The use of damping devices to increase the seismic resistance of frame buildings

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Abstract: Frame system is one of the most common types of systems in the construction and design of buildings and structures due to their "flexibility" in the choice of design solutions, which, as a result, allows you to use this system in buildings and structures for various purposes, and in different natural and climatic conditions, including in conditions of high seismic activity. However, the analysis of consequences of strong earthquakes showed that many of the frame buildings during seismic effects get serious damage caused by the destruction of their joint connections, and as a consequence, instability of the frame to seismic shocks, therefore, the issues of reliability and safety of operation of buildings are important for their functioning. One of the ways to increase seismic resistance is the use of various means of seismic protection, including earthquake extinguishing devices in the form of dampers, which are widely distributed in the world. However, their application in the domestic practice of earthquake-resistant construction is limited. The article presents an overview of damping devices and conducted a computational study of the effectiveness of traditional and non-traditional solutions in the form of dampers in frame multi-storey buildings to increase their seismic resistance.

1. Introduction
Among the special methods of seismic protection, which allow achieving significant damping of vibrations, in the modern world are systems with increased damping - dampers.

Dampers allow you to translate the kinematic energy of the system’s vibrations into other types of energy due to the inclusion of special devices in the building structure, whose task is to increase the dissipated energy to reduce accelerations and inertial forces in the system [1].

Based on the classification presented in the work Belash T.A. and Uzdin A.M. [2], there are three fundamentally different types of dampers, which will be considered below: deformation; viscous friction; dry friction.

Energy loss in deformation dampers occurs due to plastic deformation of the material (metal) of the damping device. Such dampers are very efficient and economical.

The contribution to the development of mechanical energy absorbers was made by Ostrikov G.M. and Maximov Yu.S. They developed and analyzed the effectiveness of plastic dampers used in the construction of multi-story steel frame buildings (Figure 1). Its developments have shown sufficient reliability as a result of tests (withstand up to 100 cycles of alternating loads) [3].
In 2018, a new type of plastic damper was proposed in China, called an oval damper (iPOD), which consists of two arches with intermediate straight arms. It is designed for inelastic deformation, for dispersion of seismic energy of building structures. A series of tests proved the effectiveness of this damper [4].

Examples of application of various plastic damper systems are shown in Figures 2, 3 and 4.

**Figure 1.** Elastic-Plastic energy absorbers [3]: a-ring type; b-tubular; C – beam type; d-single.

**Figure 2.** An Example of using a plastic deformation damper [5].

**Figure 3.** School building with a plastic deformation damper [6].
Viscous friction dampers provide the possibility of obtaining significant viscous resistance forces at relatively small sizes, and also smoothly switch on and do not cause high-frequency oscillations. However, the relative high cost and complexity of operation limits their mass application.

Currently, in earthquake-resistant construction, mainly two types of viscous dampers are used: lead dampers and liquid dampers. Lead dampers were developed by specialists from New Zealand V. Robinson and R.I. Skinner (1971). Energy dissipation in such dampers occurs due to overcoming the forces of plastic deformation of lead arising when extruding it through an extrusion hole (Figure 5) [2,7].

Lead dampers have several advantages over other damping devices, for which they are becoming more widespread in earthquake-resistant construction abroad. These benefits include:

- Long service life - the process of lead deformation is carried out in a hermetically sealed volume, and plastic mass loss does not occur, which allows not to change dampers after an earthquake;
- A large allocation of temperature, contributing to the rapid restoration of the crystalline structure of lead and, accordingly, ductility.

An advantage of damping devices of lead dampers is the possibility of damping vibration energy in any horizontal direction.

Viscous type hydraulic dampers from Maurer Suhnes and FIP Industriale are widely used. Hydraulic devices are designed to repeatedly absorb loads from design earthquakes and should not be replaced with new ones after design seismic effects [2].

In the late 1980s, engineers of the Japanese company Sumitomo Construcktion Company the viscous friction wall damper was developed and successfully tested (Figure 6). By 1992, this damper was installed in more than 100 building projects [8]. The principle of the wall is shown in Figure 7.
In dry friction dampers, the main factor absorbing seismic vibrations is the dry friction forces arising in dampers.

