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COEFFICIENT OF SUBSOIL REACTION CALIBRATED BY PSO METHOD

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Abstract: *The Particle Swarm Optimalization (PSO) method is used for calibration and verification of the FEM model of a bridge. The measured and numerically achieved values did not match well at the beginning. The question was how to identify crucial parameters which influence the results mostly. It was found that one of the most important parameters is the coefficient of subsoil reaction. Thus, two values K_x -in horizontal and K_z-in vertical direction were optimized using the PSO method. The PSO is an optimization method that uses swarm of particles as a problem-solving candidate. The localization of particles in the search space represents the configuration of all variables needed for solving the problem. The quality of the particle's position is evaluated by a cost function. As the particle moves in the search space, the values of the cost function change. The cost function usually compares a few eigen frequencies, modes of vibration, etc. In the paper, only the eigen frequencies were used. The method is general and can be used for calibration and verification many different parameters, such as coefficient of subsoil reaction, stiffness, or mass distribution.*

Keywords: PSO Method, Bridge, FEM Model, Eigen frequencies, Coefficient of subsoil reaction.

1. Introduction

It is a good practice to verify in-situ test results with a computational model. In this article, the ANSYS (Ansys®, 2017) program was used for FEM analyses. To check the results, it is necessary to make a complex and accurate model. The problem with creating such a precise model is that it is not enough to keep only the geometry of the structure, but it is necessary to correctly estimate also the boundary conditions and material characteristics. Manually controlled analysis is time consuming because it is necessary many times to compare numerically obtained frequencies with those from the test and after that it is needed to manually change some characteristics to achieve better new results. (Lamperová et al., 2020).

There are currently many different theories for model calibration (Ferraioli et al., 2018; Marwala, 2010; Sokol and Venglár, 2017; Ventura et al., 2001; Wu and Li, 2004). For example, iteration tuning or calibrating according to genetic algorithms (GA), or many others (Tran-Ngoc et al., 2018; Ventura et al., 2001, 2005). For the purposes of this article, PSO optimization method has been used for tuning the model. PSO is a numerical method based on the joint search for the best solution of the Swarm of Particles. The position of each particle in the searched area provides the configuration of variables of the solved problem. The quality of the position of each part is evaluated in the comparison function. For the purposes of this article, the goal was to compare natural eigen frequencies with measured ones. These parameters were tuned during the analysis in order to obtain good match of the frequencies in numerical model and the measured frequencies.

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2. Description of the tested bridge

The bridge close to city Šaľa in Slovakia was considered. It consists of 14 simply supported beams. Two railway tracks laying on one pier. One track was built of simply supported truss beam, second one of box girder (Sokol et al., 2019)(Fig. 1). Individual spans are about 31 m and they are placed on concrete pillars using roller bearings. The concrete pillars are of variable height and some have their foundations out of river and some are located in the river Váh. In this article, we have focused on box girder beam, with pillars founded out of river. Since these pillars have different foundations characteristics (height of the foundation or coefficient of subsoil reaction), the results of the measured frequencies were different at particular fields.

Fig. 1: Šaľa – Trnovec bridge

3. FEM model of bridge

A 3D numerical model of the bridge was created in software ANSYS. The basic model was supported at the left-hand side by hinged support and at the other side by a sliding hinged support. (fig. 2a). This model did not provide a good match of the numerically obtained eigen frequencies with measured ones. (tab. 1) It was necessary to also include the bridge concrete pillars to achieve better matches. In the second step, rigid supports of these pillars were assumed (fig. 2b) The results of such a model were a bit better but still did not provide a good match.

