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SEISMOISOLATION FOR UPGRADING OF EXISTING HISTORICAL BUILDINGS AND CHURCHES

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Abstract. *In the beginning of the 70-th a program of analytical and experimental investigations of structure seismoisolation was carried out in Earthquake Engineering Research Center, TsNIISK, Russian Construction State Committee.*

As a result of the research program different structural systems of seismoisolation are designed. Different seismoisolated structures were constructed taking into account the investigation results. More than 500 buildings and historical monuments are seismoisolated in Siberia, Far East, Crimea, Caucasus, Middle Asia and other earthquake hazardous areas of Russian Federation.

Some examples of seismoisolation for upgrading of existing historical buildings, including a bahk building and churches in Irkutsk-city (Siberia) are presented. All steps of installment of the steel-rubber supports in the bank building and church foundations are given.

Seismoisolation was used in the designs of two churches in Irkutsk-city as well: Kharlampiyevskaya (Mikhailo-Arkhangelskaya) and Spasskaya churches which are historical and cultural monuments built in 1779-1790 and 1706-1713 accordingly.

The structural concept includes an asymmetric in plan, columnless brick masonry structure. The building consists of several parts with different design, connected by walls in one unit, except for the porch. Its walls do not have bonding with main building walls.

Also two cultural centers have been strengthened in seismic high earthquake hazardous areas using steel-rubber seismic isolation. One is the Chechen Republic Cultural Center Building Complex, which was damaged during the war. The other building was the Gorno-Altaysk National Drama Theater. Both complexes are situated at sites with design seismic intensity MSK 9 degree.

INTRODUCTION

A program of analytical and experimental investigations of structural seismoisolation was carried out Earthquake Engineering Research Center, TsNIISK, Russian Construction State Committee, Eisenberg [1].

The strong motion accelerograms up to the present time demonstrated very different predominant periods of earthquake ground motions not only during different earthquakes but sometimes even during the same earthquake at distant and the close distances, for example, during Loma-Prieta, 1989, earthquake. The mathematical semi-probabilistic models of earthquake inputs were developed which take in consideration the uncertainty of the predicted spectra and other motion parameters of the future earthquakes and artificial design accelerograms were computer generated, Eisenberg [1], in the early 70-th of XX century.

Experimental part of the investigation program included:

1. Shaking table model and fragment tests;
2. Full scale building dynamic tests using large exciters. The maximum dynamic loading of the structure by means of an exciter corresponded to the design load of 9 MM – intensity and more;
3. Static and dynamic tests of the elements of seismoisolation system (flexible supports, dampers, dry friction elements a.a.).

As a result of the research program different structural system of seismoisolation are designed and buildings are constructed recently in Siberia, Far East, Crimea, Caucasus, Middle Asia and others earthquakes dangerous areas. Specific for these systems is that they are simple in construction and are not expensive. Different structures using seismoisolation were constructed taking into account the investigation results. More than 500 buildings and bridges are seismoisolated in Russia and in former USSR countries.

The prevailing amount of constructed seismoisolation systems in Russia is non-rubber seismoisolation. The seismoisolation effect is achieved by using two and sometimes more than two elements. The two elements are 1 – flexibility elements and 2 – dampers. The flexibility elements are flexible columns in the ground storey of the building, or rocking supports (rocking columns, rocking converted mushroom type supports, other configuration rocking supports). The dampers are mild steel hysteretic elements or RC damaged during earthquake diaphragms, or dry friction elements.

The main design demands are large enough critical horizontal displacements of the flexible columns or rocking supports. Several dozens building are constructed on sliding supports and sliding belts of controlled damping. Usually the steel-teflon pairs were the controlled friction elements. Additional elements of seismoisolation used in Russia are horizontal displacement rigid limiters (stops) and reserve disengaging elements for energy dissipation and for frequency spectra adaptation.

Recent years steel-rubber supports were used in some seismoisolated buildings constructed in Russia, Smirnov, at al [6]. Now some buildings with steel rubber seismoisolation supports are in design process. One of these buildings will be constructed at Alexandrov-city, Sakhalin (a 4 storey school building). The steel-rubber supports for this building are produced in China, Shantou, "Vibro-Tech" Company.

