SEISMIC REACTION OF FRAME BUILDINGS WITH A COMBINED SEISMIC PROTECTION SYSTEM

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Abstract. *The aim of the study is to search for methods to improve the efficiency of the earthquake protection systems with rubber-metallic seismic insulating supports by combining them with dry friction and brittle uncoupling elements. The research is based on dynamic modelling methods. The computational dynamic model of the combined earthquake protection system and the system of differential equations of the seismic motion of a five-story frame building were compiled and an algorithm for estimating the efficiency and selection of the optimum parameters of the earthquake protection system was developed. Horizontal shifting seismic forces, maximum mass movements and maximum movements of rubber-metallic seismic insulating supports at different intensities and prevailing periods of seismic soil oscillations were determined. It is shown that, by using a combined earthquake protection system, seismic loads on frame buildings can be reduced by a factor of 1.5-2 and maximum mass movements – by 4-5 times. In addition, the area of rational application of seismic isolation systems with rubber-metallic supports in relation to the prevailing periods of seismic ground oscillations is expanding substantially.*

Keywords: *seismic actions, frame buildings, rubber-metallic seismic insulating supports, elements of dry friction, shutdown elements, horizontal shearing seismic forces, maximum mass movements, maximum movements of rubber-metallic seismic insulating supports*

INTRODUCTION

Modern provision of seismic resistance is quite an expensive task, especially for objects of increased responsibility. Therefore, the search for ways to effectively improve the seismic resistance of buildings and structures in recent decades has been aimed at developing an active seismic protection system. A detailed list of copyright certificates in this direction is given in the work. [1].

Unlike traditional methods of ensuring earthquake resistance associated with increasing the load-bearing capacity of structures, active seismic protection systems can reduce the levels of inertial forces that occur in buildings during an earthquake, i.e. seismic loads. For the first time, a proposal on the use of seismic protection systems in the form of roller supports and columns with spherical upper and lower supports was published by M. Viscordini in 1925.

Since that moment, a number of active seismic protection systems have been investigated and implemented in construction [2 -27].

Problem statement. Seismic-insulating rubber-metal supports [6], which have sufficient rigidity in the vertical direction and good pliability in the horizontal plane, are more widely used to ensure earthquake resistance and reliability of buildings and structures. If they have sufficiently high efficiency in buildings of rigid design solutions, then in flexible buildings there are problems associated with their unacceptably large movements during seismic impacts with prevailing low frequencies of soil vibrations. As one of the ways to solve this problem, this article examines a system of seismic insulation with rubber-metal supports, supplemented with dry training elements and switching-off elements.

One of the largest manufacturers of seismic insulating supports in Europe is the Italian company "FIPINDUSTRIAL". This company produces a wide range of rubber-metal supports, which are classified depending on the types of rubber into soft, normal and hard. In addition, they are made with and without a lead core. In this paper, rigid rubber-metal supports with a lead core are considered as more effective for flexible buildings. Figure 1 shows the design scheme of the combined seismic protection system under study.

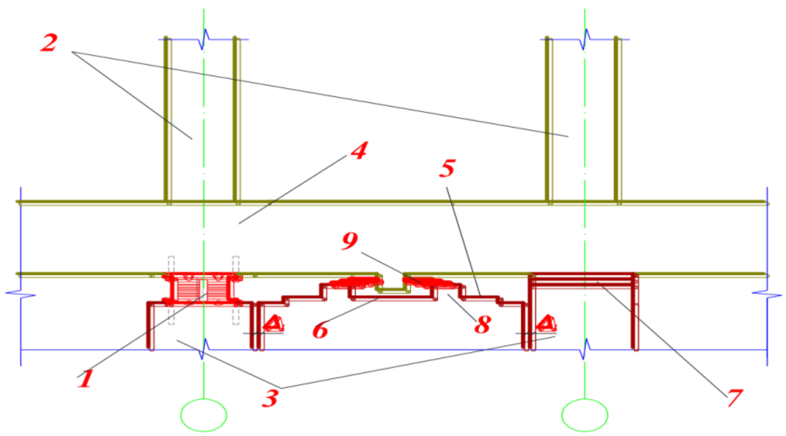


Fig.1. Combined seismic protection system:

