Strengthening of Historical Monuments in Seismic Regions

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SUMMARY:
There are many ways to provide seismic resistance of constructions; on one side the traditional approaches to increase the bearing capacity of buildings, and on the other side – a way to modify or change the dynamic behavior of buildings and to provide availability of the seismic isolation elements and damping. Despite the fact that there is a great number of different proposals for reconstruction or strengthening buildings, which could be used in architectural monuments, not all of them have been implemented at specific buildings and tested by earthquake. This paper deals with research and practical application of the seismic isolation for reconstruction of historic buildings and cultural heritage located in seismic hazardous areas of Russia.

Keywords: monuments, reconstruction, seismic isolation.

1. INTRODUCTION

Architectural Monuments were built, usually over a long period of time and were built and were accompanied by numerous changes in the original plan and have a complex geometric shape. Evaluation of seismic resistance of buildings and structures of this type is a complex problem, which requires the use of modern technologies of the research and the use of numerical methods, providing computer modeling of the object based on its actual geometry and the actual technical condition.

Modern approach to the protection of cultural heritage should introduce criteria for protection buildings from earthquake effects considering all the specificities of the object and the expected level of seismic influence, as well as specific characteristics of the monuments, their historical and cultural importance, their design features and characteristics of original materials. Recently, the performance of new materials and technologies is actively developed. However, to accept new materials and technique for mass application, it is necessary to carry out a sufficient number of investigations to reveal their efficiency and safety, durability and compatibility with existing materials.

Seismic isolation system is considered to be very efficient, when applied to masonry structures due to the rigidity of the masonry elements. It follows that seismic isolation system has emerged as an effective technology for the protection of historical and monumental buildings, which are presented in the form of masonry.

At present, the efficiency and versatility of the seismic isolation opens new application areas, which include seismic protection of masonry structures. Unfortunately, seismic isolations cannot always be applied to the restoration of historic buildings. The possibility of their use is mainly based on the actual configuration of structure. However, the reconstruction, requiring the application of seismic isolation systems can be very expensive; for example, often structures are based on massive foundation slabs, or sometimes on the ground. Therefore, the use of seismic isolation requires the introduction of new slabs and new foundations.

Seismic isolation system is a simple way to reduce the seismic loads applied to structural elements. Seismic codes provide the methods of reducing seismic loads affecting to historic buildings, unfortunately these methods are often neglected in practice.

2. SEISMOISOLATION FOR RETROFIT OF AN EXISTING HISTORICAL BUILDING IN IRKUTSK-CITY

The traditional methods which are usually used during the reconstruction, strengthening or repair of buildings located in seismic-prone areas of Russia. However, in some cases it’s impossible to use conventional methods to protect architectural and historical monuments, as we must preserve the external and internal view of the building, therefore it is not allowed to violate the architecture and change the structural configuration. Seismic isolation system enables to maintain the existing morphology and even the original materials and doesn’t cause significant changes in constructions.

2.1 The Spasskaya Church

The primary building of the Spasskaya Church (see Fig. 1) was built in 1706 - 1713 years. This is one of the first stone buildings in Irkutsk-City. Four-story bell tower was attached in 1758 – 1762 years and the northern two-story stone chapel was built in 1777. The church acquired the status of historical and cultural monument of federal significance in 1948. It has acquired the modern form as a result of restoration work in 1968 - 1981 years. The church was handed over to the Irkutsk Diocese of the Russian Orthodox Church, which served as the impetus for another round of restoration in 2008.

