Structural Identification and Fatigue Assessements of the Aarwangen Bridge Using Load-Test Data

Romain Pasquier[1] and Ian F.C. Smith[1]

[1] *Applied Computing and Mechanics Laboratory (IMAC), School of Architecture, Civil and Environmental Engineering (ENAC), Swiss Federal Institute of Technology (EPFL), CH-1015 Lausanne, Switzerland,*
rpasquie@gmail.com, ian.smith@epfl.ch

ABSTRACT: A composite bridge is measured under static-load tests and data are used to identify the behavior of the structure through physics-based models. A model-falsification approach is used to discard model instances that are not compatible with measured data. The candidate models that are identified are then used to improve fatigue assessments of critical joints through two complementary population-based prognosis methodologies. Since model falsification allows robust identification in the presence of systematic modeling errors [1], extrapolations of remaining-fatigue-life estimations from candidate models are possible [2].

Test Structure and Measured Data

The Aarwangen Bridge is a composite-steel-concrete bridge over the Aar River and located in Switzerland. The bridge has two spans of 47.8 m with welded tubular steel trusses connected in a composite manner to the concrete deck that is 8.3 m wide. The cross-section of the finite-element (FE) model and the bridge general overview are displayed in Figure 1. This bridge carries the bidirectional traffic with two lanes (west and east) of a main road. On average, 2’572 trucks with an average weight of 18 tons cross the bridge in both directions every week.

Figure 1: Finite-element model cross-section (left, reprinted with permission from ASCE [3]) and general overview (right)[1].

The static load tests involve two trucks positioned according to three different configurations as shown in Figure 2. Deformations were monitored using 18 strain gages placed on truss members at different locations (see Figure 2).

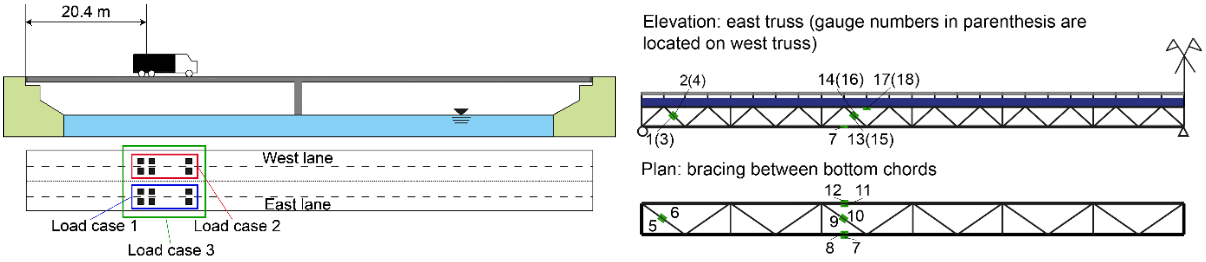

Figure 2: Static-load-test configurations (left) and strain-gage locations (right). Reprinted with permission from ASCE [3].

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[1] The bridge picture has been adapted from http://www.muniberg.ch.

Bridge drawings, test results and monitoring data were provided by ICOM (Steel Structures Laboratory), EPFL. Ansys APDL implementations are available on http://imac.epfl.ch > Research > Thesis > Appendix.

SHM Methodology and Results

The purpose of this case study is to improve the fatigue reserve-capacity estimation of two K-joint connections (four welded joints overall) of the truss as shown in Figure 3 using information provided by measurements.

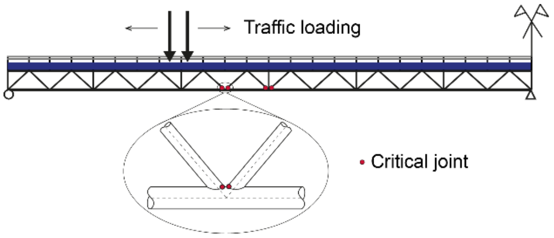

Figure 3: Critical joints that are evaluated. Adapted from Pasquier et al. [4].

The data obtained from the three static-load tests are used to identify the values of six unknown physical parameters of the FE model including material Young's moduli and connection stiffnesses. The structural-identification technique that is used is error-domain model falsification (EDMF) [1]. An initial population of 15'625 model instances is generated through sampling values of the six parameters and model instances that are incompatible with measurements are falsified. Probabilistic threshold bounds that are determined based on estimations of the modeling and measurement uncertainties are used to discard inadequate model instances.

Using seven strain measurements (#1, 2, 3, 13, 15, 17, 18) and three load cases, 15'556 model instances are falsified leading to a population of 69 candidate models. These seven measurements are at locations that are the most sensitive to changes in parameter values.