1 - seismic insulating rubber mount; 2 - columns of the above-foundation part of the building; 3 - racks of the basement of the building; 4 - reinforced concrete support belt at the bottom of the column; 5 - stiffening diaphragm between the columns, 6 - gap between the shoulder of the belt and the stops of the stops; 7 - elements of dry friction; 8 - stop limiter; 9 - switching elements; Δ1 - gap between the pillars of the basement and the diaphragm of rigidity in the basement

Research methods. The calculated dynamic model of the combined seismic protection system under study is represented in the form of a cantilever rod n+1 by the number of concentrated masses, as shown in Fig. 2.

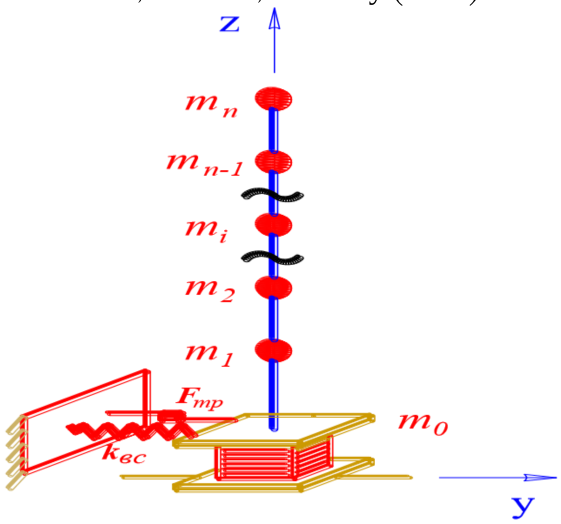


Fig.2. Dinamic model of the building with a combined seismic protection system, including rezinometallic bearings, dry friction elements and switching elements

The system of differential equations of motion of the above-mentioned nonlinear dynamic model subjected to seismic action is represented as:

$$m_0\ddot{y}_0 + c_0\dot{y}_0 + c_1(\dot{y}_0 - \dot{y}_1) + R(y_0) + F_{тр}sign\dot{y}_0 + €y_0 + k_1(y_0 - y_1) = -m_0\ddot{y}_{гр}$$

$$m_1\ddot{y}_1 + c_1(\dot{y}_1 - \dot{y}_0) + c_2(\dot{y}_1 - \dot{y}_2) + k_1(y_1 - y_0) + k_2(y_1 - y_2) = -m_1(\ddot{y} \quad + \ddot{y}_0)$$

m_0 - the mass concentrated at the level of the top of the rubber- metal supports, $m_1,\ m_2, .., m_i,\ ...,\ m_{n-1},\ m_n$– concentrated masses at the floor levels; $k_1,\ k_2,\ ..., k_i\ ..., k_{n-1},\ k_n$– floor stiffness of the building; $c_0,\ c_1,\ c_2,\ ...,\ c_{n-1},\ c_n$– floor attenuation coefficients; $\ddot{y}_{гр}$– seismic impact, represented as a real accelerogram or a non–stationary random process; $R(y_0)$– nonlinear restoring force in rubber–metal supports; y_0- displacement at the top level of rubber-metal supports; $y_1, y_2, ..., y_n$- displacement of the corresponding masses, $\dot{y}_0, \dot{y}_1, ..., \dot{y}_n, \ddot{y}_0, \ddot{y}_1, ..., \ddot{y}_n$ – the velocity and acceleration of these masses.

The restoring force is $R(y_0)$represented in the form of [24]

$$R(y_0) = Ay_0(1\text{-sign}\omega) + (By_0 + ς(F_1\text{-}Bd_1))\frac{1}{2}(\text{sign}\omega + (1\text{-sign}\psi))(1\text{- sign}\eta) + (Ay_0 + ς(AC + F_1\text{-}D))\text{sign}\eta. \quad (2).$$

In the system (1) - the friction force in the sliding supports.

