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MODERN METHODS OF ENSURING SEISMIC RESISTANCE OF HIGH-RISE BUILDINGS AND STRUCTURES

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Annotation: This article describes in detail the most commonly used methods currently used to ensure the seismic resistance of buildings and structures designed for construction in seismically hazardous areas.

Key words: seismic resistance of buildings and structures, traditional methods, non-traditional methods, active seismic protection, passive seismic protection.

Аннотация: В статье подробно описаны наиболее часто используемые методы обеспечения сейсмостойкости зданий и сооружений, проектируемых для строительства в сейсмоопасных районах.

Ключевые слова: сейсмостойкость зданий и сооружений, традиционные способы, нетрадиционные способы, активная сейсмическая защита, пассивная сейсмическая защита.

Annotatsiya: Ushbu maqolada seysmik xavfli hududlarda qurish uchun mo'ljallangan bino va inshootlarning seysmik chidamliligini ta'minlashning eng ko'p qo'llaniladigan usullari batafsil tavsiflangan.

Kalit so'zlar: bino va inshootlarning seysmik chidamliligi, an'anaviy usullar, noan'anaviy usullar, faol seysmik himoya, passiv seysmik himoya.

Introduction

Earthquake resistance- is an important characteristic that a building or structure must have when it is built in a seismically active region. And when designing high-rise buildings, the impact of an earthquake should be taken into account, even with a low probability of its occurrence. In addition, it is important that the effects of seismic loads on the lower and upper floors are different.

For example, decoding seismograms recorded in Tashkent in 2010 and 2016 showed that earthquakes with a magnitude of up to 4 points at ground level lead to effects on the upper floors corresponding to impacts of 6, 7 and more points.

In Uzbekistan and many foreign countries, two fundamentally different directions for increasing the seismic resistance of buildings and structures have currently been formed: traditional and special (non-traditional).

MAIN PART

1. Traditional methods of ensuring seismic resistance

The traditional approach to designing earthquake-resistant buildings is based on increasing the strength of the building's supporting structures and its ability to resist the impact of transverse dynamic loads. In this approach, seismic resistance is increased using space-planning and design measures. In this case, the following principles, which are included in the current regulatory documents and are given below, must be observed.

1. The principle of symmetry. Seismic masses and rigidities must be distributed evenly and symmetrically relative to the center of gravity of the structure.

2. The principle of harmony. The geometric parameters of the building must be proportional, and the length or height must not be extremely large.

3. The principle of mass reduction. The building must be designed from lightweight structures with the center of gravity located at the lowest possible height.

4. The principle of elasticity (ultimate compliance). Construction materials used for load-bearing and enclosing structures must have elastic properties, and structures made from them must be homogeneous.

5. The principle of a closed loop. Load-bearing structures must form closed loops in both vertical and horizontal directions.

6. The principle of fundamentality. Foundations must be laid deep enough with the replacement of the rigid connection between the foundation and the structure by using a plastic binder.

Increasing the load-bearing capacity of structures by simply increasing strength leads to additional costs of building materials and money.

In addition, these actions lead to an increase in mass and, as a consequence, inertial seismic loads.

2. Non-traditional methods of ensuring seismic resistance

Since it is practically impossible to predict the behavior of a building during an earthquake, therefore, along with traditional methods of ensuring seismic resistance of buildings, various seismic protection systems have been widely used in recent years - special (non-traditional) methods.

They are based on changing the mass or rigidity, as well as damping the system depending on its movements and speeds, which allows not only to reduce the costs of strengthening the structure, but also improves the strength characteristics and reliability of the entire building. The principles on which special methods are based include reducing the natural frequency of vibrations of a structure compared to the prevailing frequencies of seismic impact, constructing foundations without rigid connections to the structure, using dynamic dampers of various types, etc. In industrially developed countries, there are many objects, including buildings with a high degree of responsibility (reactor departments of nuclear power plants, airports, space industry facilities, high-rise buildings, etc.), in which various seismic isolation means are used. Among the means of special seismic protection, active (having an additional energy source) and passive can be distinguished.

2.1. Passive seismic protection

Despite the fact that earthquakes rarely damage the foundation, it plays an important role in ensuring the seismic resistance of the entire building. The stronger its connection with the ground, the higher the seismic loads formed in the supporting structures of the building, transmitted from the ground by the foundations. With the help of a passive seismic protection system, it is possible to reduce the connection between the building and the ground.

