# Research of Residual Deformations of Seismic Isolation Systems with Rubber-Metal Supports with Lead Core Under Seismic Effects

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*Abstract* – **The influence of the type of constructive system of buildings, their number of floors, as well as the parameters of seismic impact on the residual deformations of seismic insulating rubber-metal supports with lead core installed at the level of the top of foundations is investigated. By constructive solution, the structures are divided into frame, wall and frame-wall. Floors are taken equal to 5, 9 and 12. Seismoisolating rubber metal supports with a lead core are classified into flexible, semi-rigid and rigid. The characteristics of rubber-metal supports offered by the Italian company "FIN INDASTPIALE" are taken as the basis. The seismic impact is modeled on a computer in the form of a non-stationary random process with an intensity of 9 points and a duration of 20 seconds. The predominant period of soil oscillations under seismic effects is assumed to vary from 0.1 s to 2.0 s. Considering that in the considered structures the center of masses and the center of rigidity coincide in the plan, and their overlaps are hard disks, the calculated models of the structures are taken as a multi-mass cantilever rod, where the lower mass is located at the top of the rubber-metal supports. The "Force-displacement" dependence characteristic of rubber-metal supports with a lead core is approximated in the form of a bilinear elastic-plastic dependence. The original system of differential equations of oscillations is integrated on a computer by a numerical method. The maximum residual deformations in rubber-metal supports with a lead core under seismic effects with prevailing periods of soil oscillations varying from 0.1 s are determined. up to 2.0 s. in increments of 0.1 s. At the same time, the maximum acceleration of ground motion is assumed to be 400 cm/s$^2$. The analysis of the obtained results was carried out and the areas of effective use of rubber-metal supports of different stiffness with a lead core in the structures of the frame, wall and frame-wall structural systems were determined.**

***Keywords – structures; rubber support with a lead core; seismic effects; residual deformations.***

## I. Introduction

The area of ensuring seismic stability of buildings and structures is currently divided into two directions. One of them is based on the application of traditional methods, where seismic resistance is provided by strengthening the structures of buildings and structures, primarily by increasing the cross sections of these structures. The second direction is based on special methods of seismic protection, which allow reducing the seismic response of buildings and structures by, first of all, creating horizontal connections that are pliable between the aboveground and underground parts of buildings. In the last decade, the second direction has been developing more intensively, as it allows to reduce the costs of seismic amplification of buildings and structures and increase their reliability. Among these systems, rubber-metal supports are more popular in practice, mass production of which is established in many developed countries [1-4]. The support itself is made without a core and with a lead core, which increases the damping properties of the supports. They are more effective when used for seismic isolation of highly responsible objects and with seismic effects of intensity of 9 or more points.

## II. Problem Statement

Rubber-metal supports with lead core supports are not yet fully understood. First of all, it concerns the residual deformations in the supports during strong earthquakes. Lead, as is known, is a plastic material, so it is important to study its work of rubber-metal supports beyond the elastic limit. It is known that seismic effects, as a rule, have different spectral and other characteristics. And seismic loads acting on buildings and structures depend on their dynamic characteristics, which are determined by the constructive solutions of these buildings and structures. To assess the effectiveness of seismic isolation, it is necessary to take into account this complex interaction of seismic impact characteristics, seismic isolation systems, buildings and structures.

## III. RESEARCH QUESTIONS

The use of rubber supports for seismic isolation of buildings and structures is widespread in countries exposed to seismic effects. Initially rubber mounts were used for bridge piers, later they were used for seismic insulation of buildings [5-7]. In the horizontal plane, the supports provide the possibility of a flexible movement of the building, while in the vertical plane they have a rather high rigidity. Rubber-metal supports are metal plates, alternating with layers of polymeric material (neoprene, rubber, rubber). Depending on the damping characteristics, rubber-metal seismic isolating supports are distinguished from low (without core) and high (with lead core) damping. Fig.1 [6-7]

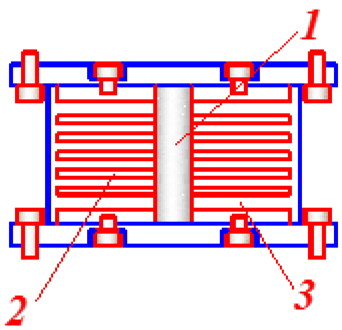



Fig. 1. Lead-core seismic isolating rubber metal support 1-lead core, 2-steel plate, 3-high-strength rubber (caoutchouc).

Rubber supports with a lead core with strong effects can get large residual deformations that reduce their effectiveness or preclude their use as elements of seismic isolation. The possibility of large residual deformations in these supports confirms the characteristic type of dependence "Restoring force-displacement" for supports with a lead core shown in Fig. 2.