With the same number of them with rubber-metal supports

$$F_{тр} = f_{тр}0,5\sum_{i=1}^{n} m_i g \quad (3)$$

$F_{тр}$ where, - is the coefficient of sliding friction in the supports.

$$\text{sign}\dot{y}_0 = \begin{cases} -1, \text{когда } \dot{y}_0 > 0 \\ 1, \text{когда } \dot{y}_0 < 0. \end{cases} \quad (4)$$

The restoring $€y_0$ force in the switching elements is indicated by. Here, according to the "Force-displacement" relationship shown in **Fig. 3**

$$€ = \begin{cases} \boldsymbol{k}_{\text{вс}\mathbf{1}}, \text{когда } |\boldsymbol{y}_{\mathbf{0}}| < \boldsymbol{b}_{\mathbf{1}} \\ \boldsymbol{k}_{\text{вс}\mathbf{2}}, \text{когда } \boldsymbol{b}_{\mathbf{1}} \le |\boldsymbol{y}_{\mathbf{0}}| < \boldsymbol{b}_{\mathbf{2}} \\ \boldsymbol{k}_{\text{вс}\mathbf{3}}, \text{когда } \boldsymbol{b}_{\mathbf{2}} \le |\boldsymbol{y}_{\mathbf{0}}| < \boldsymbol{b}_{\mathbf{3}} \\ \mathbf{0}, \text{когда } \boldsymbol{b}_{\mathbf{3}} \le |\boldsymbol{y}_{\mathbf{0}}| \end{cases} \quad (5)$$

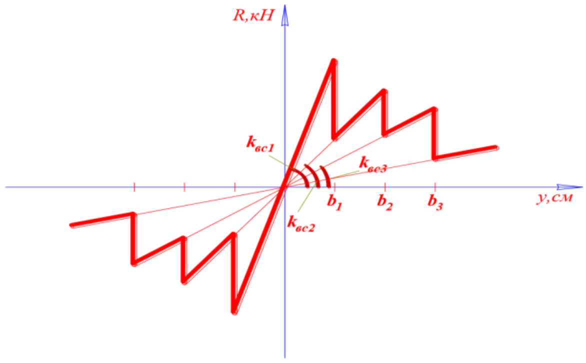


Fig.3. The plot of the «Restoring force-displacement» relationship for a system of three consecutively-off elements

$\boldsymbol{k}_{\text{вс}\mathbf{1}}$ –rigidity in the state of operation of all switching-off elements;

$\boldsymbol{k}_{\text{вс}\mathbf{2}}$ – rigidity in the state of switching off the elements of the I-th level;

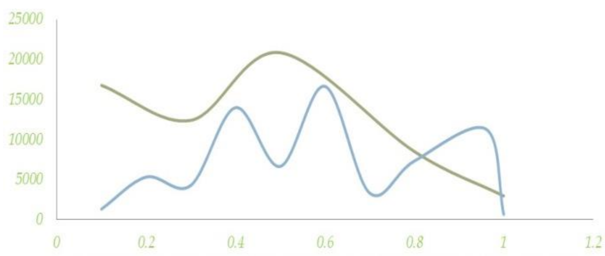
$\boldsymbol{k}_{\text{вс}\mathbf{3}}$ – rigidity in the state of switching off the elements of the II-th level;

$\boldsymbol{b}_{\mathbf{1}}$ – displacement, in which the elements of the first level are turned off; $\boldsymbol{b}_2$– displacement, in which the elements of the second level are turned off; $\boldsymbol{b}_3$– displacement, in which the elements of the third level are turned off.

The following are the results of a study of the effect of switching-off elements and dry friction elements on the movement of rubber-metal seismic-insulating supports and the top of columns in 5-storey frame buildings.

