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RESEARCH PROJECT TITLE

Investigation of High-Strength Bolt-Tightening Verification Techniques

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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tech transfer summary

The main function of bolted connections is to join structural members to safely transmit loads from one component to the other. As such, bolted connections are critical components of any steel structure.

Problem Statement

The current means and methods of verifying that high-strength bolts have been properly tightened are very laborious and time consuming. In some cases, the techniques require special equipment and, in other cases, the verification itself may be somewhat subjective. While some commercially available verification techniques do exist, these options still have some limitations and might be considered costly, time-consuming, and impractical to use in the field.

Background

The ability of a connection to transfer loads through the components relies heavily on whether the connection is properly installed. In a bolted connection, it is important to obtain an adequate initial clamping force and to ensure that the initial clamping force does not dissipate over time. Therefore, proper inspection of the connection and verification of the likely clamping force are needed to help ensure that such connections are capable of performing their functions safely.

Objective and Scope

The primary objective of this project was to explore the current state-of-practice and the state-of-the-art techniques for high-strength bolt tightening and verification in structural steel connections. This project was completed so that insight could be gained on available technologies that could lead to investigating the feasibility of developing and implementing new alternatives.

Research Description/Methodology

A literature search and a survey of state departments of transportation (DOTs) were conducted to collect information on various bolt-tightening techniques such that an understanding of available and under-development techniques could be obtained.

Because it is known that there are some bolt-tightening verification techniques used by other industries, the search effort was extended to fields outside of structural engineering so that an understanding of available and under-development techniques could be obtained. Also during the literature review, the requirements for materials, inspection, and installation methods outlined in the Research Council on Structural Connections (RCSC) specification were reviewed and summarized.

The set of online survey questions was created and disseminated via the Iowa DOT bridge engineer to his colleagues across the nation. The goals of this survey were to identify technologies currently in use by other states and to help guide the research and discover new techniques. The survey asked general questions about bolt tightening, common practices used, and whether respondents were considering any new alternatives or aware of any relevant technologies under development.

Finally, a number of people/organizations within Iowa State University (the Institute for Transportation, the Ames Laboratory, the Center for Nondestructive Evaluation, etc.), the Iowa DOT, the Iowa consulting engineering community, and the Iowa contractor community may have knowledge related to improving the state-of-the-practice with respect to bolt-tightening verification.

To facilitate discussion among these resources and other interested parties and guide the search for finding new alternatives and technology development, a working group meeting was held at the Institute for Transportation (InTrans) October 12, 2015. The main goals of the meeting were to identify existing bolt-tightening verification technologies including those not readily utilized and to brainstorm new means and methods (e.g., instruments with innovative metallurgical properties) that may provide viable options if additional research were to be conducted.

Summary of Working Group Discussion

The demand is high for a device that can be used to determine the stress within a bolt in the field. By determining the stress, it is possible to calculate the tension within the bolt. For example, in structural steel connections, any pretensioned joint requires that the bolt within the connection meets a specified pretension.

Currently, there are a few different ways to determine/estimate this stress. However, it seems that the accuracy of these determinations/estimations is the most challenging aspect of developing a device, especially in light of the variation in bolt sizes, types, and connection configurations.

The technique that seems to be the most likely candidate for further development would use ultrasound waves to measure the change in bolt length (using time-of-flight). Today, there are simple handheld products that utilize ultrasound waves for the purpose of bolt tightening and verification. The devices are small enough to be used in tight conditions in the field.

The downfall is the uncertainty in terms of accuracy for using them in a variety of situations, with bolts whose exact initial length is not known, and interpretation of results when “notable” amounts of stick-out is present. Thus, the devices currently on the market may be useful for approximate results (e.g., distinguishing that the pretension is significantly off from the desired value). However, for critical conditions where accuracy is needed with little to no error, the devices may fall short without further calibration.

In regards to developing new technology, consideration can be given to the possibility of employing magnetics. A positive aspect of this potential is the simplicity of creating a magnet and establishing a handheld device.

As with the other devices, however, the obstacles to overcome would be to ensure accuracy. Strict calibration standards would need to be designed so that the device can adjust to different metal types, bolt sizes and types, and connection configurations. Even with the obstacles in place, it is agreed that the potential is there along with the market demand.

Another potential concept that may warrant further investigation is to develop an enhanced system that measures the strain in the bolt. Such a concept might consist of the insertion of a wire into the middle of the bolt, which could be calibrated to measure the bolt strain and then used to estimate the stress and/or load in the stressed portion of the bolt.

