Article: Fatigue Behaviour of Welded Shear Studs in Steel-Concrete Composite Bridges

Authors: Spencer Arbuckle*; Matthew Sjaarda, PhD#; Prof. Scott Walbridge*, PhD

* University of Waterloo

École polytechnique fédérale de Lausanne

Text:

Steel-concrete composite systems are commonly employed in small-to-medium span highway bridges due to their many advantages, including cost effectiveness and ease of erection, among others. In order for this system to achieve its full potential, the two materials must be utilized efficiently and composite action must be exploited, i.e. the two elements must act in unison to obtain a higher overall moment of inertia and increased stiffness. Therefore, the connection between the two elements is a critical component of the system, as it is an essential component to resist the longitudinal shear forces acting across their interface and minimize interfacial slip. The current industry standard for this shear connection is the welded stud. The simplicity of the in-situ stud welding, paired with the associated material and labour cost savings, make the welded stud an attractive solution. However, the inherent defects induced from the welding process, combined with the cyclic nature of the typical live loads on highway bridges, results in fatigue performance being a chief design consideration.

The current design procedure for welded shear studs in Canada is the same as other fatigue details. However, studs are fundamentally different from most other fatigue details sharing the same design process. Each stud is uninspectable and part of the redundant set of studs, which together resist force and slip along the shear interface. It follows that shear studs should perhaps have a different level of reliability than other fatigue details, and that they should perhaps be treated differently in design. Evidence of the uniqueness of the stud detail is the process through which it was assigned its fatigue category in the first place. Most fatigue details receive their category by being tested, and finding a “characteristic” fatigue curve corresponding with a 97.7% survivable probability. Shear studs, however, receive their category from the mean (50%) curve from tests called “push tests”, which are said to conservatively approximate the actual behaviour of studs in beams. A recent large-scale beam testing program at Waterloo (see Figure 1(a)) showed that studs in beams tested in flexure undergo lower stresses and therefore can endure more cycles, rather than direct shear push-tests which do not include the same contribution of friction and stress redistribution between several studs. Following this extensive testing program, there was still a need to complete testing in the high-cycle fatigue life range, since beam tests do not lend themselves well to high frequency, long-life testing.

The design of the shear connection of most highway bridges is almost always governed by fatigue, due to the high number of cycles they must be designed to withstand. Despite this fact, there remains a significant lack of laboratory test data in the high cycle (long life) domain. The fatigue limit was increased in the recent edition of the bridge code (CSA S6-19) due to a review of the existing fatigue test data and past experience (CSA S6.1-19). However, there remains a need for a considerable amount of further testing in the high cycle domain to validate this revision or propose a more appropriate change. The current fatigue limit (also referred to as an ‘endurance’ limit) results in the shear connection of many composite bridges being over designed, as the push test results the curve is based on do not include high-cycle fatigue data. Following the completion of the extensive full-scale steel-concrete composite beam fatigue testing program at the University of Waterloo, the goal of the present study is to develop a simple small-scale shear stud testing apparatus to investigate the fatigue behaviour in the very long life domain in a cost and time effective manner, in comparison to traditional push and beam tests. A direct-shear specimen (see Figure 1(b)), composed of a steel plate with a machined radius contacting an individual stud welded to a steel plate, has been refined and utilized for ~20 intermediate-life constant-amplitude fatigue tests for two stud diameters (7/8" and 1"). Overall, the test results to date exhibit evidence of reasonably good testing procedure repeatability (see Figure 2). However, the small-scale data generally falls below the beam test data from a previous Waterloo study. This can be explained by differences in the stud loading for the two different test types. One way to resolve this difference, which will be explored in the next steps of this project will be to use finite element (FE) analysis as a tool to understand these differences and – if possible – collapse the test data onto a single curve. Future testing plans also involve long life testing under simulated in-service variable amplitude loading conditions and investigating the effect of stud repair by conventional arc welding.

In support of this research effort, the Ontario Ministry of Transportation (MTO) recently installed strain gauges on several studs during the reconstruction of a rural Ontario highway bridge (see Figure 3). A load test was carried out after construction of the composite bridge was completed. Prior to this test, strain gauges were installed on the welded studs and steel bridge girder at several cross sections of one of the girders along the span. The data obtained from this test will provide a glimpse into the behaviour of shear studs subjected to in-service loading on an actual bridge. The effects of load reversals, the dynamic load allowance, and friction between the slab and the girder will be investigated using this field data. Again, it is planned to us FE analysis to consider these effects on the stud loading, so their influence on the fatigue performance of welded studs in service can be characterized.

