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RATIONAL DESIGN OF LIGHTWEIGHT EARTHQUAKE RESISTANT BUILDINGS WITH FRICTION DAMPERS USING THE PARTICLE SWARM OPTIMIZATION

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Problem statement. According to the principles of sustainable development and circular economy, an important task of Civil Engineering is the design and employment of light-weight economic structures characterized by low resources consumption throughout the all stages of their life cycle. The resistance of such structures to seismic loads is provided by special devices: seismic insulation, inertial vibration dampers and friction dampers. In recent years, dry friction dampers are widely used because of the simplicity and reliability of the design, low costs, easy installation and maintenance, as well as high dissipative properties [1].

Determining the location of friction dampers inside a building is a complex task that requires a comprehensive analysis of the dynamic properties of the structure and, as a rule, cannot be solved within the framework of classical design approaches. Therefore, a crucial problem is the development of novel methods for simulation of structures with dry friction dampers allowing finding optimal design solutions to minimize dynamic and seismic impacts.

Purpose of the study. Several studies have been devoted to predicting the optimal properties and placements of friction dampers (e. g., see papers [2; 3] 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 method [4]. In recent years, the methods of artificial collective intelligence are rapidly developed providing a number of advantages comparing to the classical procedures [5]. 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 [6].

Main results. As an illustrative example, the 2D model of a six-storey concrete frame building with three friction dampers is considered (Fig. 1). The dampers can be installed as braces in the central span of the building. The places of possible locations of the dampers are indicated at Fig. 1 by dash lines. 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 discrete dynamic model of the building is adopted in the form of a vertical cantilever rod with lumped masses. The governing system of differential equations of motion is introduced. The presence of friction dampers involves a significant nonlinearity into the input problem.

The applicability of the proposed discrete model is verified by comparing its natural frequencies with the results of the modal analysis of the original structure performed in FEM package LIRA-SAPR. The obtained analytical and numerical solutions are in a good agreement. The displacement patterns of the lowest six normal modes evaluated in LIRA-SAPR confirms the validity of the physical assumptions of the lumped mass model.

In order to determine the rational location of friction dampers, two types of objective functions need to be minimized: 1) the maximal displacements of the stories and 2) the maximal inter-storey drifts. 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 by the PSO method employing the population of 16 particles, while the number of iterations does not exceed 10.

In the case of a periodic load, the load frequency is assumed to be equal to the fundamental frequency of the structure 2.96 Hz, which falls into the interval of typical predominant frequencies of seismic accelerograms 0.5…10 Hz. The horizontal acceleration amplitude of the basement is 0.4*g*, which corresponds to the 9th level of the seismic intensity. The rational locations of the dampers are predicted using the method of particle swarm optimization with a population of 16 particles. For the both objective functions the same optimal solution is obtained implying installation of the all three dampers at storey 1.

The seismic load is described by a zero-mean normal random process simulated by a superposition of harmonic waves with different frequencies and random phases [7]. The power spectral density is determined using Kanai-Tajimi model [8] for the peak ground acceleration 0.4*g* (Fig. 2). 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.

Conclusions. The analysis of the results shows that installing friction dampers at the optimal locations allows reducing the displacements up to 45 %, the interstorey drifts up to 50 % and the accelerations up to 70 %. The developed dynamic models and the proposed methods can be used in the design of houses and structures with enhanced resistance to seismic and dynamic impacts, as well as for the reconstruction of existing buildings to increase their seismic protection. The developed PSO approach can be extended to various problems of the optimal design of buildings and structures.

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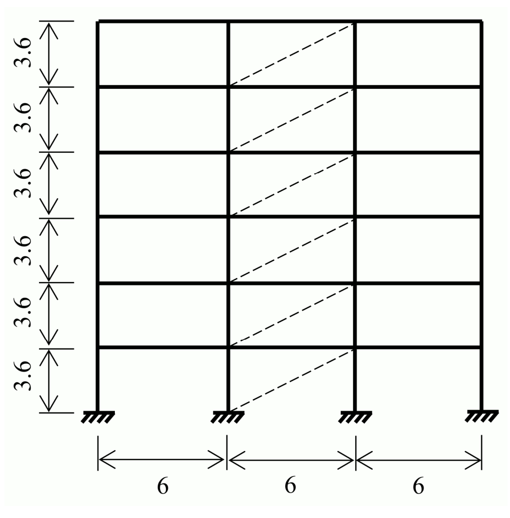

