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COMPARISON OF STRUCTURAL MODELS FOR DYNAMIC ANALYSIS OF A PEDESTRIAN BRIDGE

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Summary. High strength of modern structural steel allows to build pedestrian bridges with increased flexibility, lightness and span length. This leads to smaller natural frequencies that may be close to the walking and running frequencies of pedestrians crossing the bridge. As a consequence, excessive vibrations caused by resonance with dynamic loads may occur. For light bridges serviceability criteria for pedestrian induced vibrations can become the dominant design criterion. In order to avoid over dimensioning of the bridge, it is important to use accurate structural models and realistic dynamic load models. In this work, we analyze a model steel bridge and compare different structural models based on solid and shell elements from the perspective of dynamical analysis.

1 INTRODUCTION

The current architectural and economical demands for pedestrian bridges lead towards light and slender structures, where dynamic behaviour plays a big role in terms of stability and comfort of users. The European design standard[1] requires that appropriate dynamic models and comfort criteria should be defined but leaves a more detailed specification to the designer and/or national annexes. Consequently, different guidelines and load models have been developed[2-4]. The practical problem with the current methodologies is that they are very sensitive to design parameters such as natural frequencies and damping properties of the material. This tends to reduce the robustness of the design because it is possible to tune the bridge characteristics so that serviceability criteria is satisfied.

The present work studies variation in obtained results with different finite element methods for dynamic analysis of a model steel bridge. The modal shapes and natural frequencies of the model bridge are calculated with Comsol Multiphysics using solid and shell elements. Six different models are studied: Two different element distributions of solid elements and four different distributions of shell elements.

2 MODEL PROBLEM

The superstructure of the model pedestrian bridge subject to analysis consists of two parallel steel beams of rectangular cross-section linearly increasing their height towards the center of the bridge length. A corrugated steel plate is welded to the beams and constitutes the bridge deck.

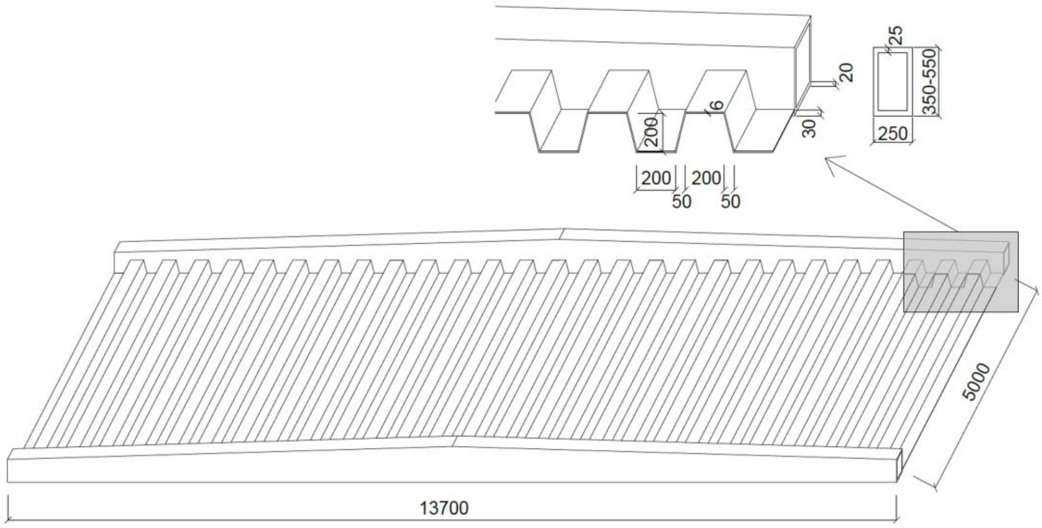

Figure 1: Geometry of superstructure of the model bridge.

The bridge superstructure is assumed to carry a dead load corresponding to the weight of the steel parts and the surface filling. The surface filling is considered purely as an additional mass with no effect on the stiffness of the structure, see Figure 2. In practice, the varying weight of the bridge filling is incorporated to the density of the steel deck.

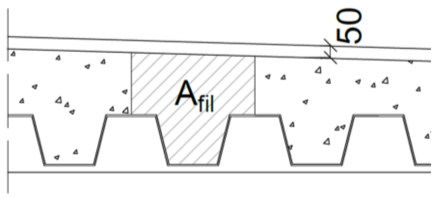

Figure 2: Geometry of the surface filling of the model bridge.

