Development of Earthquake Protection Structural Systems Based on Response Control

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SUMMARY:
Around 50% of Russian Federation territory is located on earthquake hazardous areas: Far East, Siberia, North Caucasus.

In the beginning of 70th of the XX Century several seismoisolation and other new systems of structural seismic protection were developed in Central Research Institute for Building Structures, Earthquake Engineering Department. Seismoisolation, energy dissipation and some other devices were developed for seismic response reduction. Mass implementation of seismoisolation has began in the 70th in earthquake hazardous areas of Russia, Ukraine, Kazakhstan and other former USSR countries. More than 200 large panel buildings were base isolated at the northern shore of Lake Baikal, were the design seismic intensity is 8 to 9 MSK degree depending of the soils properties. The base isolation system consisted of flexible columns, steel elastic-plastic disengaging elements and RC supports-limiters of horizontal displacements.

The lead elements and the mild steel braces increase the energy dissipation. Combining the parameters of the seismic protection elements the seismic response control is achieved.

Multi-story buildings were constructed at Altay (Siberia), Petropavlovsk (Kamchatka), Grozny-city (Chechen) with use of seismic response control devices.

Keywords: energy dissipation, steel-rubber bearings, fuse reserve elements, seismic response control.

1. INTRODUCTION

Kamchatka, Sakhalin, North Caucasus, Lake Baykal shores, many areas of former USSR (as Kazakhstan, Armenia, Azerbaijan, Georgia, Ukraine, Uzbekistan, and other) are located on highly seismic hazardous regions. Large industrial, cultural centers are located on these areas. The problems of population safety, economical problems in these regions have led to development of new scientific approaches and technologies in earthquake engineering.

In the end of 60th and beginning of 70th of the XX Century a broad research Program has started in the Earthquake Engineering Research Center in Moscow Institute TsNIISK (Eisenberg, J.M., 1976). The Program goal is developing scientific fundamentals for developing new technologies and design codes for structures with high seismic safety or high economical parameters, or both. The main part of the mentioned Program was developing of dynamic mathematical models and technical decisions for buildings and other structures based on seismic response control.

Two types of seismic control were investigated. They are based on structural seismoisolation systems without rubber and systems with using rubber as part of the bearing systems. Specific mathematical models of seismic inputs were developed for seismic control systems. More than 600 buildings and other structures were designed and constructed now in Russia, and other countries of the former USSR. These implementation results are based on the mentioned research Program. They are presented in this paper.

2. SEISMOISOLATION WITHOUT RUBBER

2.1. Adaptive Seismoisolation Systems with Reserve Elements

Mass scale seismoisolation implementation started in USSR during Baykal-Amur railway construction. It was 1973-74. A new city - North-Baykal-city was constructed that time at the Baykal shores. All buildings were seismoisolated in this city (Fig. 1). The seismoisolation system was proposed and designed by our Center. It was an adaptive system with switching off reserve elements, changing rigidity and vibration limits, during construction of apartment houses, public facilities, and kindergartens in North-Baykal-city, the town of railroaders. Application of seismoisolation system have protected the buildings against destruction and saved people's lives during the strong earthquakes.

