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Numerical evaluation of dynamic response of a steel structure model under various seismic excitations

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Abstract

The present paper reports the results of the study, which was designed to perform a numerical evaluation of dynamic response of a single-storey steel structure model. The experimental model was previously subjected to a number of different earthquake ground motions during an extensive shaking table investigation. The analyzed structure model was considered as a 1-DOF system with lumped parameters, which were determined by conducting free vibration tests. In order to solve the dynamic equation of motion, Newmark's average acceleration method was adopted. The results obtained from the numerical analysis confirm the accuracy in assuming lumped parameters to characterize the analyzed single-storey structure.

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Keywords: earthquakes; dynamic excitations; seismic performance; numerical analysis.

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1. Introduction

Earthquakes are identified among the most severe and unpredictable threats to the building structures and, therefore, have become an issue of major concern of professional and research communities (see, for example, [1-4]). Strong ground motions may cause a lot a damage (see [5,6]) in a wide variety of ways, leaving sometimes thousands of casualties in their wake. During the last few years alone, the world has witnessed many major earthquakes, five of which have caused far-reaching consequences of a national scale for Haiti (January 2010), Chile (February 2010), New Zealand (February 2011), Japan (March 2011), and Turkey (October 2011).

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Shaking table testing is the most commonly adopted approach to simulate earthquake forces. It allows to analyze the seismic performance and provides a valuable insight into the dynamics of building structures, which helps to improve their future safety and reliability. The present study aims to conduct a numerical evaluation of dynamic response of a single-storey steel structure model, which was previously examined during an extensive shaking table investigation. In order to perform the numerical research, lumped-mass system was employed. The results obtained from both experimental and numerical studies were compared and discussed.

2. Experimental model and shaking table investigation

In order to conduct the experimental investigation, a single-storey steel structure model was firstly prepared. The welded steel frame was constructed using the rectangular hollow section elements (RHS 15×15×1.5 mm). The columns were arranged in a rectangular pattern with spacing of 0.465 m in the longitudinal direction and 0.556 m in the transverse one. Additional diagonal bracing was used in the sidewall planes to counteract transverse and torsional vibrations. Moreover, two concrete plates (50×50×7 cm) were used to simulate the weight of the floor and foundation slabs. The single-storey structure model consisting of one steel frame and two concrete plates was 1.20 m high and weighs 95.12 kg (see Fig. 1). The seismic response of the experimental model under a number of earthquake ground motions was extensively studied during a comprehensive shaking table investigation carried out with the use of a middle-sized shaking table located at Gdańsk University of Technology, Poland. The results obtained from the shaking table study for both single- and two-storey steel structure models have already been presented in previous publications (see [7-9]).

Fig. 1. Single-storey steel structure model mounted on the shaking table platform.

3. Numerical analysis

In order to perform the numerical evaluation of dynamic response of the experimentally examined single-storey steel structure model, lumped-mass system has been applied. The experimental model was idealized as a single-degree-of-freedom (SDOF or 1-DOF) system, for which the dynamic equation of motion is given by [10,11]:

$$m\ddot{u}(t)+c\dot{u}(t)+ku(t)=-m\ddot{u}_g(t) \tag{1}$$

in which $\ddot{u}_g(t)$ denotes the ground acceleration, $u(t)$, $\dot{u}(t)$, and $\ddot{u}(t)$ the displacement, velocity, and acceleration of the structure model, respectively. Additionally, the 1-DOF system is characterized by three parameters: lumped mass m concentrated at the roof level, lateral stiffness k, and viscous damping c, which were defined as follows:

$$m=47.56\,\mathrm{kg} \tag{2}$$

$$k=\omega^2 m=20571\,\frac{\mathrm{N}}{\mathrm{m}} \tag{3}$$

$$c=2m\omega\xi=10.48\,\frac{\mathrm{kg}}{\mathrm{s}} \tag{4}$$

where ω denotes the natural circular frequency and ξ the damping ratio of the single-storey steel structure model. The dynamic characteristics of the experimental model were previously determined by conducting free vibration tests. The fundamental frequency of the experimental model was calculated to be 3.31 Hz, whereas the damping ratio 0.53%. In order to solve the second-order differential equation of motion (Equation 1), the unconditionally stable Newmark's average acceleration method was applied (see [12]), as it is the most frequently used integration procedure in the case of seismic analyses of structures. The 1-DOF system considered in the present study was subjected to the same dynamic excitations which were previously applied to the experimental model during the shaking table investigation.

