INTRODUCTION OF SYSTEMS OF SEISMIC ISOLATION IN PRACTICE OF CONSTRUCTION PRODUCTION IN RUSSIA

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ABSTRACT

About a third of the territory of Russia is located in seismically hazardous areas. Building and structure protection against the dangerous effects of earthquakes is one of the priorities set by the government of Russian Federation to engineering community. One of the ways to protect buildings from seismic impacts is seismic isolation. Seismic isolation systems are actively introduced into the practice of earthquake-proof construction in Russia. This is evidenced by many unique objects using seismic isolation systems. Their design and construction is conducted in the Russian Federation with the participation of specialists from the Research Center of Earthquake Engineering, which is the part of the Research Institute of Building Construction and Russian Association of Earthquake Engineering. Among such objects it is necessary to note the high-rise Akhmat-Tower in Grozny city (Chechen Republic), “Kommunar” Cinema in Novokuznetsk and others. The application of seismic isolation systems served as the development of a number of normative documents in the area of seismic construction and among them SP (Set of Rules) ”Seismically isolated buildings. Design rules” and standards for seismic isolation systems.

Keywords: seismic isolation; earthquake engineering; reconstruction, bridge

1. INTRODUCTION

Every year around the world there is 150-200 earthquakes with a magnitude of 7.0 and above: Turkey, Greece, Taiwan, China, Italy, Chile, Japan and other. Powerful earthquake caused in these countries huge financial losses. Earthquakes are accompanied by significant destruction of buildings and the enormous loss of lives.

About a third of the territory of Russia is located in seismically hazardous areas. Zones in which vibrations of crust measuring 8-9 points were registered is Altai, the North Caucasus, Krasnodar Region, the Chechen republic, Baikal with Transbaikalia, the Kuril Islands, the Kamchatka peninsula, the Sayansk ridge and the island of Sakhalin and other. On one hand, these territories are major industrial complexes, enterprises for extraction of natural resources such as oil, natural gas and coal. On the other hand, it is a favorite vacation spot of many Russians, such areas, first of all, include Krasnodar region and the Crimea. Population of the resort towns is increasing during the holiday season that can lead to a large number of casualties in the earthquake. Damage from earthquakes and their secondary effects, the impossibility of accurate prediction of this natural phenomenon have led to the fact that the provision of a comprehensive seismic safety of Russian Federation territory has become one of the priorities of the Government of the Russian Federation and remains so for many years. Likely to further increase seismic activity of Russian Federation territory, including due to anthropogenic impacts, a large. This fact increases the possibility of occurrence on the territory of our country catastrophic earthquakes with a high degree of destruction. The need to preserve lives and health of people, prevent and reduce level of material losses and environmental damage defines a complex task: to ensure the seismic safety of the population and sustainability of logistical facilities within the indicators of acceptable risk.

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For many decades the solution to this problem remains one of the priority directions of state policy in the field of scientific and technical development, construction, housing and communal services in Russian Federation (Zvezdov AI et al. 2017).

One way to protect buildings from seismic impacts is seismic isolation. Seismic isolation systems are actively introduced into the practice of earthquake-proof construction in Russia. This is evidenced by many unique objects using seismic isolation systems. Their design and construction are conducted in the Russian Federation with the participation of specialists from the Research Center of Earthquake Engineering (RCEE), V.A. Kucherenko TsNIISK, JSC RCC and Russian Association of Earthquake Engineering (RAEE).

2. RUSSIAN BUILDING CODE IN DESIGN OF BUILDINGS WITH SEISMIC ISOLATION

Application of seismic isolation systems served as the development of a number of normative documents in the area of seismic construction. By order of the Ministry of Construction of Russia we have developed Russian Set of Rules (SP) "Seismically isolated structures". In this Building Code developed requirements only tested on seismic isolation system, which received recognition in the world of earthquake engineering and have undergone a real earthquake.

In the preparation of the Code has benefited foreign Codes in the design of buildings with seismic isolation systems: European standards – Eurocode 8, to American standards – IBC-2012, Japanese, Chinese, Italian, Armenian and other standards.

In recent years the Russian normative and technical base of earthquake engineering was supplemented by a set of standards in the field of earthquake engineering. In 2016 three state standards were approved, that was a result of many years of hard work of specialists from RCEE:

- GOST R 57353 – 2016 Structural bearings – Part 2: Sliding elements;

3. THE HISTORY OF INTRODUCTION OF SYSTEMS OF DYNAMIC REGULATION OF SEISMIC REACTION IN RUSSIA

More than 600 buildings with different seismic isolation systems and systems of dynamic regulation of seismic reaction, were built in seismic areas in Russia has built since 1972.

