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An analysis of the dynamics of seismically isolated structures taking into account its torsional vibrations

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Abstract

In this paper are researched torsional fluctuations of structure located on the pendulum system of seismic isolation (SIS). Torsional oscillations are caused by the incongruence of the center of rigidity (CR) with the center of mass (CM) of the structure and influence of rotational ground motions. In the calculations given below is considered only the first reason. The lack of coincidence of CR and CM leads to an asynchronous motion of different pendulum devices and to their different longitudinal deformation. Thereby, the tension and compression forces of the devices are different. This leads to the torsion, rocking and vertical displacement of the seismically isolated structure. This paper investigates the influence of the above-mentioned effects.

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Keywords: pendulum system of seismic isolation; mathematical model; torsional oscillations.

1. Introduction

The analysis of seismic isolation systems (SIS) is generally performed under kinematic excitations defined by horizontal ground motions. The influence of vertical and rotational components of earthquake excitation on the

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response of SIS (Basu, Whittaker, & Constantinou, 2015) and the influence of the related with these components torsional vibrations of the structure is practically not investigated (Basu et al., 2015).

However, these excitations significantly affect the oscillation behavior of the idealized system: Protected Superstructure (PS)-SIS and may reduce the effectiveness of SI devices.

The influence of the rotational excitations can be clearly seen on the example of the pendulum type SIS. The ground rotation and thus the base rotation of the structure leads to an asynchronous motion of different pendulum devices and to their different longitudinal deformation. Thereby, the tension and compression forces of the devices are different. This leads to the torsion, rocking and vertical displacement of the seismically isolated structure. Similar considerations can be made with regard to seismic isolation based on the application of rubber bearings. The main purpose of this research is to investigate the influence of the above-mentioned effects. This paper presents the analysis of the structure behavior isolated by pendulum type SIS.

A mathematical model that allows investigating the influence of not only horizontal but also vertical and rotational components of earthquake excitation on the response of SIS is analyzed. This mathematical model consists of several groups of equations.

This paper presents the analysis of the degree of influence of the eccentricity between the center of mass and rigidity on the SIS efficiency.

2. Statement of the problem

If only the horizontal components of the ground motion are considered in the dynamic analysis, then we can simplify this problem to a single degree of freedom system (SDoF), shown in Fig. 1:

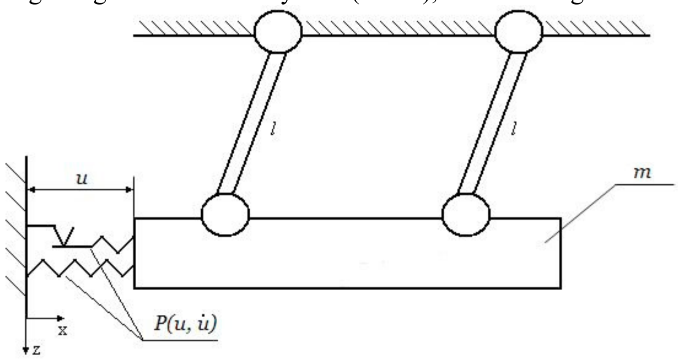

Fig. 1. Dynamic model of the pendulum type SIS idealized by a SDoF system

In Cartesian coordinates *x, z*, the equation describing the model in Fig. 1 has the form (Rutman 2012):

$$m\frac{l^2}{l^2-u^2}\ddot{u}+ml^2\frac{u\cdot\dot{u}^2}{\left(l^2-u^2\right)^2}=-m\left(g-\ddot{z}(t)\right)\frac{u}{\sqrt{l^2-u^2}}-P\left(u,\dot{u}\right)-\alpha\dot{u}-m\ddot{x}(t) \tag{1}$$

Where m is the mass of the superstructure (protected structure (PS)), l is the length of the pendulum, g is the acceleration due to gravity, x and z are the coordinates, describing the motion of the structure foundation, u is the coordinate that describe the displacements of the protected system related to the foundation, α is the linear damping constant and the $P\left(u,\dot{u}\right)$ is the bilinear restoring force of the plastic damper of the pendulum type SIS.

When deriving the equation (1) it was assumed that the pendulum rods, constituting the SIS were absolutely rigid. In fact, the rods can deform in their longitudinal direction. As a result of this, vertical and torsional oscillations of the PS will occur. If we take into account the deformation of the rods and consider the PS as a rigid body, the SIS becomes a 6 DoF system. Taking into account the principal properties (its structure and geometry) of the considered pendulum bearings, the model of the Idealized system: protected object – SI device has the following view, Fig. 2: