Response to October 2020 STRUCTURE Article

By Jason B. Lloyd, Ph.D., P.E., Robert J. Connor, Ph.D., P.E., and Karl H. Frank, Ph.D., P.E.

The October 2020 STRUCTURE article, *Coating Preparations Reduce the Strength of Bridges*, presents information and opinions on potential problems with the fatigue resistance of steel bridges prepared for coatings using grit blast cleaning methods. Some of the information in this article is misleading with unsubstantiated claims regarding the safety of existing and future steel bridges. These topics are addressed below.

Blast cleaning has been used in the coating process of steel bridges for decades. Shot and grit blasting techniques are approved cleaning methods used in fabrication shops, as well as field painting for new and existing bridges. The most common media used is a shot/grit mixture. The blast cleaning processes are regulated by state department of transportation specifications for bridge design or rehabilitation projects. These generally are consistent with the AASHTO *LRFD Bridge Construction Specifications* where it states in article 13.2.3.1 that blast cleaning "shall leave all surfaces with a dense and uniform anchor pattern of not less than 1 mil or more than 3 mils, as measured with an approved surface profile comparator" (AASHTO, 2017). The methods for removal of foreign material for surface preparation for liquid coatings generally also conforms to either the SSPC-SP 6 or SSPC-SP 10 preparation specifications with additional guidance provided by AASHTO/NSBA Steel Bridge Collaboration S8.1 (2014). Surface preparations for thermal spray coatings are performed in accordance with SSPC-CS 23.00/AWS C2.23/NASCE No.12, as well as additional guidance provided by AASHTO/NSBA Steel Bridge Collaboration S8.2 (2017), specifying a surface roughness between 2.5 and 5 mils.

Example large-scale fatigue test of steel bridge girders (Hebdon et al., 2017).

The opinions in the October 2020 article are based on the misapplication of the work by Padilla, Velasquez, Berrios, and Puchi Cabrera of the University of Venezuela, which was published in 2002. The cited research is thorough and adept with an important field of application listed as dynamic components of helicopters. We do not take issue with the research; however, we fully disagree with applying those results to steel bridge fatigue life design and safety.

The research by Padilla et al. (2002) included the comparison of fatigue life of rotating-beam specimens having three different surface conditions; mechanically polished (described as "mirror-like"), grit blasted, and grit blasted with hard facing thermal spray coating. The specimens were made from SAE 4140 steel (which is not a structural steel used in bridges) with a measured yield strength reported as approximately 127 ksi. The specimens were tested in a rotating beam apparatus and were subjected to reversed bending at very high stress levels. This type of fatigue testing is sensitive to surface condition effects and yield strength. Thus, it would be sensible for a researcher to choose these relatively quick and affordable tests when wanting to observe the influence of different surface conditions on fatigue life for a particular base material. The rotating beam tests were performed at high stress ranges, including approximately 69, 74, 79, and 84 ksi (54, 58, 62, and 66% of the yield strength, respectively). The elevated stress ranges accelerate the fatigue testing and help amplify the influence of minor surface condition parameters. The reduction in fatigue life caused by the grit blasting relative to the polished surface is expected and an important consideration for machined components.

The October 2020 article stated that grit blasting "significantly degrades the strength of steel bridges, endangering safe design." This statement is based upon the reduction in the rotating beam specimens relative to a <u>mirror-like</u> surface observed by Padilla et al. However, the mirror-like surface commonly used in rotating beams tests is vastly different than the as-fabricated and as-rolled surface conditions of steel used in highway and railway bridges. The fatigue design requirements in the AASHTO specifications are based upon full-scale girder tests with as-received mill scale surfaces (see *Figure*), as well as bolted connection tests with blasted and blasted-then-coated surfaces (Fisher et al., 1983; Fisher et al., 1974; Fisher et al., 1970; Brown et al., 2007; Frank and Yura, 1981). The research is conclusive; fatigue resistance of all steel bridges is governed by welded or bolted connection details, not by minor surface conditions. This is particularly true at the low effective fatigue stress ranges experienced by in-service steel bridges, which, based on extensive field testing experience of the authors, is typically only about 4 to 8% of the steel yield strength. Furthermore, the fatigue life of the rotating beam tests, performed by Padilla et al., greatly exceeded the fatigue life of steel bridge welded connection details that are used throughout the United States.

Extensive fatigue studies of bolted connections with blasted and blasted-then-painted surfaces have been performed (Brown et al., 2007; Frank and Yura, 1981). These studies showed that the coated specimens had a slightly higher fatigue resistance due to the reduction in fretting caused by slippage of the connection. The uncoated blasted surface fatigue life equaled or exceeded the Category B fatigue design strength for bolted connections. These large-sized bolted connections, which included both weathering and non-weathering steel and realistic surface preparations, confirmed the adequacy of the AASHTO specifications.