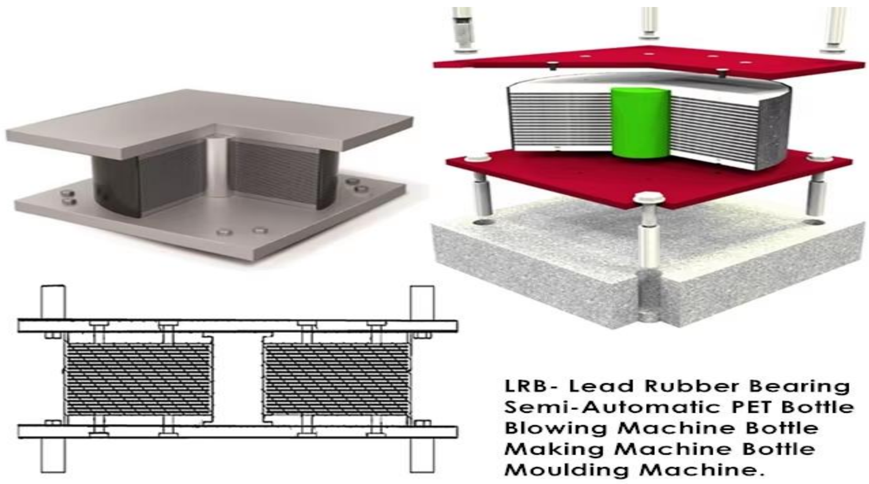
According to the underlying principle, these systems are divided into two directions, in one case the principle of friction-sliding is used, and in the other - friction-rolling.

2.1.1. Layered elastomeric bearings

The most common means of passive seismic protection in Russian and foreign construction are multilayer seismic isolators. Another name for multilayer seismic isolators is layered elastomeric bearings (LEB). Multilayer seismic isolators structurally consist of metal plates and rubber sheets, alternately laid one after another. Due to the elastic horizontal compliance of LEB, the foundation shifts together with the soil during an earthquake, and the fundamental frequency of natural oscillations of structures decreases, and parallel switching off of elastic-plastic devices leads to significant attenuation of oscillations.

The basic diagram of an elastomeric seismic isolator is shown in Figure 1.

In the overwhelming majority of cases, steel is used as the material for the metal plates. These plates prevent bulging of rubber sheets under vertical loads and provide vertical strength and rigidity to the supports.



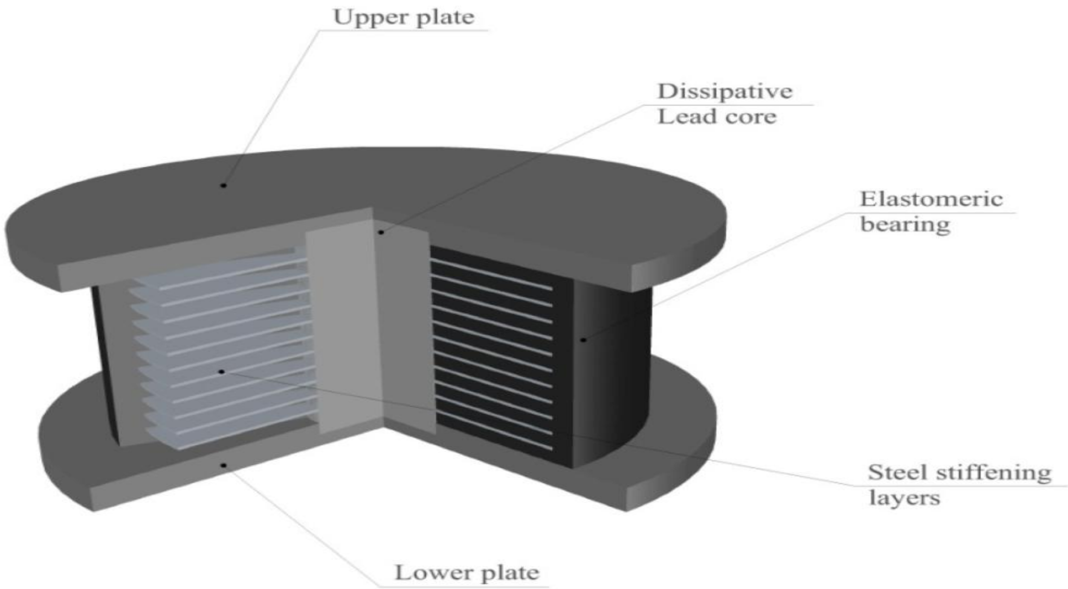


Figure 1 - Schematic diagram of an elastomeric seismic isolator

Polymer sheets are made of natural and artificial rubber. Possessing low shear rigidity of rubber, they are responsible for the horizontal compliance of supports.