Fig. 1. 2D model of a six-storey building

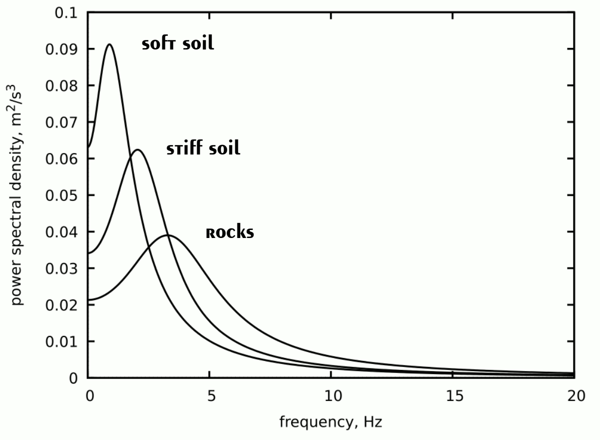

Fig. 2. Power spectral density of the earthquake

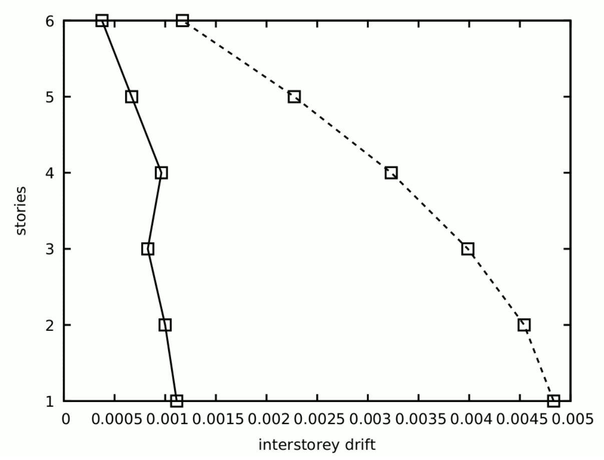

Fig. 3. Interstorey drift

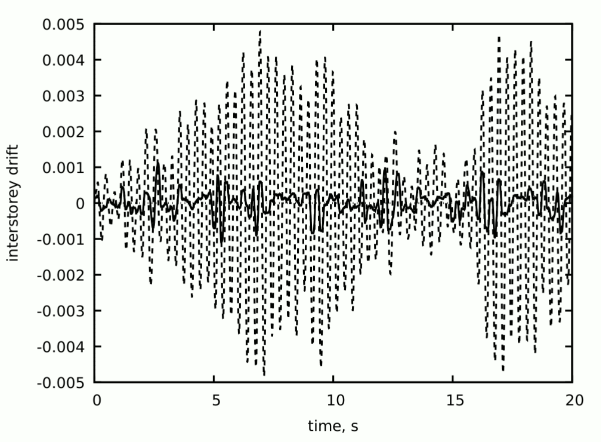

Fig. 4. Interstorey drift at storey 1

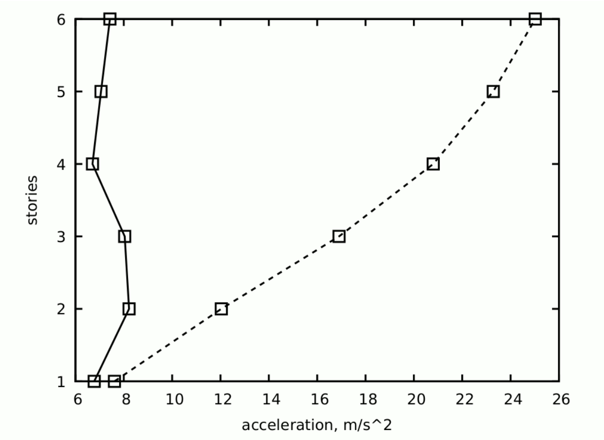

Fig. 5. Accelerations of the stories

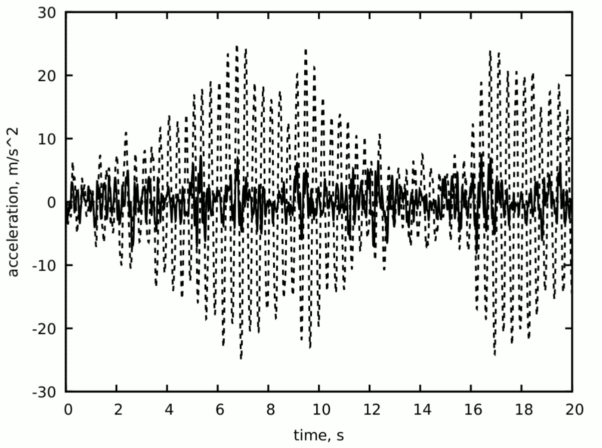

Fig. 6. Acceleration of storey 6

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