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REFINING FINITE ELEMENT MODEL OF CONCRETE VIADUCT WITH ERROR-DOMAIN MODEL FALSIFICATION TECHNIQUE USING VIBRATION AND STRAIN DATA

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Abstract

This study employs acceleration and strain-based finite element model updating (FEMU) techniques on a half-century-old multi-span concrete highway viaduct. While most FEMU studies on bridges rely only on acceleration data due to lower costs and ease of implementation, this research incorporates strain measurements taken at mid-span under truck passages, in addition to frequencies and mode shapes from acceleration data. The analyses were conducted separately for acceleration data (natural frequencies and mode shapes), strain data and a combination of acceleration and strain data. Three variables representing Young's modulus adjustment factors for different structural elements were updated. The intuitive error-domain model falsification (EDMF) proved itself over traditional FEMU techniques, such as residual minimisation, as it allows the incorporation of acceleration and strain data without the need to specify the weights for each of them. Furthermore, once an additional source of data (strains) is added, the information gained becomes clearly visible, and the results of the FEMU are more sensible from an engineering perspective. This confirms the necessity of having data from various sources for a quality FEMU. The results showed an overestimation of the internal main girders' design stiffness, ranging from 25-50%.

Keywords: viaduct, bridge, finite element model updating (FEMU), error-domain model falsification (EDMF), structural health monitoring (SHM)

1 Introduction

Ageing infrastructure and growing loads emphasise the importance of preventive maintenance and inspections, both visually and via Structural Health Monitoring (SHM). In SHM, several strategies for finite element model updating (FEMU) are used, depending on static and dynamic responses. An extensive overview of the methods used for FEMU and damage detection can be found in [1] and [2].

Error-domain model falsification (EDMF) is a methodology for structural identification that has been gaining popularity in recent years. It follows the concept that in science, models cannot be fully validated by data; instead, they can only be falsified. Its most significant added value in this paper is the integration of experimental data from multiple sources, i.e. from the vibrations measured on the deck and from heavy vehicle-induced strains at mid-spans of the girders, which significantly reduces the range of the updated variables.

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2 Measurements and finite element (FE) model

The over 50-year-old case study viaduct is located in the Southwestern part of Slovenia. It comprises a 16-span precast I girder-type deck with an overall length of 560 m. One breaking unit, which is approximately ¼ of the entire viaduct, was considered (Figure 1).

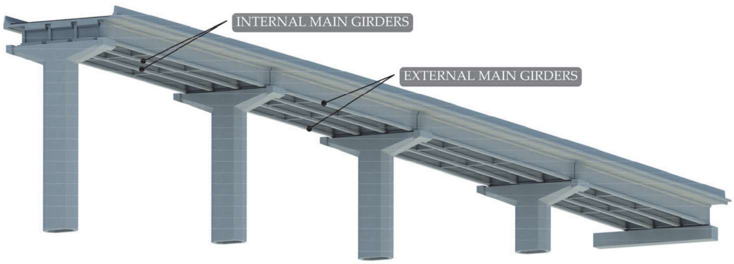

Figure 1 Finite element (FE) model of the viaduct

The viaduct was modelled in the Abaqus FE analysis software [3] using 0.50 m hexahedral 20-node quadratic (C3D20R) elements for the deck and 10-node quadratic tetrahedral elements for the substructure. Abaqus - Python scripting was developed to prepare FE models with different variable values. EDMF followed the general principles from [4] and [5].
Two sources of experimental data were used in this study. The first considered modal parameters (natural frequencies and mode shapes) from the ambient and traffic-induced vibrations (denoted as B-1, B-2, MG_B-1 and B-3 in the following). 10 accelerometers in 4 setups (40 measurement points overall) were used for this experimental campaign. The second data source considered the maximum strains caused by three different trucks driving on the driving lane and measured by the strain gauge sensors at the mid-span of internal (IMG) and external main girders (EMG) (one sensor per girder, four sensors per span). A detailed description of the latter test can be found in [6].