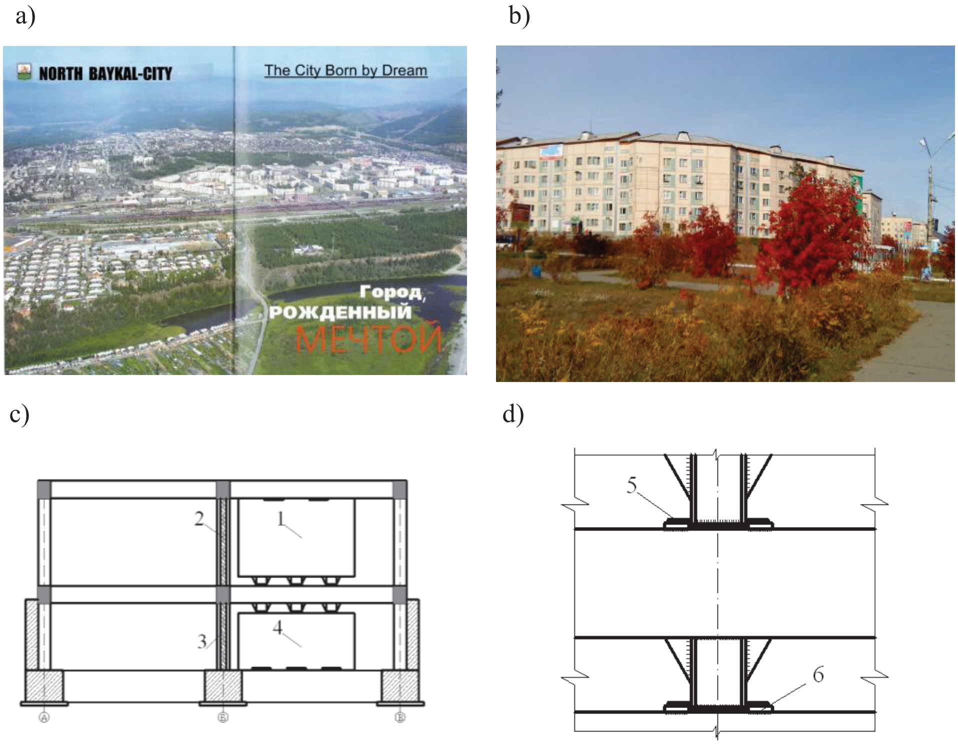


Figure 1. Seismoisolated large panel buildings in North-Baykal-city
a) the view of North-Baykal-city, b) the view of the building,
c) cross-sectional view of the lower floors, d) switching off reserve elements
1, 2, 3 and 4 diaphragms, 5 - switching off reserve elements, 6 - vibration limiters

An approximate analysis of the probability of failure and safety of simple structures with disengaging elements has been carried out. Systems with one and many reserve elements are considered. The problem is solved on the basis of the overshoot theory. In the case of systems with *n* reserve elements the 'death process' is employed.

The analysis results mentioned in the references, reveal the role of the reserve elements as an effective means of structural earthquake protection.

One of the effects is relevant to the situation when the structural design must take into account several types of narrow-band soil motions, differing in their dominant periods. The disengagement of the reserve elements in this case assists in adaptation of the structure to high frequency earthquake motions owing to the transformation of its dynamic characteristics, i.e. stiffness and natural frequencies. The structural seismic response in this case can be several times lower than that in the case of a structure with constant dynamic characteristics.

The other effect concerns the reserve element itself, that is the formation of, so to say, additional ‘defence lines’. This effect works not only in the case of narrow-band processes, but also in the case of wide-band earthquake processes when the frequencies of the system at belong to the effective section of the earthquake motion spectrum. As was demonstrated by the numerical example, the design seismic load acting on systems with reserve elements can be reduced by 25 to 50 per cent compared with similar systems without reserve elements.

Transforming systems with reserve elements therefore are effective with any kind of earthquake motion as well as when taking into account wind loads in addition to earthquake action. Qualitatively, the efficiency characteristics of transforming systems with reserve elements are different depending on the predicted types of effects.

Around 200 buildings are constructed using this type of seismoisolation. The upper stories bearing walls are of brick masonry or of stone masonry. The statical and dynamical tests on full scale buildings approved the seismoisolation effectiveness.

2.2. The Buildings with Kinematic Support Elements (KSE)

Later other kinds of structural design of building seismoisolation were developed, tested, and used in practice (Eisenberg, J.M., at all, 1999). Seismoisolation of buildings on kinematic supports is most spread in two Siberian seismic regions of Russia. 82 dwelling-houses were built in the Irkutsk region (near Baikal Lake) in 1984-2003 and 25 buildings in the Kemerovo region in 1997–2005 (Fig. 2).