It must be kept in mind that the current AASHTO fatigue design specifications are derived from experimental data representing the 95 percent confidence limit for an approximate 97.5 percent survival for each detail type. Extensive fatigue data was accumulated over many years of testing to develop the AASHTO categories. The fatigue design curves statistically correspond, therefore, to the shortest lives experimentally observed for each category, which, of course, would have been governed by the most severe discontinuity. What resulted are AASHTO fatigue design curves representing the detail with the most severe discontinuity and predicting, with high statistical confidence, that it will survive the desired service life. This also means that a substantial majority of details in a given category will have longer fatigue lives than predicted by a design curve.

There is an extensive experimental database that was used to develop the AASHTO fatigue design provisions, which are based upon large-scale test specimens having surface conditions, constraints, residual stresses, random flaw distributions, and welding procedures used for actual bridges. An extrapolation of rotating-beam fatigue test data for surface roughening to the fatigue behavior of some industries may be acceptable, but it is inappropriate for fabricated steel bridges. Likewise, a claim that bridge designs are "in jeopardy" due to fatigue is egregious. The claimed reduction in fatigue strength has not been found in large-scale fatigue tests of bridge components nor in the observed excellent in-service fatigue performance of steel bridges over the past 45 years.▪

References are included in the PDF version of the article at **STRUCTUREmag.org**.

Jason B. Lloyd is a Bridge Steel Specialist with the National Steel Bridge Alliance.

Robert J. Connor is the Jack and Kay Hockema Professor in Civil Engineering and the Director of the Center for Aging Infrastructure and S-BRITE Center at Purdue University.

Karl H. Frank is a Professor Emeritus at The University of Texas at Austin, the Chief Engineer at Hirschfeld Industries, Ret., and a Consultant.

References

AASHTO (2017). *LRFD Bridge Construction Specifications*, 4th Edition. American Association of State Highway & Transportation Officials. Washington, DC.

AASHTO/NSBA Steel Bridge Collaboration. (2017). *S8.2 Specification for Application of Thermal Spray Coating Systems to Steel Bridges*. Available online: **https://store.transportation.org/Item/PublicationDetail?ID=3910**

AASHTO/NSBA Steel Bridge Collaboration. (2014). *S8.1 Guide Specification for Application of Coating Systems*. Available online: **https://store.transportation.org/item/publicationdetail/2355**

Barsom, J. M. (1981). *Fatigue Considerations for Steel Bridges*. Fatigue Crack Growth Measurement and Data Analysis, ASTM STP 738, S. J. Hudak, Jr., and R. J. Bucci, Eds., American Society for Testing and Materials, pp. 300-318.

Brown, J. D., Lubitz, D. J., Cekov, Y. C., and Frank, K. H. (2007). *Evaluation of Influence of Hole Making Upon the Performance of Structural Steel Plates and Connections*. Report No. FHWA/TX-07/0-4624-1. University of Texas at Austin. Austin, TX.

Fisher, J. W., Mertz, D. R, and Zhong, A. (1983). *Steel Bridge Members under Constant Amplitude Fatigue Loading*. NCHRP Report 267. Transportation Research Board. Washington, DC.

Fisher, J. W., Albrecht, P.A., Yen, B. T., Klingerman, D. J., and McNamee, B. M. (1974). *Fatigue Strength of Steel Beam with Welded Stiffeners and Attachments*. NCHRP Report 147. Transportation Research Board. Washington, DC.

Fisher, J. W., Frank, K. H., Hirt, M. A., and McNamee, B. M. (1970). *Effect of Weldments on the Fatigue Strength of Steel Beams*. NCHRP Report 102. Transportation Research Board. Washington, DC.

Frank, K.H., and Yura, J.A. (1981). *An Experimental Study of Bolted Shear Connections,* Report No. FHWA RD-81/148, University of Texas at Austin, Austin, TX.

Hebdon, M. H, Bonachera Martin, F. J., Korkmas, C., and Connor, R. J. (2017). *Load Redistribution and Remaining Fatigue Life of Steel Built-up Members Subjected to Flexure Following a Component Failure*. Journal of Bridge Engineering, ASCE. DOI: 10.1061/(ASCE)BE.1943-5592.0001087.

Padilla, K., Velasquez, A., Berrios, J. A., and Puchi Cabrera, E. S. (2002). *Fatigue Behavior of a 4140 Steel Coated with A NiMoAl Deposit Applied by HVOF Thermal Spray*. Elsevier Press, Vol. 150, pp. 151-162. Amsterdam, Netherlands.