CRITIQUE

Comparative Effectiveness of Tightening Techniques for A490 1 1/4-in. Diameter Bolts

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INTRODUCTION

This critique highlights what the study readily admits, that prescribed strain measurements (bolt tensions) were not obtained in the tests reported because the plate stacks simulating connections were not adequately "snugged." While the "snugging" procedure followed for turn-of-nut was the one specified by the RCSC Specifications,[1,2] the "snugging" procedure followed for DTIs was not. *Consequently all of the conclusions relevant to DTIs are invalid.*

SNUGGING

Both RCSC Specifications state, "The snug tight condition is defined as the tightness that exists when all plies in a joint are in firm contact." They further state in their Commentaries, "This may usually be attained by a few impacts of an impact wrench or the full effort of a man using an ordinary spud wrench." The study quotes this statement but does not recognize the problem with it.

With regard to turn-of-nut, the 1985 RCSC Commentary states, "Consistency and reliability is dependent upon assuring that the joint is well compacted and all bolts at a snug tight condition prior to application of the final part turn." The 1988 Commentary rephrases this to read, "Consistency and reliability (of this) method is dependent upon ensuring that the joint is well compacted and all bolts are *uniformly tight* at a snug tight condition prior to application of the final required partial turn." The degree of "tight" (tension) required in the various sizes and grades of bolts as they may be used in connections of various forms, thickness and grades of structural steel is not specified. Rather, the same torque is suggested for all bolts and all joint configurations. A knowledgeable inspector can override this when he recognizes visually that all of the plies are not in firm contact. Unfortunately the researchers performing this study did not exercise that prerogative.

With regard to snugging DTIs the RCSC Specifications have some changes going from the 1985 edition to the 1988, but the provisions remain specific. The 1985 edition states, "...bolts shall be installed in all holes of the connection and brought to a snug tight condition." The 1988 edition reads, "...bolts shall be installed in all holes of the connection and tightened until all plies of the joint are in firm contact and fasteners are uniformly snug tight. Snug tight is indicated by partial compression of the direct tension indicator protrusions." The Commentary of the 1985 edition reads, "and the bolts tightened to approximately one-half the specified tension." The 1988 Commentary reads, "and the bolts tightened to approximately one-half the specified tension (deformation of the formed arches by about one-half the amount required to compress them to the specified gap) to ensure that plies of the joint have been brought into firm contact." Thus, when these instructions are followed, the level of tension in the bolts to achieve a "snug" connection is automatically built into the bolt system, the larger the bolt, (implicitly the thicker the plates) the larger the "snugging" force. The fact that researchers performing this study did not follow these specific instructions is its major flaw.

Rather than tailoring the snugging procedure to fit the conditions of the plate stacks, or following the RCSC Specification for DTI "snugging," an arbitrary torque of 200 ft-lbs was used to "snug" the stacks of plates. While such a "bedding" torque might snug a connection of thin plates using 3/4-in. bolts (with a resulting bolt snug tension of 16 kips, using a "nut factor" of 0.20) this torque could not snug a connection of heavy plates using 1 1/4-in. bolts (with a bolt snug tension of only 10 kips). Referring to the literature[3] (see pg. 55) it can

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be implied that proper snugging for turn-of-nut requires a tension of 50 percent of the specified bolt tension, or 50 kips for 1¼-in. A490 bolts. Similarly, 50 kips of bolt tension is required to developed noticeable protrusion compression on a 1¼-in. Type 490 DTI. Notice the use of an arbitrary torque value assures smaller snugging forces for larger plate assemblies, which is contrary to common sense.

TENSIONING

After inadequate "snugging," torque was applied to meet the second requirement of turn-of-nut (measured rotation) and DTI (protrusion compression) tension inspection procedures. The article then presents an assessment of the resulting tensions. It is not the purpose of this critique to extensively review these, they are not relevant since the joints were not properly snugged. Note however, the report specifically states, "A drawback to the turn-of-nut method is the difficulty of bringing bolts to a consistent snug condition." Also, the discussions and conclusions gloss over the fact that a significant number of inadequate tensions were recorded in the turn-of-nut short and long bolt tests as well as the DTI (under the head) tests.

It should be obvious then that inadequate strains were obtained not from failure of the turn-of-nut or DTI inspection methods but because plate packs were not properly "snugged."

DTI DESIGN, MANUFACTURE AND CERTIFICATION

The hardness of the DTIs used is reported as 40/41 HRC. This hardness is peculiar and is not typical of the hardness of DTIs furnished by J&M Turner which run from 33 to 35 HRC for this size and type. Evidently no test certificates were furnished for the DTIs as would be proper for a construction project. The researchers should have required the supplier to furnish a test report in accordance with ASTM F959 which would have indicated the test load, manufacturer, lot number, etc. Therefore, it cannot be asserted that the DTIs used in this study conformed with the provisions of F959. If these early design DTIs were oiled for this study, contrary to the manufacturer's instructions, the protrusions would have compressed at a load lower than the test load.

