts.

3. "Tension Set" Fasteners. Several 3/4 in. and 7/8 in. diameter "Tension Set" black fasteners meeting the ASTM Specification A325 were tested and the resulting clamping tensions were recorded, as shown in Table 7. The fastener tension precision for the 3/4 in. diameter bolts was relatively small (V = 5.3%) and from the small sample of 7/8 in. diameter fasteners tested this size bolt appears to vary about the same. The average tension obtained with the 3/4 in. diameter fasteners was 10% above the specified minimum of 28,000 lbs. The black fasteners were supplied with a light oil lubricant.

"Tension Set" fasteners meeting the ASTM Specification A490, and galvanized fasteners are also available, but were not supplied for these tests. Results of tests performed by Almany Research and Testing Corporation on these fasteners should be available soon.

C. Corrosion Resistance

The corrosion resistance of load indicator washers and "Hi-Lok" nuts was tested in a salt spray chamber. Corrosion properties of the "Tension Set" fasteners are similar to a standard bolt and nut; therefore no corrosion tests were performed on this fastener. The sheared off end on an installed "Tension Set" fastener obviously would require a protective coating where aesthetics are of concern. The load indicator washer specimens were in the salt spray chamber for 7, 30, and 60 days; the "Hi-Lok" nut specimens 200 hrs, 30 and 60 days. The 200 hr (8 day 8 hour) test was conducted to compare results with a 200 hour test done on the same type of nuts by the Hi-Shear Corporation, manufacturer of the "Hi-Lok" nut.

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1. Load Indicator Washers. Two series of corrosion tests were conducted, the first using a "full paint system" on installed black load indicator washers, bolts, and nuts and the second using zinc-rich primer coated load indicator washers and galvanized bolts and nuts. The purpose of the first series of corrosion tests was to see if a "full paint system" (two applications of zinc-rich primer with a total dry film thickness of 3 mils minimum and two applications of a green finish coat with a total dry film thickness of 2 mils minimum) as used by Caltrans for painting steel structures would seal the gaps between the load indicator washer and the adjacent hardened washer, or bolt head, and thus prevent corrosion of the bolted assembly. Three sandblasted steel plates were prepared for testing by installing four 7/8 in. diameter bolts through each plate and tightening the bolts to the appropriate pre-load values. Each plate contained two A325 and two A490 bolts, one each with a load indicator washer at the nut end of the bolt, and one each with only a hardened washer and nut (no load indication washer). The plates were then painted with a "full paint system" and cured for 15 days at room temperature before placing in the salt spray chamber. The gaps around the protrusions of the load indicator washers appeared to be sealed by the paint system.

After 7 days in the salt spray chamber, one plate was removed and the bolts, nuts, and washers were disassembled and inspected. Corrosion was evident between the protrusions of the load indicator washers on both of the A325 and A490 specimens, but no corrosion was apparent on any part of either the A325 or A490 specimen utilizing only hardened flat washers. Similarly the two remaining plates were removed from the salt spray chamber, one at 30 and one at 60 days, and the bolt systems were disassembled and inspected. With both the 30 and 60 day specimens, corrosion around the protrusions of the A325 and A490 load indicator washers was significant, while corrosion of the plain washers on all remaining specimens was negligible. Pictures of the specimens removed after 7, 30, and 60 days are shown in Figures 1-5. Corrosion of the load indicator washer protrusions is of concern, as such corrosion could result in a relaxation or loss of clamping force in the bolt.

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Therefore, it is concluded that a "full paint system" as specified in the 1975 California Standard Specifications does not adequately protect the load indicator washer from corrosion. A special paint system would be required to adequately seal the gaps and preclude long term corrosion.

The concern with regard to corrosion of the fastening system utilizing load indicator washers is not only directed to corrosion of the protrusions of the washer, but also to the effect of corrosion on the shank and thread region of the bolt. Corrosion present on the shank and thread regions of the bolts was quite noticeable on the 30 day and 60 day specimens of A325 and A490 bolts on which load indicator washers were used, as shown in Figure 4. The corrosion may very well present a serious problem and cause bolt failures due to stress corrosion or hydrogen embrittlement.

The second series of corrosion tests was conducted to see how well the coated load indicator washers, currently specified for use with galvanized sign structures, are protected. Two A325 load indicator washers, coated by dipping in a 1:1 solution of zinc-rich primer and thinner as specified (approximate paint thickness 1 mil), were placed on hot-dip galvanized A325 bolts and the bolts were tightened to produce the specified average load indicator washer protrusion gap of .007 in. (see Figure 6). After 7 days in the salt spray chamber there was no noticeable corrosion on the coated load indicator washers, as shown in Figure 7. Some chipping of the primer coating adjacent to the tabs occurred during tightening but interestingly the exposed area did not corrode. These results indicate that the presently specified coating method does provide adequate corrosion protection to the load indicator washer wherever severe corrosive environments do not exist. As this test series was concluded after only 7 days in the salt spray chamber, there was no corrosion of

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the body of the galvanized bolts in evidence. A longer test period would ultimately result in corrosion of the bolts without the benefit of a positive sealant around the periphery of the load indicator washers.

2. "Hi-Lok" Nuts. This corrosion test was conducted to compare the protection provided by the 1 mil of barrel electroplated zinc, used on "Hi-Lok" nuts, with the normal hot-dip galvanized coating, averaging 6 mils, on Grade 2 H nuts. Three individual test plates, each having bolts with one "Hi-Lok" nut and one Grade 2H nut, were assembled as shown in Figure 8 and placed in the salt spray chamber. Also one each loose Grade 2H nut and "Hi-Lok" nut, neither of which had been installed, were placed in the salt spray chamber for the 200 hour test.

Figures 9, 10, and 11 show the results after 200 hours, 30 days and 60 days in the salt spray chamber. The "Hi-Lok" nuts showed minor spots of corrosion after 200 hours and extensive corrosion after 30 and 60 days, compared to minimal corrosion after 60 days on the hot-dip galvanized Grade 2H nuts. These results are understandable because of the much thinner zinc coating on the "Hi-Lok" nuts. Interestingly the bare steel part of the "Hi-Lok" nut at the torque-off groove did not appear to corrode any faster than the plated body of the nut.

The above results do not agree with test results reported by the Hi-Shear Corporation as their 200 hour salt spray tests resulted in extensive corrosion on hot-dip galvanized (2 mil thick) "Hi-Lok" nuts and no corrosion on barrel zinc electroplated (.5 mil thick) "Hi-Lok" nuts.

Probably the most important area of a fastening system which should be protected from corrosion is the threaded region of the bolt and nut. Since hot-dip galvanized Grade 2H heavy hex nuts

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are retapped prior to use and the threads are left unprotected, it would seem that the "Hi-Lok" nuts offer more corrosion protection in the threaded region where it is most important. Although the zinc electroplated "Hi-Lok" nuts corroded more rapidly than did the standard hot-dip galvanized Grade 2H nuts in salt spray chamber corrosion tests, a 1 mil minimum coating of electroplated zinc meeting the ASTM Specification A164 (Type GS coating, minimum .0010 in. zinc) is deemed adequate for corrosion protection of nuts used on slip base clamping bolts. For these installations small amounts of external corrosion would not affect structural strength or be aesthetically unpleasant.

3. "Tension Set" Fasteners. Although no corrosion tests were performed, the black "Tension Set" fastener would be protected by a "full paint system" equal to a standard black bolt and nut.

The "Tension Set" hot-dip galvanized fasteners were not available for testing. The twisted-off bolt end is susceptable to corrosion but it is not at a structurally critical point. To help protect the exposed bolt end of galvanized fasteners, the reported field practice is to coat the tip with a zinc-rich paint.

D. Sustained and Cyclic Loading

Creep and fatigue tests were not conducted during this study as it is considered that there are sufficient documented results from previous tests to evaluate the systems for these loading conditions, except as noted. Cyclic loads were applied by Cooper and Turner Inc., to a specimen using a load indicator washer for 2,718,600 cycles between 0 and 0.6 times the proof load and the results are shown in the attached Technical Report No. 26 (Figure 14). They found that bolted joints utilizing the load indicator washers with A325 bolts will safely withstand dynamic forces inducing tensile stresses slightly in excess of those permitted for bridges by "The Specification for Structural Joints using ASTM A325 or A490 Bolts".

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No fatigue tests have been conducted on "Hi-Lok" nuts. As these nuts do not meet requirements in the ASTM Specification A325 as explained in Section III E below, the manufacturer should perform sufficient fatigue tests to show that the fatigue life of "Hi-Lok" nuts is equivalent to that of Grade 2H or DH nuts before "Hi-Lok" nuts can be considered for use.

Once installed, the "Tension Set" fastener system, being equivalent to a standard ASTM A325 or A490 bolt and nut system is assumed to have equal fatigue characteristics.

E. ASTM Specification A325 Conformance Tests

1. "Tension Set" Fasteners. Past research has resulted in approval by the International Conference of Building Officials and the American Institute of Steel Construction of the "Tension Set" fastening system for use in bolted connections requiring structural fasteners conforming to requirements in either ASTM Specification A325 or A490.

2. "Hi-Lok" Nuts. "Hi-Lok" nuts were tested for conformance with hardness and proof load requirements in the ASTM Specification A325. Three different lots of nuts were tested and results are shown in Table 8. Requirements for galvanized nuts as stated in Section 1.6 of ASTM Specification A325 are that nuts shall conform to either Grade DH (ASTM Specification 563), or Grade 2H (ASTM Specification A194). Some of the most important requirements for Grades 2H and DH nuts are shown in Table 9. The three lots of "Hi-Lok" nuts tested did not meet any of the requirements, including proof load, chemical and hardness requirements, and heat treatment procedures for either Grade 2H or DH nuts.

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APPENDIX

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TABLE 1

BOLT TENSION TEST RESULTS
LOAD INDICATOR WASHER
UNDER BOLT HEAD

7/8 in. Diameter x 3-1/4 in. A325 Black Bolts
Grip Length = 2-3/8 in.

Tightened to Specified Average Gap of .015 in.							
Bolt Number	Gap measured between protrusions (in.) 1	2	3	4	5	Average Gap (in.)	Bolt Tension (lbs)
1	.013	.013	.018	.017	.015	.015	40,000
2	.015	.012	.010	.008	.014	.012	40,500
3	.013	.012	.011	.011	.014	.012	38,000
Specified Minimum Tension = 39,000 lbs						Average =	39,500
						Standard Deviation =	1,320
						(V =	3.3%)

7/8 in. Diameter x 3-1/4 in. A490 Black Bolts
Grip Length = 2-3/8 in.

Tightened to Specified Average Gap of .015 in.								
Bolt Number	Gap measured between protrusions (in.) 1	2	3	4	5	6	Average Gap (in.)	Bolt Tension (lbs)
1	.013	.012	.012	.011	.013	.014	.013	49,500
2	.014	.016	.017	.015	.014	.014	.015	47,500
3	.015	.016	.015	.014	.013	.011	.014	49,500
Specified Minimum Tension = 49,000 lbs							Average =	48,830
							Standard Deviation =	1,150
							(V =	2.4%)

Note: V = Coefficient of Variation = $\frac{\text{Standard Deviation}}{\text{Mean}} \times 100\%$

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TABLE 2.

BOLT TENSION TEST RESULTS
LOAD INDICATOR WASHER
UNDER HARDENED WASHER AT NUT
7/8 in. Diameter x 3-1/4 in. A325 Black Bolts
Grip Length = 2-3/8 in.