Key Findings

The conclusions and discussion gleaned from the literature review, survey, and working group meeting, as well as the research team’s preliminary evaluation on select non-destructive evaluation (NDE) techniques follows:

- The survey and literature review showed that all methods recognized by the RCSC are currently being utilized although some are more popular than others. The nationwide survey revealed that the most frequently used methods are turn-of-nut and DTI pretensionings. The use of tension-control bolts appears to be increasing. The Skidmore-Wilhelm tester appears to be the most commonly used device for wrench calibration.
- Reviewing the procedures for bolt installation in fields outside of structural engineering revealed that the same methods (i.e., turn-of-nut, calibrated wrench, direct-tension indicators/DTIs, and tension-control bolts) are often used by other industries.
- While the torque control method offers relatively easy tightening control and operation, its high sensitivity to the friction properties of an assembly may limit the reliability of this method in critical applications. The angle control method offers more consistent pretension that is less affected by friction. However, care needs to be taken during the installation process to minimize the possibility of over tightening. The use of bolt heaters does not appear to be practical in steel construction, as it may alter the mechanical properties of the adjacent components. In addition, it requires a higher level of operator awareness, as well as time to allow the bolt to properly cool.
- Among some of the installation methods used in other industries, the use of a hydraulic tensioner appears to provide relatively better accuracy over other methods. This is due to the fact that the tension developed in a fastener is directly related to its change in length. However, the use of this method is limited when the position of the connection does not allow for a hydraulic tensioner to be utilized because of its size and also the need for a pressure source.

- A micrometer or a caliper can be useful for direct measurement of bolt elongation. However, this may not be suitable for civil engineering applications given that, in many instances, the bolt elongation is very small and difficult to measure and also that both sides of the bolt may not be accessible.
- In most piezoelectric impedance methods, a damage index can be used to assess the degree of tightness or looseness of bolts. However, it appears very difficult to quantitatively determine the bolt stress using this method.
- Use of a standard resistance strain gauge or piezo-resistive-type sensor embedded or mounted to a bolt allows an effective measurement of bolt strain. Instrumenting the sensor to the body of a bolt seems challenging. Some commercially available products (e.g., smart sensor, smart bolt) have been used by other industries.
- Although fiber-optic sensors (e.g., fiber Bragg gratings/ FBGs) have been frequently used in structural health monitoring applications, the use of FBGs for bolted connections is rarely reported. Because of their advantages, including proven accuracy in other applications and electromagnetic immunity, fiber-optic sensing technologies appear to have some measure of potential to be used for real-time monitoring of bolt tension, especially when high electromagnetic interference is expected in the field. The multiplexing capability of FBGs is another advantage if a large number of bolts need to be monitored simultaneously.
- Ultrasonic NDE techniques appear to be one of the most accepted methods used for pretension verification purposes. These techniques allow for investigating the clamping force during and after bolt tightening. Some studies showed that the concurrent use of longitudinal and transverse waves in principle provides a better solution to determine the stress of bolts without disassembling the joint. However, the general concept currently used to describe the bolt stress as a function of the time delays of ultrasonic waves may need further refinement (e.g., using second order equations) to increase the accuracy.

Implementation Readiness

While some tools and methods are available that can be used to verify the tension developed in a bolted connection, it appears as though many of them are still research-based and that the accuracy of the methods identified during the literature review has not been fully validated. Therefore, further research is recommended.

Future Research Recommendations

There is merit to seeking an improved methodology within the area of automated, refined data analysis and sensor improvements. Future research efforts may be needed toward more in-depth investigation of the most useful NDE techniques followed by development of a new alternative that can be used for verifying bolt tightening with proven accuracy.

Examples of such techniques would be ultrasonic-based techniques and strain-based or piezo-resistive-based methods, as these technologies seem to possess positive characteristics including inherent cost-effectiveness and simplicity.

The research team recommends that these technologies be validated through rigorous experiments and augmented with refined analytic approaches. The future research should include a full demonstration of the method, definition of performance limitations, and engineering parameters such as features and component size, orientation, accessibility, and operating limits.

An emphasis should be placed on improved verification reliability, cost-effective validation, and transferability to a range of applications. In addition, the future research program should explore and apply new engineering approaches to develop quantitative inspection and verification techniques that are much faster, less costly, and that result in a newly developed or improved technology that is more flexible and easily managed in treating the diversity of the issues associated with bolted connections.

Implementation Benefits

Once complete, the new alternative would result in the installation of safer and more reliable connections. It would serve as a pivotal technology in the efficient management of the Iowa DOT's transportation assets.