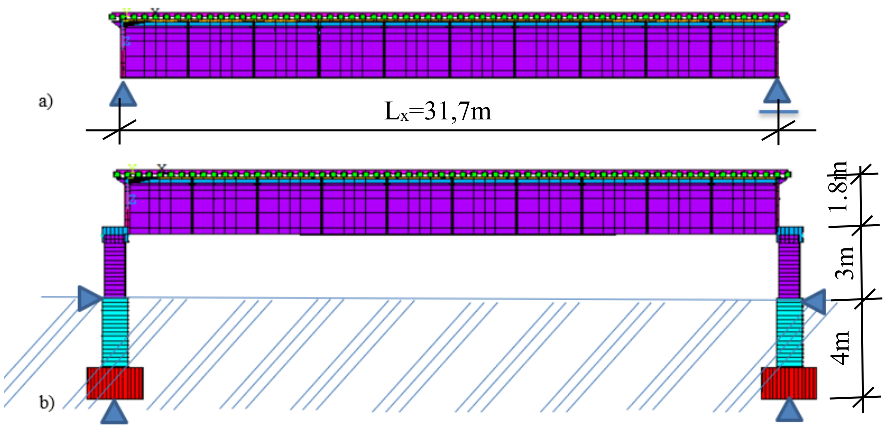


Fig. 2: a) Numerical model A, b) Numerical model B

The numerical model had slightly higher frequencies than were actually measured (Sokol et al., 2019). It has been founded that the value of coefficients of subsoil reaction (both horizontal and vertical values) play a crucial role in the overall stiffness of the bridge and will reduce the stiffness significantly.

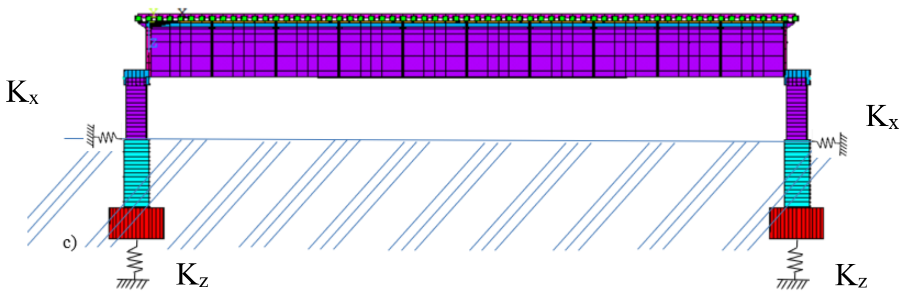


Fig. 3: c) Numerical model C

We tried to set coefficients of subsoil reaction in both Z-direction (K_z) and X-direction (K_x) (Fig. 3), but it is very difficult to estimate the correct stiffness characteristics of the subsoil. The initial values of these coefficients has been taken from geological survey. (Turček, 2019)

4. PSO Method for calibrating of soil stiffness

The PSO method is today very known technique that was first described by Kennedy and Eberhart (1995). How it works is detailed described in many references (Hu et al., 2003; Marton et al., 2021). It is essential for us that the PSO is looking for unknown parameters based on the evaluation of the conformity of the natural frequencies. The search space (fig. 4) is bounded by a lower boundary (LB) and upper boundary (UB). We know from experience that for the type of subsoil that is in the given locality we can use for the lower limit of the coefficient in the Z-direction 40 MNm^{-3} the upper limit can be set to 100 MNm^{-3}. For the horizontal direction, we set boundaries - minimum 10 MNm^{-3} and maximum 50 MNm^{-3}.