Initial Tightening							
Bolt Number	Gap measured between protrusions (in.) 1	2	3	4	5	Average Gap (in.)	Bolt Tension (lbs)
1	-	-	-	-	-	-	-
2	.012	.015	.015	.015	.015	.014	41,000
3	.017	.014	.016	.020	.019	.017	40,500
4	.010	.017	.025	.017	.010	.017	38,500
5*	.016	.013	.014	.017	.018	.016	36,000
						Average =	39,000
Specified minimum tension = 39,000 lbs						Standard Deviation =	2,280
						(V =	5.8%)

Tightened to Specified Average Gap of .010 in.							
Bolt Number	Gap measured between protrusions (in.) 1	2	3	4	5	Average Gap (in.)	Bolt Tension (lbs)
1	.010	.022	.020	.002	.000	.011	43,500
2	.006	.008	.011	.009	.007	.008	41,800
3	.011	.006	.007	.013	.015	.010	42,300
4	.006	.011	.013	.011	.002	.009	41,000
5*	.011	.009	.009	.010	.010	.010	38,500
						Average =	41,420
						Standard Deviation =	1,870
						(V =	4.5%)

Bolt Number	Final Tightening		Bolt Tension (lbs)
1		-	43,500
2	Gap completely closed	-	46,500
3	at some point around	-	45,000
4	the load indicator.	-	43,000
5*		-	43,500
		Average =	44,300
		Standard Deviation =	1,440
		(V =	3.3%)

*Load indicator adjacent to hardened washer under bolt head.

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TABLE 3.

BOLT TENSION TEST RESULTS
LOAD INDICATOR WASHER
UNDER HARDENED WASHER AT NUT

7/8 in. Diameter x 3-1/4 in. A490 Black Bolts

Grip Length = 2-3/8 in.

Tightened to Specified Average Gap of .010 in.								
Bolt Number	Gap Measured between protrusions (in.) 1	2	3	4	5	6	Average Gap (in.)	Bolt Tension (lbs)
1	.010	.007	.004	.007	.016	.016	.010	45,000
2	.002	.003	.018	.018	.009	.006	.009	43,000
3	.010	.008	.013	.016	.007	.005	.010	44,000

Specified minimum tension = 49,000 lbs

Average = 44,000

Standard Deviation = 1,000

(V = 2.3%)

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TABLE 4.

BOLT TENSION TEST RESULTS
LOAD INDICATOR WASHERS
COATED WITH ZINC-RICH PRIMER*
UNDER BOLT HEAD

7/8 in. Diameter x 4-1/2 in. A325 Galvanized Bolts

Grip Length = 3-3/8 in.

Tightened to Specified Average Gap of .007 in.**							
Bolt Number	Gap Measured between protrusions (in.) 1	2	3	4	5	Average Gap (in.)	Bolt Tension (lbs)
1	.005	.010	.012	.005	.002	.007	43,500
2	.004	.009	.006	.003	.002	.005	39,000
3	.006	.005	.005	.004	.006	.005	43,500
Specified minimum tension = 39,000 lbs						Average =	42,000
						Standard Deviation =	2,600
						(V =	6.2%)

*Load indicator washers dipped in a 1:1 solution of zinc-rich primer and thinner.

**A gap of .007 in. is specified in the California Special Provisions for use with A325 bolts on sign structures when using load indicator washers coated with zinc-rich primer.

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TABLE 5.

BOLT TENSION TEST RESULTS
HI-LOK NUTS

7/8 in. Diameter x 4-1/2 in. A325 Galvanized Bolts

Grip Length = 3-1/8 in.

Outside Groove Diameter .943 in.		
Bolt Number	Torque (ft-lbs)	Tension (lbs)
1	85	9,900
2	79	10,500
3	88	8,350*
4	86	8,500*
5	85	9,250
6	80	9,200
7	70	7,500*
8	81	7,600*
9	84	8,550
		Average = 8,820 Standard Deviation = 1,000 Target Preload = 11,000 (V = 11.3%)

Outside Groove Diameter .954 in.		
Bolt Number	Torque (ft-lbs)	Tension (lbs)
10	115	14,600
11	108	12,700*
12	117	14,500
13	120	14,700
14	115	15,500
15	120	13,950
16	120	14,400
17	115	14,400
		Average = 14,350 Standard Deviation = 790 Target Preload = 15,000 (V = 5.5%)

*Bolt head turned while tightening

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TABLE 6.

BOLT TENSION TEST RESULTS
HOT-DIP GALVANIZED GRADE 2H NUTS

7/8 in. Diameter x 4-1/2 in. A325 Galvanized Bolts
Lubricant; Nox-Rust X-185

Bolt Number	Torque (ft-lbs)	Tension (lbs)
1	120	16,400
2	120	15,800
3	120	14,400
4	120	15,400
5	120	14,800
6	120	14,800
7	120	11,500
8	120	10,800
9	120	12,900
10	120	12,900
11	120	10,300
12	120	10,200
		Average = 13,350
		Standard Deviation = 2,220
		(V = 16.6%)

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TABLE 7.

BOLT TENSION TEST RESULTS
TENSION SET FASTENERS

3/4 in. Diameter x 3 in. A325 Black Bolts

Bolt Number	Tension (lbs)
1	31,800
2	27,800
3	32,000
4	29,500
5	32,000
6	33,000
7	29,500
8	31,000
9	31,000
Specified minimum tension = 28,000 lbs	Average = 30,840 Standard Deviation = 1,630 (V = 5.3%)

7/8 in. Diameter x 3-3/4 in. A325 Black Bolts

Bolt Number	Tension (lbs)
1	39,500
2	40,500
3	45,000
Specified minimum tension = 39,000 lbs	Average = 41,670 Standard Deviation = 2,930 (V = 7.0%)

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TABLE 8.

ASTM SPECIFICATION A325 NUT CONFORMANCE TEST RESULTS

HI-LOK NUTS

Proof Load and Hardness
7/8 in. Diameter

Lot Number	Nut Specimen Number	Proof Load (lbs)	Type of Failure
1	1	65,350	Nut threads stripped
	2	65,600	Nut threads stripped
2	3	57,300	Nut threads stripped
	4	58,500	Nut threads stripped
3	1	76,000	Nut threads stripped
	2	77,700	Nut threads stripped
	3	77,000	Nut threads stripped

Brinell Hardness
(Standard Ball)

Specimen Number	Hardness
1	150
3	130
5	241

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TABLE 9.

ASTM SPECIFICATION REQUIREMENTS FOR
GRADES 2H (A194) AND DH (A563) NUTS FOR
A 7/8 in. DIAMETER BOLT SIZE

A. Chemical Composition

Grade of Nut	Carbon %	Manganese %	Phosphrus %	Sulfur %
2H	.40 min.	-	.04 max.	.05 max.
DH	.20-.55	.60 min	.04 max.	.05 max.

B. Mechanical Property Requirements

Grade of Nut	Proof Load (lbs.) Using Mandrel	Brinell Hardness
2H	80,850	248-352
DH	92,400	248-352

C. Heat Treatment Requirements

Grade of Nut	Method
2H Nuts	1. Quench in a suitable medium from a temperature above the upper transformation temperature. 2. Temper at a minimum temperature of 850°F
DH Nuts	1. Quench in liquid medium from a temperature above the upper transormation temperature. 2. Temper at a minimum temperature of 800°F.

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Note:

The following Figures 1 through 11 are reproductions of colored prints and are included with this report only to depict general types and sizes of specimens tested. These copies do not clearly show areas where rusting or oxidation of steel and zinc coatings have occurred. A limited number of reports, including colored prints which do show areas of significant corrosion, are on file at the California Department of Transportation, Division of Structures and Transportation Laboratory.

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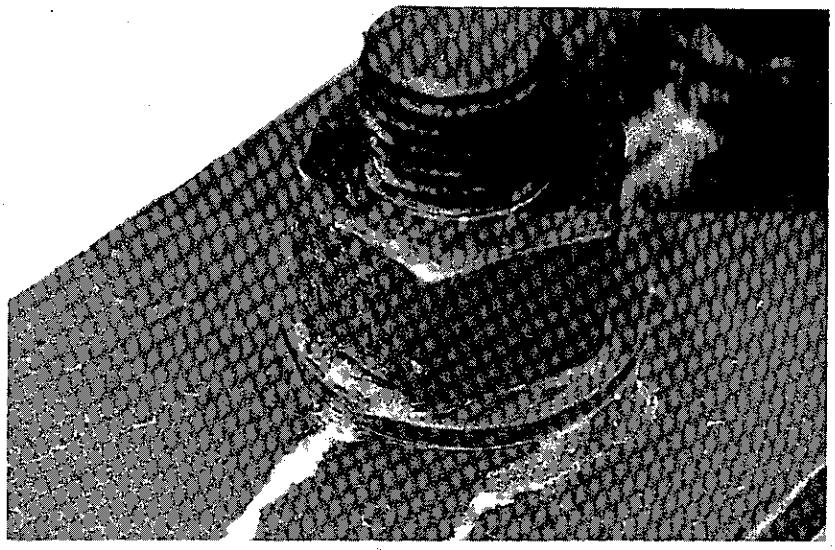
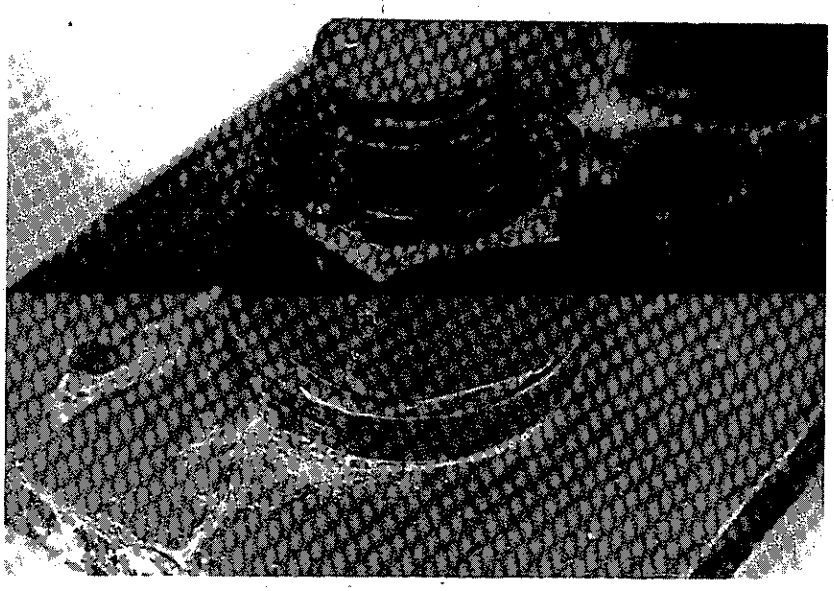
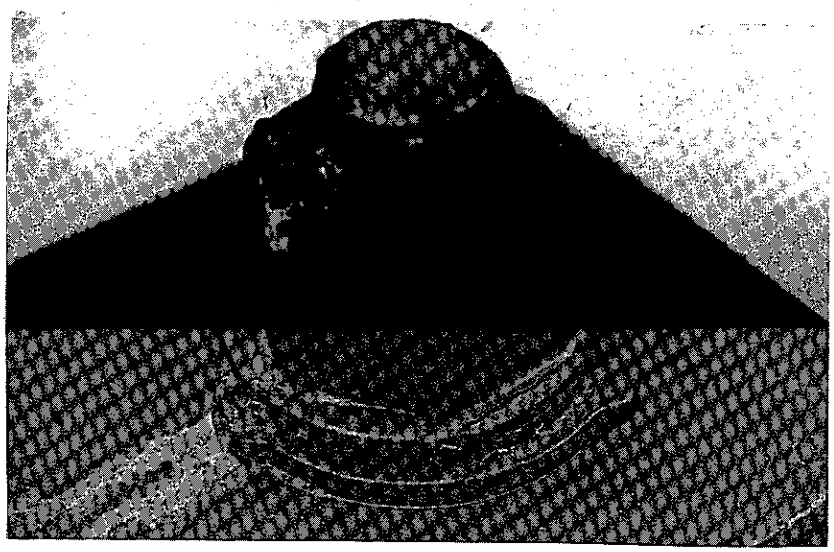


A490 bolt
with hardened
washer-no LIW
(A325 similar)



A325 bolt
with LIW



A490 bolt
with LIW

Figure 1. Assembled painted specimen after 7 days of salt spray test - High strength bolts with and without load indicator washers.

