Analysis of the reaction of reinforced concrete buildings with a varying number of stories with a seismic isolation sliding belt to an earthquake

Oleg Mkrtychev and Salima Mingazova

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia

Abstract. This article deals with the application of an active seismic protection system in the form of a seismic isolation sliding belt at the foundation level to ensure the seismic stability of a building or a structure. The type of seismic protection studied in this paper is simpler in design, cost-effective, and at least as efficient as widely used metal-rubber supports (MRS). Currently, the considered seismic isolation system does not have an adequate mathematical model to describe its operation in the building-seismic isolation-foundation-base system. The efficiency of using a seismic isolation sliding belt to ensure seismic stability of a structure was studied as exemplified by a cast in-situ reinforced concrete building with a varying number of stories (three-story, five-story, nine-story, sixteen-story building). As a result of the calculations, the relative displacements and accelerations and the intensity of stresses in the most loaded structural element were obtained. The analysis of the obtained results shows the efficiency of using a seismic-insulating sliding belt at the foundation level to ensure the seismic stability of buildings and structures.

1. Introduction

About 30% of the Russian population lives in seismically active zones, where there is a probability of a high-intensity earthquake. Therefore, ensuring the seismic stability of buildings and structures being erected in earthquake-prone areas is an urgent and practically significant task in construction.

Passive and active seismic protection methods are used to ensure the seismic stability of buildings and structures. Currently, passive seismic protection methods are mainly applied. However, these methods are not always efficient: when the cross-section of the load-bearing elements of a structure increases, its total mass increases as well, which can lead to an increase in inertial forces, and therefore to an increase in the external seismic impact. In some cases, it is advisable to use the active methods of seismic protection.

There are various systems of active seismic protection [1-4], among which the most popular at present is seismic protection in the form of rubber metal supports (MRS). The type of seismic protection studied in this paper in the form of a sliding support at the foundation level is simpler in design, cost-effective, and no less efficient. However, the necessary calculation justifications of this system are not fully available at this time.

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 [2] and O. V. Mkrtychev [7], A. M. Uzdin [8], John M. Kelly [9], N. Kani [10] and other scientists [15-20]. 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. The efficiency of the type of seismic protection considered in this article has been proved by experimental studies. However, there are still little-studied issues regarding the development of adequate mathematical models and appropriate methods of calculation.

2. Methods
Reducing the seismic impact on buildings and structures when using seismic isolation is achieved by introducing special structural elements, seismic isolators (Fig.1.a and b), into the structure making the structure more pliable and reducing the peak accelerations in the system [13].

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

The basis of seismic isolation in the form of a sliding belt at the foundation level is the implementation of a sliding system, which includes a component to minimize friction and a component to limit large horizontal movements. Various materials are used as a friction minimizing component: graphite flexible coating, stainless steel, PTFE plates, etc. In the study, PTFE plates were considered as the friction minimizing component. When the total inertial force of a certain value is exceeded, slippage occurs in the support elements of the seismic isolation mechanism, thus decreasing the acceleration peaks in the system.

When solving the problem, the following differential equation was considered, which is as follows in the matrix form [14]:

\[
\mathbf{M} \ddot{\mathbf{u}} + \mathbf{C} \dot{\mathbf{u}} + \mathbf{K} \mathbf{u} = \mathbf{f}^d
\]

Let us consider the solution of the problem by a direct dynamic method using an explicit integration scheme:
\[ M \ddot{u}_t + C \dot{u}_t + K u_t = f_t^a \]  

For accelerations, speeds, and displacements, we will have:

\[ a_t = M^{-1} \left( f_t^{ext} - f_t^{int} \right) \]  

\[ v_{t+\Delta t/2} = v_{t-\Delta t/2} + a_t \Delta t \]  

\[ u_{t+\Delta t} = u_t + v_{t+\Delta t/2} \frac{\Delta t_t + \Delta t_{t+\Delta t}}{2} \]

The subject of the study was a cast in-situ reinforced concrete building with a varying number of stories (3, 5, 9, 16 story) (Fig.3, 5), with seismic isolation (Fig.4) and without seismic isolation, on a rigid base.

The building structural diagram is a cross-wall construction. Spatial rigidity is provided by the joint effect from walls and stiffening cores with disks of cast in-situ floor slabs. Load-bearing structures are made of B25 concrete, with A500 main reinforcement. A typical floor height is 3.0 m. The building length is 24.7 m, width 19.8 m, and height 49.2 m. Walls and stiffening cores are 0.2 and 0.25 m thick. Floor slabs are 0.22 m thick. Floor girders are of rectangular section and 0.4 x 0.4 m in size.