Two complementary population-based fatigue prognosis approaches are proposed that improve fatigue assessments of such structures. The first approach uses the 69 candidate models to predict maximum stress ranges based on a constant axle-loading traffic and nominal stress method from codes [3]. Then, stress-ranges are compared with S-N curves from codes in order to derive the remaining-fatigue-life predictions. In the second approach, the 69 candidate models are used to predict variable hot-spot stresses at the weld toe of the critical joints under a probabilistic traffic-load model [4]. First, a reference axle loading is used to compute the influence lines of chord and brace internal forces for the two K-joints. Then, the damage index is determined through a Monte-Carlo analysis over candidate-model samples using traffic simulations for computing internal-force spectra, nominal-stress spectra, hot-spot stress spectrum, rainflow analysis and S_{rhs}-N curve comparison. Finally, from the damage index, the distribution of remaining-fatigue-life predictions is evaluated.

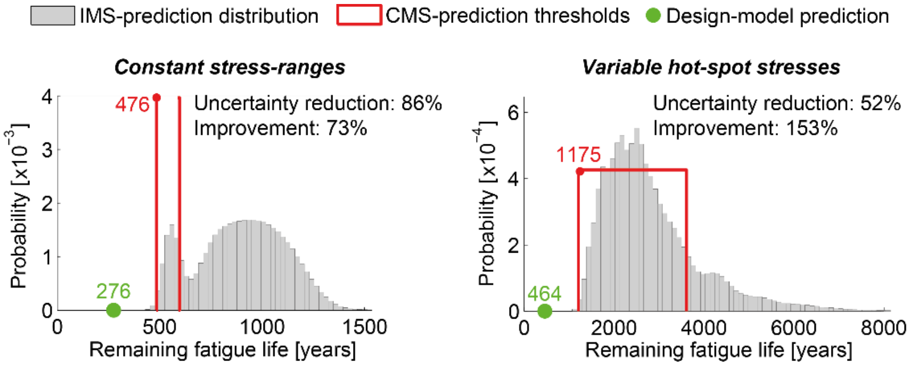

Figure 4: Comparison of remaining-fatigue-life predictions with the initial model set (IMS), the candidate model set (CMS) and a design model for a single critical joint using the constant stress-range [3] and the variable hot-spot stress approach [4].

Figure 4 presents the remaining-fatigue-life predictions that are obtained using both population-based prognosis methodologies for a single critical joints. This figure compares predictions made with the initial population of model instances (prior to having measurements), the candidate model set (including data interpretation) and a design model.

For both approaches, it reveals a great reduction of uncertainty between estimations made prior and posterior to interpreting measurements. This figure presents also a great improvement of estimations between CMS-prediction lower bound values and design-model predictions.

Although the variable hot-spot stress approach improves the fatigue evaluations further compared with the constant stress-range approach (more than two times), it should be noted that this difference depends on the detail category that is used in the nominal stress method. For example, the nominal stress method has shown to be non-conservative for tubular hollow sections such as the ones composing the Aarwangen Bridge and this leads to an over-conservative fatigue category (71).

Lessons Learned

A challenge of the application of EDMF for the Aarwangen Bridge is the selection of an appropriate measurement set. Using measurements at locations that are not sensitive to the parameters is inefficient in the falsification process. In addition, for effective use of the model falsification approach, outliers need to be removed. In order to ensure the robustness of diagnosis, it is verified that a single measurement is not responsible for discarding more than 90% of the initial model instances. Among the 11 strain gages that are not used, four are not functioning properly (#9, 10, 12, 14) and seven are redundant measurements (#4, 5, 6, 7, 8, 11, 16). These redundant measurements are not sensitive to changes in the parameter values. However, they confirm compatibility of the candidate-model predictions with observations.

Several model-falsification iterations are needed to focus on a set of seven measurements. More generally, for the identification of complex structures, the task of model-class building and uncertainty qualification and estimation result from several iterations combining data interpretation and engineering heuristics [5] that are necessary to gradually increase knowledge of the structural behavior.

Acknowledgements

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References

[1] J.-A. Goulet, I. F.C. Smith, *Structural identification with systematic errors and unknown uncertainty dependencies*, Computers & Structures, 128 (2013) 251-258.

[2] R. Pasquier, I. F.C. Smith, *Robust system identification and model predictions in the presence of systematic uncertainty*, Advanced Engineering Informatics, (2015), in press. doi: 10.1016/j.aei.2015.07.007

[3] R. Pasquier, J.-A. Goulet, C. Acevedo, I. F.C. Smith, *Improving fatigue evaluations of structures using in-service behavior measurement data*, J. of Bridge Engineering, 19 (2014) 04014045.

[4] R. Pasquier, L. D'Angelo, J.-A. Goulet, C. Acevedo, A. Nussbaumer, I. F.C. Smith, *Measurement, data interpretation, and uncertainty propagation for fatigue assessments of structures*, J. of Bridge Engineering, (2015), in press.

[5] R. Pasquier, I. F.C. Smith, *Iterative structural identification framework for evaluation of existing structures*, Engineering Structures, 106 (2016), 179-194. doi: 10.1016/j.engstruct.2015.09.039