DTIs are now manufactured in accordance with the provisions of F959-94a. This requires a lot number on each DTI providing traceability of product for conformance. In addition, revised specification provisions for inside diameter, and protrusion location assure that the protrusions are always located under the bolt washer face. Also, redesign of the protrusion configuration means less time required for installation and now the same compression resistance whether the DTI is "dry" or "oiled."

HOLE SIZE AND WASHER REQUIREMENTS

The report states that the holes in the plates were oversized. The report is silent as to whether the RCSC specified procedures for placing $\frac{5}{16}$-in. thick hardened washers over the holes was followed. If the DTIs were not supported by washers they would have collapsed into the holes, leading to under tensioned bolts.

STRAIN MEASUREMENTS

There is some question about the strain gage procedure. Consultants advise that "If the bolt is not placed during tightening, to have the strain gage plane oriented for maximum bending, then the true axial strain and corresponding load conversion is adversely affected. It would have been more appropriate to use four strain gages oriented 90 degrees apart,[4] '...each pair in opposite areas of a Wheatstone bridge.' When four strain gages are mounted, and connected as above, the strain measured by one gage should not differ from the average of the four by more than 6 percent.[5] Similar caution is advised when measuring strains in reports from SPS Laboratories."[6]

INSTALLATION TIME AND EFFORT

The report addresses the time for torque application to reach the finish of the tensioning procedure. For both methods the reported time of wrench application included the subsequent "snugging" which was necessary because the plate stacks had not been fully "snugged" in the first place. Hence they are not representative of the time necessary to tension. With regard to DTIs, it is obvious that some extra nut travel and hence time is required to install a bolt using a DTI. But if the bolts with DTIs had been snugged to the point where the DTI protrusions were beginning to compress, properly snugging the plate stack, the subsequent time of torque application to tension the bolts would have been much less. The 10 second rule, quoted in the report is not a specification as indicated, but merely a rule-of-thumb. If it is exceeded, for popular size bolts, it alerts users to problems. It is not valid for large diameter bolts, particularly A490. After proper snugging, 20 seconds is more appropriate, with any bolt tension inspection method.

COMMENTS ON REFERENCES

With regard to reference 15 of the report, it was an unpublished oral presentation. The report misrepresents reference 15 in that it includes an incorrect statement attributed to an investigator who purportedly found "a significant percentage of installed 1¼-in. A490 bolts using load indicating washers not achieving the required minimum preload." A J&M Turner representative who heard this presentation met with Mr. Oswald on January 26, 1993 to discuss the events leading to his presentation. He revealed the following. The DTIs in question were used in a lower tier column splice on a power plant. The DTIs were placed under the nut (turned element) but the protrusions were oriented in the wrong direction, toward the work, as the result of a detailing error. Measure-

ments were made of the bolt lengths before and after removal and the tension strains recorded. Removal of the bolts from the holes required the use of a sledge hammer. The bolt shanks were severely scored. From this it was agreed that the bolts were trapped. The compressed (misassembled) DTI indicated tension had developed in the thread length, but the entire length of the bolt was not tensioned due to the trapping. Of course, with the DTIs "upside-down," refusal of the feeler gage is not indicative that the required tension had been achieved because the DTI is not properly supported. Integrating the measured strain over the entire length of the bolt caused the researchers to initially conclude that the lack of tension was the fault of the DTI, without considering the "trapping" options, let alone the effect of misassembly. It should be noted that the only bolt tension inspection method which will alert the user to "trapping" is a DTI *under the head of the bolt with the nut turned.* Turn-of-nut will not.

With regard to reference 16 of the article, this work was funded by J&M Turner and did indicate that DTIs, as made then, required more time to develop bolt tensions than turn-of-nut. This was expected since energy is required to both tension the bolt and compress the DTI. Using the results of that study J&M Turner engineered changes in protrusion design, including a reduction in the protrusion height. These changes significantly reduce the amount of energy, and consequently time, required to compress the protrusions while providing a positive indication of bolt tension.

It is unfortunate that the article does not reference another paper (6). This paper reports strain measurements on 1⅛-in. A490 bolts. Two large, similar aircraft assembly hangers were designed by one firm, fabricated by one firm and erected by one firm side by side at the same time. One used DTIs for bolt tension inspection, the other turn-of-nut in the roof trusses. The owners requested that J&M Turner verify bolt tensions in those bolts using DTIs and investigate bolt tensions in those bolts using turn-of-nut. Strain measurements were made using an ultrasonic technique, measuring length in place and length after removal. All of the 18 bolts measured which were installed with DTIs had the required minimum tension save one, which was slightly below, probably because the DTI was not fully compressed. Of the 9 bolts tested which had been installed using turn-of-nut inspection, only two had the requisite tension. Four of the bolts had tensions less than 50 percent of that required. It is not known what "snugging" procedure was used, or if match marking was used.