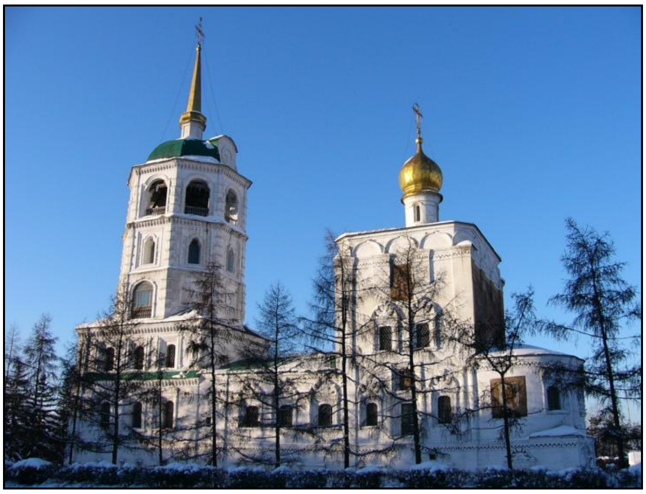


Figure 1. General view of the Spasskaya Church

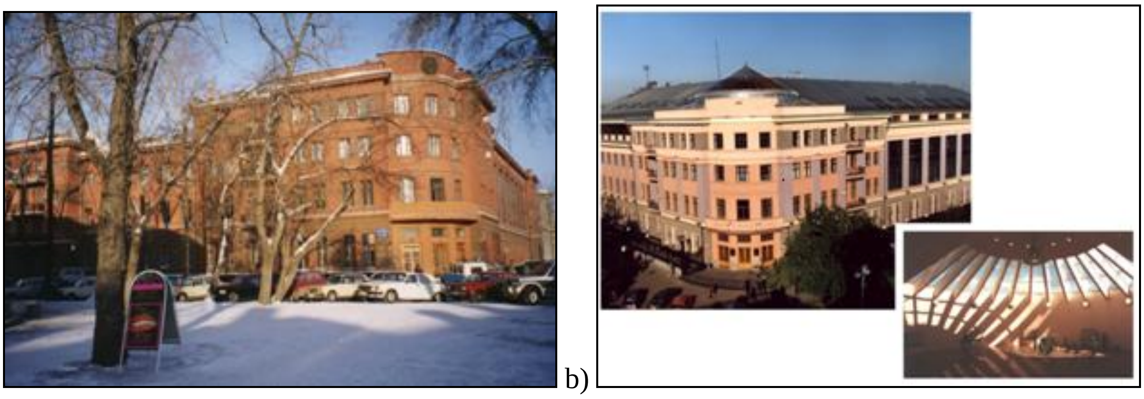
The church building is a three-part structure, including a temple with an altar, refectory and bell tower. The plan of the church has the rectangular shape of width 10.8 m and a length of 39.7 m. Temple of the church with an adjoining altar has a length of 15.2 m, a refectory - 10.0 m and bell tower - 14.5 m. Part of the structure has a different height. The thickness of the brick walls and piers up to 1.5 m in some places.

Digital three-dimensional model of Church was created. Geometrical parameters of the model are equal to original sizes of the building and all bearing elements were included. The problem was solved using three-dimensional finite elements, since the thickness of the walls is commensurate with the height of the floors and width of piers. The use of traditional design diagrams, consisting of rod and plate (shell) elements were improper in this case. This allows simulating the arch covering and other details of the construction.

An analysis of the Spasskaya church building based on the result of calculations showed that the church had a lack of seismic performance and it was necessary to take measures to improve the seismic resistance. For this purpose, project of seismic isolation system has been developed with the use of lead-rubber bearings and the appropriate calculations were made.

2.2 The Central Bank

The building of Central Bank (see Fig. 2) in Irkutsk-City was built in 1934. A historical building of the Irkutsk Bank needed retrofitting and upgrading as observation and analysis have brought to conclusions that the seismic reliability of the building didn't meet the current Seismic Building Code requirements.

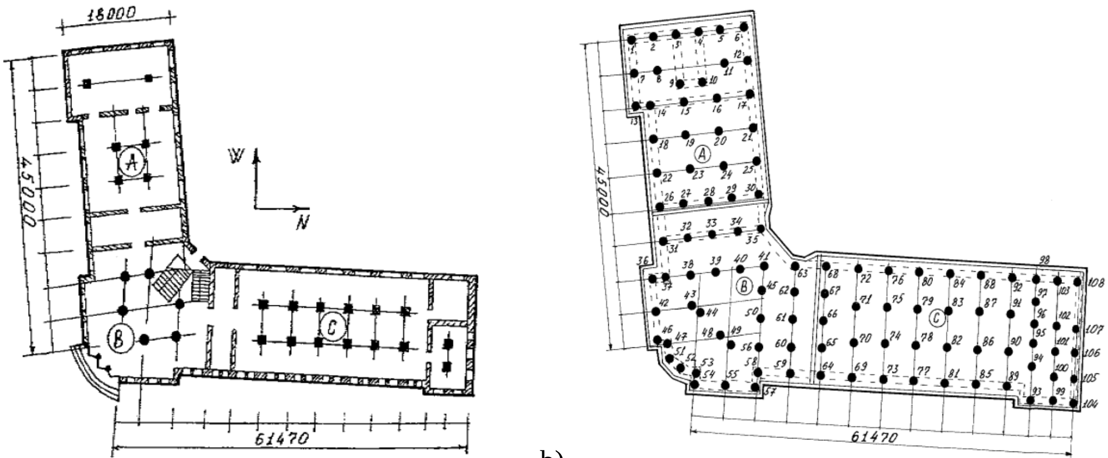


a) b)