The intensity of seismic impact is 8 points according the MSK-64 scale.

\[ \text{Figure 3. The finite element diagram of the building: a) three-story building; b) five-story building; c) nine-story building; d) sixteen-story building} \]
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. 6).

The analysis of the results of the behavior of a cast in-situ reinforced concrete building with a varying number of stories, with and without seismic protection, in case of a seismic impact was performed. The main results of the study are given below: graphs of relative displacements and accelerations along the X-axis, stress intensity, and a comparative table of results for all the considered numbers of stories.

3. Results
You will find below some graphs of relative displacement (Fig.7) and acceleration along the X-axis of the top point of a 9-story reinforced concrete building (Fig.8) and a graph of the intensity of stresses in the most loaded element of the 1st level of a 9-story building (Fig.9), paintings with isopoles of displacements, stress intensities, strain intensities (Fig.10-14) as well as a comparative table of the results obtained for all the considered numbers of stories (Table 1). The graphs show the results for a building with and without seismic isolation.
Figure 7. Moving the top point of a 9-story building relative to the foundation along the axis X, [m]

Figure 8. Acceleration of the top point of a 9-story building relative to the foundation X axis, [m/s²]

Figure 9. Stress intensity in the most loaded element of the 1st floor 9-storey building, [Pa]
Figure 10. The picture with isopoles of displacements at time $t = 9$ s 9-storey building: a) without seismic isolation; b) with seismic isolation, [m]

Figure 11. The picture with isopoles of stress intensity at time $t = 9$ s 9-storey building: a) without seismic isolation; b) with seismic isolation, [Pa]

Figure 12. Picture with isopoles of strain intensity for the 9th building: a) without seismic isolation b) with seismic isolation
Figure 13. Picture with isopoles of stress intensity for the 1st tier of the 9th building:
   a) without seismic isolation b) with seismic isolation, [Pa]

Figure 14. Picture with isopoles of strain intensity for the 1st tier of the 9th building:
   a) without seismic isolation b) with seismic isolation

Table 1. Comparative table of results for buildings with seismic isolation and without seismic isolation

| No | Number of storeys | The maximum value of displacement along the X axis, [m] | Ratio | The maximum value of acceleration along the X axis, [m/s^2] | Ratio | The maximum value of the voltage intensity, [MPa] | Ratio |
|----|-------------------|-------------------------------------------------------|-------|----------------------------------------------------------|-------|-------------------------------------------------|-------|
|    |                   |                                                       |       |                                                          |       |                                                 |       |
|    | three-story building |                                                      |       |                                                          |       |                                                 |       |
| 1  | without seismic isolation | 0,0016                                               | 3,2   | 0,364                                                    | 2,82  | 4,74                                            | 1,4   |
|    | with seismic isolation   | 0,0005                                               |       | 0,129                                                    |       | 3,33                                            |       |
|    | five-story building |                                                      |       |                                                          |       |                                                 |       |
| 2  | without seismic isolation | 0,018                                               | 9     | 7,3                                                      | 14,9  | 33,7                                            | 5,58  |
|    | with seismic isolation   | 0,002                                               |       | 0,49                                                     |       | 6,04                                            |       |
|                      | nine-story building | sixteen-story building |
|----------------------|---------------------|------------------------|
|                      |                     |                        |
| 3                    | without seismic     | 0.027                  |
| isolation            | isolation           |                        |
|                      | 2.25                | 2.045                  |
|                      | 5.64                | 2.99                   |
|                      | 2.7                 | 56.3                   |
|                      | 30.7                | 2.18                   |
|                      | 2.46                |                        |
|                      | with seismic        | 0.012                  |
| isolation            | isolation           |                        |
| 4                    | without seismic     | 0.107                  |
| isolation            | isolation           |                        |
|                      | 2.6                 | 2.57                   |
|                      | 7.69                | 25.82                  |
|                      | 2.99                |                        |
|                      | 56.3                |                        |
|                      | 2.18                |                        |
|                      | with seismic        | 0.041                  |
| isolation            | isolation           |                        |

4. Conclusions
The results of the study show that the use of a seismic-insulating sliding belt at the foundation level increases the seismic resistance of a building. The use of this seismic isolation system can reduce the seismic impact on the ground part of a building by a point or more. The analysis of the study results shows that this type of seismic protection is efficient for buildings of a minor number of stories (three-storey building), as well as for high-rise buildings (sixteen-story building).

