Fatigue Damage Estimation of Large Scale Structural Systems using Finite Element Model Updating Techniques and Output Vibration Measurements

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Abstract

The main objective of this work is to present a model-based fatigue damage estimation framework for structural systems by integrating operational vibration measurements in a high fidelity, large-scale, finite element model and applying a fatigue damage accumulation methodology. Output only vibration measurements have been increasingly used to detect changes in a mechanical system's behavior and to determine damage accumulation. Predictions of fatigue damage accumulation at a point of a structure can be estimated using available damage accumulation models that analyze the actual stress time histories developed during operation [1, 2, 3, 4]. The continuous tracking and processing of the vibration-induced response data for damage detection in structural systems, is known as structural health monitoring, which comprises methods relying on raw signal processing, such as mean, spectral densities, root-mean-square evaluation; these present shortcomings in terms of early damage detection and are further not suited for damage localization and root cause analysis. Model-based methods for structural health monitoring incorporate a numerical model of the mechanical or structural system, typically of the Finite Element type, that can integrate and reproduce ultimate limit states and failure modes. To proceed with fatigue predictions, one has to infer the stress response time histories characteristics based on the monitoring information contained in vibration measurements collected from a limited number of sensors attached to a structure [5, 6, 7]. Predictions, like the existence, the location, the time and the extent of the damage are possible if one combines the information in the measurements with information obtained from a high-fidelity FE model of the structure [8]. Such a model may be optimized with respect to the data, using state of the art FE model updating techniques and Uncertainty Quantification and Propagation (UQ&P) methods. These methods provide much more comprehensive information about the condition of the monitored system than the analysis of raw data [9, 10]. The diagnosed degradation state, along with its identified uncertainties, can be incorporated into robust reliability tools for updating predictions of the residual useful lifetime of structural components and safety against various failure modes taking into account stochastic models of future loading characteristics [11].

The proposed method is applied in a steel frame of a real city bus (Figures 1 and 2). A FE model of the frame is developed and updated to match the dynamic characteristics measured in real operating conditions. This is achieved through coupled use of numerical [12, 13] and experimental methods for identifying, updating and optimizing a high fidelity FE model. The full stress time histories of the bus frame are estimated, at critical locations, by imposing operational vibration measurements from a limited number of sensors in the updated FE model. Fatigue damage and remaining lifetime is subsequently estimated via commonly adopted engineering approaches, such as the Palmgren-Miner damage rule, S-N curves, and rainflow cycle counting. Incorporation of a numerical model of the structure in the response

estimation procedure, permits stress estimation at unmeasured locations, thereby enabling the drawing of a complete and substantially dense fatigue map consistent with the vibration measurements [14]. Fatigue predictions via the proposed framework compare favourably to experimental fatigue results, - proving the efficiency and applicability of the framework.

Keywords: **FE Model Updating, Strain and Fatigue Predictions, System Identification, Output-Only Measurements**

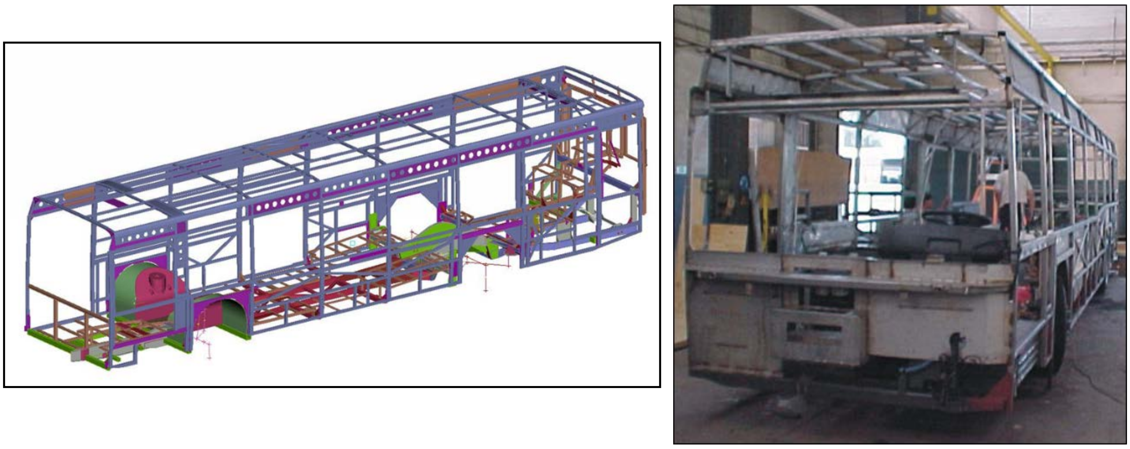

Figure 1: Finite Element Model of the Bus Frame; Real Bus.

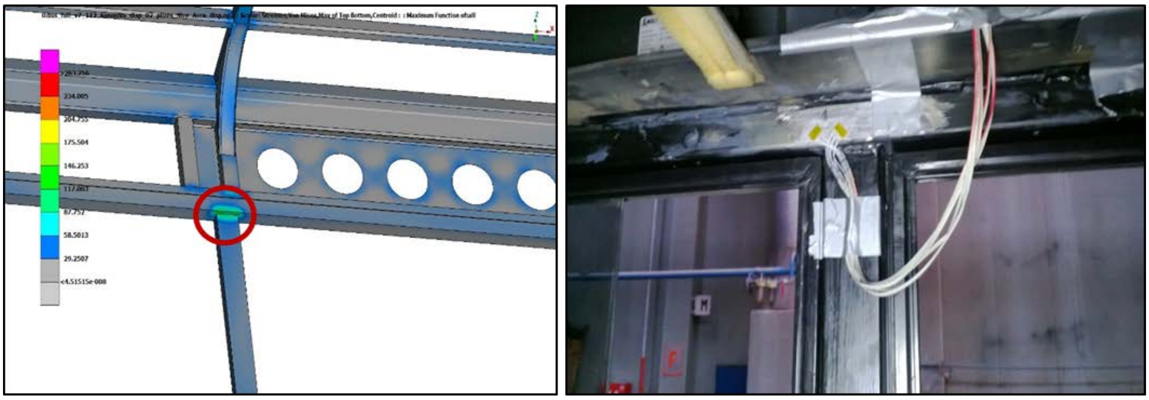

Figure 2: Estimated Critical Location.

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