Installation of support elements of multilayer seismic isolators is carried out under each frame column or at the intersection of load-bearing walls. This type of seismic isolators is designed to withstand multi-cycle tensile, compressive, shear and torsional forces.

If, when perceiving the dead weight of the building, the vertical deformations of elastomeric supports do not exceed several millimeters, then with horizontal vibrations, shear deformations reach several tens of centimeters (Fig. 2).

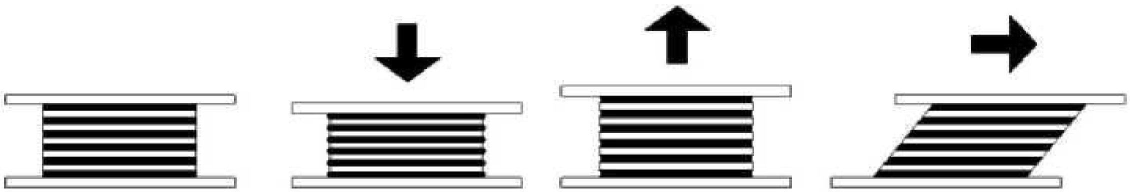


Figure 2 - Deformation of elastomeric support under compression, tension and shear

An example of the use of layered elastomer supports in construction practice is the 25-story building of the hotel and tourist complex "Sea Plaza" in Sochi, about 99 m high, in the underground part of which, to reduce seismic loads, SEOs manufactured by the Italian company "FIP Industriale SpA" were used.

This innovation made it possible to reduce seismic loads of design earthquakes by at least two times and preserve the proposed architectural appearance of the building, which does not meet some modern standards of earthquake-resistant construction in modern Countries of Independent States.

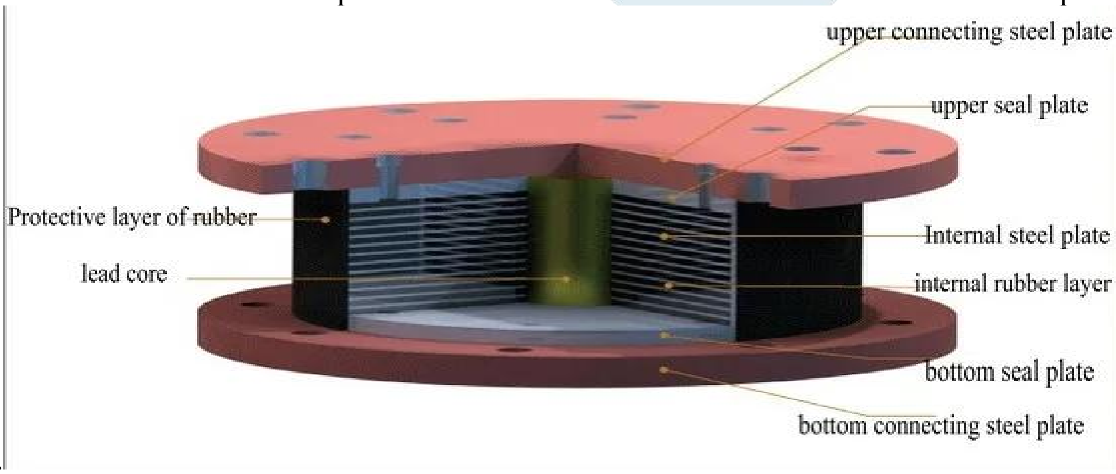


Figure 3 - Schematic diagram of an elastomeric seismic isolator with a lead core

2.1.3. Flat sliding supports

The friction-sliding principle is used to implement a method of seismic protection of a building using a sliding pair of fluoroplastic plates and polished stainless steel

(Fig. 4). They are supports or rows of supports located between the foundation edge and the lower support part of the building's load-bearing structures. In this system,

the lower steel plate, along which sliding occurs, is attached to the foundation structure, and the upper one has a rigid connection with the lower part of the building structures.

In an earthquake, the value of seismic forces will exceed the value of friction forces between the lower and upper plates, but due to the sliding of the building relative to the foundation moving together with the soil, it will maintain its equilibrium.

Flat sliding supports of dry friction are very sensitive and operate even with a small horizontal impact. In addition, the response threshold of this system is regulated by varying the friction coefficient.