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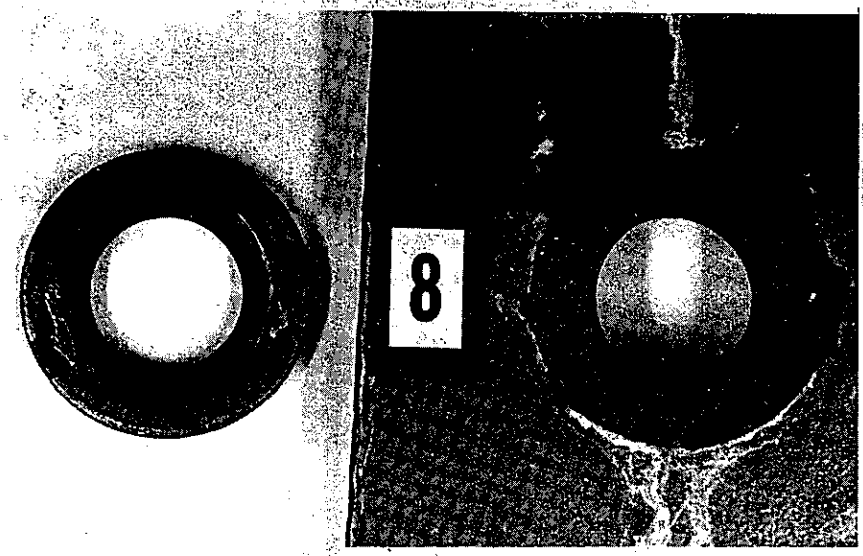
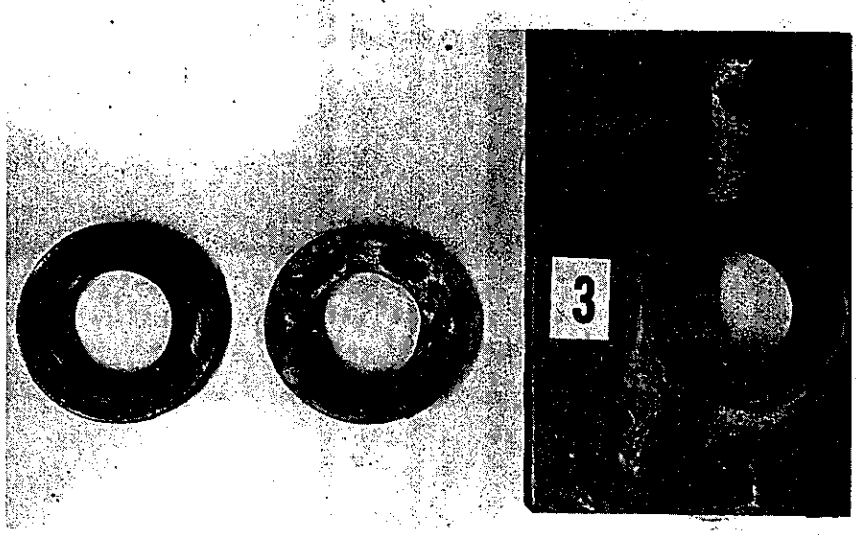
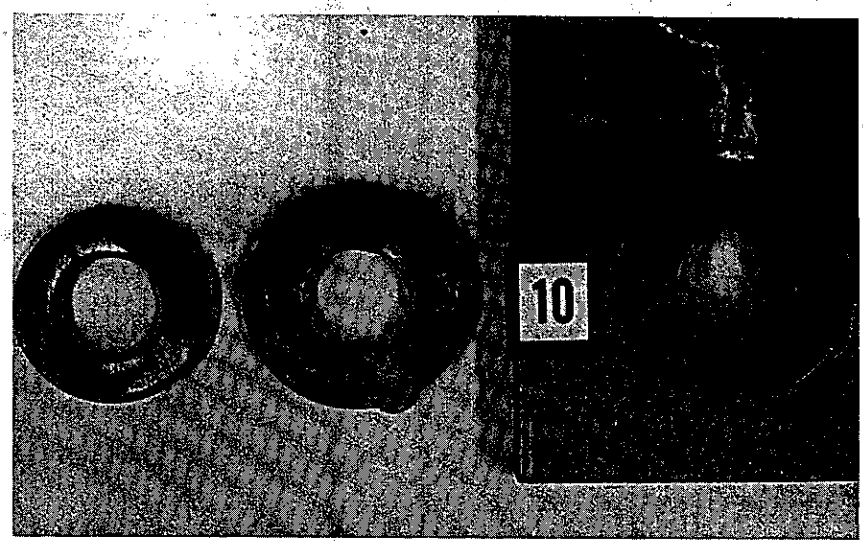


A490 hardened washer and plate surface-no LIW (A325 similar)



A325 LIW with hardened washer and plate surface



A490 LIW with hardened washer and plate surface

Figure 2. Disassembled painted specimen with and without load indicator washers after 7 days of salt spray test.

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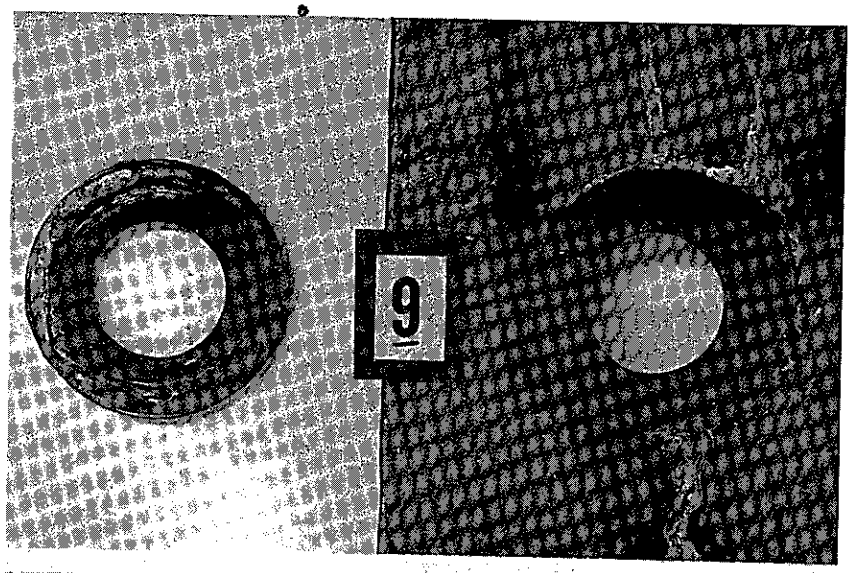
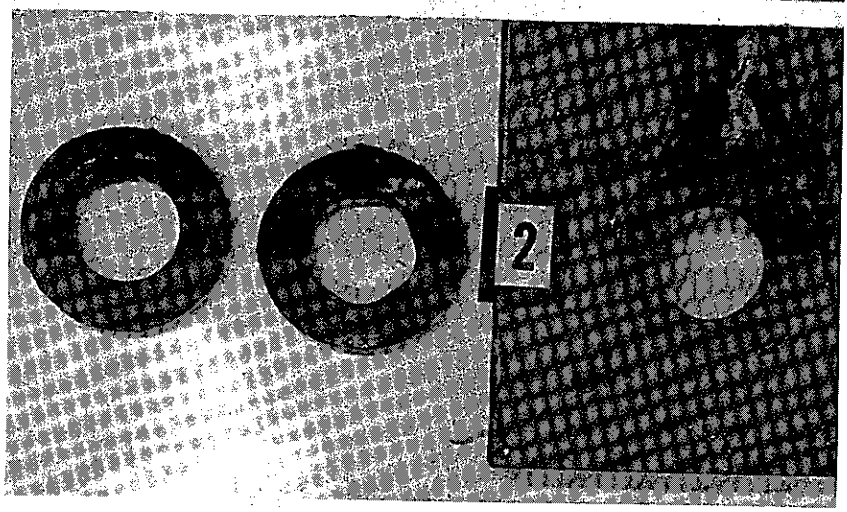
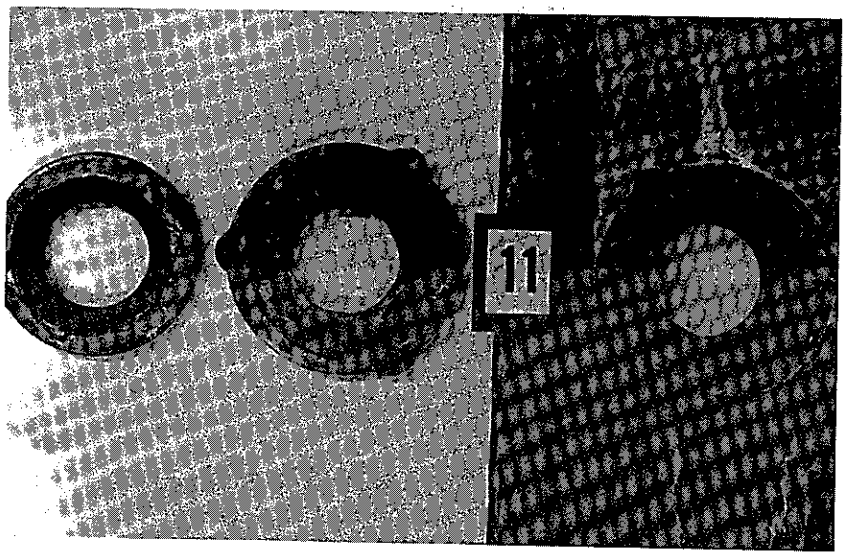


A490 hardened
washer and plate
surface-no LIW
(A325 similar)



A325 LIW
with hardened
washer and plate



A490 LIW
with hardened
washer and plate

Figure 3. Disassembled painted specimen with and without load indicator washers after 30 days of salt spray test.