Figure 2. General view of the Central Bank: a) before reconstruction;
b) after reconstruction

The purpose of the reconstruction was to provide seismic resistance of the building in accordance with actual codes, as well as alteration premises, and add 1-2 upper floors, thereby increasing the number of floors of the building to 5 storeys.

Existing building (before reconstruction) has a polygonal configuration in-plane width from 17 to 19 m and protrusions 1-2 m (see Fig. 3). The building consists of three blocks: Western, Central and Northern. The Western and the Northern building parts have length 45 m and 62 m respectively, and placed at an angle of approximately 100° to each other.



a) b)

Figure 3. The plan of the Bank: a) before reconstruction;
b) bearing installation scheme.

The building has a variable number of floors 3-4 floors and basement storey. The basement storey is absent in the central part. Height over ground storeys is 3.5 – 5.2 m, height of the basement storey is 3 m. In the central part: the outer brick wall and an inner cast reinforced concrete frame with columns of circular cross section. Floor over basement storey is cast reinforced concrete. The attic floor is wooden; intermediate floors are cast reinforced concrete and wooden. Foundation and basement storey are stone-masonry; foundations for reinforced concrete columns and brick pillars are stone-masonry.

The reconstruction project included the following steps:

- three floors parts of the building overbuilt by the fourth floor and the entire building was added the fifth attic floor;
- all wooden floors are substituted by cast reinforced concrete slabs;
- attic floor is performed in light metal structures with efficient fireproof insulation;
- foundations under the columns in the central part deepened to the gravel. In the central part of the basement storey was constructed;
- brick columns were strengthened with metallic elements.

The decision to install lead rubber bearings in the mid-level of the basement storey was taken to provide maximum seismic isolation of the existing walls and columns. The total number of seismic bearings installed was 108 (see Fig. 3). Every bearing was designed for 2500 kN load. All the bearings have equal dimensions: diameter – 510 mm, height – 216 mm.

The high-damping lead-rubber bearings were produced at the Shantou-city (Southern China) "Vibro-Tech Industrial and Development Co Ltd". The dynamic tests of supports were carried out in South China Construction University in Guangzhou with participation of Russian experts. The numerical analysis of earthquake response of this Building was carried out in EERC, Moscow by J.M. Eisenberg and V.I. Smirnov.

The method of seismic isolation of the existing bank building has revealed the advantages of this method comparing to the conventional methods of retrofitting and strengthening of the buildings located in highly hazardous seismic zones. Seismic isolation of the ground floor part of the building enabled to preserve the building exterior look and to avoid architectural features violation. To enable normal work of the bank the bearings were installed gradually.

2.3 Mikhailo-Arkhangelskaya (Kharlampiyevskaya) Church

Mikhailo-Arkhangelskaya (Kharlampiyevskaya) Church is a historical and cultural monument built in 1779-1790 in the Irkutsk-City (see Fig.5). Restoration work began in 2005. The structural concept includes an asymmetric in plan (see Fig. 4), columnless brick masonry structure. The building consists of different parts of the design decisions, tied by walls into a single block. The northern and the southern side-chapels have similar structural concept in the form of two-storey parallel bays of different length. On the east side, the bays are completed with the multifaceted apses.

The foundations are of shallow, strip, stone masonry type with the artificial subgrade, consisting of pebble and fine sandy loam mixture poured with mortar. The masonry is made of loam Flemish bricks on mortar. Wall thickness is 1.26–2.35 meters.