3.1 Buildings with Non-Rubber Seismoisolation Systems

Mass scale implementation started in USSR during Baykal-Amur railway construction. It was 1978. A new city – Severobaikalsk-city constructed at the Lake Baykal shores. All buildings were seismoisolated in this city (Figure 1). And the seismoisolation system was proposed and designed by our Center. It was an adaptive system with switching off reserve elements and changing rigidity.

Figure 1. View of the city of Severobaikalsk
3.2 The buildings with kinematic support elements

Later other kinds of structural designs of building seismoisolation were developed, tested, and used in practice: sliding belts, kinematic supports, and so on. In Siberia, in Irkutsk region, 82 residence houses with different number of storeys were built with use of seismoisolation in the form of kinematic rocking foundations. In Kemerovo region, more than 30 buildings on kinematic supports in combination with additional damping elements were built (Figure 2).

![Figure 2. View of residence house in Kemerovo-city (a) built with kinematic supports in combination with additional damping elements (b)](image)

3.3 Buildings with "flexible" down stories

The next example is how we protected from earthquake a building at a seismic hazardous site in Irkutsk-city (Figure 3). It is a site where design intensity is 8 MSK degrees. The architects wish was to have under dwelling stories an open ground story for parking and other nonresidential premises. We have used steel columns of relatively mild steel, as supports. Kind of flexible seismoisolation ground story. As you know the Reinforced Concrete columns as bearing elements in flexible soft ground stories demonstrated poor seismic behavior during many historical earthquakes (Say, San-Fernando, Gumri - Armenia, and many others). We used strong and mild steel instead of reinforced concrete columns. Both experimental and analytical investigations supported the conclusion of the satisfactory seismic resistance of this building.

![Figure 3. Building a house in Irkutsk-city with "flexible" down stories](image)

3.4 Seismoisolation for upgrading and strengthening existing buildings

Approximately 18 years ago design and implementation in construction of seismoisolation systems with rubber has begun in Russia. Firstly the steel-rubber bearings were used for existing buildings retrofitting.
First building in Russia that was seismoisolated, using rubber bearing supports, was the Bank building in Irkutsk-city. It is Siberia. The building was constructed in 1934 (Figure 4,a) without any specific anti-seismic measures and it was retrofitted in 2000 (Figure 4,b).

Seismoisolation was chosen for seismic protection. Rubber bearing supports were installed in the basement, in cuts made in walls and columns.

The next retrofitted building is a school building at Sakhalin Island, Russian Far East. Here is the rubber bearing support, which is installed in the column cut.

One is a Cultural Center in Altay, Siberia, the city Gorno-Altaysk. It includes a Drama Theater. The building was designed using no anti-seismic measures. But now the design seismic intensity at the site corresponds to 9 MSK degrees.

Another retrofitted building is located in Chechen Republic, Russia. City Grozny, Capital of Chechen. It was the State Concert Hall. The reconstruction and retrofitting were necessary not only because of the high seismic hazard at this site, but buildings survived the Chechen war with serious damage and had to be repaired. The seismoisolation bearings consist of rubber and steel layers, and lead cores. The reconstruction of the building was completed in 2009.

During the reconstruction of a hotel complex "Moscow" was also used seismic isolation. The hotel complex "Moscow" was constructed in the mid-seventies of the XX-th century in Sochi-city. For a considered hotel complex the factor of seismicity of building area has increased in 4 times according to existing maps of the general seismic zones (Figures 5).

The project of strengthening of buildings included: the device of seismic isolation supports in a combination with damper in the bottom part of a building.

The complex approach at designing of reconstruction of the existing hotel complex has allowed not only to provide its seismic resistance at design earthquake, but also to raise quantity of floors and to increase a complex total area of the hotel.
3.5 Seismic isolation of high-rise buildings

Recently, the specialists of our RCEE participated in the design and construction of many high-rise buildings with steel rubber isolation supports and with energy dissipation elements in different cities. Hotel-tourist building "Sea Plaza" was constructed in Sochi-city by the Italian Company "Codest International". After the economic crisis, the hotel has become known as "Hyatt" and completes the Turkish construction company. The height of the building is near 100 meters. Hyatt Regency Sochi – is a new luxury hotel located in the heart of the legendary Black Sea resort on the beachfront (Figure 6). Seismoisolation are elastomeric seismic isolators with high damping rubber compounds.