The acceleration time histories computed for the 1-DOF system under various seismic excitations are presented in Fig. 2-6. The comparison of the results obtained from the numerical analysis using lumped-mass model and the shaking table investigation are briefly reported in Table 1.

Table 1. Results obtained from both numerical and experimental investigation.

Dynamic excitation	Peak acceleration at the top of the single-storey steel structure model (m/s^2)	
	Lumped-mass numerical analysis	Shaking table investigation
El Centro earthquake, 18.05.1940 (NS component, PGA=3.070 m/s^2)	11.39	11.39
San Fernando earthquake, 9.02.1971 (Pacoima Dam station, N74°E component, PGA=5.688 m/s^2)	15.64	15.59
Loma Prieta earthquake, 17.10.1989 (Corralitos station, NS component, PGA=3.158 m/s^2)	13.86	13.82
Northridge earthquake, 17.01.1994 (Santa Monica station, EW component, PGA= 4.332 m/s^2)	8.73	8.73
Polkowice mining tremor, 20.02.2002 (NS component, PGA= 1.634 m/s^2)	3.50	3.53

where PGA denotes the Peak Ground Acceleration

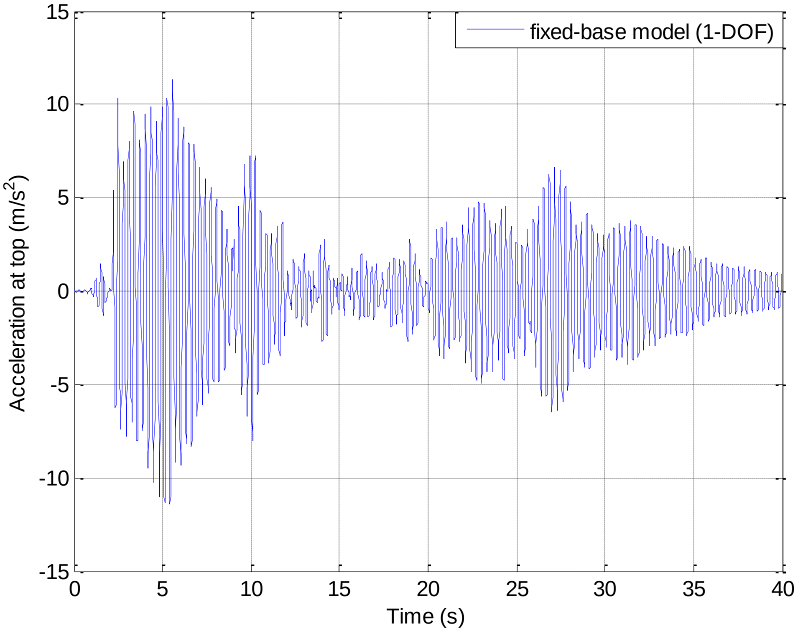

Fig. 2. Time-acceleration history plot for the 1-DOF model during the 1940 El Centro earthquake.

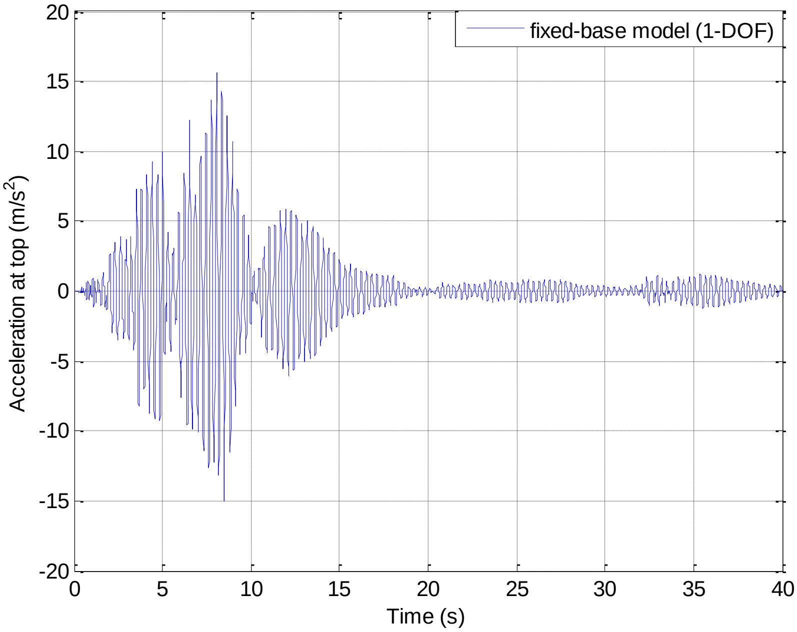

Fig. 3. Time-acceleration history plot for the 1-DOF model during the 1971 San Fernando earthquake.