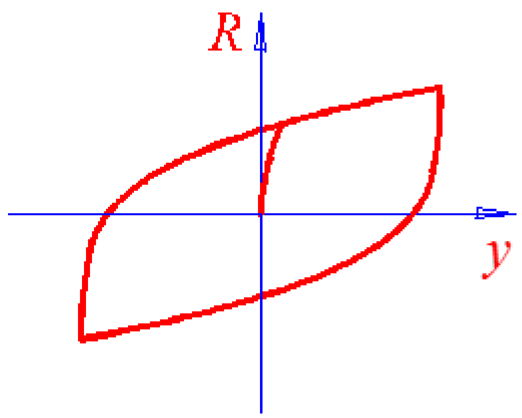



Fig. 2. Dependence “Restoring force - displacement” for a rubber-metal support with a lead core

It is an experimental, obtained as a result of testing rubber supports. Depending on the effective stiffness, the rubber-metal supports are divided into flexible, semi-rigid and rigid. The constructions themselves, proceeding from the constructive system, are divided into frame, wall, and frame-wall, differing mainly in dynamic characteristics. The article investigates residual deformations of rubber metal supports with a lead core in buildings of different heights and rigidity under seismic effects, presented in the form of synthesized accelerograms with different spectral characteristics.

## IV. PURPOSE OF THE STUDY

The purpose of the study is to determine the effectiveness of seismic isolation when using rubber-metal supports with a lead core in structures of different heights and constructive solutions for different rigidity of these structures by the criterion of the minimum of their residual deformations.

## V. METHODS AND MATERIALS

To solve this problem, we will present a design model of a building with seismic insulating rubber-metal supports in the form of a cantilever rod with concentrated masses (Fig. 3).

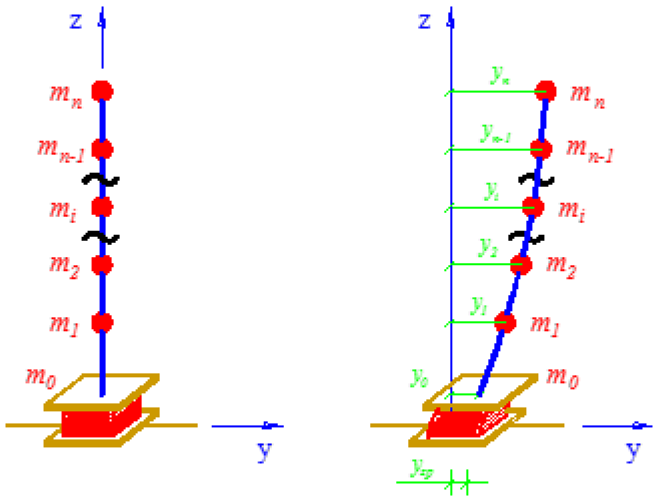



Fig. 3. Calculation model of systems with seismic rubber mounts: in steady state (a), in oscillation state (b)

The system of differential equations of motion of a system with rubber-metal seismic isolation supports is written in the form: $\boldsymbol{m_0\ddot{y}_0 + c_0\dot{y}_0 + c_1(\dot{y}_0 - \dot{y}_1) + R(y_0) + k_1(y_0 - y_1) = -m_0\ddot{y}_{\text{гр}}}$

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

..........................................................................................(1)

$$\boldsymbol{m_i\ddot{y}_i + c_i(\dot{y}_i - \dot{y}_{i-1}) + c_{i+1}(\dot{y}_i - \dot{y}_{i+1}) + k_i(y_i - y_{i-1}) + k_{i+1}(y_i - y_{i+1}) = -m_i(\ddot{y}_{\text{гр}} + \ddot{y}_0)}$$

..........................................................................................

$$\boldsymbol{m_n\ddot{y}_n + c_n(\dot{y}_n - \dot{y}_{n-1}) + k_n(y_n - y_{n-1}) = -m_n(\ddot{y}_{\text{гр}} + \ddot{y}_0)}$$

где ***i=2÷n-1***.

Where: $m_0$ - the mass is concentrated at the top of the rubber support;

$m_1,\ m_2,\ \ldots, m_i,\ \ldots,\ m_{n-1},\ m_n$ - concentrated masses at overlap levels;

$k_1,\ k_2,\ \ldots, k_i \ldots,\ k_{n-1},\ k_n$ - floor stiffness coefficients;

$c_0,\ c_1,\ c_2,\ \ldots,\ c_{n-1},\ c_n$ floor attenuation coefficients;

$\ddot{y}_{zp}$ - seismic impact, represented as a random process or a real accelerogram of an earthquake;

$R(y_0)$ – nonlinear restoring force corresponding to the construction in the level of seismic isolation supports;

$y_0$– moving in the top level of rubber supports;$y_1, y_2, \ldots, y_n$ – displacement of the corresponding masses.