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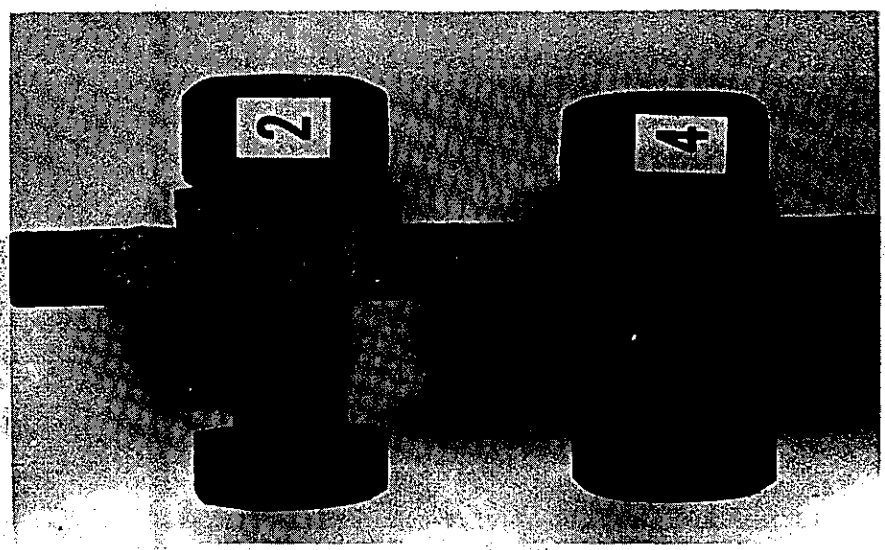
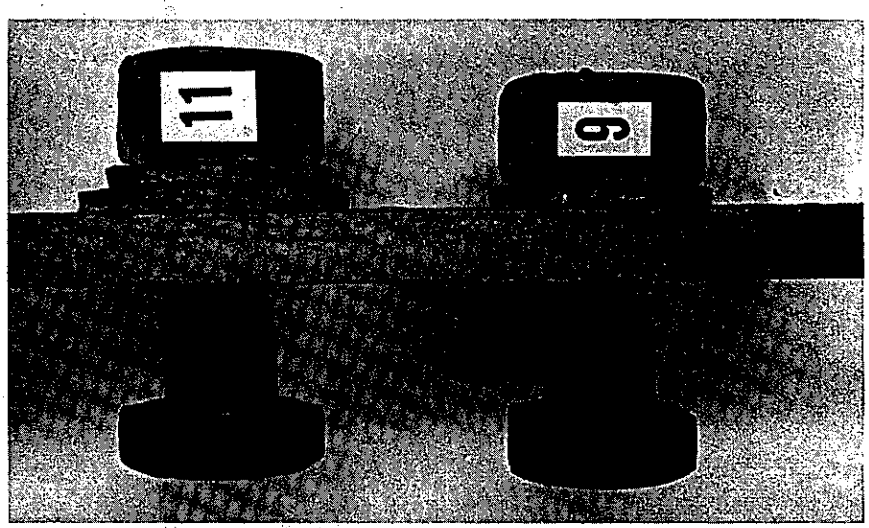


A325 Black Bolts and Nuts

Load indicator washer
and "full paint system"

Hardened washer only
and "full paint system"



A490 Black Bolts and Nuts

Load indicator washer
and "full paint system"

Hardened washer only
and "full paint system"

Figure 4. Corrosion on A325 and A490 bolt shanks of painted specimen with and without load indicator washers after 30 days of salt spray test.

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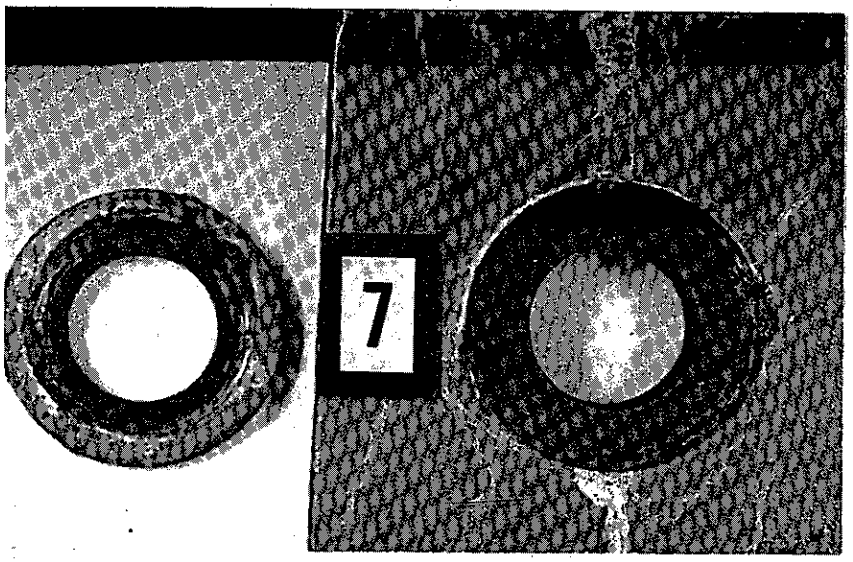
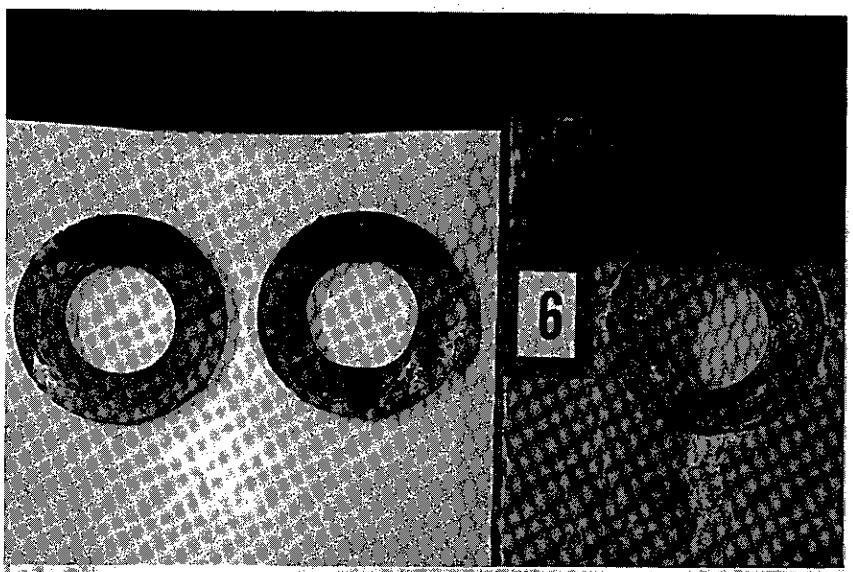
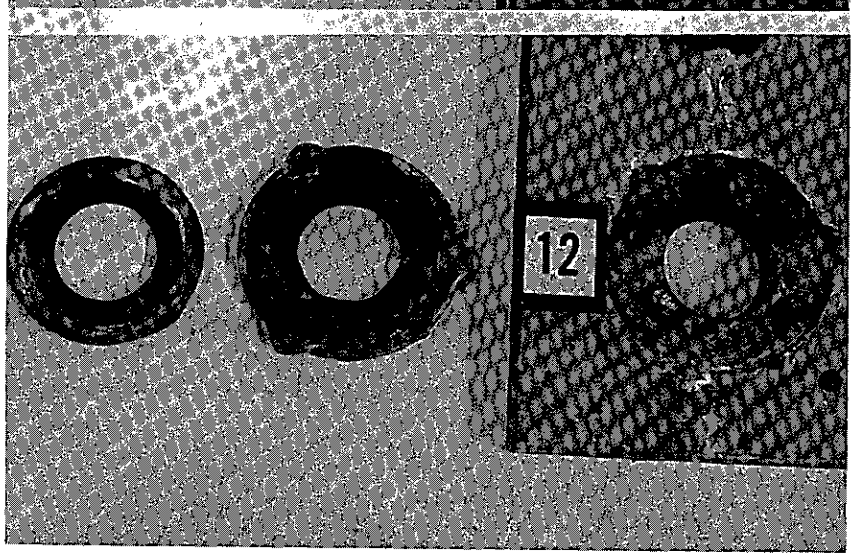


A490 hardened washer and plate surface-no LIW (A325 similar)



A325 LIW with hardened washer and plate



A490 LIW with hardened washer and plate

Figure 5. Disassembled painted specimen with and without load indicator washers after 60 days of salt spray test.

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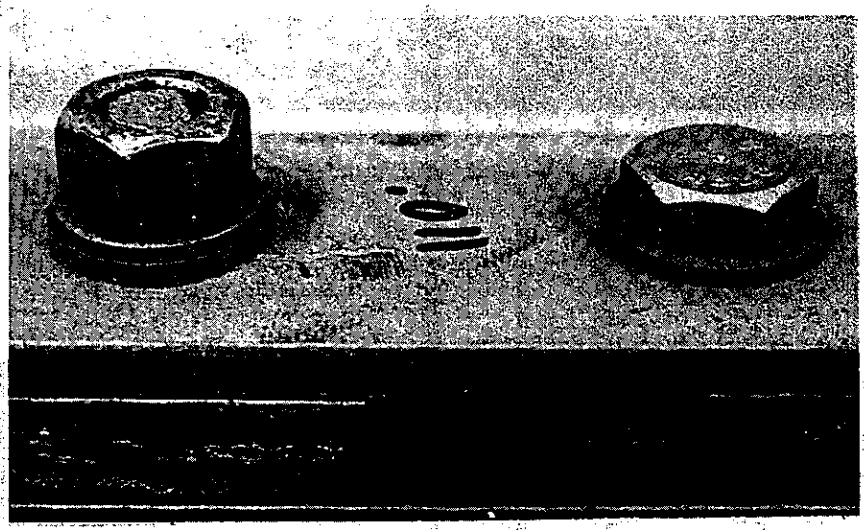
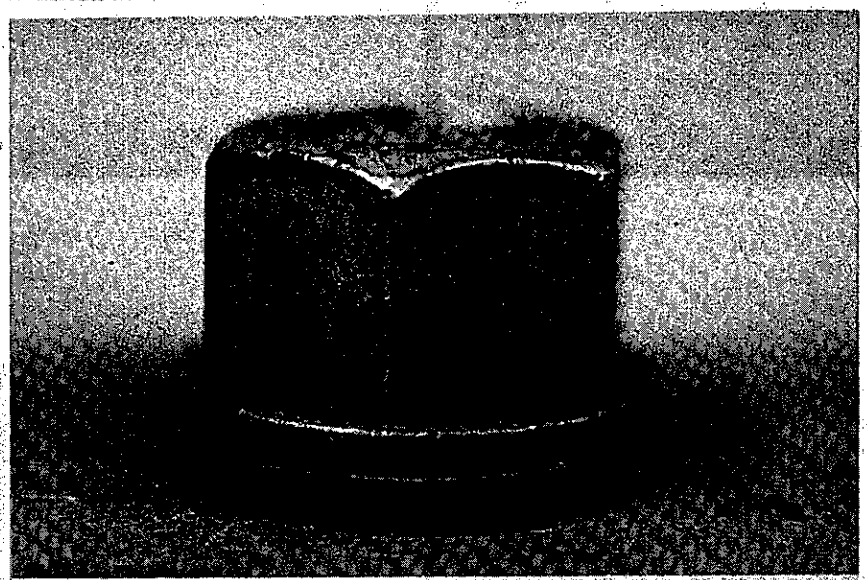
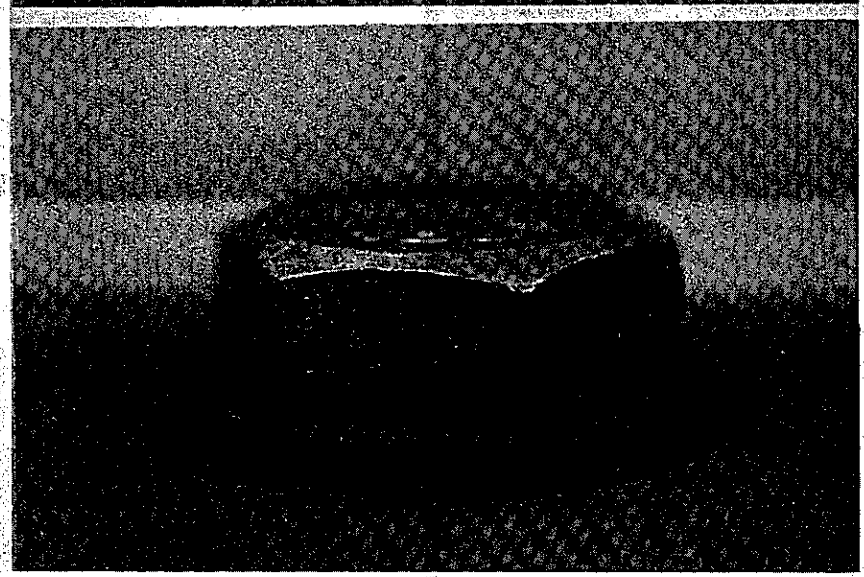


Assembled galvanized plate assembly before test
Left-LIW under nut
Right-LIW under A325 bolt head



Close-up view of grade 2H nut and LIW with zinc primer



Close-up view of A325 bolt head and LIW with zinc primer

Figure 6. Hot-dip galvanized A325 bolts and plate prior to 7-day salt spray test -- load indicator washers coated with zinc-rich primer.

