DISCUSSION

Closure: Comparative Effectiveness of Tightening Techniques for A490 1¼-in. Diameter Bolts

Paper by DAVID SHARP and RONALD FLUCKER (2nd Quarter, 1996), critique of paper by JOAN S. DAHL, LE-WU LU, JOHN W. FISHER, and JOHN ABRUZZO (1st Quarter, 1996)

Discussion by Joan S. Dahl, Le-Wu Lu, John W. Fisher, and John Abruzzo

CLOSURE

The interest in the paper by J&M Turner Inc., specifically the contributions of Messrs. David Sharp and Ronald Flucker in the form of the published critique is acknowledged. The discussion focuses on, but is not limited to, the procedural aspects of the experimental program. All experimental data should be welcomed with skepticism and critically examined for possible bias as a consequence of the test procedure. This closure will clarify the objective of the research and address specific criticism presented in the discussion.

The objective of the research is to determine the comparative effectiveness of tightening 1¼-in. diameter A490 bolts under adverse joint and bolt conditions. There is some concern that the techniques used to install large diameter A490 bolts in the field may not provide the proper pretension given the variability of field conditions. One justification for concern is simply that the data used to develop bolt installation techniques does not include A490 bolts with diameters greater than 1 inch. The results of this study can be used to determine, or obtain a feel for, the robustness of the installation techniques by altering the ideal conditions to simulate field conditions in a controlled manner and allow for direct comparison. The research also generates data for validation of the installation methods for A490 bolts with diameters greater than 1 inch.

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Snug Tight

It is the opinion of Messrs. Flucker and Sharp that the data for bolt installations using the load indicating washers or compressible-washer-type direct tension indicators [DTIs] is invalid because the joints were not sufficiently compact. It is the opinion of the authors that insufficient joint compactness had a detrimental effect on the performance of the DTIs but cannot exclusively account for the failure of the bolts installed using DTIs to achieve the proper pretension. It is also the opinion of the authors that the difference in time and energy demands of bolt installation using the DTIs is insignificantly effected by the variations of joint compactness encountered within the study .

Obviously, one attribute of the robustness is sensitivity to joint compactness. Joint compactness or stiffness is a function of the number and thickness of plies, restraint on the plies, flatness of the plies, and misalignment or gaps between restrained plies. Short bolts are generally installed through relatively thin plies such as the three ⅞-in. thick plies used in the short bolt jig. Long bolts are generally installed through thick plies, possibly 3 inches or thicker. To simulate the joint stiffness achieved with restrained thick plates, as might be encountered in the field, the test jig for the long bolts consisted of eight 1½-in. thick plies. Given three plates of ⅞-, 1½-, and 3-in. thickness, the ratio of flexural stiffness is 1:5:40. One can see that the flexural stiffness of eight 1½-in. thick plates is comparable to a 3-in. plate. Furthermore, the two jigs used in the study provide a considerable variation in joint compactness.

The joint compactness has a significant effect on the bolt pretension for a group of bolts. It is possible for previously tightened bolts to lose pretension upon tightening of adjacent bolts in sequence, "crosstalk." As each bolt is installed, the joint becomes more compact. If this change of compactness is large, the previously tightened bolts will experience significant unloading. With regard to the turn-of-nut method, compensation for variability of joint stiffness is accommodated by specifying additional rotation for longer bolts beyond snug rather than altering the definition of snug tight.[1] Prior tests of bolt installation using DTIs were conducted with the same 200 ft.-lbs. of torque to achieve a snug condition with positive results.[2] The 1985 RCSC Specification[3] and the 1988 RCSC LRFD Commentary[4] suggest a pre-load of 50 percent of the minimum specified pretension to achieve firm contact when using DTIs. The intent is to minimize the problem associated with "crosstalk". Thus, while the DTIs were not snugged to 50 percent of the pretension to facilitate direct comparison of data, the recorded final strains are measured prior to the tightening of adjacent bolts.