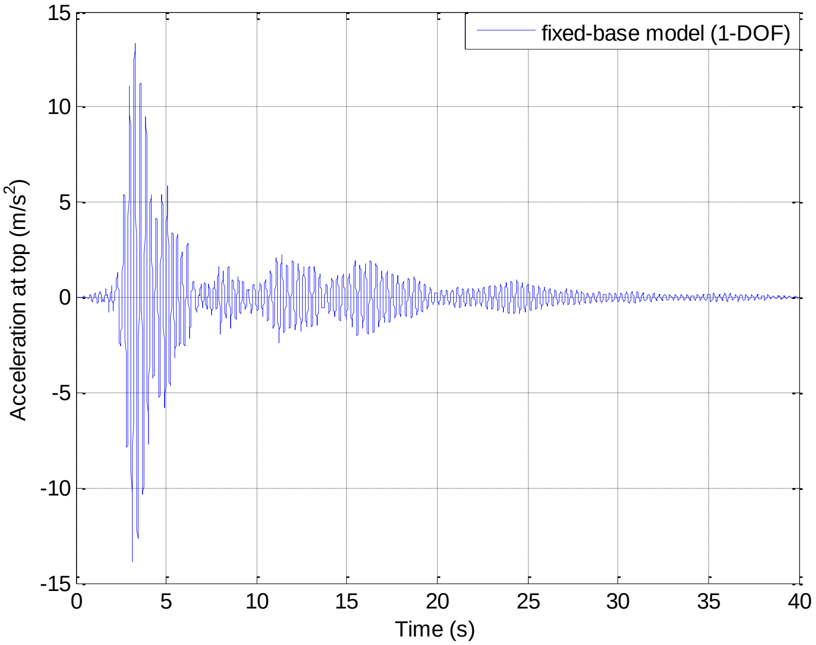

Fig. 4. Time-acceleration history plot for the 1-DOF model during the 1989 Loma Prieta earthquake.

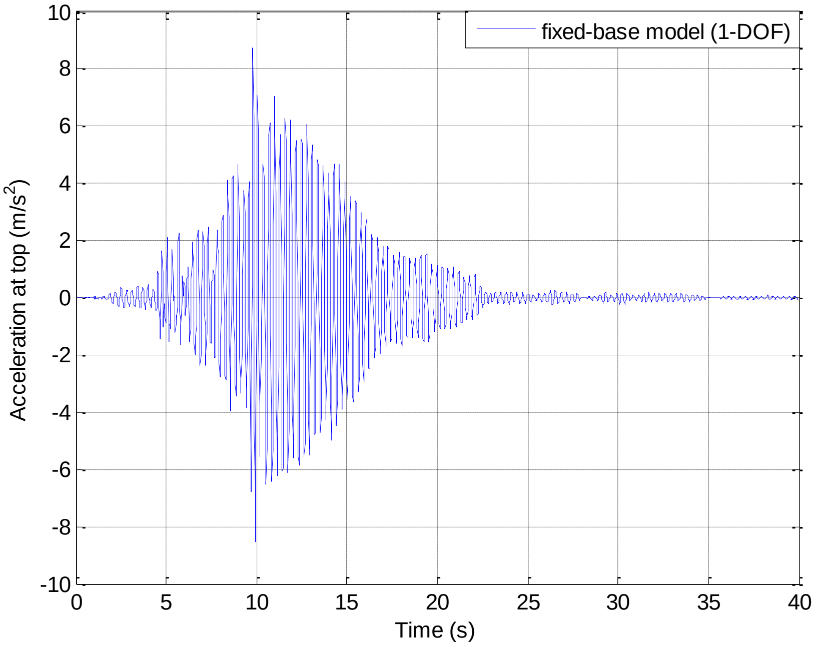

Fig. 5. Time-acceleration history plot for the 1-DOF model during the 1994 Northridge earthquake.