In the process of designing dampers of this type, the following tasks are solved [10,11]:

- To create the necessary friction forces, it is necessary to ensure a balance between the coefficient of dry friction and the compression force of the rubbing pairs. Therefore, it is necessary to carefully select the working materials, since an error in the selection of material can lead to unstable operation of the mechanism.
- It is necessary to create the possibility of adjusting the dry friction forces at the stage of construction and operation, to ensure the most accurate damper settings.
- Since during the operation of dry friction dampers there is an abrupt change in the forces acting on the amplification object, such devices must be used in buildings whose designs smoothly turn on in order to reduce the effect of the appearance of unfavorable “spurious” oscillations of the entire system.

An example of a dry friction damper is a QUAKETEK damping device, which is shown in Figure 8 and 9.
As the analysis showed, the damping devices considered have high dissipative properties and are effective when working during an earthquake, but in the practice of domestic construction, such devices have not been widely used, so to assess the possibility of their use in domestic earthquake-resistant construction, computational and theoretical studies were conducted.

2. Methods

As the object under study, a project of a 15-story frame frame-and-link residential building made of monolithic reinforced concrete was considered.

Based on the selected planning solution, a simplified building model was described in the SCAD 21.1 settlement complex that describes the supporting structures of the frame. Cross-section of the core elements of the frame is 400x400 mm. The thickness of monolithic floor slabs and coating slabs is 160 mm. The thickness of the walls of the stairwell and elevator shaft is 250 mm. Elements material - concrete B25. Connections are present in the design of the elevator shaft and stairwell, which are connected with the frame at the level of each floor using steel plates with a width of 150 mm and a thickness of 12 mm, thereby the walls forming the shafts of the communication structures will work together with the frame and act as a stiffener that meets the standards of earthquake-resistant construction. This model, conventionally designated as model 1, does not have any seismic protection devices, and is the source for the following options described in Table 1. The second model provides for the traditional reinforcement of the frame using stiffness diaphragms. A distinctive feature of the third model is the presence of a dry friction damper in the building frame. The damper design was adopted as a QUAKETEK [12] device.

Loads were set in accordance with domestic regulatory documents [13-15]. For all three models, the loading is the same. Damper properties were evaluated by varying the attenuation coefficient. The
A computational and theoretical study was performed using a linear-spectral method using normative recommendations [16].

**Table 1. Description of calculation models.**

| Number of model | Description                      |
|-----------------|----------------------------------|
| 1               | Original model                   |
| 2               | As a seismic protection, the traditional method was used, by installing stiffening diaphragms made of B25 concrete with a thickness of 120 mm, for the entire height of the building. |
| 3               | The structure of the frame includes friction-type damping devices on the 13th, 14th, and 15th floors of the building |

Note: for clarity, 3D models 2 and 3 have been disabled elements that simulate floor slabs.

### 3. Results and discussions

At the first stage of the study, the seismic resistance of buildings without traditional seismic protection structures and without dampers in seismic effects of 9 points was evaluated. Commissioning of stiffness models over the entire height of the building in the form of wall structures. A study of a multi-story frame building using dampers was conducted. Various options for placing devices in plan and on the floor were considered.

A comparative evaluation of the results of the study showed that the behavior of the building without additional means of protection can get a serious buildup, while the movements in the level of the upper floors reach up to 200 mm. The oscillation period of such a system is 1.4 s. The introduction of traditional means of protection leads to a decrease in displacements, the period of natural oscillations decreases to 1.1 s, which affects the value of the seismic load. A significant effect is provided by the use of dry friction dampers, which reduce both the seismic load and improve the stress-strain state of the frame system.

### 4. Conclusions

- Frame system is one of the most well-known in the construction of buildings for various purposes, widely used in complex climatic and seismic conditions of construction, and the impact of seismic impact can be very significant.
- To increase the earthquake resistance of frame buildings, in the world practice of earthquake-resistant construction, along with traditional solutions, special means of seismic protection, which include damper devices, have become widespread.
- An analysis of the existing design solutions of various types of dampers showed that among these devices, viscous and dry friction dampers are the most effective, and dry friction
dampers are more preferable due to their relatively low cost, ease of manufacture, and stability of operation during an earthquake.

- An assessment is given of the possibility of using dry friction dampers in the designs of multi-story frame buildings made of reinforced concrete elements to ensure its earthquake resistance.
- It is established that the introduction of dry friction dampers provides not only the necessary level of reduction of seismic loads, but also allows you to maintain the stability of the stress-strain state of the frame building.
- It is shown that the introduction of dry friction dampers, in comparison with traditional solutions for increasing the seismic stability of frame buildings, made, for example, by installing stiffness diaphragms in the form of wall structures between racks of the frame, is a more effective and preferred means of seismic protection.

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