The data shows the turn-of-nut method of installing twelve bolts through three ⅞-in. thick plies, following the bolting sequence described in Figures 5 and 6 of the paper, provides a mean pretension force greater than the minimum specified. The snug tight level of pre-load, achieved with the 200 ft.-lbs. of torque, provides approximately 100 kips of compression force on the flat stack of three plates. Surely, this is enough to justify firm contact of three flat, unrestrained plates. There were no visible gaps in the stack of plies. The installation technique using DTI method #1 (the DTI is between the unturned bolt head and a hardened $^5/_{16}$-in. washer, gap 0.015 inches) for similar conditions did not achieve the same level of pretension. It should be noted that even if the snug condition is inadequate, one would expect the bolts tightened last in the sequence to have achieved the proper level of pretension. At the time when the later bolts are tightened, the joint is essentially compacted to the level in excess of 50 percent pretension. Using the same installation technique but a different assembly, proper results were achieved using DTI method #2 (the DTI is sandwiched between two $^5/_{16}$-in. hardened washers under the turned nut, gap 0.005 inches). All of the bolts installed with this method exceeded the minimum specified pretension. Likewise, the data reflects similar patterns for the long bolts with the exception that the average pretension obtained using DTI method #2 almost meets the minimum specified pretension yet is clearly higher than that obtained by DTI method #1. Considering the data carefully, one can see that the results are certainly affected by the joint compactness and thus the snug condition, but failure to achieve the minimum specified pretension cannot exclusively be attributed to an inadequate snug condition. It is beyond the scope of this study to further investigate the failure of the bolts installed using DTIs to obtain the minimum required pretension.

Certification and Condition of DTIs

Messrs. Flucker and Sharp question the assertion that the DTIs conformed to ASTM F959 specifications because of the apparent disparity of hardness with regard to the product produced by J&M Turner, Inc. The assertion is made because the DTIs were certified by the supplier to meet ASTM F959 specifications, the results of an independent chemical analysis conformed to ASTM F959, and the compression load of a DTI tested in a universal test machine per ASTM F959 was 106 kips. There is no hardness requirement specified in ASTM F959. The DTIs had the proper markings and were clean when installed.

Washer Requirements and the Ten Second Rule

The installation methods used in the testing conform to the 1985 RCSC and 1988 LRFD RCSC specifications with two exceptions. The requirements of section 8(d) which specifies that the impact wrenches shall be able to perform the required tightening of each bolt in ten seconds were not met even though the largest commercially available impact wrenches were used. This requirement is seldom met in practice when installing A490 bolts greater than one inch in diameter. The discussion relegates this requirement as a rule of thumb. Rules of thumb are usually found in the commentary not the specification. The other exception is the degree of tightness achieved at snug for the DTIs. However, as previously discussed, measuring strains after installation of each bolt should have accounted for this disparity. Both of these exceptions were noted in the paper.

Messrs. Flucker and Sharp suggest the report is silent with regard to the procedures for placing $^5/_{16}$-in. thick hardened washers over the holes. The specifications require the use of these washers and they were indeed used. The details of the test procedure were included even though anonymous feedback received from the AISC peer review process indicated that it was unnecessary and should be omitted. The authors felt it was necessary to allow readers to critically examine the data presented. The provisions for turn-of nut method require the proper use of washers with specific reference to section 7(c). The provisions for use of DTI methods also require proper attention to the use of washers especially when bolts are installed in oversized or slotted holes. Thus $^5/_{16}$-in. thick hardened washers were used and their use implied by adherence to the RSCS specification.