![Figure 6. High-rise building hotel "Hyatt" in Sochi-city](image)

Russian international Olympic university and multipurpose hotel recreational complex consists of 5 buildings and settles down along coast of Black sea and has a wrong outline in the plan. Site seismicity is 8 MSK degrees, according to engineering-geological researches. The underground parking place will take places in an underground floor. Seismoisolation system in buildings is accepted in a kind rubber bearing support with lead cores (Figure 7). By now, construction of all buildings completed.

![Figure 7. Russian international Olympic university in Sochi-city and installation steel rubber isolation supports](image)

The building of new bank office in Irkutsk-city (Figure 8) represents the 11-storeyed building with an underground part. The constructive scheme of a building – RC frames and RC diaphragms of rigidity. Vertical loadings are perceived by columns and rigidity diaphragms, horizontal loadings – vertical diaphragms of rigidity. In a building the device rubber bearing support in a cellar and branches of elevated designs from a design of a cellar and the bases by a horizontal anti-seismic gap under floor slab.
3.6 Buildings with energy dissipation elements

Here presents two buildings, where energy dissipation elements where used for earthquake effects decreasing. The first, is 23 overground stories building the Apartment housing "Estate" in Pushkin avenue of Sochi-city (Figure 9). Design earthquake intensity of site is 9 MSK degrees. The structural system is of frame-and-wall type, with monolithic reinforced concrete stiffening cores, monolithic floors and cross-shaped metal braces. On smoothly descending cascade of upper storeys roof, swimming pools were built. Additional rigid elements: x-form steel braces – are provided in the external perimeters of the buildings.

The second, are buildings of a new Irkutsk Civil Airport (Figure 10). The design earthquake is 9 MSK degrees. One building existed before Airport construction. It was not seismic resistant. The new building was situated close to the old. Energy dissipation viscose elements were fixed between the 2 buildings. They are of well-known Germany production – "Gerb" type. Now the building is accomplished.
The new railway station "Adler-city" in Sochi is ultra-modern buildings in the style of hi-tech built in 2013. The architectural design of the building to the form of run-on "Sea wave" (Figure 11). The system includes a seismic isolation building rubber bearing supports with a lead core, hydraulic dampers in the longitudinal direction and in the transverse direction. Application of complex seismic system resulted in a significant reduction of seismic loads on the building.

The complex of 7 high-rise buildings in Grozny, was named "Grozny City" (Figure 12). The buildings are located in the centre of the city. Total building height is 155 m. 41-story tower "Phoenix" is the first complex of the tallest residential building in Russia in seismic regions. Here is built of seven high-rise buildings, one 41-storey, one 30-storey, three 28-storey and two 18-storey. 41-story tower is designed on an individual project and is a 41-storey residential building with 4-level stylobate two underground and two above ground level within the dimensions of the high altitude. The structural layout of the building is a cross-wall with transverse and longitudinal load-bearing walls of reinforced concrete. The spatial rigidity of all sections under the action of wind and seismic loads ensured collaboration vertical load-bearing walls, ceilings combined drives. Seismic isolation. To improve the earthquake resistance of buildings designed in the project capacity for seismic isolation rubber bearings in the underground part of the stylobate, as well as for the separation of high-rise constructions of the design of the stylobate. Seismic isolation bearings are mounted on solid reinforced concrete columns, based on a solid foundation slab of reinforced concrete.

4. THE EXZAMPLES OF INTRODUCTION OF SYSTEMS OF DYNAMIC REGULATION OF SEISMIC REACTION IN RUSSIA IN 2015-2017

4.1 Application of seismic isolation in the reconstruction of the building of the "Kommunar" cinema in Novokuznetsk-city

Last year we carried out works on scientific and technical support for the reconstruction of the cinema "Kommunar" in Novokuznetsk-city (Figure 13).

Figure 11. Railway station "Adler-city" in Sochi

Figure 12. The complex "Grozny City" (Chechen Republic)

Figure 13. General view of the cinema "Kommunar" before reconstruction
At level of the natural conditions of the survey site belongs to the complex. The survey site is characterized by heaving of soils, and seismicity. Listed engineering-geological conditions require the design to include measures for the protection of the Foundation from hazardous engineering-geological processes. According to the results of instrumental measurements of seismic intensity equal to 8 points.

The cinema building is divided into two seismology: projected three-storey block is separated from the existing building of the theatre (single unit) earthquake-proof seam. Building structural system – frame-wall with outer and inner longitudinal and transverse load-bearing walls and inner frame in the hall, wardrobe and box office lobbies.

To ensure seismic resistance design of buildings in this project recommended the installation of seismic isolation supports with high damping – elastomeric bearings supports with lead cores. The pod should have a high horizontal flexibility, allowing for large horizontal movement, without any damage. The pod will reduce the inertial seismic loads on the building by significantly increasing their own vibration period of the building and the increased damping of the system trade.

