0962

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

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SUMMARY

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.

The building consists of three blocks. The external bearing are brick walls 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. Specific is that the vertical load on each support is comparatively high, reaching 200 to 250 ton's.

The high-damping steel-rubber supports were produced at the Shantou-city (Southern China) «Vibro-Tech Industrial and Development Co Ltd». The supports were tested in the Guangzhou University Research Center.

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.

This is the first completion of rubber-steel seismic isolation in an existing building in Russia.

Some results of the supports and of the seismoisolated building dynamic tests as well as the results of the building seismic response analysis are presented in the paper

INTRODUCTION

Systems of seismic isolation are, as a rule, used in the newly constructed buildings [1-8]. There are cases when isolation systems find their application for existing buildings retrofitting and strengthening [4, 9, 10]. Building retrofitting in seismic regions is utmost urgent for the highly important buildings, historical monuments, hospitals, dwelling houses of old construction which do not have any antiseismic reinforcement.

Up to now the following conventional methods were implemented in Russia for building retrofitting, strengthening, and upgrading: guniting on metallic grid, metallic casings, prestressed vertical and horizontal

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metallic rigid and flexible belts, reinforced concrete and metallic strengthening members built in the brick masonry and piers, special joints (anchors, keys) resisting displacement, stretching, and torsion, injection of epoxide glues, cement and polymeric solutions, introduction of additional rigid members, like walls, diaphragms, frames, etc.

The conventional methods of seismic dwelling and industrial building strengthening cannot be always used for the architectural and historical monuments, because they alter building interior and exterior, change structural layout, violate the architecture.

The existing bank building was built in 1934 in the city of Irkutsk (according to the current Seismic Zonation Maps the seismicity is 8 MSK-64). The building does not meet Seismic Building Code (SBC) requirements in respect of its dimensional and structural layout. The seismic strengthening of the building is a complex technical task.

The provision of building earthquake resistance to satisfy SBC current requirements, premises re-planning and adding the superstructure to one or two upper stores to convert the whole structure into four-storied building was the retrofit target.

OUTLINE OF THE BUILDING RETROFIT

The existing (prior to retrofit) 17 - 19 meters wide building has broken-line in plan configuration with 1 - 2 meter projections (Figure 1). The building consists of three blocks: Western, Central and Northern (Figure 2). The Western and the Northern parts of the building are, correspondingly, 45 and 62 m long, and are situated at the corner of approximately 100^o to each other. On the main facade the blocks are connected by the broken-line in plan wall of the Central part about 9 meters long. The number of stories of the building is variable (3 - 4 stories) plus the ground floor. The Central part does not have a ground floor. The height of the above-ground floors is from 3.5. to 5.2 meters , the ground floor height is 3 meters.

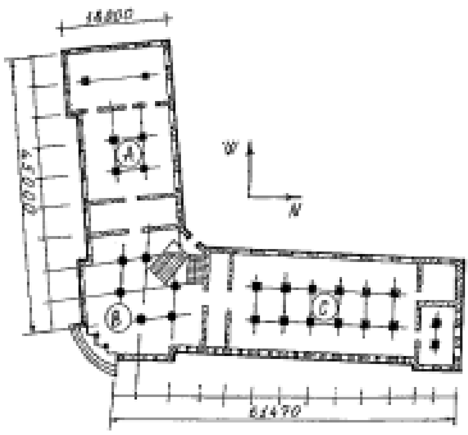


Figure 1. Plan of the first floor
A – the Western part of the building;
B – the Central part of the building;
C – the Northern part of the building

Figure 2. General view

The external brick walls, internal cross walls, and two longitudinal rows of brick columns in the Western and the Northern blocks comprise the load-bearing structures of the building. The pitch of three cross isles is 5.5 meters. The distance between the cross load-bearing walls is from 5 to 35 meters.

There are external brick walls and internal monolithic reinforced concrete frame with round cross-section columns.

The ceiling above the ground floor is of monolithic rib reinforced concrete type. The garret floor is wooden with metallic or reinforced concrete collar beams.

The intermediate floors are monolithic reinforced concrete and wooden with metallic or reinforced concrete collar beams.

The foundations and the ground floor are made of rubble (quarry stone) masonry. The reinforced concrete columns and brick piers foundations are performed of rubble (quarry stone) masonry too.

INSPECTION OF STRUCTURAL MATERIAL AND SEISMIC DIAGNOSIS

The laboratory tests of the samples cut of the external walls, showed that wall masonry was performed of the red 75 grade solid bricks on lime-and-sand 25 grade mortar. The brick masonry category in respect of earthquake resistance is below 2. The state of the walls and the piers is, in general, good. Wall cracks and wall deformation caused, probably, by the earthquakes were revealed.

