Seismic resistance increase of operated buildings using special seismic protection devices

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Abstract. In recent years, seismicity has been increased several times in the Russian Federation. The situation exerts a significant effect on the seismic resistance of existing facilities. It is known that buildings can be reinforced by using various methods among which unconventional seismic protection devices that include seismic isolation and seismic damping hold a special place, being efficiently used not only in newly built buildings, but also in operated ones. Unconventional methods implementation of the seismic resistance increase in operated buildings is shown using specific examples. Rubber-metal supports, dynamic absorber and rubbing friction dampers are used. Recommendations on their specific use to improve buildings seismic resistance are offered.

Introduction
Approximately 30% of Russian territory are within seismic areas and may be subjected to earthquakes attack with a magnitude higher than 7. In accordance with latest data in the general seismic regionalisation maps, seismicity of the Russian Federation territory significantly changed and, therefore, areas of seismic zones and the volume of expected seismic impact increased. Due to this, seismic resistance issues become very important not only in newly built buildings, but also in operated ones. This especially relates to residential buildings since a significant part of the housing stock does not meet current residents demands on qualitative characteristics and technical equipment of buildings. Many buildings within this area have already depleted their technical resources, need repairs and require retrofitting to prevent emergencies due to higher seismicity.

Based on the above, the reliable provision and trouble-free operation of existing residential buildings becomes very important and relevant. Construction practice contains two approaches to improve the building seismic resistance. These are the conventional and unconventional methods.

Conventional retrofit methods (without changing the dynamic building design) may include:
- seismic retrofitting of individual bearing buildings components (walls, partitions, columns);
- retrofitting of units between buildings elements (units of reinforced-concrete frames, units of walls intersection and interfaces, etc.);
- assembling buildings elements into a unified system to distribute load between all bearing elements.

The following measures shall be taken during seismic retrofit of individual bearing elements:
- shotcrete lining on a metal mesh;
- masonry injection;
- concrete collars, etc.

Improvement of seismic resistance of operated buildings and structures also includes the consolidation of bases and foundations.

Conventional methods to improve the building seismic resistance are described in extensive literature presented, for example, in [1–6]. However, very often builders have to deal with structures of building erected in 19–20 centuries with complex space-planning and design solutions and, due to this, the use of conventional solutions is not always possible, or the price of retrofitting becomes very high. Thus, presently unconventional seismic protection devices receive widespread use. Unconventional methods of seismic protection are based on dynamic design of facility operation and are divided into seismic damping and seismic isolation [7–14].

Seismic damping provides for the additional dampers installation, impact and dynamic absorbers. Seismic damping systems including dampers and dynamic absorbers, mechanical energy of an oscillating structure is transformed into other types of energy leading to oscillations damping, or is redistributed from the protected structure to the absorber.

Another unconventional method of seismic protection is seismic isolation providing for installation of ductile elements in foundation parts of the building to increase the natural period of oscillations and, thereby, seismic loads decrease. Seismic isolation utilisation efficiency was confirmed abroad in existing buildings that underwent seismic impact. Examples of such buildings include the Central Bank in Irkutsk, a school in Aleksandrovsk-Sakhalinsk, and other cities.

Despite the broad scope of research on the use of unconventional devices in seismic protection not only in newly built buildings, but in existing buildings, there are few methods applications to improve the seismic resistance of operated buildings, specific recommendations on their use in buildings of various purposes are not available and so forth. Due to this, there is a need for continuation of further study of the issues and a collection of required information and experience for objective assessment of the seismic resistance of operated buildings with the use of special seismic protection devices.

**Methods**

Theoretical and computational studies were performed on flat and spatial models with the use of various software complexes. Theoretical and computational studies were performed in several stages. During the first stage, a high-rise large panel building was considered and it was suggested to improve the earthquake resistance by the installation of seismic isolation foundations. Design models of considered building are presented on figure 1. General view of support member is represented on figure 2.
The building considered for retrofit is notable for a relatively rigid structural design. Therefore, it was assumed that use of seismic isolation could produce a significant effect on the seismic load decrease.

Figure 1. Design model of the building:
  a) without seismic isolation; b) with seismic isolation

Figure 2. Lead Rubber Bearings:
  a) 3D view of support; b) type of support with geometrical parameters
Schemes of differentiated motion equations for design models considered in matrix form can be written as follows:

\[ \mathbf{M}\dddot{\mathbf{Y}} + \gamma\mathbf{M}^{1/2}\mathbf{R}^{1/2}\ddot{\mathbf{Y}} + \mathbf{R}\dot{\mathbf{Y}} = -\mathbf{M}\ddot{\mathbf{Y}}_0, \]

where

- \( \mathbf{M} \) – is a lumped mass matrix;
- \( \mathbf{R} \) – is a stiffness matrix;
- \( \dot{\mathbf{Y}} \) – is a column of generalized shifts;
- \( \gamma \) – is an inelastic resistance rate.

At the second stage, the dynamic absorber use on the roof was considered as a solution for seismic protection of an operated building. The absorber design was assumed as per the suggested structure [15]. Behavioural features of dynamic absorbers in structures of operated buildings were presented in publications [16–20].

Results
The completed set of studies led to the conclusion that the introduction of rubber-metal supports (overall resultant quantity under the building is 98 pcs.) leads to a significant decrease in seismic load (twofold and lower) proving the efficiency of using seismic insulation in existing residential buildings to improve their seismic resistance.

A series of various calculations with different properties of dynamic absorber were performed to confirm the dynamic absorber use as a seismic protection device. The calculations showed that tuning-out of the absorber parameters (which is possible during operation) for buildings with rigid structures vs. initial settings is less sensitive. However, the oscillations absorber use in rigid structures showed lower results than in more flexible buildings.

It was found that significant impact on stress-strain condition of the structure is made by the absorber oscillation mode. A dynamic absorber is efficient when its weight is not more than 5% of the total mass of the building to be protected.

The following conclusions were made on the basis of studies conducted.

Summary
A methodology of the theoretical computational efficiency assessment of seismic isolation and seismic damping devices used in the seismic protection system of operated buildings was developed and implemented.

It was shown that the extent of decreasing seismic loads is a function depending on several parameters of an operated building, including the natural period of the first-mode oscillations.

The use of rubber-metal supports in operated building reduces seismic load twice or more and may ensure the building seismic resistance.

The dynamic absorber efficiency is ensured only upon availability of additional damping elements. However, the absorber weight should be 3 to 5% of weight of operated building to be protected.

It was shown that with the same weight and frequency of absorber setting, the mode of its oscillations is of substantial significance. During structural absorber design it is required that minimum first two forms of initial absorber oscillations and that of the operated building were the same.

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