3 Error-domain model falsification (EDMF) results

Figure 2 shows the acceleration-based EDMF results. 4000 grey lines are shown, each line representing values of the inputs, i.e. Young's modulus adjustment factors (α_{EMG}, α_{IMG} and α_{OTHER}) for external main girders, internal main girders and all other elements and the outputs: frequencies (f_{B-1}, f_{B-2}, f_{MG_B-1}, f_{B-3}) and modal assurance criterion (MAC) values (MAC_{B-1}, MAC_{B-2}, MAC_{MG_B-1}, MAC_{B-3}). Each line belongs to one FE model.

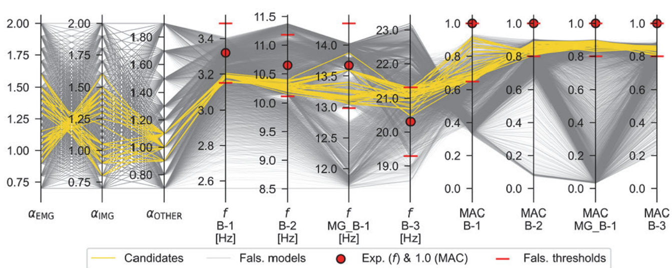

Figure 2 Acceleration-based EDMF results

Out of 4000 FE models, 35 (candidate model sets) fall within the provided thresholds for frequencies and MACs, which are shown with red ticks in Figure 2, and are defined as the ± 5 % deviation of the measured frequencies and MACs higher than 0.65 (B-1) and 0.8 (other modes).
Results of the EDMF for acceleration, strain and acceleration & strain-based results are shown in Table 1. EDMF results of the latter are graphically shown in Figure 3.

Table 1 EDMF results: ranges of the variables before and after EDMF

Variable	Initial range	Range after EDMF		
		Acc.-based	**Strain-based**	**Acc. & Strain-based**
	n = 4000	**n = 35**	**n = 199**	**n = 7**
α_{EMG}	[0.70, 2.00]	[0.90, 1.60]	[0.40, 1.20]	[0.90, 1.10]
α_{IMG}	[0.70, 2.00]	[0.80, 1.60]	[1.05, 2.00]	[1.25, 1.50]
α_{OTHER}	[0.70, 1.90]	[0.90, 1.10]	[0.30, 1.90]	[1.00, 1.10]

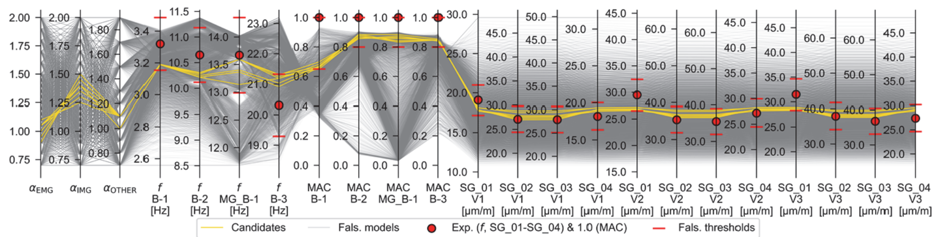

Figure 3 Acceleration and strain-based EDMF results

Table 1 shows that despite the small number of candidate model sets (indicated as “n”), the ranges of variables for acceleration-based and strain-based FEMU remain large. However, when combining acceleration and strain data, the range narrows significantly. Moreover, the candidate model sets with $\alpha_{EMG} > \alpha_{IMG}$, as suggested by acceleration-based EDMF, are dropped. Values $\alpha_{EMG} > \alpha_{IMG}$ are, due to the structural design, expected to be engineering non-sensible. Possible reasons for overestimation of the IMG’s stiffness are large amount of prestressing steel, increase of the Young’s elastic modulus with time and the fact that measurements were performed under dynamic excitation (traffic).

4 Conclusions

This study shows the EDMF’s intuitiveness and capability of combining different types of measurements within the FEMU, without having to decide which one to prioritise. After combining acceleration and strain data, the EDMF revealed the engineering-acceptable candidate model sets and narrowed the updated variable ranges in the FE model. Furthermore, the final candidate model set only contains engineering sensible variable ranges. Finally, the EDMF results overestimated the internal main girders’ design stiffness, ranging from 25-50%. The results of this study confirm the necessity of having data from various sources for a quality FEMU. Future work will investigate the EDMF for strains under different magnitudes of traffic loading and for updating the FE influence line based on the measured influence line from the bridge weigh-in-motion (B-WIM) system.

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