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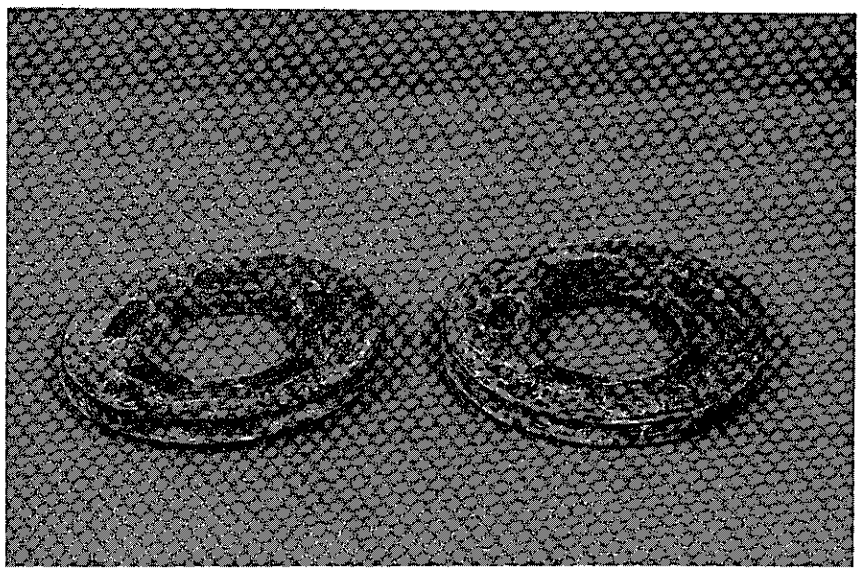
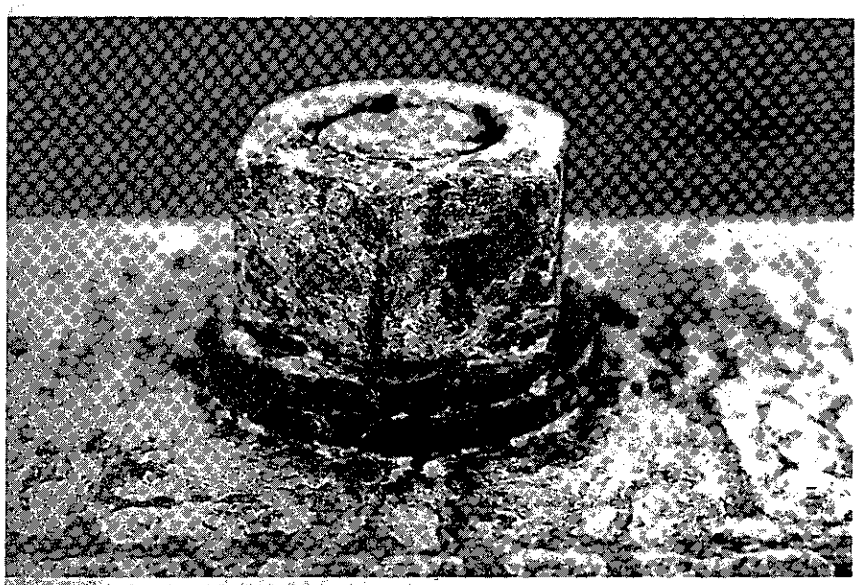


Zinc primed A325 LIW's after 7 days in salt spray

Left-LIW from under bolt head
Right-LIW from under hardened washer at nut



Galvanized A325 bolt with LIW under hardened washer at nut - before disassembly

Galvanized A325 bolt with LIW under bolt head - before disassembly

Figure 7. Assembled hot-dip galvanized specimens with zinc primed load indicator washers at bolt head/nut end after 7 days of salt spray test.

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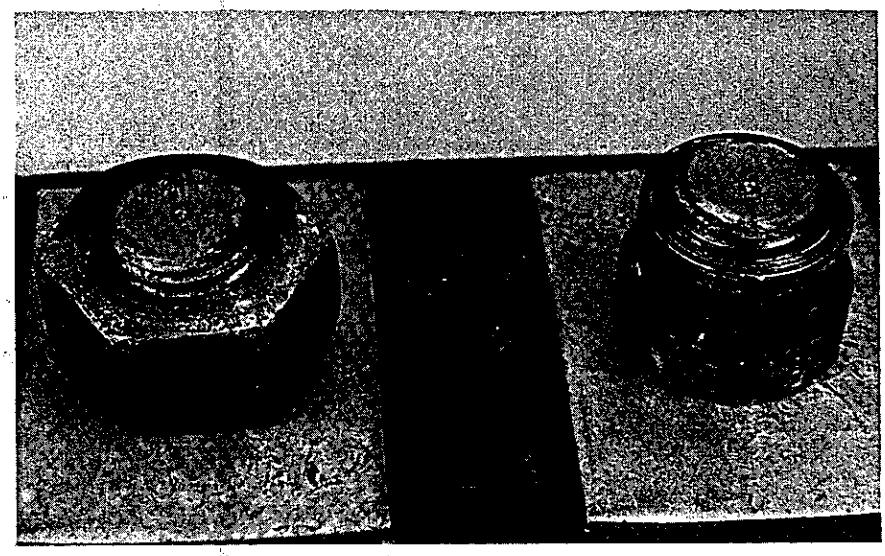
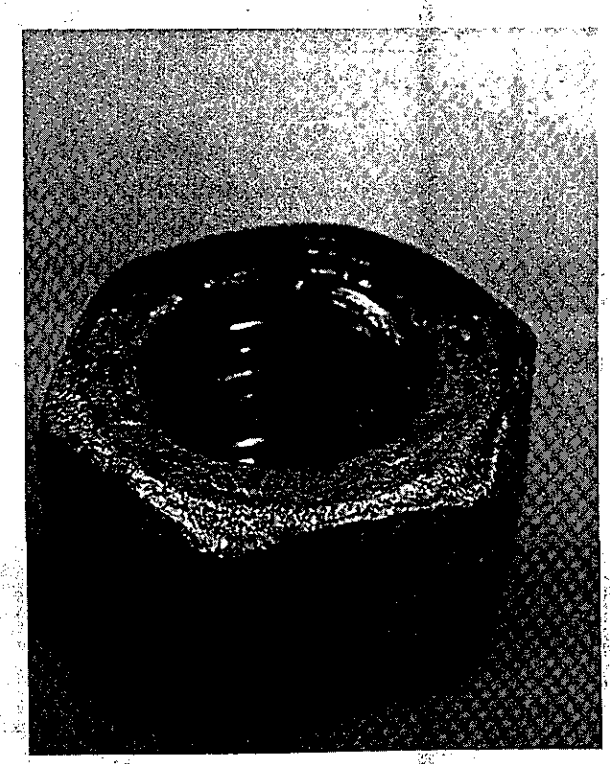


Galvanized assembly with control 2H nut (left) and installed "Hi-Lok" nut (right)



Hot-Dip galvanized ASTM Grade 2H nut

"Hi-Lok" nut prior to installation

Figure 8. Typical ASTM Grade 2H nut and "Hi-Lok" nut specimen before salt spray test.

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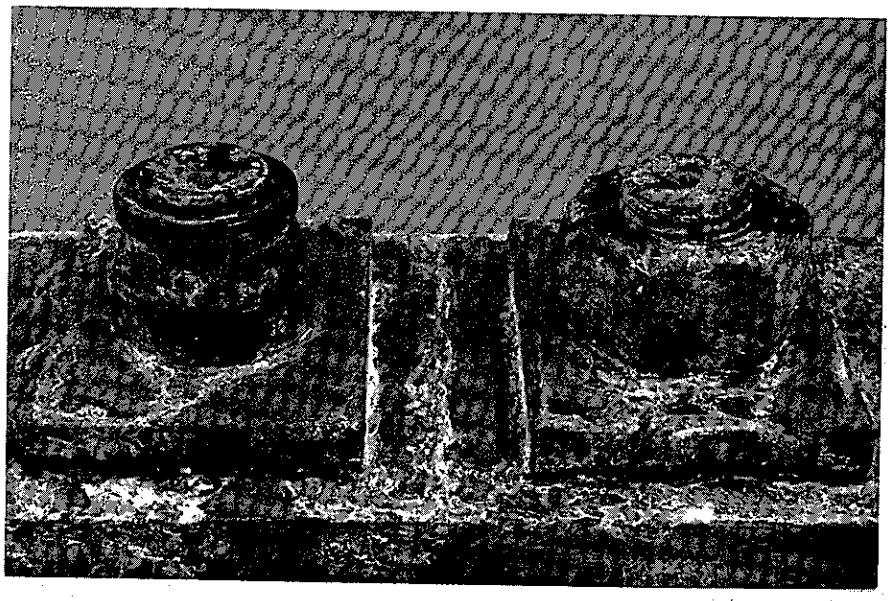
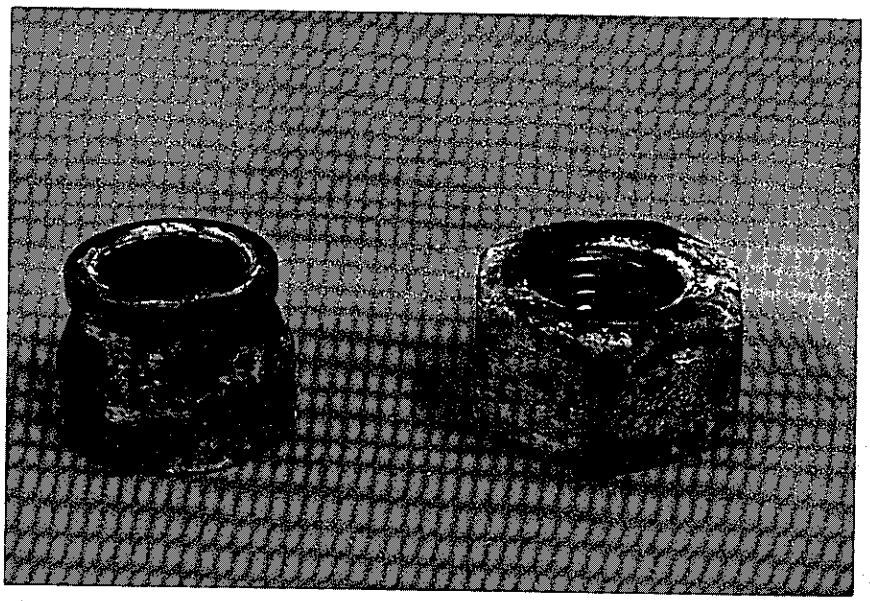


"Hi-Lok" nut Grade 2H nut

Before disassembly



"Hi-Lok" nut Grade 2H nut

After disassembly

Figure 9. ASTM Grade 2H nut and "Hi-Lok" nut specimen after 200 hours of salt spray test.