The ultimate goal of this CISC-supported research project will be to obtain a better understanding of the fatigue reliability of steel-concrete highway bridges fabricated using welded shear studs. It is hoped that this knowledge will justify a reduction in the number of studs required in these bridges, which will improve the economy of new bridge designs and enable the more accurate assessment of existing structures.

References:

[1] CSA (Canadian Standards Association). (2019). Canadian highway bridge design code. CAN/CSA-S6-19.

Figure 1 – Large-scale beam and small-scale single stud fatigue test setups.

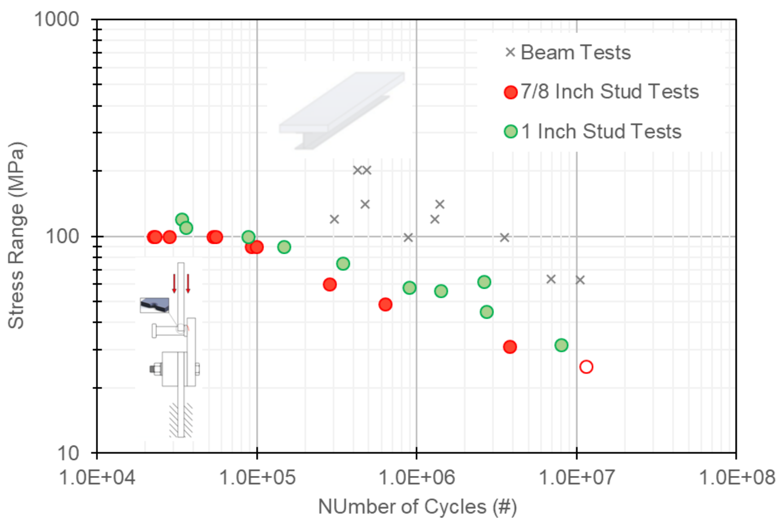

Figure 2 – Fatigue test results to date.

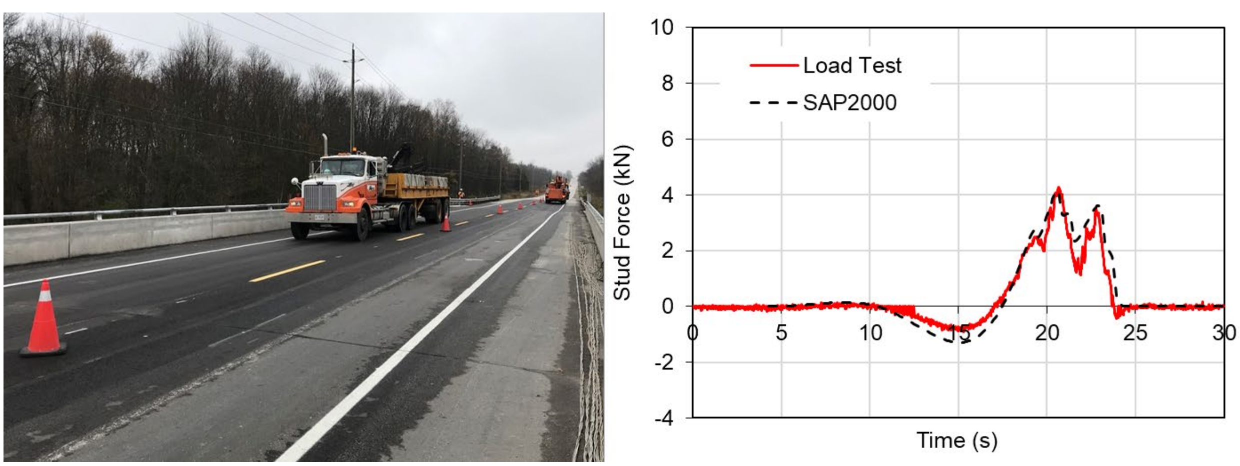

Figure 3 – Load test on highway bridge in rural Ontario.