As a result of studies in Moscow EERC the seismic safety of buildings with soft ground stories was exonerated. The reason of many buildings with soft ground stories collapses during recent earthquakes was reinforced concrete as material of bearing ground story columns, not the flexibility of the ground story itself. Design of soft ground story buildings with steel columns as seismoisolation elements combined with dampers and fuse elements is presented.

SEISMOISOLATION FOR UPGRADING OF AN EXISTING HISTORICAL BUILDING IN IRKUTSK-CITY, SIBERIA-RUSSIA

A historical building of an Irkutsk Bank needed retrofitting and upgrading as observation and analysis have brought to conclusions that the seismic reliability of the building doesn’t meet the current Seismic Building Code requirements. The bank building was retrofitted using seismic isolation to prevent the damage by earthquakes expected in the future (Figure 1).

The building consists of three blocks. The external bearing system is: brick wall, thickness is 64 cm. The internal system is reinforced concrete columns and brick masonry. The building height is 3 to 4 stories, where walls and columns lower storey were cut at their mid height and LRB’s (lead rubber bearings) were installed.

The decision to install seismic lead rubber bearings in the mid level of the ground floor was taken to provide maximum seismic isolation of the existing walls and building columns. The total number of seismic bearings to be installed is 108. Every bearing is designed for 2500 kN load. All the bearings have equal dimensions: diameter – 510 mm, height – 216 mm.

The high-damping steel-rubber supports 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. Due to the reduction of seismic force by isolation, strengthening of the structure above isolators has come to be unnecessary. The part of structure below isolators has been strengthened. A specific construction technology of supports installation in the existing building without its exploitation interruption was developed. The site dynamic tests of the full scale building to investigate the dynamic properties of the seismoisolated building and the correlation between the actual and design values were carried out.

Figure 1: General view of an Irkutsk Bank
a –before reconstruction; b – after reconstruction

The numerical analysis of earthquake response of this Building was carried out in EERC, Moscow by J. Eisenberg and V. Smirnov. The results of the investigation are that in case of the seismoisolation high damping (27% of critical damping) supports both response acceleration and response displacements are sufficiently lower comparing to non-isolated existing building.

The maximum response displacements of the seismoisolated building do not exceed 2.5 cm, maximum response acceleration are in the limits of 550 gals. These values are not hazardous for from point of view of the building safety.

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.

1. Seismic isolation of the ground floor part of the building enabled to preserve the building exterior look and to avoid architectural features violation.
2. The result of comparative nonlinear analysis of isolated and non-isolated buildings is that both displacement and acceleration in isolated buildings are significantly lower than in non-isolated ones.
3. The method of gradual isolation of lead rubber bearings in the building blocks enables normal work of the bank.

DESIGN OF A CHURCH BUILDING SEISMOISOLATION

The design of church building in Irkutsk-city seismoisolation in now carried out (Figure 2). Kharlampiyevskaya (Mikhailo-Arkhangelskaya) church is a historical and cultural monument built in 1779-1790.