3 NUMERICAL RESULTS

The numerical models under study differ in the types and number of applied finite elements. The solid element model is represented by tetrahedral elements and the shell element model is represented by triangular elements. The number of elements in each model was varied in order to analyze the computational cost and relative accuracy of the different models. Two cases concerning the solid elements (case 1a and 1b) and five different cases concerning the shell elements (cases 2a - 2e) were analyzed. The number of elements and degrees of freedom for the different cases are summarized in Table 1.

	Solid elements		Shell elements				
Case	1a	1b	2a	2b	2c	2d	2e
Degrees of freedom	1,884,801	2,382,198	139,392	250,152	365,886	493,962	4,767,156
Number of elements	316,592	400,473	9,884	18,472	27,612	37,697	385,352

Table 1 : Characteristics of the different numerical models.

Figure 3 illustrates the mesh distribution for the cases 1b and 2e within detail representing the end of the steel beam and the steel deck connection.

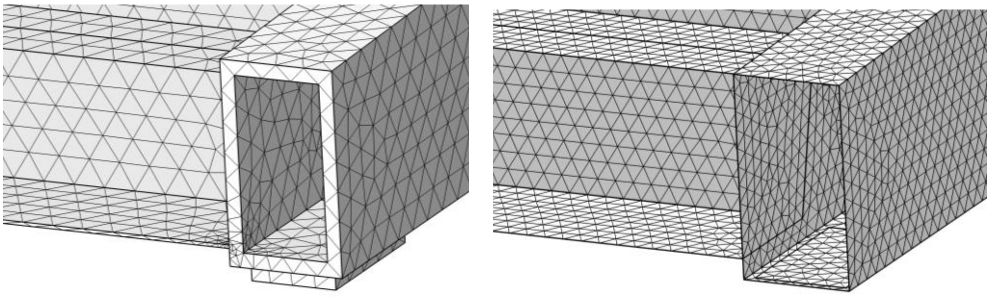

Figure 3: Mesh distribution for the cases 1a and 2e.

The analyzed cases feature only small differences in obtained results for natural frequencies as shown in Table 2. However, the solid model requires much more computing time and degrees of freedom making verification of convergence more difficult. The individual cases describe definition of mesh settings in Comsol as: 1a and 2a - Fine considering minimum element size 0.059m, 1b and 2b - Finer, 2c - Extra fine, 2d - Extremely fine and 2e - user defined considering maximum element size 0.03m.

The first two mode shapes are illustrated in Figure 4 and indicate that the lowest vibration mode of the bridge corresponds to more or less to that of a simple beam.

	Solid elements		Shell element				
Case	1a	1b	2a	2b	2c	2d	2e
Time [s]	230	362	13	24	26	33	628
1st	3.474	3.468	3.488	3.478	3.469	3.469	3.471
2nd	6.543	6.532	6.504	6.489	6.477	6.477	6.483
3rd	7.837	7.825	7.784	7.780	7.775	7.779	7.788
4th	10.027	10.004	9.656	9.651	9.653	9.658	9.735
5th	10.175	10.150	9.722	9.717	9.717	9.723	10.132

Table 2 : Eigenfrequencies calculated using the different models.

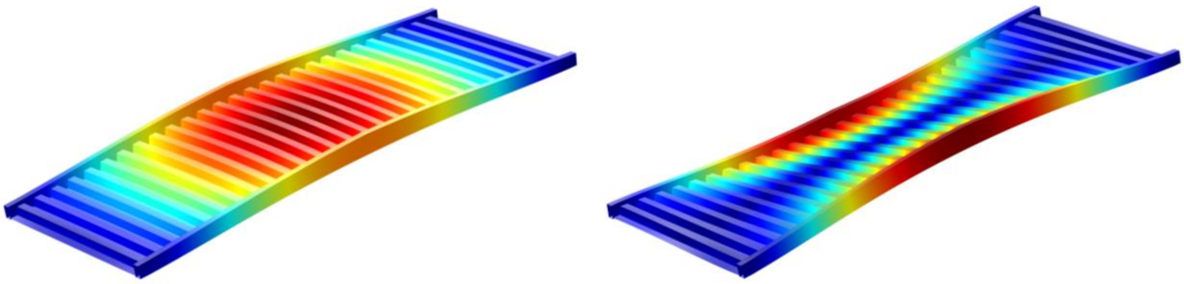

Figure 4: 1st and 2nd mode shapes of the model bridge.

5 CONCLUSIONS

We have analyzed the dynamic response of a model steel bridge using solid and shell finite elements. The results obtained with both approaches are in a good agreement but the use of solid elements requires more computer resources. While solid elements can be employed for this particular case using desktop computers, their feasibility for more complex situations and larger models can be questioned. The next steps consist of analysis of different harmonic and time-dependent models for pedestrian loads to determine the acceleration of the bridge.

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