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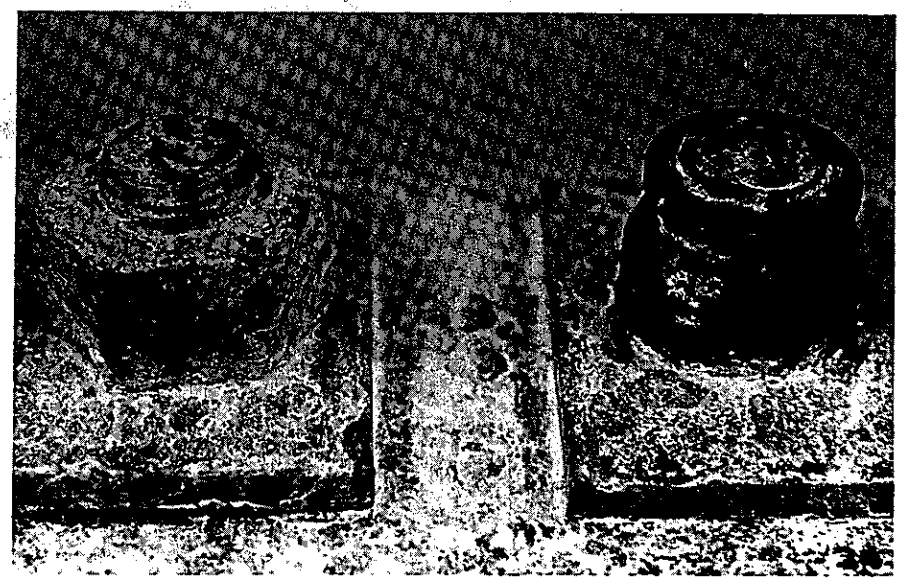
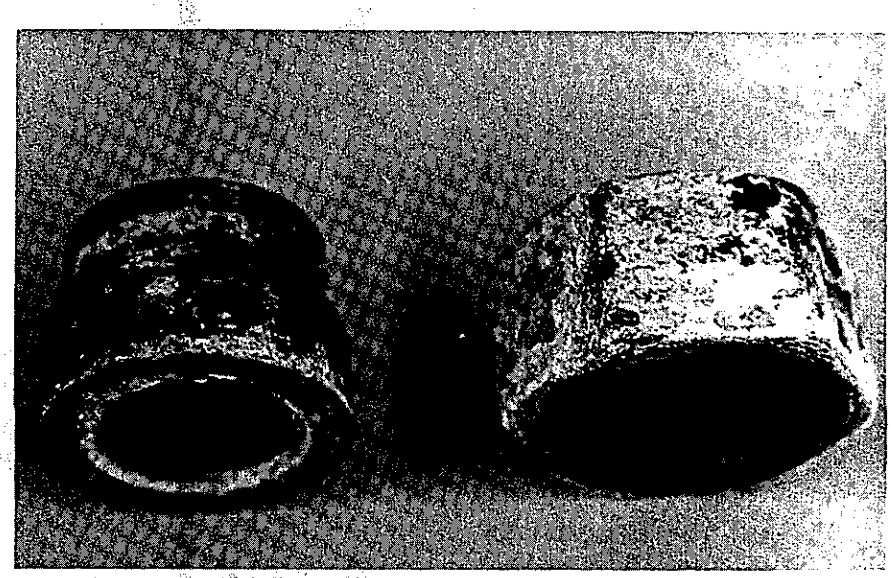


Grade 2H nut "Hi-Lok" nut

Before disassembly



"Hi-Lok" nut Grade 2H nut

After disassemblv

Figure 10. ASTM Grade 2H nut and "Hi-Lok" nut specimen after 30 days of salt spray test.

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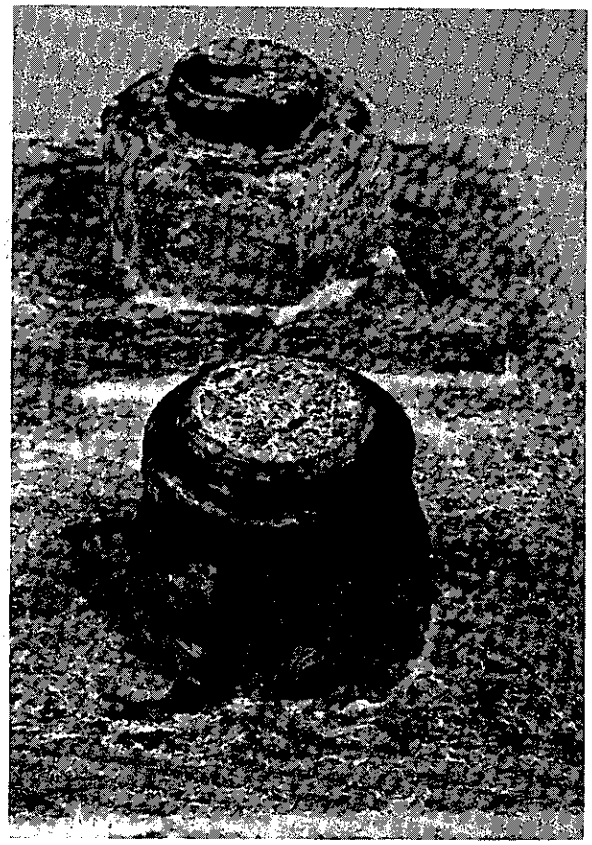
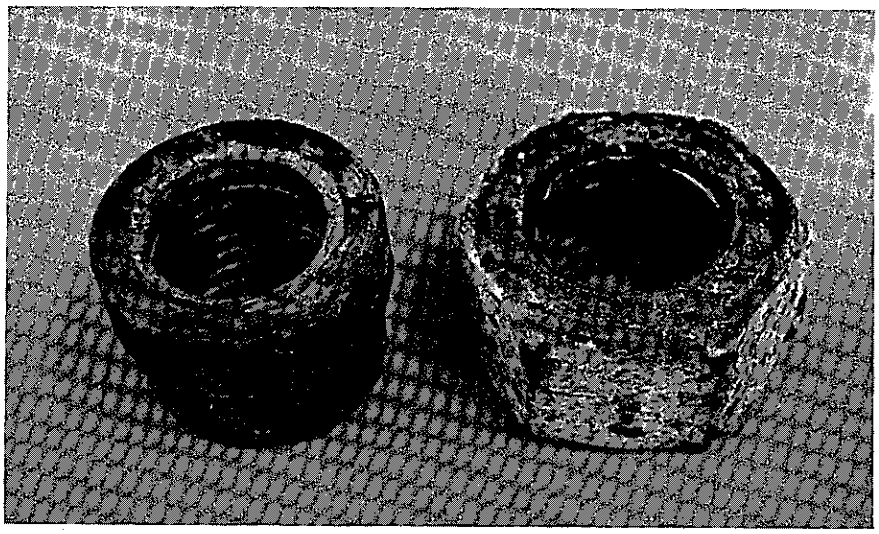


Grade 2H nut

"Hi-Lok" nut

Before disassembly



"Hi-Lok" nut Grade 2H nut

After disassembly

Figure 11. ASTM Grade 2H nut and "Hi-Lok" nut specimen after 60 days of salt spray test.

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The Bethlehem Load Indicator Washer

This direct-tension indicator is both simple and accurate . . . for the tightening and inspection of high-strength bolts. The load indicator is a hardened steel washer with a series of protrusions on one face. Induced bolt tension is indicated directly and accurately. Bethlehem furnishes the load indicator washer with a black finish.

Simple to use

Standard wrenches and sockets are used for tightening. No special tools required. No tedious calibration.

Fast

Up to 30 per cent faster on installation and inspection than other accepted methods.

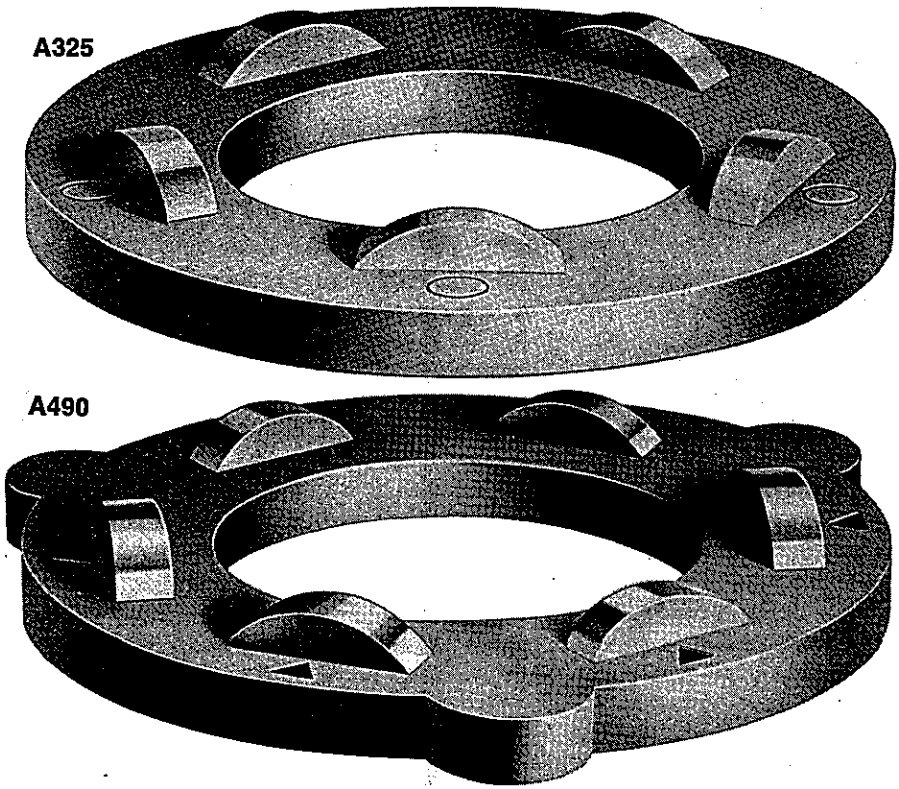

Figure 12. Features of Load Indicator Washers.

Accurate

When the bolt is tightened to the specified gap, correct bolt tension is automatically induced. There is no need to depend upon an assumed relation between torque and tension in meeting standards.

Versatile

Load indicator washers can be used under the head or at the nut end, and thus can be used with countersunk head bolts. They will take up to a 3° flange taper.

Consistent

At the specified gap, bolt tension is repeated to $^{+15\%}_{-0}$. The critical tension of the bolt will never be less than minimum required, and, as long as the gap is not completely closed, the bolt cannot be over tightened.

Ease of Inspection

Load indicator washers leave a permanent witness that proper tightening has been completed. Eye inspection gives acceptable accuracy.

Standardized

Load indicator washers are manufactured to ASTM A325 and A490, with slightly different configurations for quick identification. Specifications for the use of high-strength bolts in structural steelwork requiring that bolts be tightened to a minimum tension: AISC, AASHO, AREA, and RCRBSJ.

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Table 1 Load indicator gaps to give required minimum bolt tension

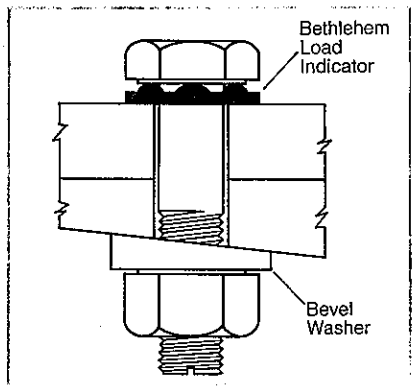
Load Indicator Fitting	A325	A490
Under Bolt Head Black Finish Bolts	0·015 in.	0·015 in.
Under Nut with Nut Face Washers Black Finish	0·010 in.	0·010 in.