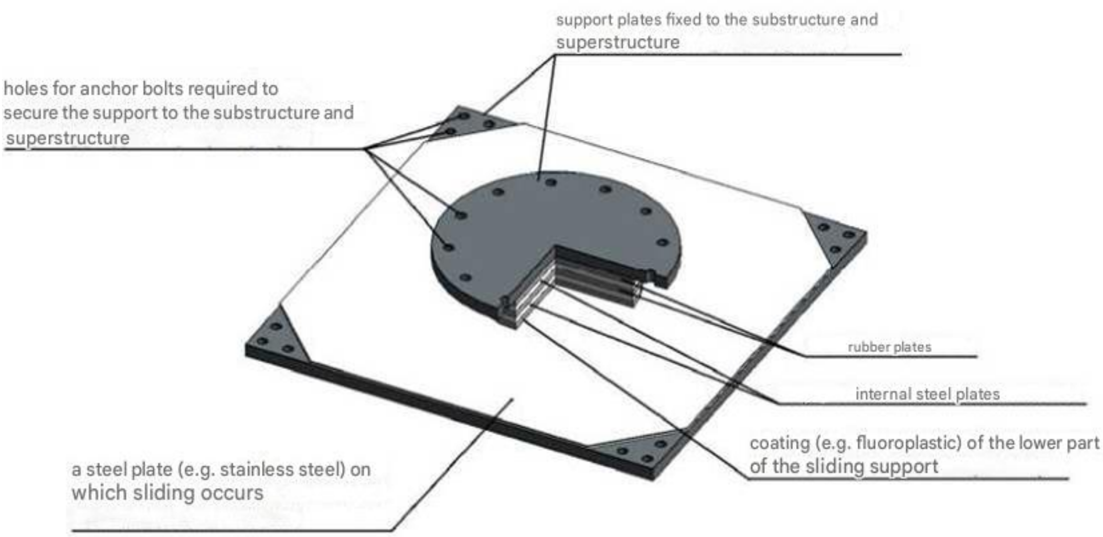


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Figure 4 - Flat sliding support

The disadvantage of flat sliding supports is the preservation of the final one-way displacements within the lower sliding plate of the seismically isolated structure even after the earthquake has ceased. This is due to the absence of restoring forces in supports of this type, which would tend to return the support to its original position. To eliminate this disadvantage, flat sliding supports are installed in a pair with elements in which restoring forces arise during horizontal displacement. An example of such a combination of a flat sliding support and a layered elastomeric support is shown in Figure 5.

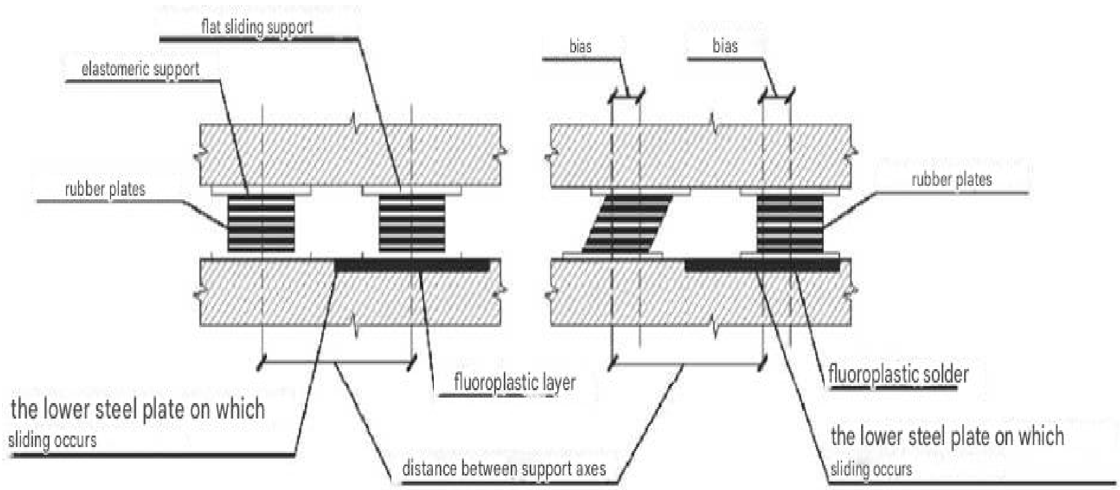


Figure 5 - Combined use of a flat sliding support and an elastomeric support

2.1.4. Pendulum sliding supports

Pendulum sliding supports are friction-moving supports with spherical sliding surfaces. These supports have the same design as flat sliding supports, but one or more of their sliding surfaces have a spherical shape.