The walls of the ground floor and wall foundations were performed of coarse-cut sandstone blocks on lime-and-sand mortar. The height of the masonry row is from 150 to 500 mm. Limestone compression strength is 150 - 200 kg/cm^2. The lime-and-sand mortar in the masonry below the ground level is saturated with moisture and is very weak. The ground floor wall and foundation state was estimated as very dangerous.

Non-destructive tests of reinforced concrete structures showed they had the required strength and did not require strengthening.

Dynamic tests were carried out and period and shape of natural vibrations were received. The analysis of structural solution of the building to identify compliance with the requirements of the current Russian SBC, the results of tests, as well as increased seismic activity of the region led to the conclusion that the bank building earthquake resistance is not sufficient, and the measures are to be undertaken to provide its resistance to the earthquakes which can occur.

REPAIR AND STRENGTHENING OF THE BUILDING

The retrofitting project included the following stages:

- the 3rd floor is to be added to the two-storied parts of the building, and the fourth garret story is arranged along the whole building.
- all existing wooden floors are to be replaced by monolithic ones;
- the garret story is to be performed as the metallic structures with the efficient fire-resistant warmer;
- the foundations for columns in the central part are to be deepened up to gravel. A basement (the ground floor) is to be arranged in the central part.

Three alternatives of earthquake protection were offered:

- the conventional method - guniting on metallic grids of exterior and internal walls, introduction of additional monolithic reinforced concrete diaphragms of stiffness, dividing of the building into three blocks by means of earthquake-resistant joints;
- strengthening of the existing load-bearing structures by means of prestressed compression strength in the horizontal masonry sections which enable resisting to earthquake load-caused shear and main tensile stresses;
- installation of lead rubber bearings in the building foundations.

Taking into consideration that the building is the architectural and historical monument as well as its value, retrofit time, and the possibility of seismic load elimination in above-ground part of the building, the decision was made to use seismic isolation in building foundations.

According to the reconstruction project the seismic isolation bearings are to be arranged under all walls, piles, and columns at the level of the ground floor. The foundations are to be additionally strengthened in accordance with seismic loads values.

INSTALLATION OF SEISMIC ISOLATORS

The basic difference between the existing bank building reconstruction and those described in references [4, 9, 10] is as follows. First, the construction works were to be performed gradually: in the first stage seismic bearings in the Western and the Central blocks were to be retrofitted and installed, the Northern part of the bank had to be available for the current work; afterwards all bank services were to be transferred from the Northern block to the Western part, and the bank would continue to work, while the retrofitting is going on in the Northern part. Second, the design structure of the building is a complex one, it means, the exterior longitudinal and cross walls and internal brick and reinforced concrete columns constitute load-bearing structures. This factor should be taken into account in development of seismic bearing installation method.

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. The layout is shown in the Figure 3. Every bearing is designed for 2500 kN load. All the bearings have equal dimensions: diameter - 510 mm, height - 216 mm.

