Study of the seismic isolation sliding belt: the case of a monolithic reinforced concrete building

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Abstract. This work highlights the application of an active seismic protection system using a sliding belt in the foundation to protect buildings and facilities located in earthquake-prone areas. The widespread type of seismic protection using rubber-metal supports (RMS) is complex and sometimes not cost-effective. The considered method of seismic protection using seismic isolation sliding belts has a number of advantages over the other types of seismic protection. However, the considered seismic isolation system still does not have an adequate mathematical model describing its action in the building-seismic isolation-foundation-base system. The study covered the efficiency of applying the seismic insulation sliding belt through the example of a 16-story monolithic reinforced concrete building. As a result of the calculations, the absolute accelerations, velocities, relative displacements, and intensity of stresses in the considered structure were obtained. An analysis of the calculations indicates the efficiency of seismic isolation using a sliding belt in the foundation for buildings constructed in earthquake-prone areas.

1. Introduction

The catastrophic consequences of earthquakes are well-known. Approximately 30% of the area of the Russian Federation is located in earthquake-prone areas with a likelihood of earthquakes with an intensity of up to 9 points on the MSK-64 scale. In this regard, ensuring the seismic resistance of buildings and facilities built in earthquake-prone areas is an urgent and significant task in construction. Currently, to ensure the seismic resistance of buildings and facilities, various active seismic protection systems are used (systems with disconnecting links [1], gravity-type systems, systems with dynamic vibration dampers, systems with suspended supports, swing sliding supports, rubber-metal supports (RMS) [2, 3, 4], and with a sliding belt in the foundation). In our country and abroad, the RMS seismic protection system is the most common. However, the high cost, as well as the complexity of installation and maintenance, have led to the search for other types of seismic protection, one of which is seismic protection using a sliding belt, which is currently not fully supported with necessary design justification.

Many domestic and foreign researchers have been engaged in research and development of active seismic protection systems. The problem of seismic resistance of buildings and facilities was covered in the works of J. M. Eisenberg [1, 5], V. S. Plevkov and A. I. Malganov [6], G. A. Jinchvelashvili and O. V. Mkrtichev [7], A. M. Uzdin [8], John M. Kelly [9], N. Kani [10] and other scientists. The works of V. P. Chudnetsov and L. L. Soldatov [11], V. D. Kuznetsov and Chen Syatin [12] are devoted to the issues of seismic protection using a seismic insulation sliding belt, and show the efficiency of this type of seismic protection.
Despite the fact that the type of seismic isolation considered in this article is fairly known and has a practical use, there are still little studied issues of developing adequate mathematical models and relevant calculation methods.

2. Methods
To ensure the seismic resistance of buildings and structures under construction in earthquake-prone areas, various methods of seismic protection are used: Passive (traditional) and active. At present, the passive methods seismic protection are the primary methods used in construction. The use of the traditional approach to ensuring seismic resistance, which involves an increase in cross-sections and load-bearing elements, leads to an increase in the weight of the building and, consequently, an increase in inertial seismic forces. In many cases, it is advisable to use active methods of seismic protection: Seismic isolation and seismic dumping. Let's consider the seismic isolation action principle in more detail.

When using seismic isolation, the reduction of seismic impact on buildings and facilities is achieved through the introduction of special structural elements: seismic isolators into the structures of buildings and facilities (Fig.1.a and b), which enhances the structure's pliability. And this, in turn, leads to an increase in displacement in the upper part of the structure. It results in a decrease in the acceleration of concentrated masses, and seismic inertial forces [13].

![Figure 1. A deformed diagram of an uninsulated building under seismic impact (a), a deformed diagram of an isolated building under seismic impact (b).](image)

Let us consider a case of a seismic protection system using a sliding belt (Fig. 2).

![Figure 2. Scheme of a seismic insulating sliding belt: 1-the lower part of the building at the foundation level, 2-fluoroplastic plates, 3-foundation, 4-damper (coarse sand), 5-waterproofing, 6-concrete preparation.](image)

Seismic isolation using a sliding belt in the foundation is based on a sliding system, which includes a friction minimizing component and a major horizontal displacement limiting component. A friction minimizing component can be made of different materials: elastic graphite coating, stainless steel,
PTFE plates, etc. PTFE plates were used as a friction-minimizing component in the study. When the total inertial force exceeds a certain value, slippage occurs in the supporting elements of the seismic isolation system, which leads to a decrease in the acceleration peaks in the system.

