

GRADIENT-BASED OPTIMIZATION OF A STEEL FOOTBRIDGE UNDER STATIC AND DYNAMIC LOADING CONSIDERING DESIGN CODE REQUIREMENTS

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Abstract

Pedestrian bridges are often designed as slender structures because the static loads are relatively limited. Such slender bridges exhibit low natural frequencies, which can lead to excessive vibration levels when resonance occurs with walking pedestrians. Therefore, verifying vibration serviceability is an important part of the design process, and the bridge may need to be equipped with vibration-mitigation devices such as tuned mass dampers (TMDs). This study presents the size and shape optimization of a steel bridge serving as a case study that includes TMDs as part of its original design. The objective is to minimize the structural weight of the bridge by optimizing the cross-sections and damper parameters. Since a realistic case is optimized, an extensive finite element model is required to accurately evaluate the design checks under different load cases. Therefore, an efficient gradient-based optimization algorithm is adopted. The static design constraints are formulated according to the Eurocode, while the dynamic constraints follow the Sétra guideline for vibration serviceability. Because these design rules are not readily compatible with gradient-based optimization, smooth approximation functions are adopted. The optimization is performed using continuous design variables, after which the result is rounded to discrete values by exploring the design space around the continuous optimum, ensuring practical feasibility. To facilitate this procedure, a catalogue constraint is incorporated during the optimization, linking the variables that control corresponding cross-sections.

The bridge is first optimized under combined static and dynamic design criteria, both with and without the inclusion of TMDs for vibration control. The result without the use of TMDs is 9% and 22% heavier than the original bridge design, targeting a minimum and medium comfort level, respectively. With the use of TMDs, the weight can be significantly reduced by 36%. Subsequently, the bridge is optimized using static design rules only, followed by a manual TMD design consistent with the conventional design workflow. This design approach yields a similarly lightweight bridge as the combined optimization with TMDs, but since the TMD mass is not yet known during the static design, the resulting bridge is slightly more conservative.