Discussion of the results. The maximum values of horizontal shifting seismic forces at the time corresponding to the maximum displacement of the lower concentrated mass are shown in Fig. 4.

a)



b)

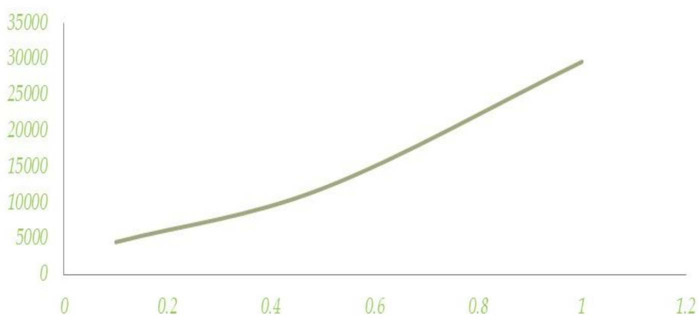


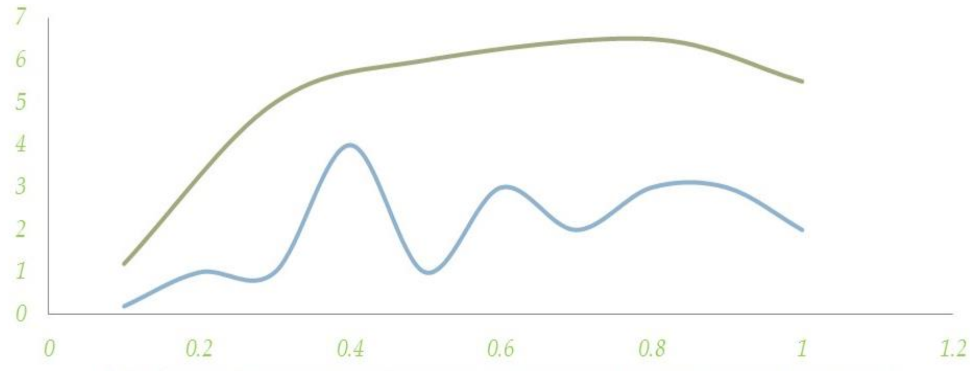
Fig.4. Graphs of horizontal seismic shifting seismic forces for a 5-story frame building: A - with a combined seismic protection system; Б - without seismic isolation

The graphs show that the use of a combined seismic protection system consisting of RMSO, dry friction elements and switching elements in frame buildings reduces the maximum floor-by-floor shear forces by almost 1.5 times at the time when the movement of the rubber-metal support is maximum.

Compared with a building without seismic isolation systems, there is an almost twofold decrease in these forces during low-frequency seismic impacts.

The maximum values of horizontal displacements of the masses of the considered system are shown in **Fig. 5**.

a)



b)

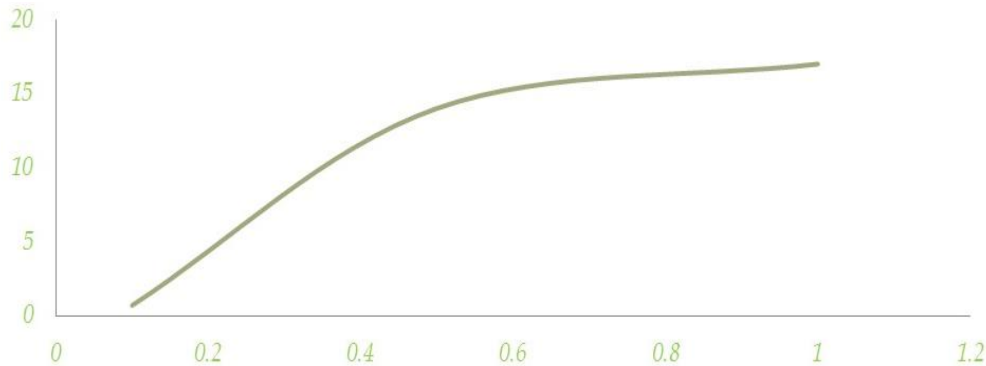


Fig.5. The graphs of the movements of concentrated masses for a 5-story frame building:

a - with a combined seismic protection system; б - without seismic isolation

It follows from Figures **5. a)** and **5. b)** that combining rubber-metal supports only with dry training elements leads to a decrease in the maximum mass displacements by 2-3 times, and with dry cooling and switching off elements – 4-5 times.

Graphs of maximum displacements and residual deformations of the RMSO are shown in Figures 6 and 7. It follows from Figure 6 that the maximum level of displacement of the top of the considered rubber-metal supports, equal to 40 cm, in the seismic protection system without switching off elements reaches at prevailing periods of seismic vibrations of soils exceeding 0.8 s, and with switching off elements – at periods exceeding 1.0 s.