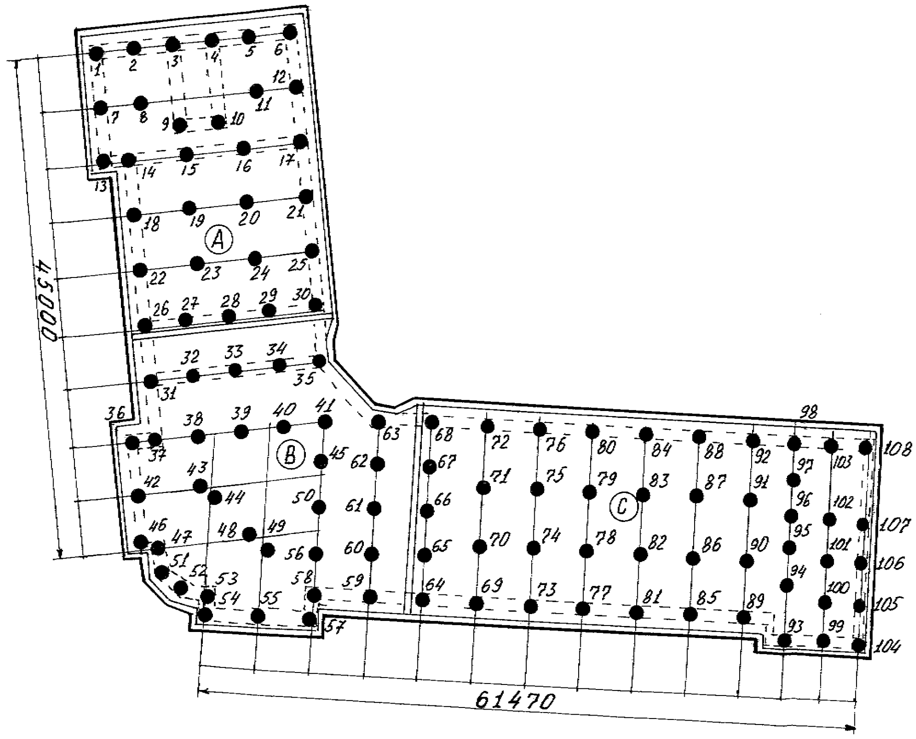


Figure 3. Layout of isolators

As a rule, jacks are used in the existing building for bearing installation. In this case the method [4] was used which, as it is shown in Figure 4, was implemented in the following sequence:

1) Brick and reinforced concrete piles.

- Pile surface is prepared for concreting (Figure 4a);
- Timbering, reinforcement cage are installed, and in the mid of pile height openings for bearing installation are provided. Then concrete is poured to timbering. Reinforced concrete casing thickness is 100 mm (Figure 4b);
- After concrete strength was achieved the mid part of piles is cut through the openings. The vertical load of the building is transferred at this time to the concrete casings (Figure 4c);
- The timbering, lower metallic frame are installed, and the bearing part for an isolator is concreted. The seismic bearing is placed in-situ. Timbering, upper metallic frame are installed, and the part above the bearing is concreted (Figure 4d);
- After all the bearings are installed in-situ, the casing concrete in the proper areas is cut, and the vertical load is transferred on seismic bearings (Figure 4e).

2) Exterior stone block walls.

- The ground from the outside and internal sides of the ground floor wall and upper part of the continuous footing is removed (Figure 4f);
- The timbering for reinforced concrete beams is installed on the external and internal side at the level of foundation top and ground floor wall bottom. Metallic frames and embedded parts for beam bracing are installed after concrete strength is achieved. The upper beams are concreted in the way which enables to leave unconcreted recesses in the areas where seismic bearings are located (Figure 4g). The lower beams are concreted simultaneously with the piles for seismic bearings (Figure 4h);
- The bearings are installed on reinforced concrete piles. Embedded parts are placed on the bearing, and the upper recess above the bearing is concreted (Figure 4i);
- Then the remaining parts of the ground floor wall between the isolators are finally dismantled, and the vertical load from the walls is transferred on the lead rubber bearings (Figure 4j).