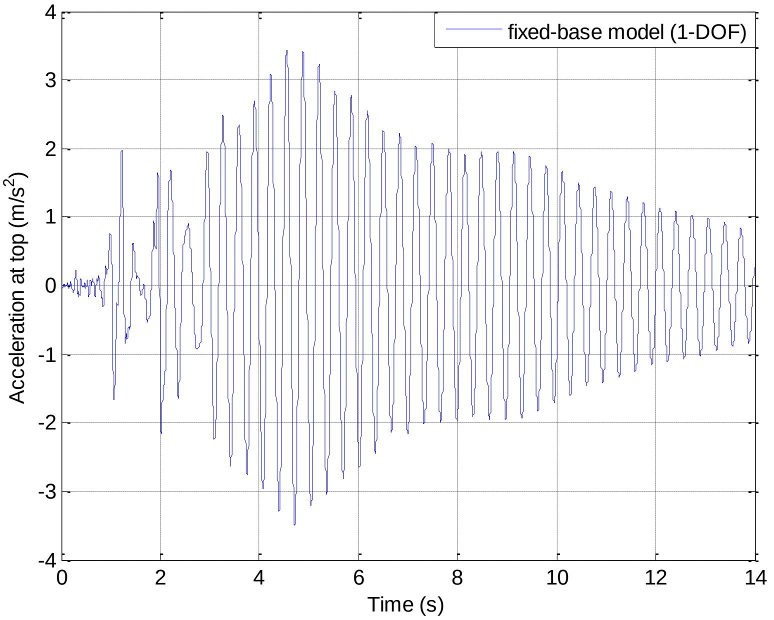

Fig. 6. Time-acceleration history plot for the 1-DOF model during the 2002 Polkowice mining tremor.

4. Final summary and conclusions

The present research was designed to perform a numerical evaluation of dynamic response of a single-storey steel structure model, which was previously examined during an extensive shaking table investigation. The analyzed structure model was idealized as a 1-DOF system and subjected to a number of different seismic excitations. In order to solve the second-order differential equation of motion, Newmark's average acceleration method was adopted.

As expected, the results obtained showed that seismic excitations may considerably deteriorate structural safety by inducting strong structural vibrations. The time-acceleration history plots computed for the single-storey structure model idealized as a 1-DOF system are consistent with those recorded during the previously conducted shaking table investigation. Close inspection of Table 1 explicitly demonstrates that the peak values of the lateral accelerations at the top of the structure model from both experimental and numerical studies are almost the same which confirms high accuracy in assuming lumped parameters to characterize the analyzed single-storey structure. These parameters will be employed in further numerical research which will cover the evaluation of seismic response of both fixed-base and base-isolated structures as well as soil-structure interaction.

References

[1] S. Mahmoud, R. Jankowski, Elastic and inelastic multi-storey buildings under earthquake excitation with the effect of pounding, Journal of Applied Sciences 9 (2009) 3250–3262.
[2] S. Mahmoud, R. Jankowski, Modified linear viscoelastic model of earthquake-induced structural pounding, Iranian Journal of Science and Technology 35(C1) (2011) 51–62.
[3] R. Jankowski, Theoretical and experimental assessment of parameters for the non-linear viscoelastic model of structural pounding, Journal of Theoretical and Applied Mechanics 45 (2007) 931–942.
[4] S. Mahmoud, P-E. Austrell, R. Jankowski, Simulation of the response of base-isolated buildings under earthquake excitations considering soil flexibility, Earthquake Engineering and Engineering Vibration 11 (2012) 359–374.
[5] R. Jankowski, Impact force spectrum for damage assessment of earthquake-induced structural pounding, Key Engineering Materials 293-294 (2005) 711–718.

[6] R. Jankowski, Assessment of damage due to earthquake-induced pounding between the main building and the stairway tower, Key Engineering Materials 347 (2007) 339–344.

[7] T. Falborski, R. Jankowski, Shaking table experimental study on the base isolation system made of polymer bearings, Proceedings of the 15th World Conference on Earthquake Engineering, Paper No. 2119 (2012) 1–8.

[8] T. Falborski, R. Jankowski , Polymeric Bearings – a new base isolation system to reduce structural damage during earthquakes, Key Engineering Materials 569-570 (2013) 143–150.

[9] T. Falborski, R. Jankowski, Reduction of vibrations of steel structure models with polymeric bearings – experimental study, Current Scientific Challenges in Concrete and Steel Structures, Material Technology and Structural Fire Protection 1 (2014) 1–8.

[10] A.K. Chopra, Dynamics of Structures: Theory and Applications to Earthquake Engineering, Prentice Hall, New Jersey, 1995.

[11] R. Clough, J. Penzien, Dynamics of Structures, McGraw-Hill, New York, 1975.

[12] N.M. Newmark, A method of computing for structural dynamics, Journal of the Engineering Mechanics Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. EM3, Paper No. 2094 (1959) 67–94.