The seismic isolation system must be provided with clearances (horizontal and vertical seams), which will allow isolated and non-isolated parts of the building are not in contact during a design earthquake.

For use in the project recommended the supports of several sizes in accordance with the calculation results. The damping characteristics of the system of seismic isolation, the maximum equivalent viscous damping provided by rubber supports should be no more than 30% and not less than 16%. Seismic isolation devices are reduce inertial seismic loads on the building by significantly increasing their own vibration period of the building and the increased damping of the system.

4.2 The stadiums of the 2018 FIFA World Cup design in seismic region of Russia

On the occasion of the 2018 FIFA World Cup our Center is engaged in designing stadiums being built in seismic regions.

For seismic isolation these objects a seismic Spherical Bearings combined with Flat Sliding Element are used, produced "Maurer Sohne" are applied. Bearings will be support roof structure in all stadiums.

New Stadium, "Krasnodar" in Krasnodar-City (Figure 14). The design of the stadium is similar to the Roman Colosseum, exterior finish will be carried out by the Italian travertine. Stadiums will have skylights. Preparatory work on the site for construction of the stadium began in 2011. The stadium is designed by the architectural firm SPEECH with gmp Architekten von Gerkan, Marg und Partner (Germany). Construction of the stadium began in May 2013 by the Turkish company "Esta".

Figure 14. Stadium "Krasnodar" in Krasnodar-City

New Stadium "Rostov Arena" builds in City of Rostov-on-Don (Figure 15). According to the general plan of the city of Rostov-on-Don, the stadium for the World Cup in 2018 will be on the left bank of the River Don. The construction of the football stadium, which is a rectangle in plan includes a football field. The building of the stadium will consist of five floors and three tiers of bleachers. Capacity mode (FIFA) – 45 000 places.
4.3 Design of high-rise multipurpose complex in height 400 m "Ahmad Tower"

In recent years, work is underway on the design of high-rise multifunctional complex with the height of 435 m "Grozny-city 2". The building symbolizes the Chechen medieval watchtower (Figure 16). The height of the building on the top of the dome is 400 meters, and with a spire reaches 435 meters. The tower is 102 storeys. The complex includes a Museum, 100 apartments deluxe hotel with 500 rooms, panoramic restaurants, offices, high-rise helipads, fitness centers, swimming pools. It will be the most difficult and the most high tech and construction in Russia. The building is designed in a seismic zone is 9 MSK degrees.

5. SEISMIC ISOLATION OF TRANSPORT FACILITIES IN RUSSIA IN RECENT YEARS

In recent years, Russia has built more than 100 transport facilities with the use of special systems of seismic isolation, especially in preparation for the XXII Winter Olympic games in Sochi, Krasnodar Krai. The region is characterized by high seismicity. Earthquakes of intensity 8 on the MSK scale have the repeatability of more than one time per 500 years and those of intensity 9 have the repeatability of more than one time per 1000 years. In some building sites there can occur earthquakes with intensity 10 on the MSK scale. The development of the city of Sochi as the place of the Olympic Games in 2014 required the construction of new railway lines. These lines include more than 50 bridges up to 500 m long and with piers up to 20 m high.

On these objects it was used a unique system of seismic isolation, which has no analogues in international practice. The application of this system was carried out during the construction of a reinforced concrete railway bridges.

The main problem was to ensure reliable operation of the facility. When braking and transverse strokes of the rolling stock must not cause the device of the permanent way. The solution to this problem led to the need to perform two customer requirements:
First, had to be excluded rubber-metal bearings. Due to the fact that the requirements of the Russian Railways deflection should be less than 1 mm, and the stiffness of the seismic isolation supports must be kept constant in the range of ambient temperatures from -20 to +50 deg.

Secondly, the limited flexibility of the supporting part, so that the stress in rail under lateral shocks and braking had a stock operation.

As a possible variant of the system of seismic isolation of reinforced concrete railway bridges were considered the device, developed by FIP Industriale, Maurer Sohnes and other well-known European manufacturers, but they are not allowed to perform the requirements of reliability established by the customer (JSC Russian Railways). As a result, the leading foreign firms on the systems of the seismic isolation of railway bridges refused. In the end it was Russian solution proposed (Figure 17). The cost of Russian design turned out the same as foreign devices.

Seismic isolation of firms FIP Industriale, Maurer Sohnes was used in the construction of highway bridges on the route Sochi – Krasnaya Polyana.

Development of Russian specialists is a seismic isolation in the form of a flexible table. The vertical load on the seismic isolation is not transmitted. At first it was planned to put the superstructure, but it could be implemented only for the case of the metal superstructure.