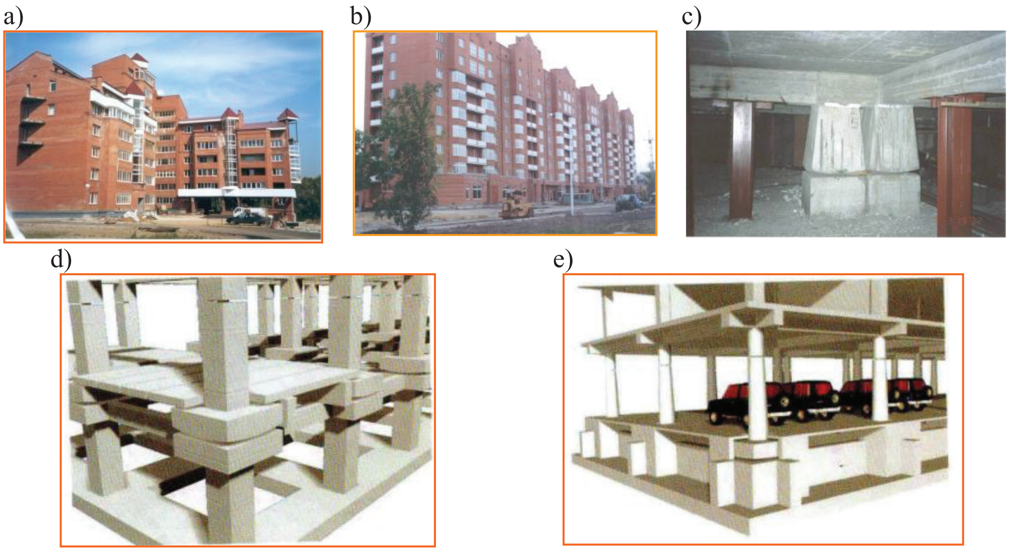


Figure 2. Seismoisolated buildings:
a) in Irkutsk-city; b) in Novokuznetsk-city; c) kinematic rocking supports with hysteretic dampers; d) application KRS in a frame building; e) ground floor of a building parking for cars

2.3. Masonry Walls Buildings Seismoisolation with Dry Friction Energy Dissipation

Low buildings with dry friction sliding belts were developed and implemented, mostly in Kirgizstan, as well in some other areas (Polyakov, S.V., at all, 1984). The sliding pair is “steel-teflon”. The measured friction coefficient was around 0,08-0,12.

3. SEISMOISOLATION WITH RUBBER

3.1. Existing Buildings Upgrading and Strengthening

For the first time in Russia, the method of application of seismoisolation rubber bearing supports was developed and used during the reconstruction of historical and architectural monument by the authors (the building of RF Bank for Irkutsk region, in 1998-2000). Site seismicity is 8 MSK degrees (Fig. 3a).

The individual project of comprehensive school in the town of Aleksandrovsk-Sakhalinsky was developed in 1988 on the basis of current Building Code «Construction in Seismic Regions» (Fig. 3b).

Two examples of the Cultural Centre Buildings seismoisolation are presented below. One is in Altay, Siberia (Fig. 3c). The other is in Chechen, Northern Caucasus, Grozny-city (Fig. 3d). The State Concert Hall in Grozny-city was damaged by Chechen war. And the actual seismic capacity is 2 MSK degrees lower than the design one if using the current Russian Code. It means seismic load 4 times higher than the initial design load. In both cases the seismoisolation systems were installed in reconstruction process to increase the seismic resistance and safety which was not enough.

a)

b)

c)

d)

Figure 3. Use of seismoisolation supports to provide buildings seismic resistance
a) the reconstruction of historical building of bank in Irkutsk; b) four buildings of school in Aleksandrovsk-Sakhalinsky; c) seismic strengthening of theater building in Gorno-Altaisk; d) reconstruction of the building of concert hall in Grozny, destroyed by military operations

3.2. Seismic Isolation with Rubber. High-rise Buildings

The city of Sochi was selected as the place of Winter Olympic Games in 2014. It is a unique place on the coast of Black sea. Designing and construction in the area of Big Sochi is quite complicated because here, besides high density of population, very complicated hydrogeological and seismological conditions take place: high region seismicity, hilly country, soil slips, possibility of mud avalanches, and so on.

Taking into account all complicated production induced factors of Big Sochi, the EERC TsNIISK offered a lot of solutions providing seismic resistance, and continues to search new approaches to new tasks in this area (Smirnov, V.I., at all, 2011).

3.3. Hotel Building "Hayat"

High-rise seismoisolated buildings are constructed also on Kamchatka and on in other Russian earthquake hazardous areas.

The 27-storeyed hotel building in Sochi-city. Building height is 93.6 m (Fig. 4). The bearing system above seismoisolation supports level consists of RC diaphragms, frames columns and monolithic walls, and RC floors. The foundation RC flat is 2000 mm thick. Columns cross sections are maximum 1500×1200 mm minimum 600×600 mm upper the 15.900 m level. The weight of the building above the isolation layer is 75000 kN.