MANUFACTURER'S INSTRUCTIONS

When a study of this kind is performed, it is usual to contact the manufacturer of the product being studied. At no time was J&M Turner contacted for samples or technical assistance for this study. However, Reference 12 of the article is the J&M Turner *Instruction Manual for High Strength Bolting with Coronet Direct Tension Indicators.* It clearly describes the correct snugging procedure, the same one specified in the RCSC Specifications. Hence the study did not "follow the manufacturer's instructions."

In addition, J&M Turner was not given any opportunity to review this paper prior to publication although in a previously released version the authors claim that the DTIs came from J&M Turner, and Figure 1 of the article is art work taken from J&M Turner literature.

TERMINOLOGY

As of 1985 ASTM no longer called a DTI a load indicating washer, as a DTI has no washer function. Since then F959 has described a DTI, in the title, as a "compressible-washer-type direct tension indicator" and, in the text, as a "direct tension indicator."

Can the word tighten be dropped from bolt literature as it is nonspecific and cannot be quantified? The words tension (to mean the condition of or the action of developing tension) and torque (to mean the force or application of torque) could be used instead. They are specific and quantifiable.

"Turn-of-nut" and "direct tension indicator" are not "bolt installation methods." Bolts are installed by the application of torque. These are "bolt tension inspection methods."

"Snug" really refers to the condition of the plies of a connection, not a stage of bolt tension.

SINCE 1992

Since 1992 J&M Turner has supplied, with 100 percent acceptance, over 500,000 DTIs for use on ASTM A490 bolts in sizes of 1⅛-in. to 1½-in. for installation on large structures. Field investigations when erectors reported an inability to compress the DTI protrusions revealed dry, dirty or rusty bolts, or severe hole misalignments. When these conditions were corrected the protrusions compressed verifying proper bolt tensions.

CONCLUSIONS

1. When DTIs meeting the current ASTM F959 are used for bolt tension inspection and the snugging and installation procedures specified in the RCSC Specifications are followed, bolt tensions meeting the requirements of Table 4 of those specifications will be achieved.
2. The RCSC Specification does not specify the amount of tension necessary to properly snug a connection when turn-of-nut bolt tension inspection is used. It does suggest a torque, but this produces different snugging tensions in different size bolts, decreasing as size increases. Consequently if this torque criteria is used for snugging, turn-of-nut cannot assure the bolt tensions required in Table 4, particularly in large size A490 bolts. Also, "match marking" by an independent inspector is not required (although recommended), and if not done leads to another causes of inadequate tensions.

AFTER WORD

The reader should understand the genesis of this study. In February, 1989 the erecting company owned by the then president of the Steel Institute of New York was constructing a project in New York City where bolt tension inspection of 1¼-in. A490 bolts was done using DTIs. A dispute arose when the DTI protrusions could not be compressed but the erector believed that the bolts were properly tensioned. J&M Turner had supplied the DTIs and so was called in for consultation by the engineer. Verification testing was performed on sample DTIs at J&M Turner's laboratory, witnessed by the project engineers. Following that, there was a site inspection conducted by J&M Turner, the engineers and an independent inspection laboratory. Some partially compressed DTIs were removed from the iron and tightened on the same bolts in a bolt tension calibrator. When torque was applied to further compress the protrusions to the specified gap all samples were reported by the testing laboratory to be indicating the required bolt tensions. (Copies of the report are available from J&M Turner, Inc.)

It was then recommended that the erector lubricate the bolts and use impact wrenches of larger capacity to match the size of the bolts. This was done and the bolts were properly tensioned, evidenced by compression of the DTI protrusions.

The Steel Institute of New York then initiated and funded a test program at the ATLSS Center, presumably to try to make a case for turn-of-nut over DTIs, in spite of the evidence on the job site that the DTIs were working properly. It is interesting to note that precisely applying "bedding" torque and match marking was not at that time normal practice in New York City. This study clearly shows that even under laboratory conditions, this procedure for turn-of-nut failed to consistently achieve proper bolt loads.

The crux of the problem on this project was the inability to tension the bolts as evidence by the *inability* to compress the protrusions to the required gap. The only difference for the wrench operator with DTIs would have been a little more required nut rotation. Any increase in time is more a factor of proper lubrication than the use of DTIs. Today's DTIs require even less nut rotation and a greater degree of precision.

REFERENCES

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