We simulate the seismic effect $\ddot{y}_{\text{rp}}(t)$ on a computer in the form of a non-stationary random process of 9-point intensity. On the basis of effective stiffness, rubber-metal supports are divided into flexible, semi-rigid and rigid [9]. The dependence $R(y_0)$ is represented in the form of a bilinear elastic-plastic dependence [10].

Integrating the system of differential equations (1) on the computer using a numerical method, we find the parameters of the seismic response of structures and rubber-metal supports.

## VI. Results

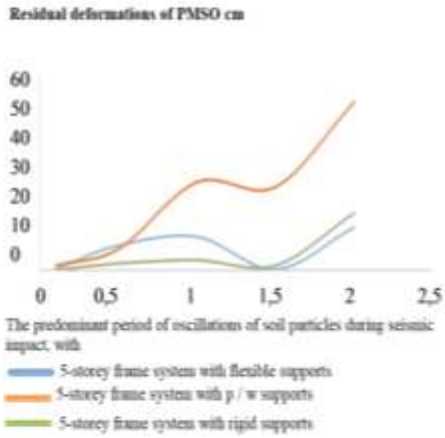
Sample graphs of residual deformations of PMSO with a lead core under seismic effects with different prevailing periods of oscillations $T_0$ are shown in Figures 4 and 5.

As can be seen from the graphs in the 5-storey structural systems significant residual deformation in the rubber-metal supports with a lead core occur when they are used in frame systems and large-period seismic effects. This is especially true of semi-rigid supports, in which the predominant period of oscillations of the soil equal to 0.8 with a residual deformation reaches 20 cm, the Magnitude of residual deformations of rigid and flexible supports in the range of the dominant oscillation periods from 0.1 s to 2 s does not exceed 18 cm.

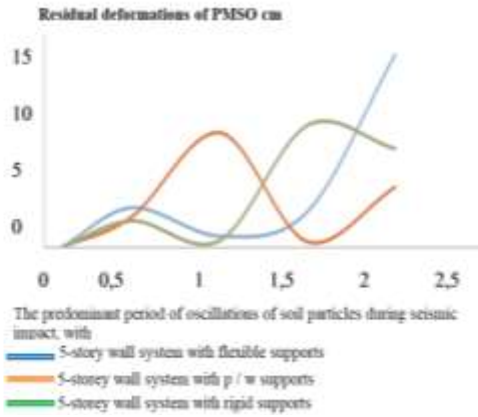
Minimum residual deformations are observed in frame-wall 5-storey systems, in which rigid supports even with the predominant period of oscillations equal to 2 s receive residual deformations not exceeding 9 cm. In 5-storey wall systems, the maximum residual deformations of the supports have the following values: for flexible supports – 15 cm, for semi-rigid supports – 8 cm and for rigid supports – 9 cm. In frame systems, maximum residual deformations receive semi-rigid supports, and minimum residual deformations are observed in rigid supports. In wall construction systems, the maximum residual displacements in high-frequency earthquakes receive flexible supports, and in rigid ones, minimal residual deformations are observed.

In 9-storeyed frame systems, semi-rigid supports receive residual deformations, the magnitude of which with large-period oscillations does not exceed the maximum allowable values of displacements of the support itself. Residual deformations of flexible and rigid supports with prevailing periods of soil oscillations ranging from 1.5 s to 2 s are unacceptably large. In the 9-storey wall and frame-wall systems, as shown in Figure 5, the residual deformations of the supports are within acceptable limits. In wall systems, semi-rigid supports are more effective, and in frame-wall ones, flexible supports are used for low-frequency seismic effects, and semi-rigid for high-frequency ones.

a)




b)




c)

