Probabilistic Analysis for Design Assessment of Composite Girders

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Summary

Continuous steel-concrete composite girders are extensively used for the construction of short and medium span bridges. In the sagging regions, where the compressed flange of the steel beam is connected to the reinforced concrete slab, the cross sections generally belong to class 1 or class 2 (compact sections) and plastic design is acceptable. In the hogging regions the cross sections commonly belong to class 3 or class 4 (slender sections), thus there is insufficient ductility for plastic design and elastic verification is required. However, in this combined design approach that uses the cross section plastic resistance in the sagging regions and the elastic resistance in the hogging regions, the design must satisfy the condition that the plastic moment in the sagging region can develop while still leaving the bending moment resisted by the hogging regions sufficiently far from the elastic limit. The objective of this work is to assess this combined elastic-plastic design approach for continuous composite girders by using probabilistic nonlinear finite element analysis. The First-Order Second-Moment (FOSM) approximation is adopted to compute the first- and second-order statistical moments (means, variances and covariances) of structural response quantities. Deterministic and probabilistic results are illustrated and discussed by using a realistic three-span continuous steel-concrete composite bridge as benchmark problem.

Keywords: steel-concrete composite bridges; continuous decks; plastic design; safety format; probabilistic analysis; sensitivity analysis; nonlinear analysis; finite element method; partial interaction.

Abstract

The structural behaviour of steel-concrete composite (SCC) beams for buildings and bridges is influenced by a considerable number of parameters describing sagging and hogging sections, layout of spans and load patterns. In the sagging regions, where the compressed flange of the steel beam is connected to the reinforced concrete slab, the cross sections generally belong to class 1 or class 2 (compact sections) according to the Eurocodes and design bending resistance can be determined by rigid-plastic theory. In the hogging regions, the compressed portion of the steel beam is unrestrained by the concrete slab and more prone to buckling, the cross sections commonly belong to class 3 or class 4 (slender sections) and have insufficient ductility for plastic design, thus elastic analysis is generally adopted for calculating the design bending resistance. However, in this combined design approach that uses the cross section plastic resistance in the sagging regions and the elastic resistance in the hogging regions, the design must satisfy the condition that the sagging plastic moment can develop while the hogging bending moment is sufficiently far from the elastic limit. In order to verify that such condition is satisfied, nonlinear analysis can be used. Some prescriptions for nonlinear analysis are given in the Eurocodes where a safety format is illustrated and recommended.

In order to properly perform nonlinear analysis according to the prescriptions and safety format of Eurocodes, a sound and efficient numerical procedure is required. The finite element model for

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composite beams with deformable shear connection developed by Dall'Asta and Zona in 2002 well serve to this end due to its computational efficiency and accuracy as verified by comparison with experimental test results. Such finite element model includes reinforced concrete and steel nonlinear behaviour (with custom-defined constitutive laws) as well as the deformability and nonlinear behaviour of shear connectors between reinforced concrete slab and steel beam, as explicitly requested by Eurocode 4 Part 1 and Part 2. To include uncertainties of material constitutive parameters, this finite element model for composite beams with deformable shear connection was augmented with response sensitivity calculations by means of the Direct Differentiation Method (DDM) by Zona et al. in 2005. In this way the formulation can be used for response probabilistic analysis by gradient-based methods, such as the First-Order Second-Moment (FOSM) approximation. The FOSM approximation is adopted in a simplified probabilistic analysis to compute the first- and second-order statistical moments (means, variances and covariances) of structural response quantities. The highly efficient FOSM approximation has been found sufficiently accurate for engineering applications in estimating mean and standard deviation of response quantities of random structural systems subjected to quasi-static nonlinear analysis when structural response nonlinearities are in the low-to-moderate range. The probabilistic response results for SCC beams with deformable shear connection obtained by DDM-based FOSM analysis were validated by comparisons with crude Monte Carlo simulation (MCS), which is a general and accurate, but computationally expensive probabilistic analysis method.

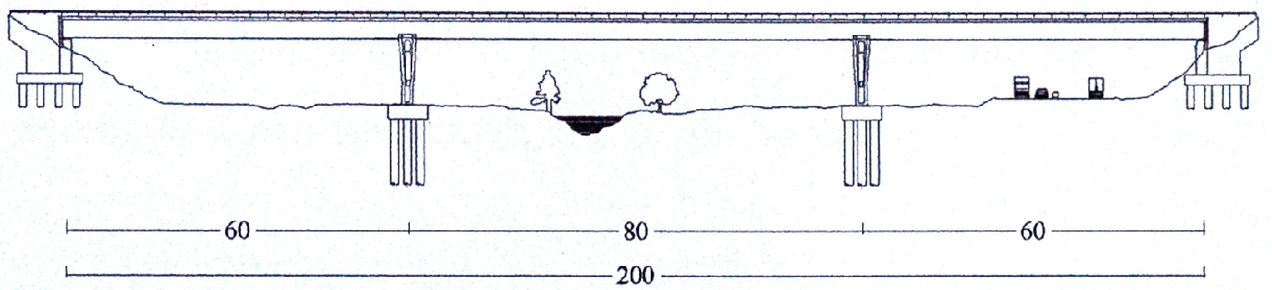

Fig. 1: Three-span continuous SCC girder used as benchmark problem (dimensions in meters)

In this work two designs of a realistic three-span continuous SCC road bridge (Figure 1) according to the Eurocodes are considered. The former design is entirely based on elastic resistance of cross sections, while the latter design is based on plastic resistance of sagging cross sections and elastic resistance of hogging cross sections. Computationally efficient probabilistic nonlinear analysis including uncertainties of the material constitutive parameters is used within the Eurocode recommended safety format as numerical tool to assess the combined elastic-plastic design approach for continuous composite girders. Selected results obtained for the benchmark problem are illustrated and briefly discussed. These results indicate that the combined design ensures safety levels comparable to those of the elastic design together with significant steel savings. More analyses are however required to generalize these conclusions to different geometries and span lengths.