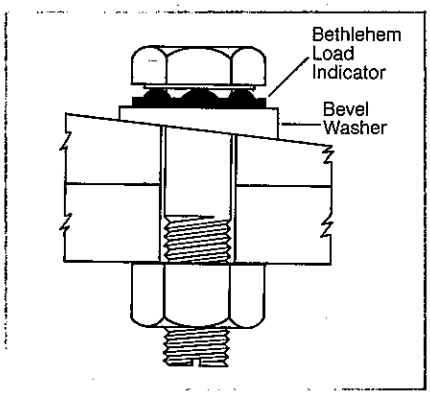
With the gaps shown above, required minimum bolt tensions will be induced as given in Table 2.

Table 2 Minimum bolt tensions

In thousands of pounds (Kips)

Bolt dia. (in.)	A325	A490
½	12	—
⅝	19	—
¾	28	35
⅞	39	49
1	51	64
1⅛	56	80
1¼	71	102





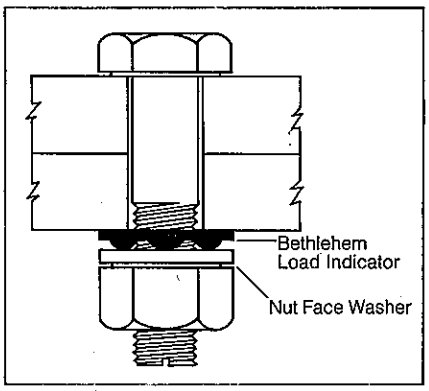


Figure 13. Specifications and Applications of Load Indicator Washers.

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Technical Report No. 26

Fatigue test on high strength bolts and 'Coronet' Load Indicators

Figure 14. Fatigue Test Report of Load Indicator Washers.

Cooper + Turner Inc

111 Founders Plaza
East Hartford
Conn. 06108
Tel: (203) 528 6513

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Introduction

It was desired to investigate the effect of vibration and axial load reversals on High Strength Bolts tightened to proof load using 'Coronet' Load Indicators to register axial tension. ASTM A325 ¾" diameter Bolts were used, together with the appropriate Load Indicators. The "Specification for Structural Joints using ASTM A325 or A490 bolts" limits the applied tension in A325 bolts to 36,000 p.s.i. and 40,000 p.s.i. for bridges and buildings respectively. The maximum applied load of 17 kips used in this test gives a stress of 39,000 p.s.i. which is in excess of the 36,000 p.s.i. limit for bridges where fatigue conditions are involved.

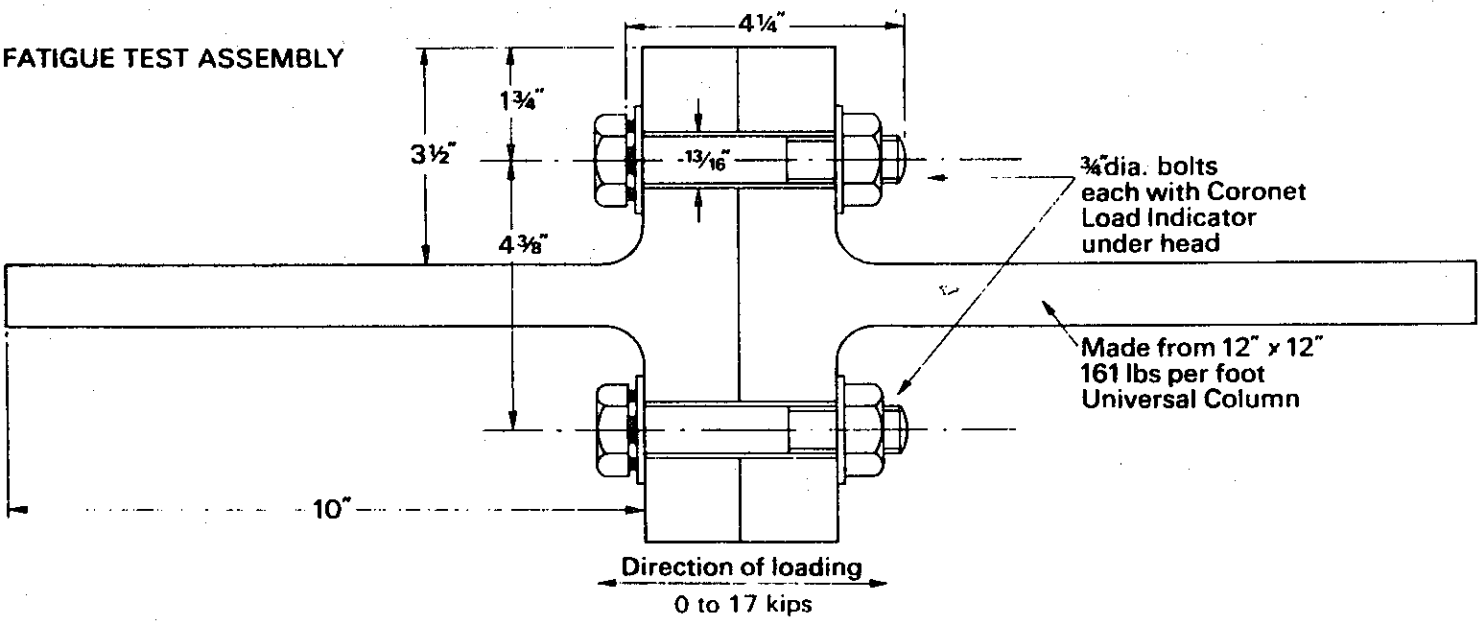
Summary

The assembly was subjected to 2,718,600 stress cycles between 0 and 0·6 x proof load without fracture. No change of bolt length was recorded.

Procedure

The test specimen comprised of two tee sections as shown in the diagram which were assembled with two ¾" diameter High Strength Bolts and 'Coronet' Load Indicators. The bolts were tightened until the average Indicator gap was 0·015" which corresponds to the proof load of 28·4 kips. The assembly was set up in a Losenhauser-U.H.S. 60 fatigue testing machine at the Laboratories of the British Welding Research Association at Abington Hall, Cambridge, England. Measurements of Indicator gaps and bolt lengths were taken at intervals during the test.

FATIGUE TEST ASSEMBLY



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Results

Test load 0 to 17 kips.

Cycles	Bolt No. 1						Bolt No. 2					
	Load Indicator Gaps — Inches					Bolt Length Inches	Load Indicator Gaps — Inches					Bolt Length Inches
						Before Tightening: 4·733 After Tightening: 4·741						Before Tightening: 4·728 After Tightening: 4·735
	1	2	3	4	Avge.		1	2	3	4	Avge.	
0	·009	·017	·020	·012	·0145	4·741	·022	·010	·006	·019	·0142	4·735
55500	·009	·017	·020	·012	·0145	4·741	·022	·010	·006	·019	·0142	4·735
698200	·009	·017	·020	·012	·0145	4·741	·022	·010	·006	·019	·0142	4·735
1253600	·009	·017	·020	·012	·0145	4·741	·022	·010	·006	·019	·0142	4·735
1887500	·009	·017	·020	·012	·0145	4·741	·022	·010	·006	·019	·0142	4·735
2381900	·009	·017	·020	·012	·0145	4·741	·022	·010	·006	·019	·0142	4·735
2718600	·010	·018	·020	·012	·015	4·741	·022	·010	·007	·020	·0147	4·735
					Bolt Extension	Inches					Bolt Extension	Inches
					Before Test:	·008					Before Test:	·007
					After Test:	·008					After Test:	·007

Cycles endured — 2,718,600
No fractures observed.

Discussion of results

There is a small increase of 0·0005" in the average Indicator gap on both bolts at 2,718,600 cycles. However it is too small to effect any measurable change in the bolt lengths and is likely to be due to some very slight seating.

The test shows that High Strength Bolts with 'Coronet' Load Indicators will safely withstand the maximum designed fatigue loading permitted by "The Specification for Structural Joints using ASTM A325 or A490 Bolts".

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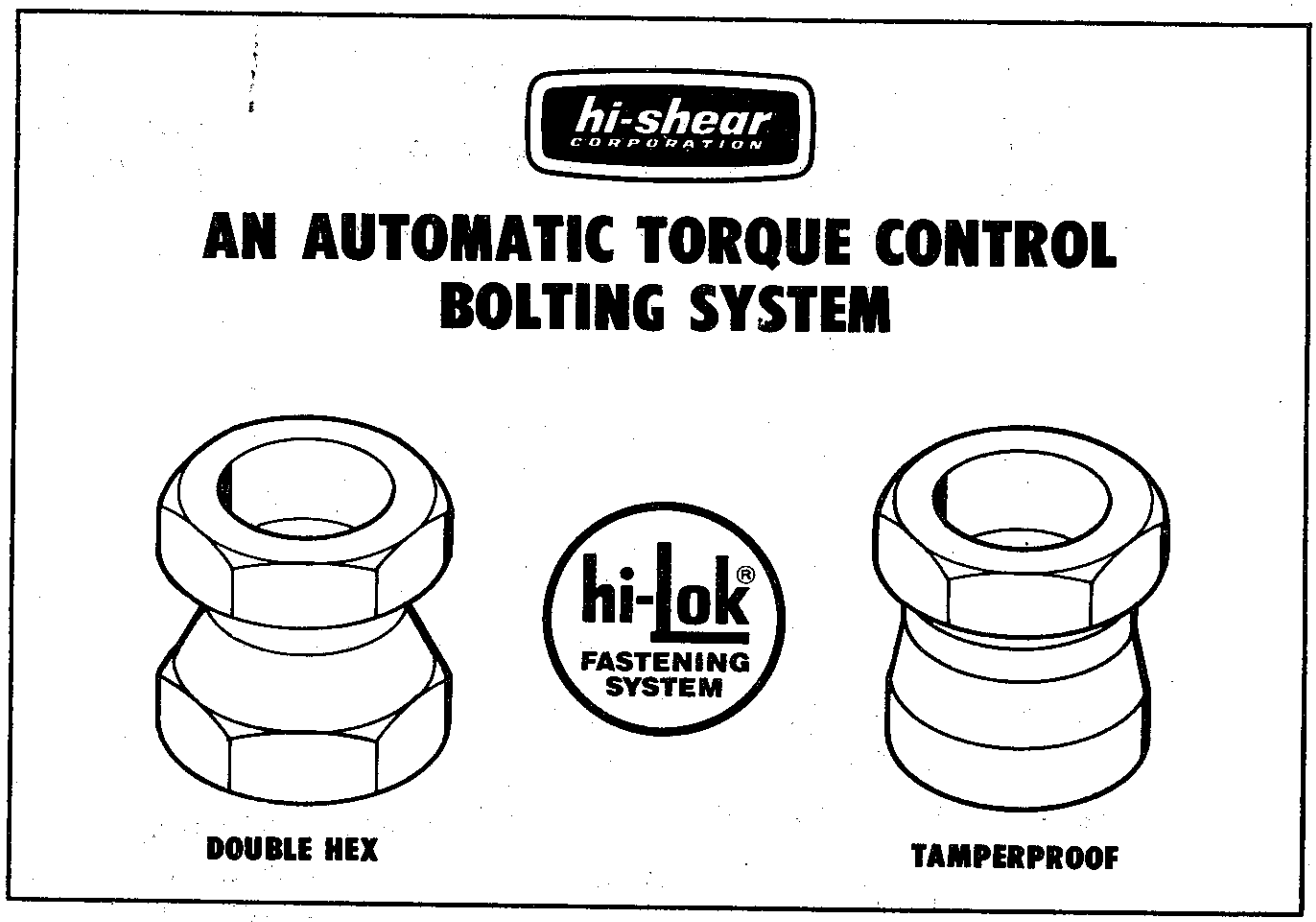

FIGURE 1

The Hi-Lok system is an automatic torque controlled bolting system. The primary features of the Hi-Lok system are:

- Precise preload control is built into the Hi-Lok torque control nut. The final torque applied to the joint does not depend on worker skill or calibrated installation tools.