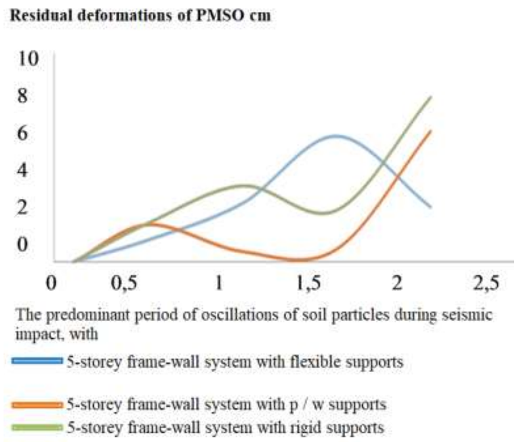
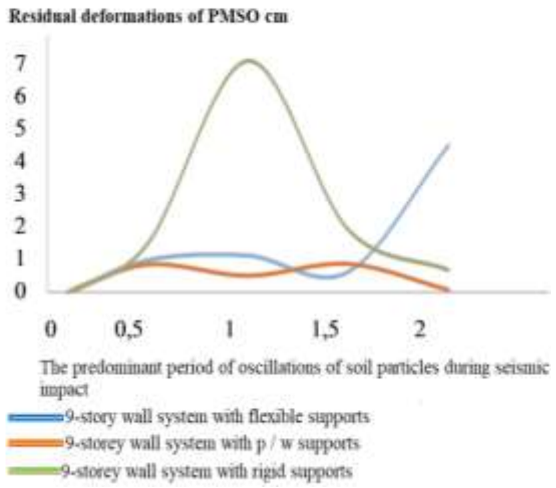



Fig. 4. Dependency graphs $|\mathbf{y_0}|_{\text{ocr}}$ from $\mathbf{T_0}$ for 5-storey systems with PMSO with a lead core: a - frame; in - wall; c - frame-wall

a)




b)

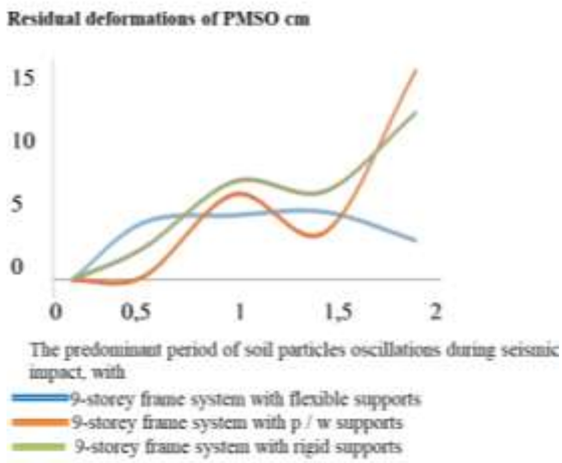



Fig. 5. Dependency graphs $|\mathbf{y_0}|_{ocr}$ from $\mathbf{T_0}$ for 9-storey systems with lead core MCOs: a – wall; b – frame and wall.

TABLE I. THE VALUES OF THE MAXIMUM RESIDUAL DEFORMATIONS OF PMSO WITH A LEAD CORE IN THE RANGE OF THE PREVAILING SEISMIC PERIODS $T_0$ FROM 0.1 S TO 2.0 S, IN CM

| **Number of system levels** | **Structural construction scheme** | **With seismic isolation in the form of rubber supports with lead core** | | |
|---|---|---|---|---|
| | | ***flexible*** | ***semi-rigid*** | ***rigid*** |
| 5 | frame | 13.6 | 51.11 | 17.39 |
| | wall | 14.6 | 8.67 | 8.9 |
| | frame-wall | 6.1 | 6.24 | 8.4 |
| 9 | frame | 51.87 | 45.85 | 40.37 |
| | wall | 4.87 | 12.55 | 11.55 |
| | frame-wall | 6.5 | 13.77 | 13.12 |
| 12 | frame | 109.3 | 21.91 | 22 |
| | wall | 8.54 | 6.25 | 6.38 |
| | frame-wall | 13.71 | 12.37 | 10.95 |

Analysis of the results of studies of 12-storey structures showed that here in frame systems only flexible supports receive unacceptably large displacements and then under long-period seismic impacts. With seismic effects with a predominant period of ground oscillations up to 1 s, rigid supports are most effective in frame systems, and with a period of oscillations of more than 1 s - semi-rigid. In the wall systems, as compared with the frame-wall and frame systems, at low-frequency seismic effects, the rubber-metal supports receive minimal residual deformations. In wall and frame-wall systems of the three types of supports, minimal residual deformations are observed in rigid supports. Table 1 shows the values of the maximum residual displacements of PMSO in the range of the prevailing seismic periods T_0 from 0.1 s to 2.0 s.

## VII. CONCLUSION

Residual deformations of PMSO with a lead core are proportional to the maximum displacements of these supports. In frame systems, they are significant, and in frame-wall and wall systems do not go beyond the permissible. In frame-wall systems, rigid PMSCs receive small permanent deformations as compared with flexible and semi-rigid ones, and in wall systems, semi-rigid PMSCs are more rational. The greater the storey of the system, the greater its rigidity must be, so that the rigidity of the seismic insulating supports themselves do not have a significant effect on their residual deformations.

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