**UDC 624.94+519.6**

# DYNAMIC MODELLING AND OPTIMAL DESIGN OF MULTI-STOREY BUILDINGS WITH FRICTION DAMPERS

**Mykola Savytskyi**, Dr. Sc., Prof., **Vladyslav Danishevskyy**, Dr. Sc., Prof.,
**Anastasia Gaidar**, Senior Lecturer
*State Higher Education Institution*
*"Prydniprovska State Academy of Civil Engineering and Architecture"*

***Problem statement.*** A challenging problem of Civil Engineering is the protection of buildings against dynamic loads and earthquake impacts. The advanced solutions employ lightweight, material saving structures equipped with special damping devices. These devices can be active or passive and their application depends, in general, on the investments for the project. The active devices change their properties depending on the structural response and they are the most expensive ones. On the other hand, passive devices are essentially cheaper and, in many cases, require minimal costs of installation and maintenance.

Last decades, passive friction dampers are widely used for the earthquake protection of multi-storey buildings [1]. The friction dampers make use of the effect of solid friction to dissipate the mechanical energy and to reduce the amplitude of the vibration of the structure. The friction is developed between two solid bodies sliding in relation to one another. As usual, pairs of metal, polymer or concrete components can be utilized. Determination of the optimal location of friction dampers inside the building presents a complicated task for the practical design.

***Purpose of the study.*** Several studies have been devoted to predicting the best properties and placements of friction dampers (e.g., see papers [2-4] and references therein). From the mathematical point of view, this is a non-linear optimization problem and, in generally, such problems can be nonconvex. They may be treated by different methods; for a general overview of the subject we refer, for example, to the well-known books [5, 6]. In recent years, the methods of artificial collective intelligence are rapidly developed providing a number of advantages comparing to the classical procedures [7]. In this study, a new approach to determine the optimal location of friction dampers is proposed basing on the method of particle swarm optimization (PSO). The PSO method presents an artificial simulation of the phenomenon of collective intelligence, which is observed in many decentralized biological systems like ant colonies, bee swarms, flocks of birds and even social groups of human individuals [8].

***Main results.*** As an illustrative example, the 2D model of a six-storey concrete frame building with three friction dampers is considered. In a case of horizontal seismic loads, the stress-strain state of the structure is determined mainly by the bending deformations of the columns, while the longitudinal deformations of the frame elements can be neglected. Following this assumption, the dynamic model of the building is adopted in a form of a vertical cantilever rod with lumped masses. Let us note that the natural frequencies and the normal modes of the proposed simplified model are in a good agreement with the frequencies and the modes of the original structure, which are determined using the FEM program package «LIRA-SAPR».

Several sets of dynamic simulations are performed. The differential equations of motions are integrated numerically by the Runge-Kutta method. The software implementation is developed using the open-source CAS Maxima. Solutions of the optimization problems are obtained employing the population of 16 particles, while the number of iterations does not exceed 10.

In the case of a harmonic resonant load, the horizontal acceleration amplitude of the basement is assumed to be equal 0.4g, which corresponds to the 9th degree of seismic intensity by the Medvedev–Sponheuer–Karnik scale. The frequency of the load is equal to the lowest natural frequency 2.96Hz. Two types of the objective functions are considered to be minimized: the displacements of stories and the interstorey drifts. For the both functions the same optimal solution is obtained implying installation of the all three dampers at storey 1. Figs. 1, 2 present the obtained results for the displacements and for the interstorey drifts. Here we denote: – uncontrolled structure without dampers; 2 – a uniform distribution of damper loads over the all stories; 3 – the optimal location of the dampers.