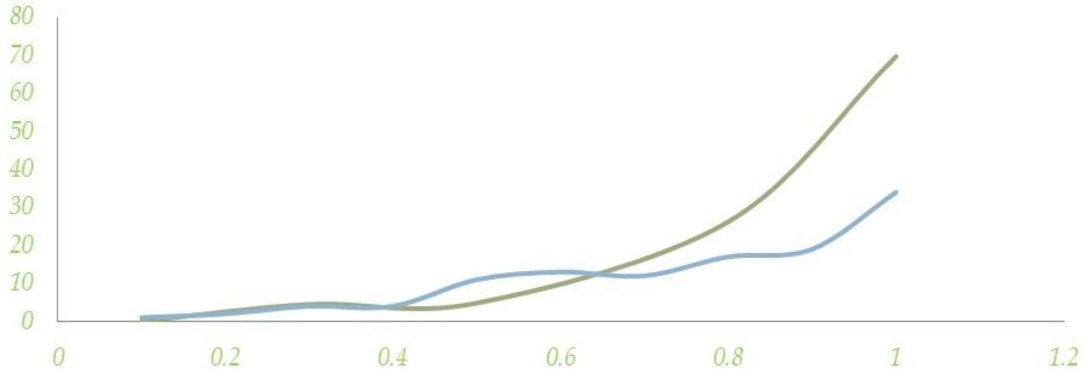


Fig. 6. Graphs of the dependence of the maximum displacement of the top of the rubber-metal supports max from the prevailing soil oscillation period for 5-story frame buildings

with a combined seismic protection system.

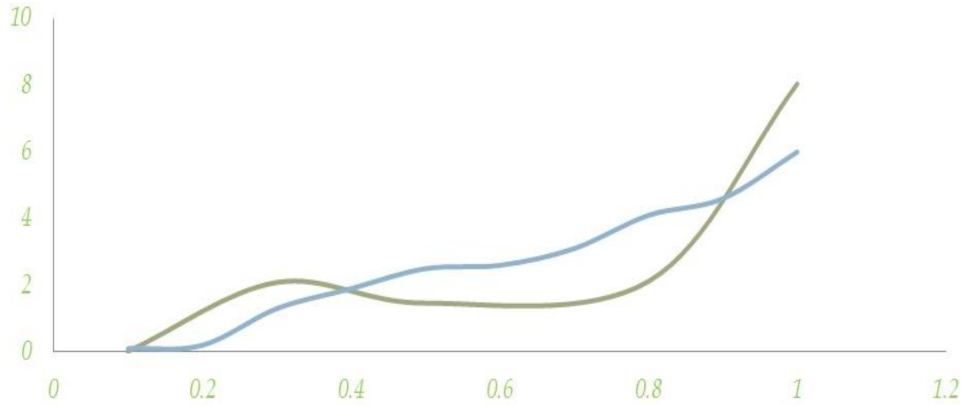


Fig. 7. Graphs of the dependence of the maximum residual displacements of the prevailing period of soil oscillation for 5-story frame buildings with a combined seismic protection system.

CONCLUSION

The introduction into the system of seismic insulation with rubber-metal supports and dry friction of switching elements, which allow the system to adapt to the resonant frequencies of vibrations of the base soils, significantly increases the efficiency of seismic protection of flexible structures under low-frequency influences.

For example, whereas in 5-storey frame systems without seismic insulation, the maximum horizontal shear force exceeds 25,000 kN with prevailing periods of seismic vibrations of soils exceeding 0.8 s, with a combined seismic protection system, the shear force does not exceed 10,000 kN. Here, the maximum movements of the building in the mass concentration levels are reduced by 4-5 times.

The introduction of switching-off elements into the seismic protection system makes it possible to expand the scope of effective use of rubber-metal supports by increasing the range of possible prevailing periods of seismic vibrations of soils, in which the maximum movement of the top of rubber-metal supports does not exceed the maximum permissible value, and reducing the maximum residual movements of rubber-metal supports with a lead core.

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