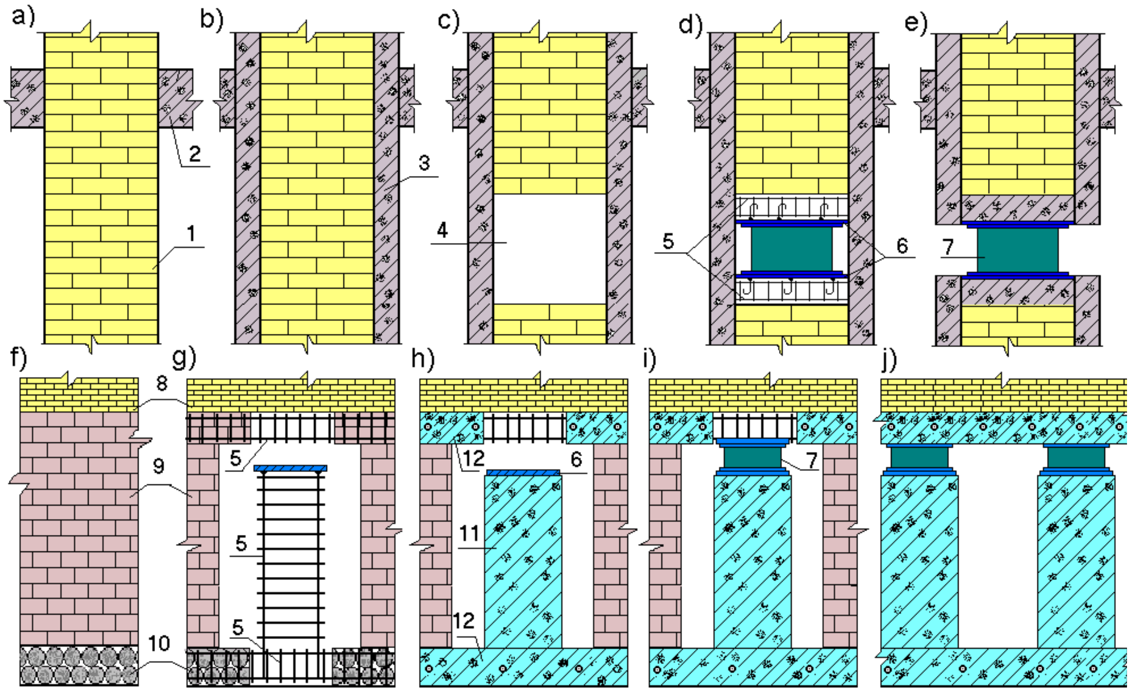


Figure 4. Remodeling of the isolators installation procedure
1 – brick masonry column; 2- reinforced concrete beam; 3 – external reinforced concrete cage; 4 – cutting portion of column; 5 – steel bar; 6 - steel plate; 7 – seismoisolator; 8 – brick masonry wall of the first storey; 9 – block masonry wall of the socle storey; 10 – stone and concrete strip foundation; 11 – reinforced concrete pole; 12 - upper and lower portion of beams

NONLINEAR RESPONSE ANALYSIS

The city of Irkutsk was many times affected by earthquakes of different intensity. Irkutsk has suffered most of all from the earthquakes with epicenters beneath in the Lake Baikal and in Mongolia. According to the latest seismologists' research [11], Irkutsk is located in the MSK intensity 8 earthquake zone. Frequency composition of the earthquakes to occur determined on the basis of empirical formulas can be characterized in the following way: frequency corresponding to the basic spectrum maximum on the Irkutsk territory equals f=2.0 Hz (T=0.5 sec.).

The full-scale dynamic tests to evaluate seismic response of the existing building prior to reconstruction were carried out. Natural periods of vibration determined by instruments in the lateral direction T=0.3 sec, in the longitudinal direction T=0.27 sec. Damping value is C=(4.2-4.8)%C_{cr}. This data is used for nonlinear seismic response analysis of the building prior to the reconstruction.

The dynamic tests of supports were carried out in South China Construction University in Guangzhou with participation of Russian experts (Figure 5a).

The numerical analysis of earthquake response of this Building was carried out in EERC, Moscow by J.Eisenberg and V.Smirnov.

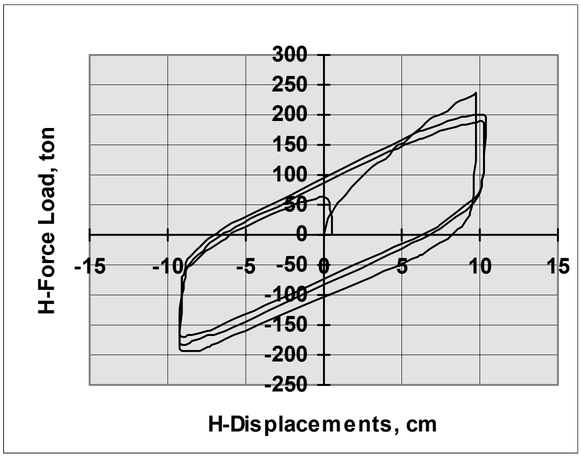
Instrumental accelerograms of 3 earthquakes were used as seismic inputs: Kobe, 1995, Bucharest, 1977 and El Centro, 1940.

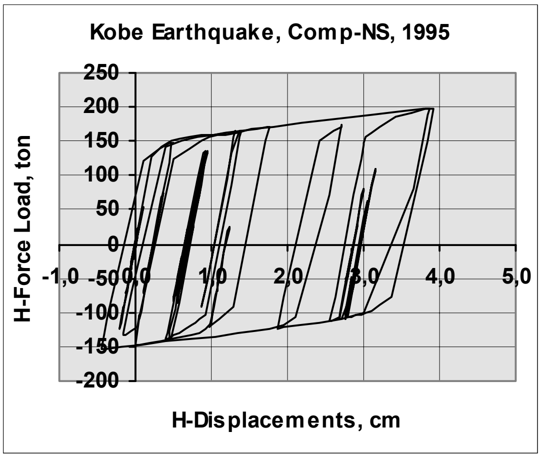
The analysis results are given in table 1 and of the figure 5 b.

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. This values are not hazardous for from point of view of the building safety.

The high damping steel-rubber supports which are produced by «Vibro-Tech» Shantou company have proved to be very effective from point of view of cost-benefit analysis as well.





a) **b)**

Figure 5. Experimental (a) and computed (b) hysteretic characteristics of high-damping steel-rubber supports with lead cores

Table 1. Seismic Response Displacements and Acceleration Comparison of Irkutsk Seismoisolated Building and Non-Isolated Building.