Figure 4. The 27-storeyed hotel building in Sochi-city
a) and b) building facade; b) the foundation and ground storey of the building;
c – f) installation of RBS

Seismoisolation - 193 elastomeric seismic isolators with high damping rubber compounds, including supports of type SI-H 1000/168 in number of 149 and supports of type SI-H 1100/168 in number of 44. The manufacturer of supports is "FIP Industrial" Italy. Supports of type SI-H 1000/168 can perceive the maximum vertical loading - 14000 kN and type SI-H 1100/168 – 18000 kN. The maximum possible lateral displacement is 250 mm. Damping is 20%.

3.4. Apartment Type Hotel «Golden Lagoon»

The building was designed under individual project (Fig. 5). It has sophisticated space-planning solution. The planning concept of the building complies with complicated construction site terrain (hillside), in section; it is a terraced multi-level structure. Due to it, stylobate part of the building performs at the same time functions of a retaining construction in separate axes. Site seismicity according to the map of general seismic zoning is 9 MSK degrees.

a)

b)

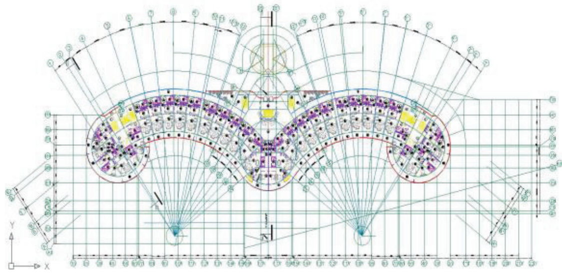


Figure 5. Apartment type hotel «Golden Lagoon»
a) building facade; b) location of isolation supports in building plan view

High-rise part of the building represents three volumes with different number of stories, separated from each other with anti-seismic gaps: the central block and two adjoining mirror-symmetric blocks. High-rise part of the building has structural wall system with cross and lateral load-bearing walls, including exterior walls. Spatial building stiffness at wind and earthquake loads is provided by joint action of vertical load-bearing walls, connected by floors.

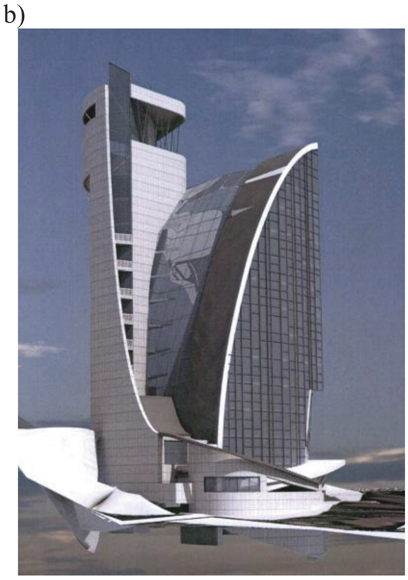
Walls are reinforced concrete, monolithic, with variable height thickness. They provide resistance to both – vertical load and 9 MSK design earthquake action. The floors are monolithic reinforced concrete slabs.

3.5. Hotel Building in the City Petropavlovsk-Kamchatsky

The 16-storeyed hotel building in the city Petropavlovsk-Kamchatsky is shown at the Fig. 6. The building has a complicated architectural design, with vertically changing volume and non-symmetrical mass and rigidities plane distributions. The sizes are 65 m to 43 m at the base floor and 41 m to 35 m at the 14th floor level.

a)

b)



c) d)

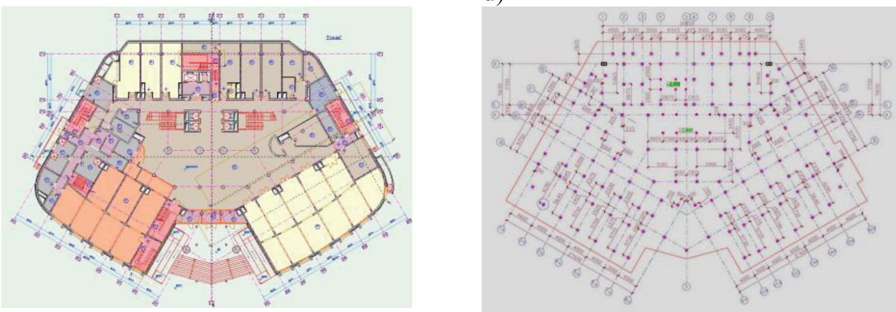


Figure 6. Hotel building in the city Petropavlovsk-Kamchatsky
a) and b) the building facade; c) the first floor plan; d) location of RBS in building plan view