To conclude about the efficiency of using a seismic isolation sliding belt to reduce external seismic impacts on the building and its degree, it is necessary to conduct studies of a specific building, taking into account the parameters of the seismic impact by solving the problem using a nonlinear dynamic method.

The proposed approach to ensuring seismic stability of buildings and structures is practically acceptable and does not require significant costs for implementation of anti-seismic measures.

References
[1] Eisenberg Y M 1976 Off-line facilities for seismic areas (Moscow: Stroizdat) p 232
[2] Dzhinchvelashvili G A and Bunov A A Study of lead rubber bearings operation with varying height buildings at earthquake Procedia Engineering 2014 91 pp 48-53
[3] Mkrtychev O V and Bunov A A 2016 Reliability of reinforced concrete buildings with a seismic isolation system in the form of rubber-metal supports during an earthquake ACB Publishing p 121
[4] Bunov A A 2017 Are search on Performance Efficiency of Rubber Metal Support Structures IOP Conf. Series: Materials Science and Engineering 269 012067 doi:10.1088/1757-899X/269/1/012067
[5] Eisenberg Y M , Akbiev R T , Granovsky A V, Smirnov V I and Chigrin S.I 2007 Seismic Safety: Research, Norms, Design Industrial and Civil Engineering 3 pp 22-25
[6] Plevkov V S and Malganov A.I 2010 Reinforced concrete and stone structures of earthquake-resistant buildings and structures (Publishing house of the Association of construction universities) p 290
[7] Mkrtychev O V 2010 Safety of buildings and structures during seismic and emergency impacts. (Moscow: Publishing House Association of Construction Universities) p 152
[8] Uzdin A M, Sandovich T A and Samikh Amin Al-Nasser-Mohomad 1993 Fundamentals of the theory of earthquake-resistant construction of buildings and structures (St. Petersburg: Publishing House VNIIG them. B.E. Vedeneeva) p 176
[9] Kelly J M 1991 Base isolation in Japan, 1988. Report to the National Science Foundation. Report No. UCB/EERC-88/20 (Berkeley: University of California) p 90
[10] Kani N 2008 Current State of Seismic – Isolation Design The 14th World Conference on Earthquake Engineering pp 110-120
[11] Chudnetsov V P and Soldatova L L 1979 Buildings with a seismic insulating sliding belt and elastic displacement limiters Earthquake-resistant construction 14 5 pp 1-3
[12] Kuznetsov V D and Chen Syatin 2011 Sliding belt with fluoroplast of an earthquake-resistant building Engineering and Construction Journal 3 pp 53-58
[13] Polyakov V S, Kilimnik L Sh and Cherkashin A V 1989 Modern methods of seismic protection of buildings (Moscow: Stroizdat) p 320
[14] Klafl R and Penzien J 1979 The dynamics of structures (Moscow: McGRAW-HILL BOOK COMPANY New-York) p 316
[15] Kuznetsov V D and Lyadsky V A 2010 Seismic isolation of public buildings based on fluoroplastic Civil Engineering Journal 3 pp 53-58
[16] Abakarov A D and Zainulabidov H R 2016 Evaluation of the areas of rational use of the seismic isolation system of buildings with a sliding foundation belt Bulletin of the Dagestan State Technical University. Technical sciences 1 (40) pp 77-85
[17] Zaynulabidov H R 2015 Assessment of the influence of the number of storeys on the effectiveness of the use of seismic isolation systems with a sliding belt Science Week - 2015. Collection of abstracts of reports XXXVI of the final scientific and technical conference of teachers, employees, graduate students and students of Dagestan State Technical University pp 138-140
[18] DavydoVA G V, Ermoshin A A, Uzdin A M and Rumyantsev A Yu 2007 Assessment of the movement of buildings with a seismically insulated sliding belt Earthquake-resistant construction. Safety of facilities 3 pp 34-37
[19] Apsemetov M Ch, Andashev A Zh, Shamshiev N U and Apsemetov A M 2018 Fluctuations in the model of low-rise buildings with a seismic insulating belt under seismic influences Bulletin of the International Institute of Management 1 pp 68-73
[20] Gian Michele Calvi and Paolo M. Calvi, Matteo Moratti 2017 Seismic isolation of buildings using devices based on sliding between surfaces with variable friction coefficient Innov. Infrastruct. Solut DOI 10.1007/s41062-017-0081-8