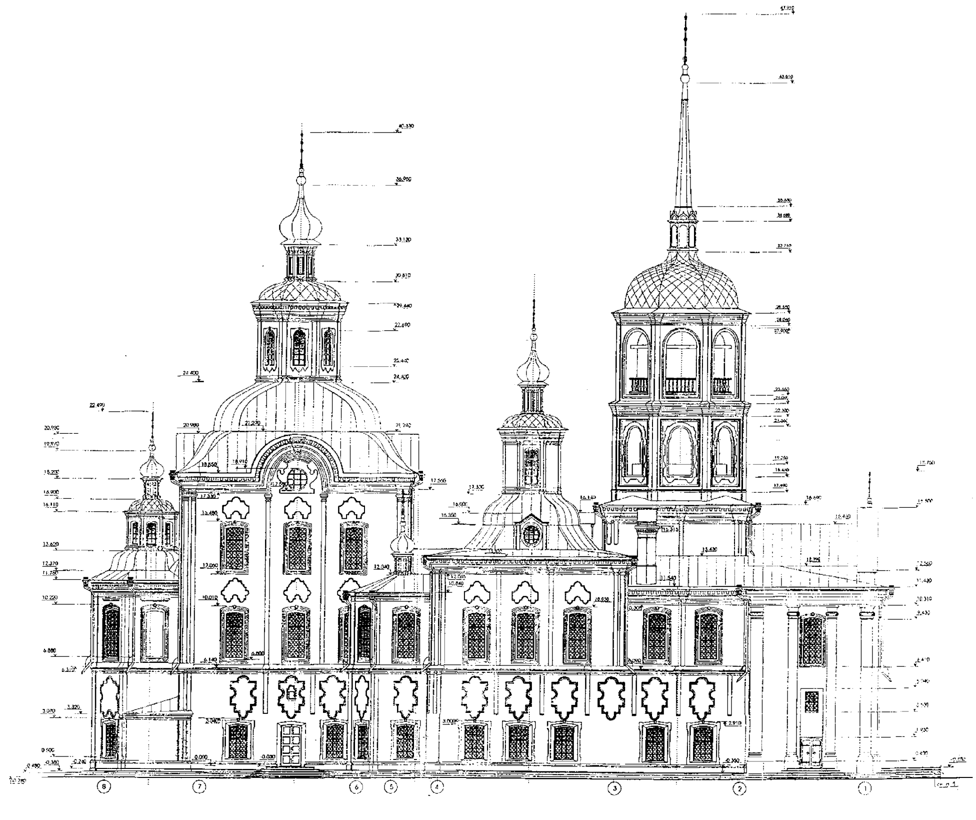

Figure 2: Church buildings

The structural concept includes an asymmetric in plan, columnless brick masonry structure. The building consists of several parts with different design, connected by walls in one unit, except for the porch. Its walls do not have bonding with main building walls. The northern and 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.

Side-chapels' ground floor is spanned with cylindrical brick vaults, including strippings in the wall vaulted bay. In the first floor, the northern side-chapel narthex and the southern side-chapel refectory are spanned with cylindrical brick vaults. The northern and southern side-chapel churches and the southern side-chapel altar are spanned with octagonal tent brick vaults. The altar apses in the ground and the first floor are spanned with multifaceted closed brick vaults.

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. To provide building earthquake stability seismoisolation system, including metal-rubber supports is used in Mikhailo-Arkhangelskaya church foundations.

In order to reduce lateral seismic loads, metal-rubber isolators are installed on the church building superstructures. It is enabled by pliable bracing between building superstructures and foundation. It also provides seismoisolating support dampening quality. These measures are used to increase building natural period of vibrations and to decrease transmission of earthquake power and ground motion to the building superstructures. Estimated building weight is 158060 кN. Total number of rubber-metal seismoisolating supports are 92.

The following sequence of works was offered for supports installation in the existing church building (Figure 3). Foundation replacement and exterior wall seismoisolation installation are carried out in the following sequence:

1. The mortar is injected via injectors (1), to reinforce the upper zone (4) of ground pad (5) (Figure 3a).
2. The antiseismic belt (8) is provided (Figure 3c, d):
- 3 meter long trenches (24) are dug with some intervals;
- Trench bottom is smoothed and covered with two layers of polyethylene film (7);
- Formwork panels (6) are installed;
- Support antiseismic belt (8) with embedded parts (26) for seismic supports fixing (Figure 3c).

3. After the support antiseismic belt is arranged in the whole building, each second hole is open in places where seismic supports are to be installed (25), the walls must be fastened (10), pillar formwork (11, 12) is provided, and support columns (14) for seismic supports are cast in situ (Figure 3e).

4. Wells in ground-and-concrete mass (4) are drilled via holes (27), left in support seismic belt, and coupling bolt studs (9) are passed through them. Bolts are tightened, wells pressure grouting via special channels (18) is carried out, and additional strengthening of ground-and-concrete is provided (4).

5. Each second foundation column along the perimeter is dug out (after reaching 70 percent concrete strength), hole bracing is dismantled, and formwork is removed. Then foundation slabs (19) are installed and foundations are connected (31) (Figure 3f, g).

6. The rest foundations are erected with separate foundation slabs connected into a continuous belt.

7. The foundations for the interior walls are laid down in a similar way.

8. After all foundations are ready and the support antiseismic belt is underpinned, the trench under the whole building is to be open for ground floor arranging. Basement solid-cast reinforced-concrete walls (20) and solid-cast reinforced-concrete ceiling over the basement (22), resting on support antiseismic belt and rigidly connected with it are erected (Figure 3g).