Due to the fact that when using this type of support in the event of a seismic impact, the seismically isolated structure will perform movements similar to the movements of a pendulum with friction, such supports are called pendulum sliding supports.

The composition of a pendulum sliding support includes: one or more concave spherical sliding surfaces, one or more sliders and flanges on the sliding surfaces that limit the horizontal movement of the sliders.

Like sliding supports, pendulum supports are made of stainless steel, and the sliding surfaces are covered with special materials that provide the required friction coefficient. In addition, metal structures require careful maintenance to ensure their reliability and durability.

The advantage of the supports in question over flat sliding ones is that after the seismic impact ceases, they return to their original position. This effect is achieved by using concave spherical surfaces in which the horizontal component of gravity tends to return the slider to a state of stable equilibrium, i.e., to its initial position.

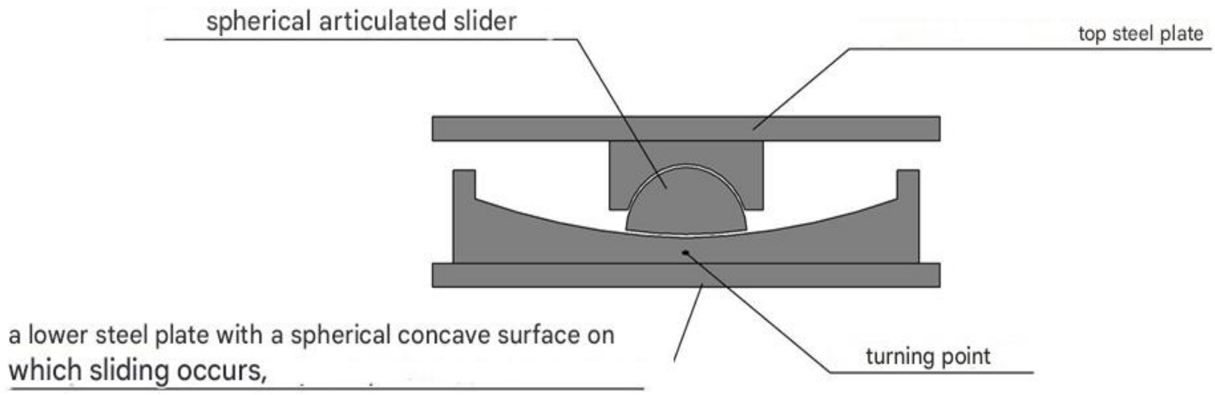


Figure 6 - Single-pendulum sliding support

The properties of a single-pendulum sliding support depend on the radius of curvature of the spherical sliding surface and the friction coefficient of the slider on it. The spectrum of natural oscillations of an isolated object mainly depends on the radius of curvature of the sliding surface. With supports of this type, it is possible to increase the period of natural oscillations to 3 seconds or more, and mutual horizontal movements of the base and the seismically isolated object to 1 m or more. The operating principle of a single-pendulum sliding support is shown in Figure 7.

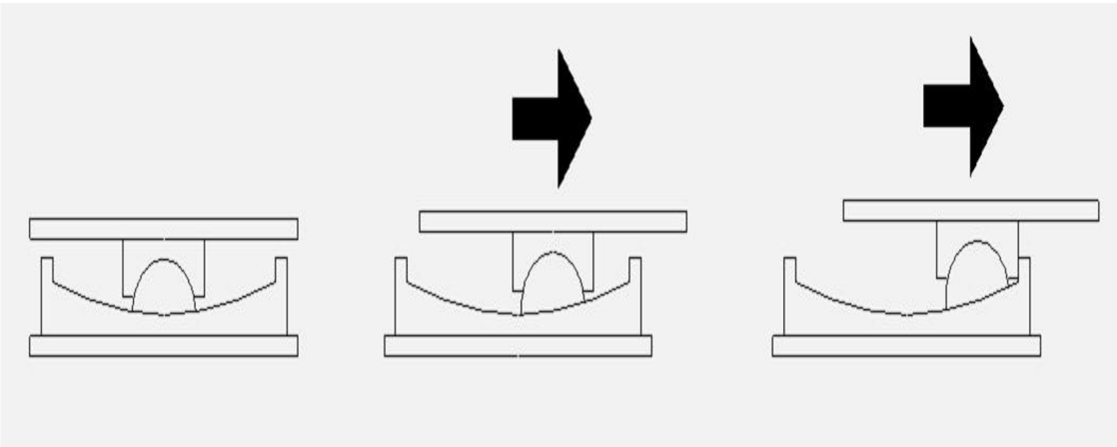


Figure 7. Operating principle of a single-pendulum sliding support

Figure 11 shows a diagram of a double-pendulum sliding support. This support consists of two horizontal plates, each of which has a concave spherical sliding surface, and two sliders located between the plates.