The foundation is a flat plate 800 mm thick. The seismoisolation supports are mounted on the foundation plate. To make possible the seismic motion of building part above isolation supports a RC retaining wall around the underground building part was envisaged.

4. BUILDINGS WITH ENERGY DISSIPATION ELEMENTS

4.1. Apartment Housing Estate in Pushkin Avenue of Sochi-city

Two buildings in Sochi were designed with energy dissipation elements for earthquake response decreasing. The structural system is of frame-and-wall type, with monolithic reinforced concrete stiffening cores, monolithic floors and cross-shaped metal braces. Number of storeys are three underground floors; the first block has 22 storeys superstructure; the second block has 23 stories superstructure. Building height is the top point of 23rd storey of the second block – 80.1 m. On smoothly descending cascade of upper storeys roof, swimming pools were designed and built (Fig. 7).

Figure 7. Apartment housing estates «New Alexandria» with damping system of metal braces

Construction site design seismicity according to the map of general seismic zoning is 9 MSK degrees. It was one of the first objects of high-rise construction in Sochi, for which damping braces were used and technical specifications developed.

4.2. The Building of New Irkutsk Civil Airport

The airport building consists of two rectangular blocks of the overall size of the axes of 98.0x29.95 m (Fig. 8). The bearing system is frame pattern in the transverse direction and frame with diaphragms in longitudinal direction. As a load-bearing structures coating used steel farm spans 24 m, with the consoles to 6 m. Airport was commissioned in 1976.

Figure 8. New solution for seismic protection of the building of Irkutsk Civil Airport
a) airport building before reconstruction; b) airport building after strengthening;
c) the energy dissipation elements in working condition

The basic idea of seismic protection of the airport building was in the compound construction of new and existing buildings with the help of special damping devices. We considered a variant of connected buildings at around 7.75 m in the top level of the columns of the existing building. Energy dissipation viscous elements were fixed between the 2 buildings. They are of well known "Gerb" type. Now the building is accomplished.

5. DEVELOPMENT OF SEISMIC DESIGN CODE AND SOME DESIGN PROVISIONS

5.1. Russian Seismic Design Code, SNIP II-7-81*, Actualized Version was approved by Russian Federation Ministry for Regional Development, May 20, 2011.

The Code includes design rules for seismoisolated structures. The Code design rules are compulsory.

5.2. Design Recommendation with Reserve elements. These and other listed design provisions are advisable.

5.3. Provisions for building design and construction design of seismoisolation with sliding belts.

5.4. Building Seismoisolation with RC rocking supports upside-down mushroom type Design Provisions.

5.5. Multi-Story Buildings with rocking RC columns Seismic Design Provisions.

CONCLUSIONS

1. The above examples of seismic protection application innovation technologies in the cities and towns Sochi, Irkutsk, Gorno-Altaisk, Aleksandrovsk-Sakhalinsky, Grozny, Petropavlovsk-Kamchatsky show quite obviously the growing interest of engineers to introduction of seismoisolation systems in regions of Russia earthquake hazardous.

2. The efficient seismoisolation systems – different types of supports and damping, available to engineers, enable to regulate structures seismic response and to ensure the appropriate degree of protection. The reliability of seismoisolation systems was proved by full-scale testing and long-term operation in structures (Kelly, J.M., 1979).

3. Seismic isolation has become an advanced modern method of seismic protection. Its practical application is gradually growing. Use of seismoisolation systems in earthquake regions with 7-9 MSK seismicity enables to reduce seismic loads several times, depending on specific conditions of the site and building construction. It means that construction cost can be reduced.

4. Several Design Provisions are prepared in Russia for seismic design of seismic isolated buildings and other objects.

5. In 2011 an Actualized version of the Seismic Buildings Design Code was prepared and it was approved by the Russian Ministry of Regional Development as the compulsory design document.

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