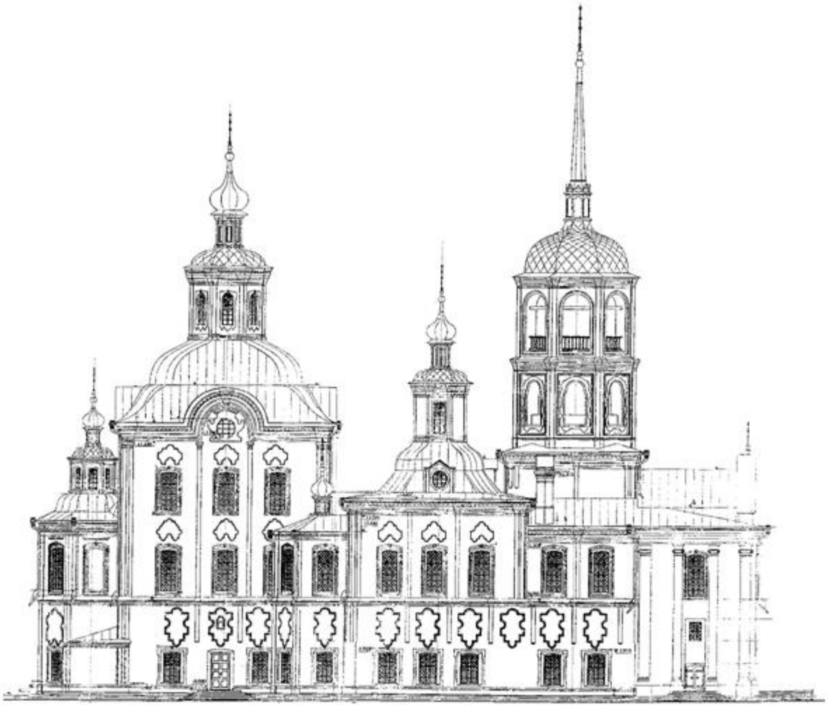
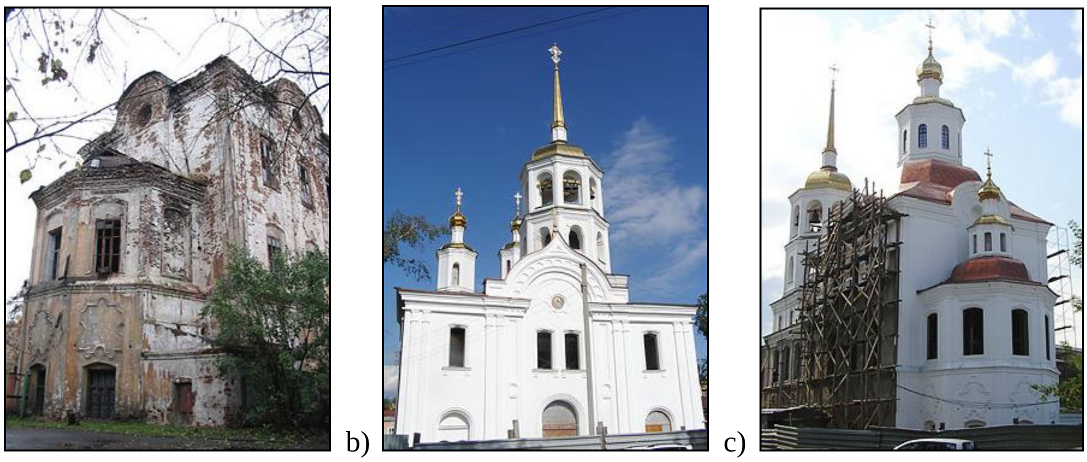


Figure 4. Church buildings in-plan



a) b) c)

Figure 5. Mikhailo-Arkhangelskaya (Kharlampiyevskaya) church: a) before reconstruction, b) and c) after reconstruction

Project of seismic isolation system in the form of lead-rubber bearings in the foundation of the church is used to provide seismic stability of the building. Total number of lead-rubber bearings is 92. These measures are aimed at increasing the natural periods of vibration of the building and the reduction of energy transmitted from the ground to the superstructure.

CONCLUSION

The examples of the use of seismic isolation systems for the reconstruction of historic buildings and monuments are presented in the article. The application of seismic isolation systems has significant advantages over traditional methods of strengthening. Minimum design activities were carried out in the above-ground parts of buildings, required in accordance with the codes. The cost of this method of amplification was lower in comparison to traditional techniques. Reliability of the buildings with seismic isolation is much higher than buildings with a traditional strengthening under seismic action. This is due to that the seismically isolated building admits significant deformation without destruction of structures under seismic action, and in a building with traditional strengthening is impossible to avoid the development of cracks and structural destruction.

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