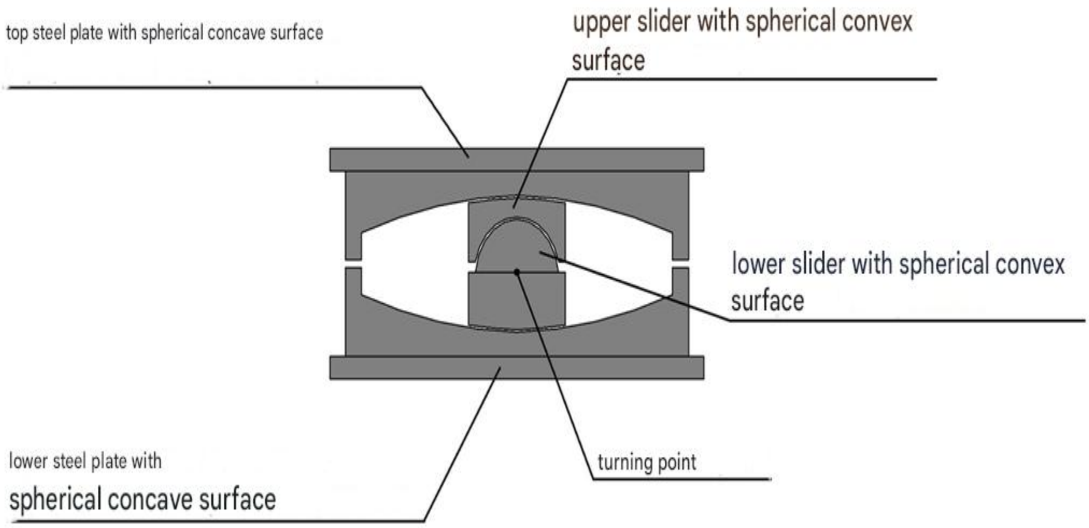


Figure 8. Double-pendulum sliding support

The properties of a double-pendulum sliding support also depend on the radii of curvature of the spherical sliding surfaces and the friction coefficients. These parameters can be the same for the upper plate and slider and for the lower plate and slider, or they can be different. The advantage of double-pendulum sliding supports over single-pendulum ones is that they have more compact dimensions. The operating principle of double-pendulum sliding supports is shown in Figure 9. Due to the fact that in these supports sliding can occur both on the lower and upper surfaces, the mutual displacement of double-pendulum sliding supports will be twice as large as that of single-pendulum supports of the same size.

The ability to vary the value of the radii of curvature and friction coefficients for the upper spherical surface and for the lower one allows increasing the seismic insulation properties of these supports.

