Comparison of various calculation models for the bridge dynamic analysis

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Abstract. The purpose of this study is to determine the rational use areas of various computational models types while dynamic analysis. This topic is relevant because of the need to carry out precise dynamic calculations for structures at the high-speed rail, in order to ensure the design of a reliable structures. The object of the study is a single-span girder for the high-speed rail. Research methods are numerical analysis using various models; modal calculation of the oscillation shapes and frequencies; comparative analysis. The result of this study are recommendations on the areas of rational use of various types of models.

1. Introduction
Dynamic analysis of structures requires the use of modern software systems [1-4]. However, for each specific type of calculation, a rational choice of the most appropriate calculation model is necessary: it should allow obtaining reliable results at minimal amount of time.

In this article three different types of models of single-span girder for high-speed railroad were compared, a detailed comparative analysis was made, and recommendations on the areas of rational use of each type were given [5-7].

2. Description of the study object and models
The study was based on the project of reinforced concrete single-span girder for high-speed railroad. It has a box cross section with inclined walls. The total length is 34.2 m; the calculational length is 33.1 m. Near the support zones (within 1.5 m on each side), the span has a thickening of the slabs and walls. The material of the girder is B35 concrete [8-9].

During the study, several finite element models of this girder were developed:
- model based on beam finite elements
- model based on shell finite elements
- model based on three-dimensional (volume) finite elements

For modeling and calculation were implemented FE-analysis software packages [10-14]. A model based on beam finite elements was made using two cross sections - above the support and in the middle of the span – with taking into account the transition part between them.
Shell model was made using rectangular shell elements that simulate the walls and slabs of the girder. All oblique elements of the girder (haunches, transition sections) are made by stepwise approximation to rectangular plate elements.

A model based on three-dimensional finite elements was created using an automatic 3D-model meshing. This model is closest to the real structure geometry.

The total masses of all models were slightly different due to the various modeling specifics. The masses errors were equalized by adjusting the mass of the material.

In the research process a modal analysis of the considered models was made.

3. Frequency analysis of various girder models

The first (bending) oscillation mode by the beam, shell and volume models shows a high correlation in the oscillations type and in the frequencies values (Figure 1). Deviations of the frequency of beam and shell models from the frequency of the volume model are just 3.76% and 2.15% respectively.

- a) beam model 5.58 Hz
- b) shell model 5.37 Hz
- c) volume model 5.46 Hz

Figure 1. 1st bending oscillation mode.

By the 1st torsional frequency, three models show a high correlation (Figure 2). At the same time, the beam model has the highest frequency among all. The higher torsional frequency of the beam model is explained by the fact that this model has a higher transverse stiffness, because all the cross sections in it are absolutely rigid according to the plane-sections hypothesis. The shell model is divided into separate elements not only in the longitudinal but also in the transverse direction; therefore, it has a lower transverse rigidity and, consequently, a lower torsional frequency. The model based on volume finite elements has lower transverse rigidity as well.

- a) beam model 15.78 Hz
- b) shell model 14.58 Hz
- c) volume model 15.65 Hz

Figure 2. 1st torsional oscillation mode.

The 2nd flexural oscillation form, as well as the 1st one, shows a fairly broad correlation for the beam, shell and volume models: 16.96, 14.67 Hz and 15.51 Hz, respectively. Deviations of the beam and shell models frequencies from the frequency of the volume model are 7.6% and 0.82%. The difference in frequencies is explained again by the different stiffness of the cross sections. By the type of oscillations of the shell and volume models, it can be noted that the cantilever part of the sections oscillates synchronously with the beam part, but has a different oscillations amplitude (Figure 3).

- a) beam model 16.96 Hz
- b) shell model 14.67 Hz
- c) volume model 15.51 Hz

Figure 3. 2nd flexural oscillations mode.

The 3rd bending oscillation mode shows similar correlation.
4. **Investigation of intermediate oscillation modes**

In general, a big amount of intermediate oscillation modes characterize the shell and volume models. In the shell and volume models exists a mode of horizontal oscillations caused by horizontal deformations of the structure (Figure 4). The beam model does not show this oscillation mode. In this case, the shell and volume models show a high correlation (the deviation is 3.11%).

![Horizontal oscillation modes of the girder.](image)

Figure 4. Horizontal oscillation modes of the girder.

In this part some forms of local oscillation model based on three-dimensional elements are considering. Due to the high dimensionality of this model type, it becomes possible to take into account any oscillation modes of each structural element.

This is well reflected using an example of girder upper slab oscillations (Figure 5).

![The girder upper slab oscillation modes.](image)

Figure 5. The girder upper slab oscillation modes (volume elements model).

5. **Comparative analysis**

According to the models calculation and comparison results, the following conclusions can be drawn:

The beam model shows the main oscillation modes of the structure. The oscillations of the slab part and the beam part in each section are identical in phase and amplitude, because during calculation, the hypothesis of plane sections is used. Thus, using this model, the basic, most high-amplitude oscillations of the entire structure can be estimated. However, this model does not allow tracing the individual structural elements oscillations, first of all the upper slab, which can also negatively affect the superstructure reliability and its operation safety. The beam model advantage regarding to dynamic calculations is a lower dimension, and, consequently, a higher calculation speed.

The shell model allows to calculate a much larger amount of oscillation modes and to track local modes and frequencies. In the calculation by this model it is possible to take into account the oscillations...
of the girder slabs - both the cantilevers of the upper slab and the sections of the upper and lower slabs between the walls.

However, the shell model has a significant drawback, namely, the high modeling complexity at its low precision: transitional zones are modeled by averaged rectangles; many difficulties arise during the connecting different structural parts into a single model.

The model based on three-dimensional (volume) elements has all the advantages of the shell model, also it has a much higher accuracy and provides the biggest amount of different oscillation shapes and frequencies.

6. Conclusion
Taking into account the above factors, we can conclude that the model based on beam elements is suitable for the calculation of the most common oscillation modes, specific to the whole structure. In particular, this type is well suited for approximate calculations during the variant designing of structures: it does not require much time and high computational power.

The model type based on three-dimensional finite elements is the most applicable for deeper dynamic analysis, especially for the calculation of individual structural elements.

Thus, the volume model allows to completely calculate the spectrum of the structure possible oscillations, which makes it possible to prevent the resonance effects occurrence of the whole structure or its individual elements.

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