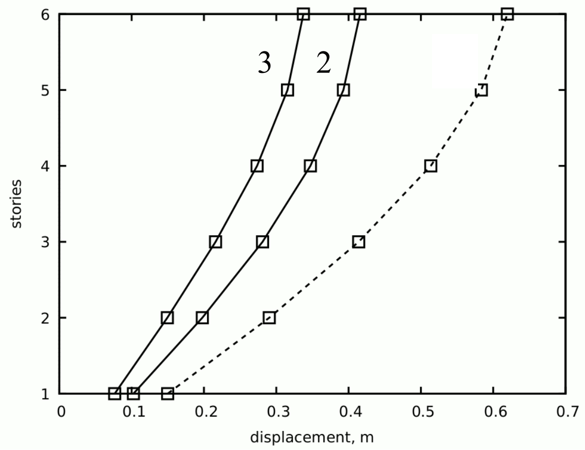


*Fig. 1. Displacements of stories under the harmonic resonant load*

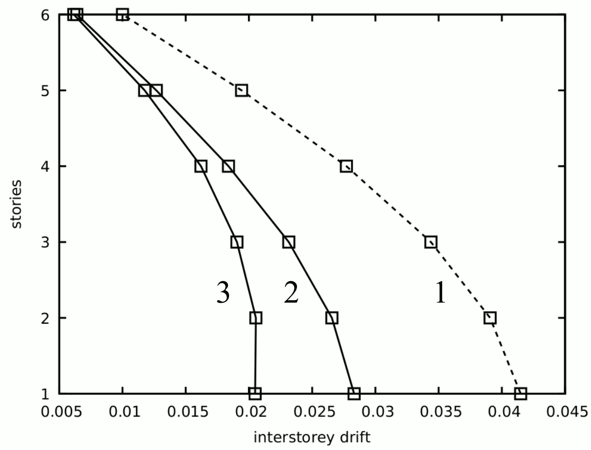


*Fig. 2. Interstorey drifts under the harmonic resonant load*

The seismic load is described by a zero-mean normal random process simulated by a superposition of harmonic modes with different frequencies and random phases [9]. The power spectral density is determined using Kanai-Tajimi model [10]; the peak ground acceleration is 0.4 g. The minimal displacements are achieved installing the dampers at stories 1, 3, 4, while for the minimal interstorey drifts the optimal location of the dampers is predicted at stories 1, 2, 3. The latter solution ensures also the minimal accelerations of the stories, which makes it the most reasonable from the engineering point of view. Numerical results are displayed at Figs. 3–6. Dashed curves correspond to the uncontrolled structure without dampers and solid curves – to the obtained optimal solution.