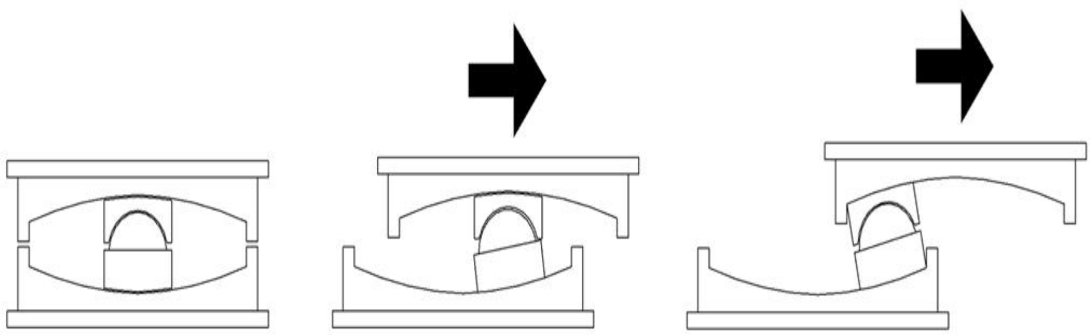


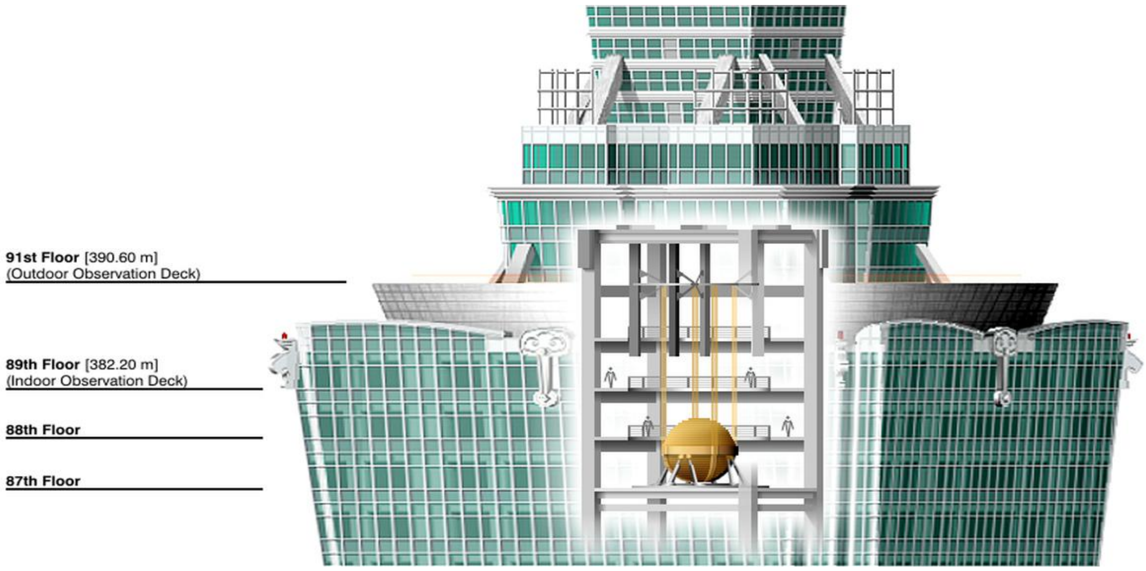
Figure 9. Operating principle of a double-pendulum sliding support

2.1.5. Inertial damper

In addition to the above methods of passive seismic protection, inertial damper systems are used in high-rise construction practice, which weaken the effect of horizontal seismic impact in high-rise buildings.

They are special weights that are suspended or installed on hydraulic fastenings on the upper floors of towers. The operating principle of such a damper is that during an earthquake and a deviation of the building in any direction, it moves with the same frequency, but in the opposite direction, thereby allowing the amplitude of vibrations to be kept within safe limits for the building.

In one of the world's famous skyscrapers, Taipei 101 in Taiwan (509 m high), a 728-ton pendulum-plumb line placed between the 78th and 92nd floors ensures the stability of the upper part of the skyscraper during strong winds and allows it to withstand a 7.0 magnitude earthquake (Fig. 10)



Inertial damper on the Taipei 101 high-rise building

Typically, a mass damper, also called a mass absorber, which is one of the vibration control devices, is a massive concrete block installed on a high-rise building or other structure, which vibrates at the resonant frequency of the given object by means of a special spring-like mechanism under seismic load.

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Figure 10 - Inertial damper on the Taipei 101 high-rise building located in Taipei, the capital of Taiwan

2.1.6. Spring seismic isolators

Spring supports are widely used in construction, especially industrial facilities, not only as seismic isolators, but also as vibration isolators in general. The design of a spring isolator consists of several cylindrical helical steel compression springs that are attached to the upper and lower support plates. The general appearance of such a support is shown in the figure 11.