- Inspection for correct torque is visual, and in no way depends on an inspector's judgement.

- The Hi-Lok torque controlled nut can be procured in a tamper-proof configuration. Once installed, a standard wrench cannot be used for removal or re-torquing.

- A self-locking feature can also be provided.

Figure 15. "Hi-Lok" Fastening System Features.

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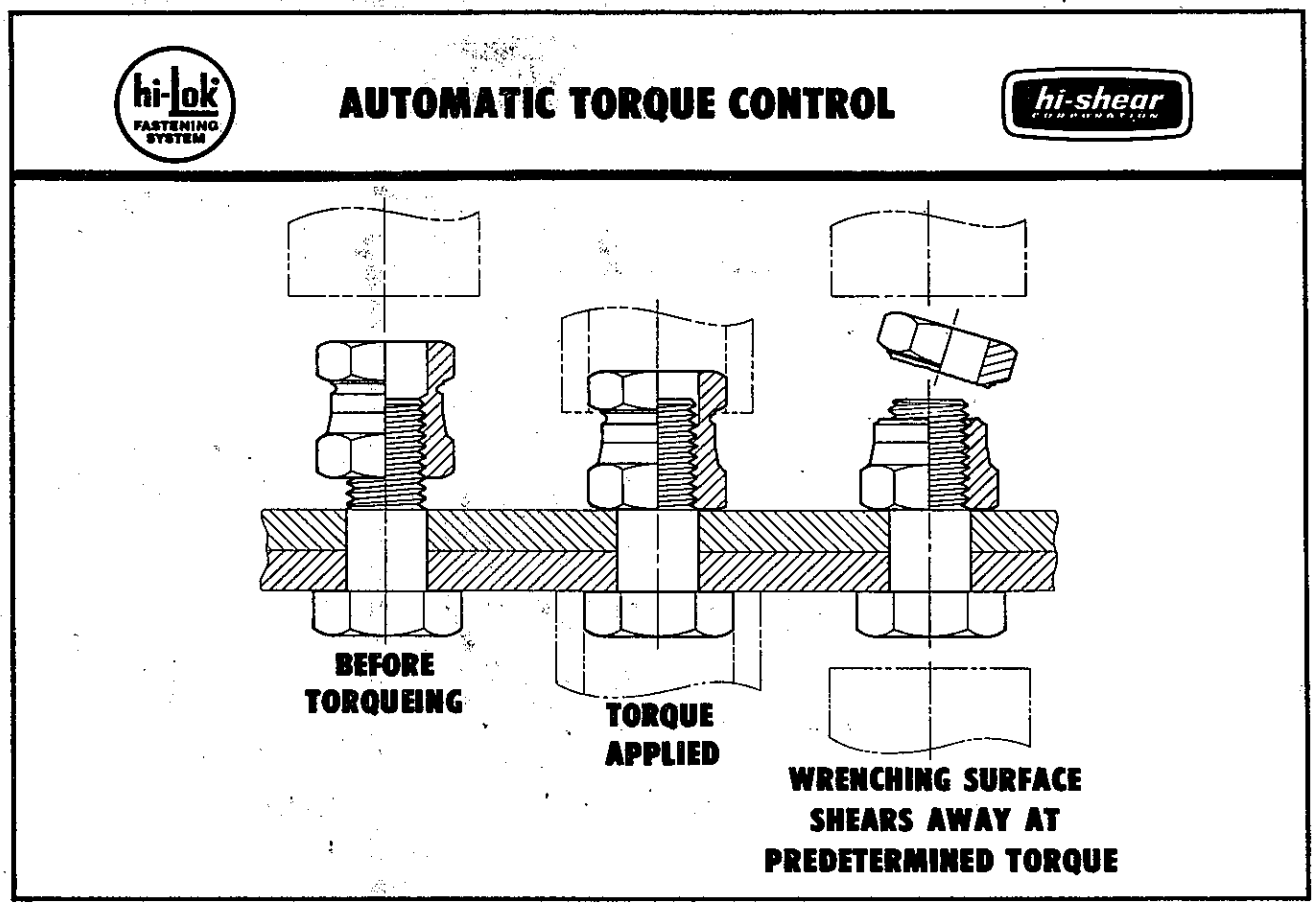

FIGURE 2

Figure 2 illustrates the installation of a Hi-Lok torque controlled nut. In the left hand diagram, the nut is being run onto the bolt. In the center diagram, the nut is snug, and the applied torque is increasing the tension in the bolt. Note that the installation torque is applied to the upper wrenching surface only. In the right hand diagram, the prescribed installation torque has been reached, and the upper wrenching surface has sheared away from the structural body of the nut.

The remaining nut portion is designed with sufficient strength to develop the full structural capability of the mating bolt.

Figure 16. Illustrated Installation of a "Hi-Lok" nut .

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TS NEW WAY

FASTENING SYSTEM FOR STRUCTURAL JOINTS

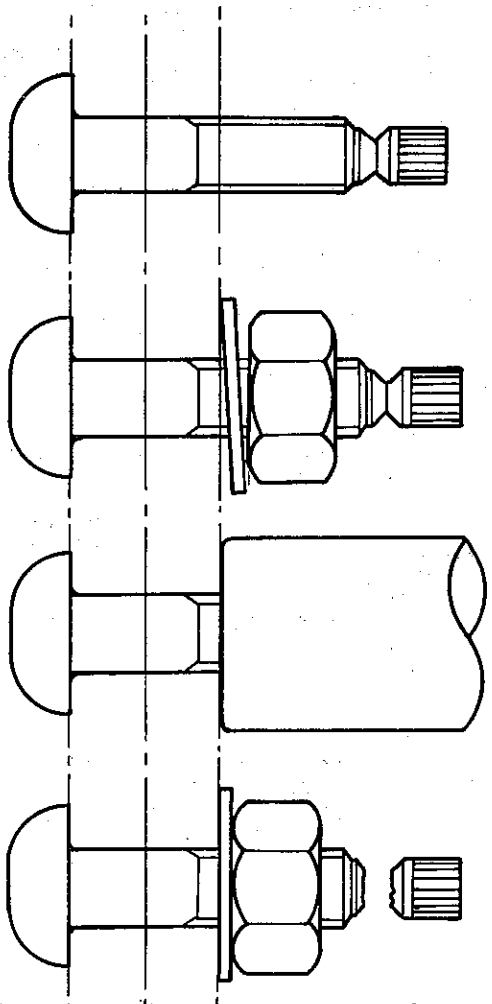

Figure 17. Tension Set Fastening System Features.

- VISUAL INSPECTION – NO TORQUING REQUIRED
- CONTROLLED TORQUE
- GUARANTEE PRELOAD AND HIGH CLAMP-UP
- ONE MAN OPERATION
- SILENT INSTALLATION (OSHA STANDARDS)
- CANNOT BE OVER-TORQUED
- BOLT REACTS ROTATION OF NUT
- INTERCHANGEABLE WITH OTHER HIGH TENSILE FASTENERS (A325 – A490 SERIES)
- STANDARD BOLT HOLE SIZE
- FASTENER PERFORMANCE UNAFFECTED BY TOOL OR TOOL WEAR
- AIR, ELECTRIC & HAND TOOLS AVAILABLE
- TAMPER PROOF FROM HEAD SIDE

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The Tension Set Fastening System

represents the ultimate in today's technology directed toward fastening structural steel joints. This Fastening System utilizes the best of known structural fasteners, the Hot Rivet and High Tensile Bolts.

By virtue of design, the installation of TS fasteners guarantees proper tension and clamp-up without the use of torque controlled tools, as each fastener has its "own built in torque control device".

This design feature alone saves enormous amounts of time and money because Hand Indicator Torque Wrenches are not required to measure the torque (stretch) of each bolt.

TS

INSTALLATION PROCEDURE

Installation of the TS Fastening System is the same as Hi Tensile Bolts and Washer/Nut combination. The TS bolt is placed into the prepared hole and the washer/nut is hand spun on a few threads to hold assembly.

The installation tool is simply applied to the TS fastener, engaging both the bolt and nut and driven until the torque control groove of the bolt shears off.

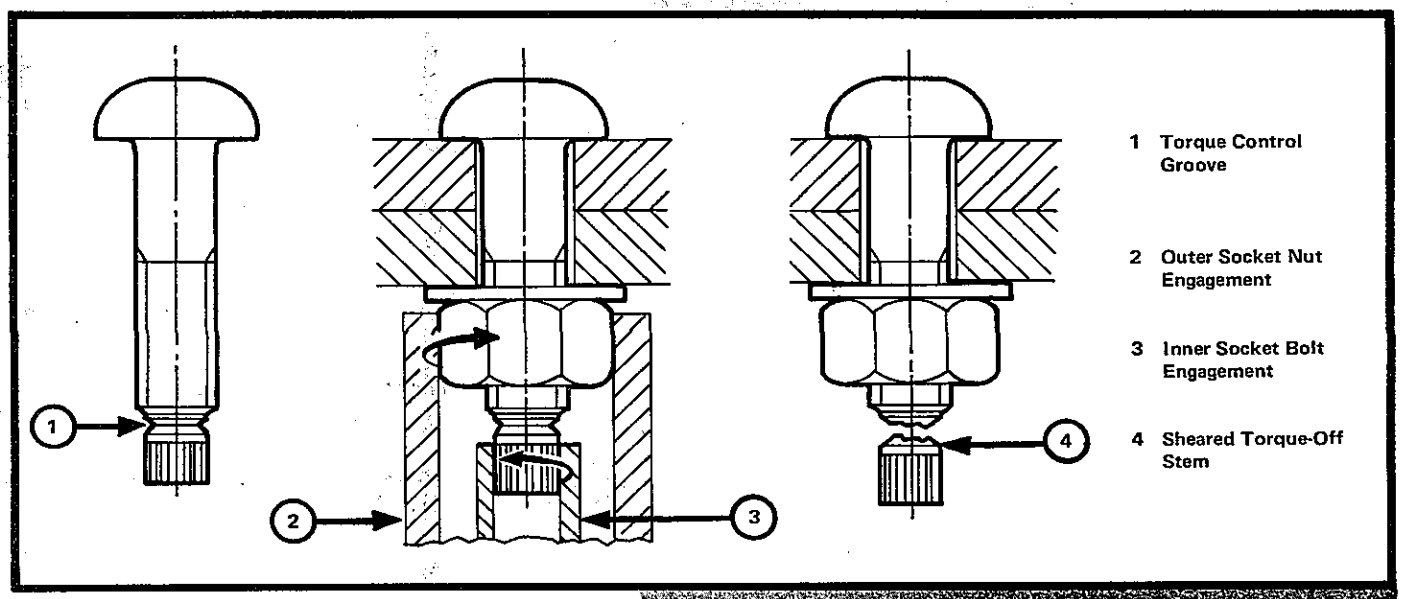

Figure 18. Illustrated Installation of Tension Set Fastener.

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