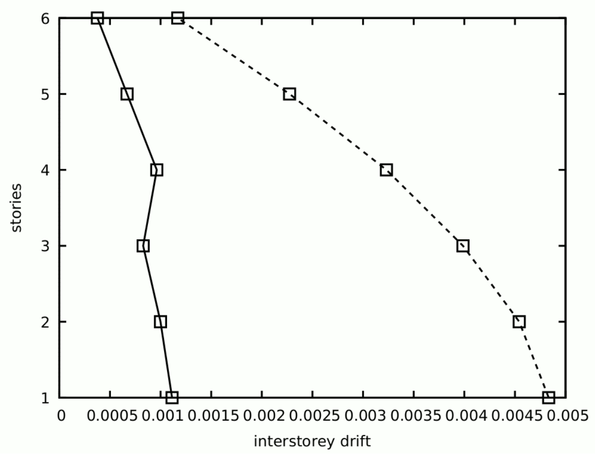


*Fig. 3. Interstorey drifts under the seismic load*

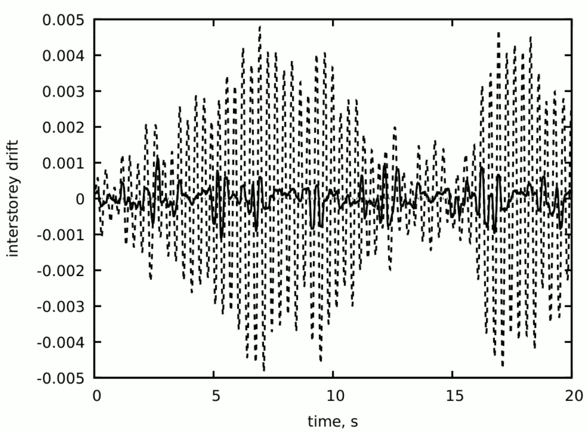


*Fig. 4. Interstorey drift at storey 1*

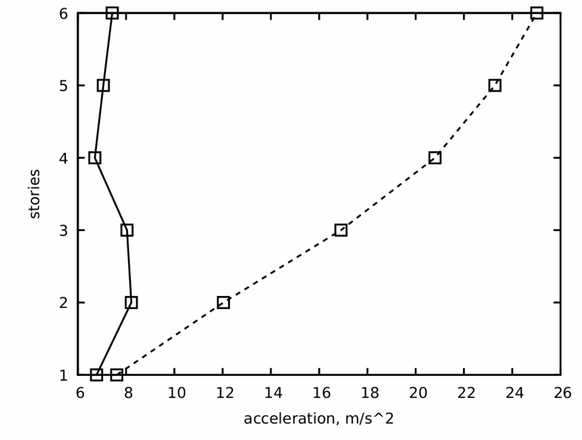


*Fig. 5. Accelerations of the stories under the seismic load*

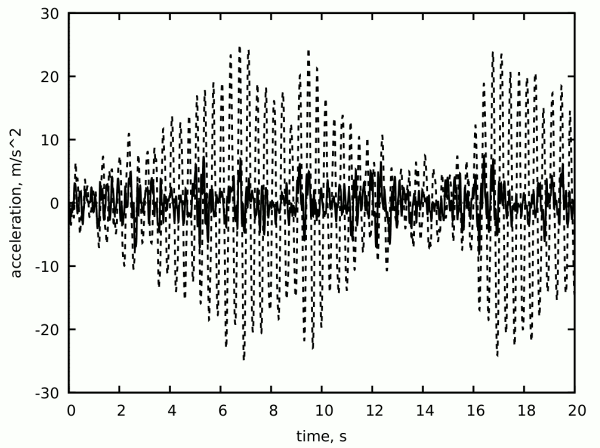


*Fig. 6. Acceleration of storey 6*

***Conclusions.*** The analysis of the results shows that installing friction dampers at the optimal locations allows reducing the displacements of the stories up to 45 %, the interstorey drifts up to 50 % and the accelerations up to 70 %. The developed approach can be extended to various problems of the optimal design of buildings and structures.

***Acknowledgement.*** This work is supported by EU Horizon 2020 project "A novel decentralized edge-enabled prescriptive and proactive framework for increased energy efficiency and well-being in residential buildings", grant ID 958284.

## References

1. Soong T.T. and Dargush G.F. Passive energy dissipation systems in structural engineering. Chichester, New York : Wiley, 1997, 368 p.

2. Ontiveros-Pérez S.P., Miguel Letícia F.F. and Miguel Leandro F.F. A new assessment in the simultaneous optimization of friction dampers in plane and spatial civil structures. *Mathematical Problems in Engineering*. Vol. 2017, 2017, 18 p.

3. Ontiveros-Pérez S.P., Miguel L.F.F. and Riera J.D. Reliability-based optimum design of passive friction dampers in buildings in seismic regions. *Engineering Structures*. Vol. 190, 2019, pp. 276–284.

4. Nabid N., Hajirasouliha I. and Petkovski M. Adaptive low computational cost optimisation method for performance-based seismic design of friction dampers. *Engineering Structures*. Vol. 198, 2019.

5. Mordecai A. Nonlinear programming: analysis and methods. Mineola, New York: Dover Publishing, 2003, 512 p.

6. Ruszczyński A. Nonlinear optimization. Princeton: Princeton University Press, 2006, 464 p.

7. Simon D. Evolutionary optimization algorithms: biologically-inspired and population-based approaches to computer intelligence. Hoboken, New Jersey: Wiley, 2013, 784 p.

8. Eberhart R., Shi Yu. and Kennedy J. Swarm Intelligence. Morgan Kaufmann, Elsevier, 2001, 512 p.

9. Shinozuka M., Jan C.-M. Digital simulation of random processes and its applications. Journal of Sound and Vibration. Vol. 25, 1972, p. 111–128.

10. Kanai K. An empirical formula for the spectrum of strong earthquake motions. *Bulletin of the Earthquake Research Institute*. Vol. 39, 1961, p. 85–95.