Thus, the device allows you to perceive three types of stresses arising from lateral blows from braking or starting of the rolling stock with seats, while centrifugal forces for bridges on a curve perceived flexible table. Since construction almost five years of operation (2013) disruption of the permanent way has not yet been identified. Thus actual load is intense, and the bridges are in areas of the stations on a curve and centrifugal force is a regular load.

For the first time was implemented the principle of PBD. As MDE was made on 9-point effects.

Table 1. Scenario of damages accumulation.

<table>
<thead>
<tr>
<th>Input</th>
<th>Lifetime, years</th>
<th>Number of shifts</th>
<th>Maximum shift, sm</th>
<th>Residual silt in the FMJ, mm</th>
<th>Bearing travel, sm</th>
<th>Peak acceleration of the pier top, m/s²</th>
<th>Peak acceleration of the span, m/s²</th>
<th>Dynamic factor, β</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULS earthquake</td>
<td>100</td>
<td>49</td>
<td>9.5</td>
<td>21.7</td>
<td>12</td>
<td>10</td>
<td>1.9</td>
<td>β_pier=3.257; β_span=0.618</td>
</tr>
<tr>
<td>Design earthquake-8</td>
<td>100</td>
<td>42</td>
<td>5.6</td>
<td>16.6</td>
<td>8.5</td>
<td>7.2</td>
<td>1.8</td>
<td>β_pier=3.64; β_span=0.91</td>
</tr>
<tr>
<td>Design earthquake -7</td>
<td>100</td>
<td>42</td>
<td>2.2</td>
<td>1.19</td>
<td>4</td>
<td>6</td>
<td>1.7</td>
<td>β_pier=4.32; β_span=1.22</td>
</tr>
</tbody>
</table>

Figure 17. Three levels of bridge seismic protection
The seismic action was simulated under the construction by the method of Dolgaya A.A. (Uzdin AM, 2005). The calculated accelerograms built on the basis of the results of seismostratigraphy, was used as a check of the design solutions. When designing with the use of calculated accelerograms was projected that at 9 points with a repeatability of 200 years the residual displacement was 2.2 cm by 8 points is 1.67 cm, 7 points – 1 cm and by 6 point is in normal operating mode requires no stop motion, no repairs.

The proposed protection system was used for more than 15 railway bridges in Sochi. All these bridges have reinforced concrete continue heavy beam spans. To sustain seismic loads from the span, only one pier is used. It is impossible without seismic protection devices.

The view of one of the protected bridges is shown in figure 18, as an example. Some of piers with movable bearings are supply with dampers of Ltd. “Vibroseism”. These dampers are described in these proceedings by Dr.Kostarev. The high of used dampers is about 55 cm. The diagram of damper installing is shown in figure 19.

![Figure 18. The view of one of bridges with proposed protection system](image1.jpg)

![Figure 19. The diagram of damper installing](image2.jpg)

The view of flexible fixed bearing, more accurately a flexible table without sustaining vertical loads on it, is shown in figure 20. It includes 198 flexible bars manufactured of high-strength steel with design resistance equal to 880000 kPa/m². The high of used flexible table is about 90 cm. The diagram of flexible table installing is shown in figure 21.

![Figure 20. The view of flexible table](image3.jpg)

Regarding transport facilities, it should be noted that after the construction objects in Krasnodar Krai, Sochi before the XXII Olympic winter games currently, the use of seismic isolation in the transportation construction in Russia is not conducted.

Under a unique bridge across the Kerch Strait in the area of high seismic activity is carried out without using any special systems trade. Seismic stability of this facility is provided by increasing the number of piles and development of sections of the bridges.
6. CONCLUSIONS

1. It should be noted that the authors of the report making heroic efforts to use innovative technology for seismic protection of buildings and structures, namely, seismic isolation, in the cities of Sochi, Irkutsk, Novokuznetsk, Grozny and other seismic regions of Russia. As a rule, very difficult to convince the Customer and designers to use seismic isolation and damping devices.

2. Seismic isolation in combination with dampers not only leads to reduction of total seismic load, it also enables to considerably reduce relative horizontal interstorey displacements («drift»). It reduces the scales of local damage and economic losses, as well as improves psychological comfort for population.

3. So, we could state, that innovation approach to high-rise buildings seismic isolation has found large-scale practical application in Russia.

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7. REFERENCES


Bubis A, Smirnova L Development of Base isolation and Damping technologies in Russia Proceedings of the 16-th European Conference on Earthquake Engineering, 18-21 June 2018, Thessaloniki, Greece