Seismic Response	Earthquake	Non-isolated existing building P=(0.3-0.4) sec, (C=5% Ccr)	Base Isolated
Displacements, Y_{max}, cm	Kobe, NS, Y_0''=817.82 cm/sec^2	9.04	2.22
	Bucharest, NS, Y_0''=217.5 cm/sec^2	1.88	0.14
	El Centro, NS, Y_0''=341.7 cm/sec^2	1.52	0.22
Accelerations, Y''_{max}, cm/sec^2	Kobe, NS, Y_0''=817.82 cm/sec^2	2561	530
	Bucharest, NS, Y_0''=217.5 cm/sec^2	463	242
	El Centro, NS, Y_0''=341.7 cm/sec^2	888	379

CONCLUSIONS

The proposed method of seismic isolation of the existing bank building has revealed the advantages compare to the conventional methods of retrofitting and strengthening of the buildings located in highly hazardous seismic zones.

1. Seismic isolation in the ground floor part of the building enabled to preserve the building exterior look and to avoid architectural features violation.
2. Lead rubber bearing based seismic isolation system has eliminated the necessity of upper building part strengthening. Only minimum structural measures to meet Seismic Building Code requirements were undertaken in the above-ground part of the building.
3. The method of gradual installation of lead rubber bearings in the building blocks enables normal work of the bank.
4. This method cost has proved to be lower in comparison with the costs of the traditional strengthening technologies.
5. The reliability of the considered building with seismic isolation is considerably higher than that of a buildings with the conventional strengthening. It is due to the fact that a building with seismic isolation

assumes significant supports deformation without structure collapse at seismic action. It is impossible to avoid crack development and structure destruction in a building with the conventional strengthening.

6. 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.

REFERENCES

1. Eisenberg J.M. 1976, *Disengaging Reserve Elements Structures for Earthquake Regions*, Stroyizdat, *Moscow, (in Russian). p. 229.*

2. Eisenberg J.M., Smirnov V.I., Dashevsky M.A. *1995.* («Seismic Isolation of Buildings. New Applications and Design Rules in Russia.») *International Post-SMIRT Conference Seminar on Seismic Isolation. Santiago, Chile. pp. 457-463.*

3. Eisenberg J.M., Smirnov V.I, Uzdin A.M. 1997, («Progress in Applications and Development Rules for Base Isolation and Passive Energy Dissipation of Civil Buildings, Bridges and Nuclear Reactors in the Russia Federation.»), *International Post-Smirt Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Seismic Vibration of Structures, Taormina, Sicily, Italy,. pp. 97-112.*

4. Melkumian M.G. 1997, («The Use of High Damping Rubber Isolators to Upgrade Earthquake Resistance of Existing Building in Armenia.»). *International Post-Smirt Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Seismic Vibration of Structures, Taormina, Sicily, Italy, pp. 861-868.*

5. Miyzaki M. 1992, («Applied Design Examples of Base-Isolated Buildings.»). *Proceedings of International Workshop on Recent Developments in Base-Isolation Techniques for Buildings, Tokio, Japan, Apriil, pp. 243-264.*

6. Polyakov S.V.,Kilimnik L.S, Soldatova L.A., 1984. *The Experience of Construction of Buildings Belts, TsNIISK, Moscow, (in Russian), p.320.*

7. Skinner R.I., Robinson W.H., McVerry G.H. 1993. *An Introduction to Seismic Isolation.* John Wiley and Sons. p. 423

8. Zhou F.L., 1997, («Progress of Applications, New Projects, R&D and Development of Design Rules for Base Isolation and Passive Energy Dissipation of Civil Buildings, Bridges and Nuclear and Non-Nuclear Plants in the P.R. China.») *International Post-Smirt Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Seismic Vibration of Structures, Taormina, Sicily, Italy, pp. 45-56.*

9. Kawamura S., Ogura K., Tanaka S., Yajima A., ("Base and Mid Story Seismic Isolation Retrofit of Middle Rise RC Buildings.") p*p. 1-12*

10. Watanabe S., Saito S., Kobayashi K., Hiramatsu M., Kawamura S., ("Repair of Severely Damaged Department Store in 1995 Hyogoken-Nambu Earthquake."). *pp. 1-12.*

11. Golenetsky S.I. 1997, Earthquakes in Irkutsk. Name, Irkutsk, (in Russian). p. 94