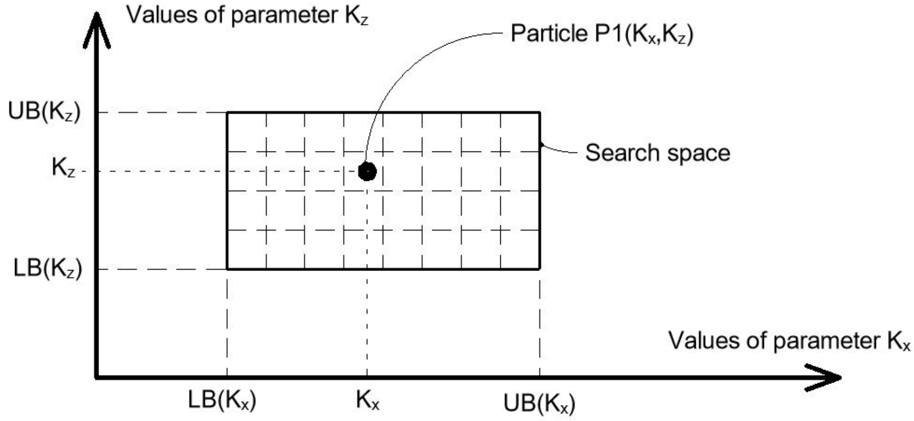
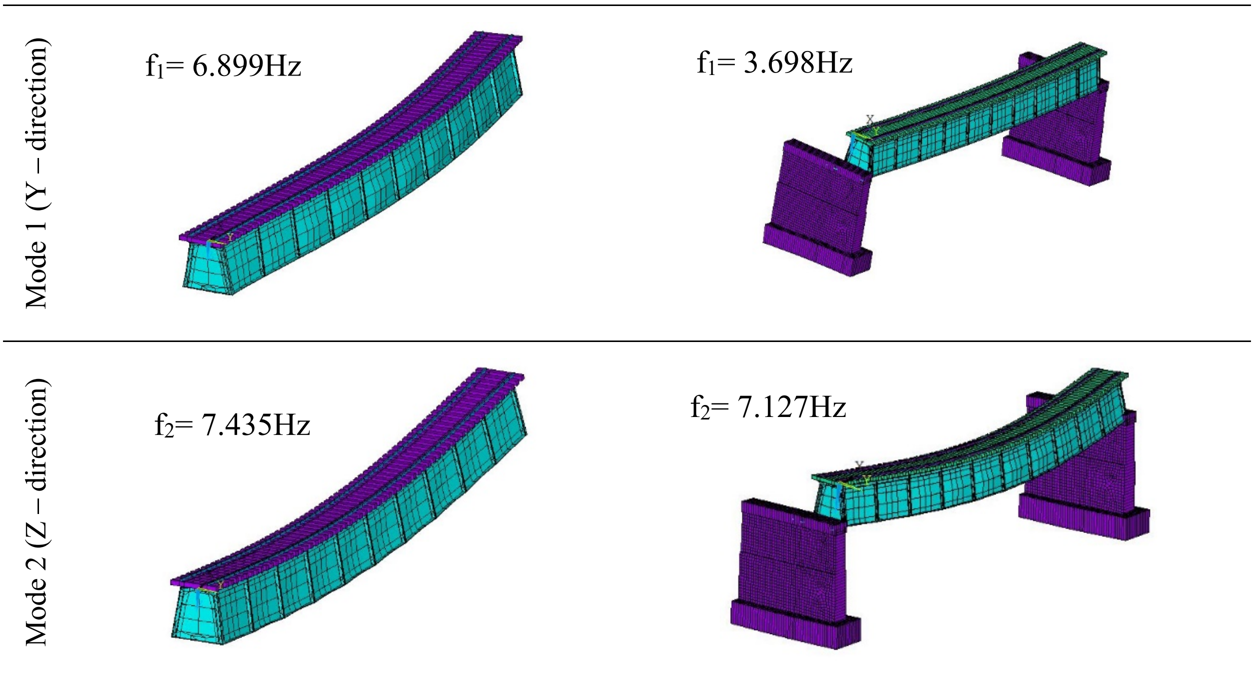


Fig. 4: Particle position scheme

4.1. Identified parameters by PSO method

Finally, the parameters K_z =69 MNm^{-3} and K_x =16 MNm^{-3} have been identified after performing PSO optimalization. Eigen frequencies finally match well with the measured ones (see last column - Model C in Tab. 1). One can see (figure 5) differences in frequencies and mode shapes (1st -horizontal and 2nd vertical mode of vibration) between model A and model C.



a) Numerical model A (without pillars), b) Numerical model C (complete foundation model)

Fig. 5: Eigen modes and frequencies

These results are acceptable and provide with calibrated FEM model of good quality for next analyses.

Tab. 1: Comparison of natural frequency values

Shape mode	**Direction of vibration shape**	**Calculated eigen frequencies [Hz]**			**Measurement eigen frequencies [Hz]**
		Model A	Model B	Model C	
1	Dir. Y	6.899	6.327	3.698	3.70
2	Dir. Z	7.435	8.083	7.127	7.10
3	Dir. Y	19.225	17.363	10.247	11.30

5. Conclusions

The PSO method for determining appropriate soil parameters has been used. The resulting coefficients of subsoil reactions were K_Z=69MNm^{-3} and K_X=15MNm^{-3}. Both were far away from estimated values from geological survey. Proper use of PSO can improve the solution and save a lot of time. PSO can be very helpful, especially in solving more extensive tasks. In the future, we want to focus on the application of the PSO method for solving a larger number of parameters. In this case, we should additionally pay attention also to measured deflections and stresses and incorporate them into comparison function. It should bring more reliable results.

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