Bolt Instrumentation

The strain measuring techniques used in the research are adequate for measuring the axial force in a bolt. In conjunction with the strain gage data, bolt elongation is also measured. Both bolt elongation and strain were calibrated in the pre-testing phase of the study to determine the axial force. The bolt elongation measurements were used to corroborate the strain readings. The objective is to measure axial bolt force or pretension for bolts installed in the joint. Messrs. Flucker and Sharp question the strain gage procedure used in the study. They suggest that four rather than two strain gages should have been used in accordance with References 4 and 6. These references are MIL STD 1312B, Appendix C and SPS Laboratories, "Procedures for Utilizing Strain Gages," respectively. MIL STD 1312B, Appendix C is titled "Alignment and Load Verification of Axial-Load Fatigue Testing Machines." It provides instructions for the building of a load cell to measure the applied axial force in a bolt or fastener over a period of time. The load cell is to be mounted in series with the bolt or fastener to be tested for tensile fatigue strength in a universal testing machine. The requirement that none of the gages should differ from the average of the four by more than 6 percent is needed to insure that minimal bending is introduced in the bolt due to misalignment in the test fixture. This is irrelevant to a non-fatigue related study where the bolt force must be measured in the joint. Reference 6 suggests the use of four gages, one in each arm of a Wheatstone Bridge when instrumenting a load cell to measure axial load. However, immediately following this discussion, an alternative arrangement using two gages 180 degree (similar to that used in the study) apart is also suggested. Both of these citations specifically address the instrumentation of a load cell, not a bolt to be installed in a joint.

Review of References

Messrs. Flucker and Sharp claim that the information reported in Reference 15 "Measurement of Pretension in Field Installed High-Strength Bolts" is invalid because the bolts were trapped when installed. They also claim the reference is an unpublished oral presentation. They include an additional reference "So You Think Your Bolts 'Sound' Tight?" published October 1992 in *Fastener Technology International*.

Reference 15 was presented at the 72nd Annual TRB meetings and was available in written form from the authors. The paper will be published in ASCE's *Journal of Bridge Engineering*, Vol. 1, August 1996.[5] Whatever conversation the J&M Turner representative had with the presenter at the TRB meetings as described in the discussion is not substantiated in the paper to be published. According to an author of the paper presented (Reference 15), the allegations of trapped bolts as described by Messrs. Flucker and Sharp are inaccurate as the conditions described in the discussion do not portray the actual conditions encountered at the site.

Reference 7, "So You Think Your Bolts 'Sound' Tight," does not provide any information on 1¼-in. A490 bolts. It clearly indicates both successful and unsuccessful applications of installing 1⅛-in. A490 bolts, but does not provide enough detail to be useful otherwise, in that it provides no details of the joints, etc. Also, as stated in the reference, the details of the installation procedure for the unsuccessful application are not known; thus one cannot conclude that the turn-of-nut method was actually employed. Regardless, this may certainly provide evidence that improperly pretensioned bolts exist in the field. An additional field study conducted by Kulak and Birkemoe[6] has recently been published. They investigated bolt pretension at a number of bridge and building sites. The study did not include any applications where A490 bolts greater than 1 inch diameter were used.

After the "After Word"

The authors emphatically deny the study was conducted to "make a case for turn-of-nut over DTIs." The Steel Institute of New York [SINY] graciously provided partial funding for the research, the ATLSS Engineering Research Center provided the remainder. SINY provided no input or suggestions regarding the procedures and methodology used for this study. The particular problem mentioned in the discussion which was a catalyst for funding such a research program, clearly indicates that the equipment was not adequate to compress the DTIs. This has nothing to do with the pretension in the bolts when the DTIs are compressed. Again, the objectives of the research were to determine the comparative effectiveness of tightening 1¼-in. diameter A490 bolts under adverse joint and bolt conditions.

The research was conducted from 1989 through 1991. An ATLSS report was published in 1992 and the paper submitted for publication in 1993. J&M Turner Inc. has been actively improving their DTI as described in the discussion, having redesigned the DTIs in 1994 as an attempt to reduce installation time. There has been no research using the new DTIs at the ATLSS Center. However, based on the data for both turn-of-nut and DTI methods, further study is recommended.

In conclusion, the authors feel there is little substance to the criticisms offered by Messrs. Sharp and Flucker. Some of the referenced material is inappropriate, many of the assertions are unjustified and their conclusions are unsubstantiated. The authors believe that the research reported is valid and adequately substantiated. The test procedure has been described to enable critical review of the data and conclusions presented in the paper. The authors certainly encourage critical review of all published data and further research effort with regard to pretension of these large diameter high strength bolts.

REFERENCES

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