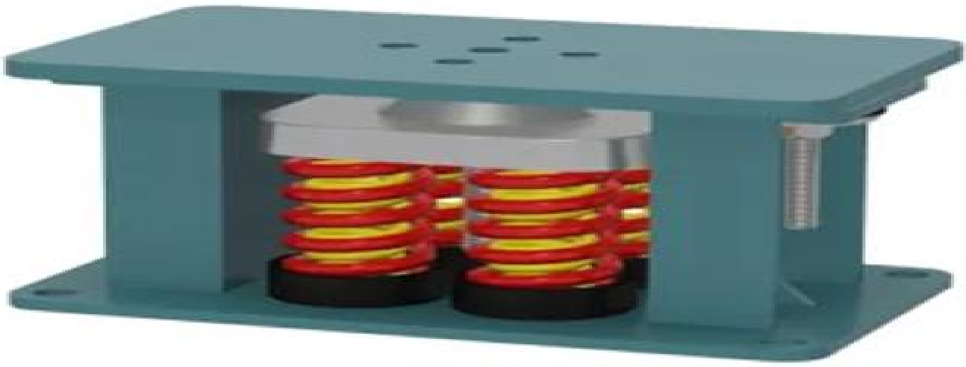

Figure 11. Spring support

The most important element of spring supports are the springs themselves (Figure 16). The insulating properties of the support as a whole depend on their properties. Conventional springs that are under compressive load for a long time or when used in a high-temperature zone begin to lose rigidity. For this reason, it is recommended to use pre-relaxed springs to prevent a decrease in their rigidity.

The seismic insulation properties of these supports can be varied within wide limits by changing the properties of the springs that make them up or even the number of springs in one support.

The disadvantage of such supports is very low damping (damping in metallic materials such as steel is much lower than, for example, in rubber). To increase the damping of spring supports, a damper is introduced into their composition. An example of a spring support with a damper is shown in Figure 12.

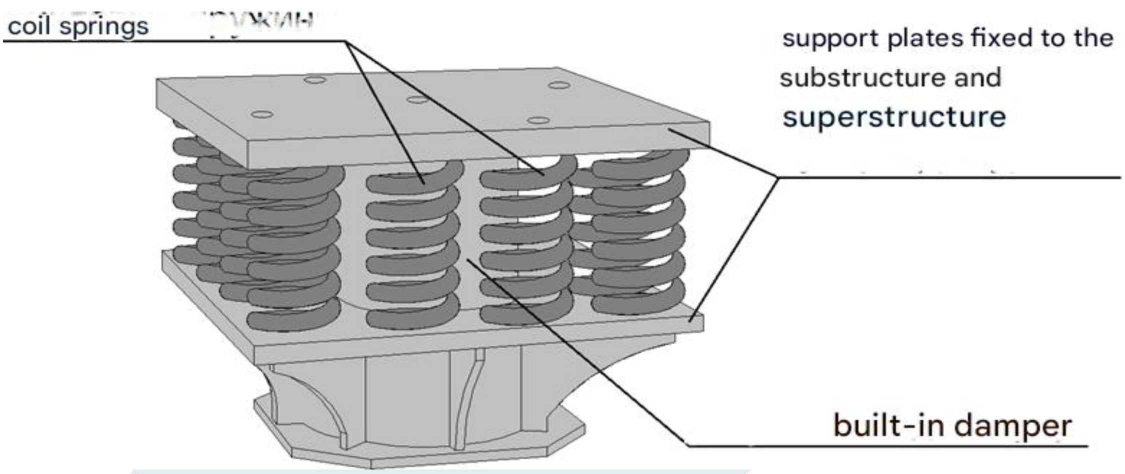

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Figure 17. Spring support with a damper

A major advantage of spring supports is the ability to reduce seismic loads on an isolated structure not only under seismic impact with a predominant horizontal component, but also with a vertical one. Sliding supports are rigid under vertical impact, which means they do not isolate the structure from vertical (or close to them) seismic shocks. This means that the use of sliding supports in regions where the vertical component of seismic impacts is large or prevails over the horizontal one is impossible. In such cases, it is necessary to use spring supports.

However, the cost of a spring support with a damper is significantly higher than the cost of a spring support without it, in addition, if a large number of spring supports with dampers are used for seismic isolation, the rigidity of the structure increases, and the supports cease to create an isolating effect. For these two reasons, the most rational use is a combination of spring supports without and with dampers. Determining the number and placement of supports with and without dampers is a complex engineering problem, one of the tasks that calculation engineers deal with.

3. Conclusion

The types of seismic isolators are quite diverse. Their use is a rational way to achieve the required level of seismic resistance of a building or structure.

One or another type of seismic isolation can be selected based on the characteristics of the expected seismic impact at a specific construction site, as well as the design solution of the building and the operational requirements imposed on it. However, it should be remembered that while the type of seismic isolators used can be selected based on general assumptions, the specific insulating characteristics of the selected seismic isolators, as well as the scheme of their arrangement, must be determined based on the results of special dynamic calculations.

The use of seismic isolation allows buildings to be erected even in areas where high-intensity earthquakes may occur. It is possible to isolate both individual parts of a structure (for example, foundations for equipment) and entire buildings (for example, schools, hotels, residential buildings).

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