Differential equations of the motion of a system with a finite number of degrees of freedom in the matrix form [14]:

\[ M\ddot{u} + C\dot{u} + Ku = f^a, \]

where \( u \) is the unknown vector of nodal displacements;
\( \dot{u} = v \) – nodal velocity vector;
\( \ddot{u} = a \) – nodal acceleration vector;
\( M \) – mass matrix;
\( C \) – damping matrix;
\( K \) – stiffness matrix;
\( f^a \) – vector of applied loads.

The solution of the system (1) can be obtained by using explicit and implicit schemes of direct integration of motion equations. When using methods that implement an implicit integration scheme, expression (1) at a time point \( n+1 \) can be presented as:

\[ M\ddot{u}_{n+\Delta t} + C\dot{u}_{n+\Delta t} + Ku_{n+\Delta t} = f^a_{n+\Delta t}, \]

Difference approximation of nodal accelerations \( \ddot{u} \), velocities \( \dot{u} \), and displacements \( u \), as follows:

\[ \ddot{u}_{n+\Delta t} = \frac{1}{\alpha\Delta t^2}(u_{n+\Delta t} - u_n) - \frac{1}{\alpha\Delta t} \dot{u}_n - \left(1 - \frac{1}{2\alpha}\right)\ddot{u}_n, \]

\[ \dot{u}_{n+\Delta t} = u_n - \Delta t(1 - \delta)\ddot{u}_n + \delta\Delta t \dddot{u}_{n+\Delta t}, \]

\[ u_{n+\Delta t} = u_n + u_n \Delta t + \left[\frac{1}{2} - \alpha\right] \dddot{u}_n + \alpha\dddot{u}_{n+\Delta t}\Delta t^2, \]

where \( \alpha \) and \( \delta \) are the integration parameters.

When using an explicit scheme of integration of the system motion equation, the following is obtained:

\[ M\ddot{u}_t + C\dot{u}_t + Ku_t = f^a_t, \]

Acceleration vector:

\[ a_t = M^{-1}(f^\text{ext}_t - f^\text{int}_t), \]

where \( f^\text{ext}_t \) is a vector of external forces; \( f^\text{int}_t \) is a vector of internal forces.

Velocity and displacement vectors at the corresponding step:

\[ \mathbf{v}_{t+\Delta t/2} = \mathbf{v}_{t-\Delta t/2} + \mathbf{a}_t\Delta t. \]
\[
\mathbf{u}_{t+\Delta t} = \mathbf{u}_t + \mathbf{v}_{t+\Delta t/2} \frac{\Delta f_t + \Delta f_{t+\Delta t}}{2}.
\]  

(9)

An explicit integration scheme was used in the calculation.

The object of the study was a 16-story monolithic reinforced concrete building (Fig. 3 and 4) with seismic isolation and without it on a rigid base.

![Figure 3. Construction of the finite element circuit.](image)

![Figure 4. Typical floor plan.](image)

The calculation uses a direct nonlinear dynamic method in the LS-DYNA multi-purpose finite element software package. The analytical model used rod and shell solid finite elements.

Below is a one-component accelerogram of external seismic impact (Fig. 5).

![Figure 5. Accelerogram of external seismic impact (component X).](image)

The analysis of the results of the action of a system with and without seismic protection under seismic impact. See below the main results of the study (Fig. 6 to 9, Table 1).

3. Results

Below are the absolute accelerations and velocities of the top point of the building (Fig. 6 and 7). Relative displacements of the building top point along the X-axis (Fig. 8) and the stress intensity of the most loaded element of the building (Fig. 9) are shown in the diagrams below.

The diagrams show the results for buildings with and without seismic isolation.
Figure 6. Absolute accelerations of the top of the building along X.

Figure 7. Absolute velocities of the top of the building along X.

Figure 8. Relative displacements of the top point of the building along X.
4. Discussion
Based on the results obtained, a comparative analysis of the action of a monolithic reinforced concrete building with and without seismic isolation was performed (Fig. 6 to 9, Table 1). As can be seen, the use of seismic isolation using a sliding belt in the foundation significantly reduces seismic forces. Absolute accelerations decreased up to 2.6 times, velocity up to 2.8 times, relative displacements up to 2.7 times, and stresses up to 2.4 times.

The works [15, 16, 17, 18, 19, and 20], too, studied the efficiency of using a sliding seismic isolation system, but in a less strict set-up. The results obtained in the present study are in good agreement with the results of studies in these works and indicate the efficiency of this method of seismic isolation.

5. Conclusions
The results of the study of a 16-story reinforced concrete monolithic building with a seismic isolation sliding belt in the foundation show a significant decrease (2.4 to 2.8 times) in the system response parameters (acceleration, velocity, displacement, and stress).

The considered approach makes it possible to reduce the cost of construction of reinforced concrete buildings in earthquake-prone areas while ensuring the required level of safety and reliability.

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