9. Cantilevered solid-cast reinforced-concrete plate (21), rigidly built in the outside branch of support antiseismic belt, which has to overlap the distance between the belt and basement wall is installed along exterior walls contour. A horizontal antiseismic joint, 50 mm high, separating the building overground part from the underground part is provided between the upper basement wall batter and cantilevered plate (21). The joint is stuffed with mineral wool plate, wrapped in polyethylene case, and is sealed with thiokol sealant.

10. After complete basement closing seismic supports are erected.

11. Seismic supports underpinning is to be provided in the following succession:

– Seismic supports (16) are hung in the recesses which were left when concreting support columns (Figure 3f, g) to the top embedded parts (27) with four bolts (29);

– Lower embedded parts (similar to 27) with foundation bolts (15) are hung with the help of four bolts on the lower connecting plates of seismic supports;

– Reinforced concrete support pads (17) (Figure 3f, g) are concreted under embedded parts, 50 mm gap is to be left between a support pad and an embedded part which must be carefully caulked with firm fine concrete, grade V20.

12. After all seismic supports are installed, they are loaded by filing off and removing support columns (30) from under antiseismic support belt.

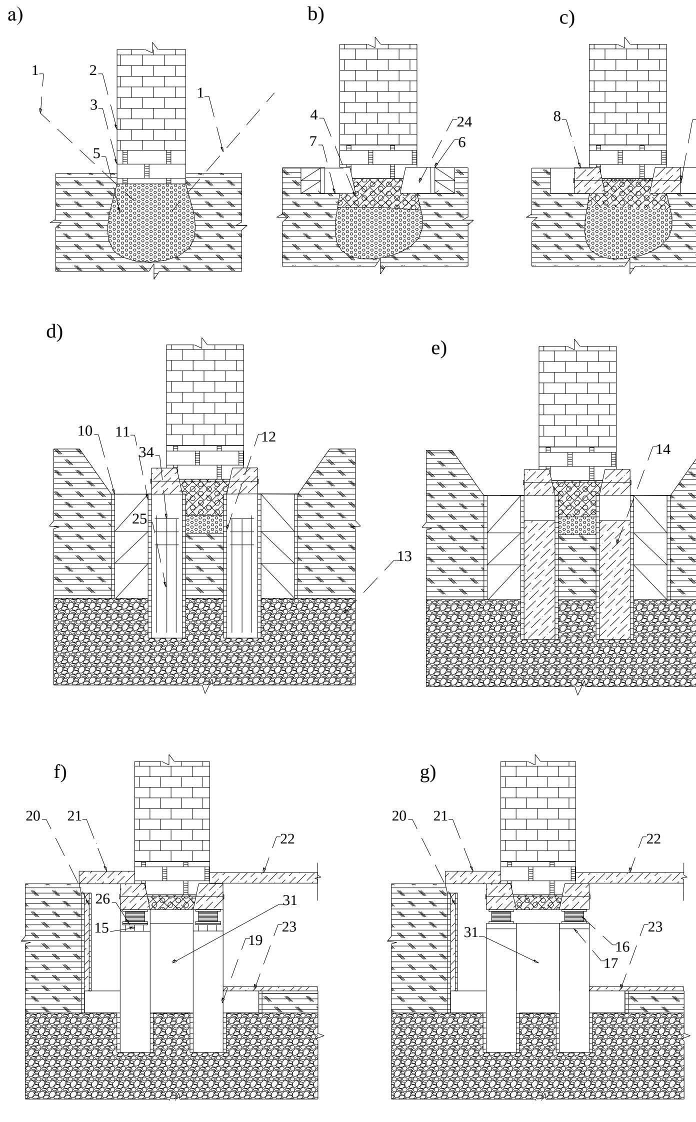

Figure 3: The sequence support installation

CONCLUSIONS

Some new Projects of historical seismoisolated structures used in Russia recently are presented.

Among them are newly constructed buildings and existing buildings, which are strengthened.

Rubber and non-rubber seismoisolation supports were used.

Provisions for seismoisolated buildings of different seismoisolation types were prepared.

Mild steel columns or frames as base isolation elements are presented. Two aspects of their seismoisolation ability are taken into account in design. The one is the building flexibility achieved using these columns. The other aspect is energy dissipation and large enough permissible (safe) horizontal displacement.

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