Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2016, 3(3):128-139

ISSN: 2394-2630
CODEN(USA): JSERBR

Research Article

First Attempt in Retrofitting Design for the 4-Story Existing Damaged Stone School Building By Combination of Base Isolation with Reinforced Concrete Jackets

Mikayel Melkumyan

Center of New Construction Technologies" at Arm project OJSC, Yerevan, Armenia

Abstract Several remarkable projects on retrofitting by base isolation of the existing buildings like apartment, school and bank buildings, as well as hospital and city hall municipality buildings are briefly mentioned in the paper to demonstrate the retrofitting experience accumulated in Armenia. The given paper, however, mainly focused on retrofitting design of the existing damaged stone school building constructed in the city of Yerevan in 1959. Structural concept of retrofitting by base isolation developed for this building on the basis of the acquired experience is presented. In the same time special attention is given to strengthening by reinforced concrete (R/C) jackets of the damaged parts of existing stone load-bearing walls. Created solution envisages extension of the basement throughout the whole built surface of the building. Results of the earthquake response analysis of the base isolated school building by the Armenian Seismic Code and acceleration time histories are also given in the paper.

Keywords Structural Concept, Existing Stone Building, Damages, Reinforced Concrete Jackets, Retrofitting Experience, Base Isolation, New Solution, Response Analysis

Introduction

Isolation of structures from horizontal ground motions is gradually becoming a more common method of providing protection from earthquake damage. By reducing the seismic forces transmitted, isolation protects the contents and secondary structural features as well as the main structure; the safety of occupants and bystanders is thus also enhanced. Moreover, it is practicable to design the isolation system so that the structure responds elastically to the design level earthquake. Thus, repair cost should be greatly reduced and continued serviceability of the structure assured [1].The rehabilitation of existing structures by the insertion of isolators at foundation level has been carried out on historic buildings such as the Oakland City Hall, San Francisco City Hall [2, 3], Salt Lake City and County Building [4, 5]. For these, isolation may provide the only viable means that is not unduly intrusive and damaging for the appearance of the building. The retrofitting technique using base isolation has great potential also for rehabilitation of ordinary civil structures such as apartment blocks and critical facilities such as schools, hospitals [6].

The first retrofit of existing stone apartment building has been carried out in Armeniain1995-1996 [7].The developed structural concept aims at retrofitting an existing building using a simple and innovative working approach [8] according to the technology developed by the author of this paper (Patent of the Republic of Armenia #579). This is a unique and pioneering seismic isolation project implemented for an existing 5-story stone building. The idea is to furnish this building with seismic isolation by gradually cutting the isolators into the load-bearing walls made of tuff stones at the level of foundation upper edge by means of a two-stage system of R/C beams. Seismic isolators are located by upper and lower recesses provided by annular steel rings bolted to outer steel plates which are connected to the reinforcement in the upper continuous and lower foundation beams; the isolators themselves are not bolted to the structure. This method of connection helps to minimize the cost of the isolators themselves and simplifies their installation on site [9]. Because the bearing is simply located in a recess, no tapped holes for bolted connections are needed in the end-plate. The side, top and bottom rubber cover layers ensure the steel plates are protected from corrosion. This project was accomplished without re-settlement of the dwellers. There has been no similar precedent in the world practice of retrofitting apartment buildings.

After this successful start other project was developed and implemented in Armenia in 2001-2002 for retrofitting of the 60 years old non-engineered existing 3-story stone school #4 building. The base isolation system was created at the level of the school basement in the middle part along the height of its load-bearing walls made of tuff stones [10]. This approach implied some differences in retrofitting of the school building in comparison with that of the apartment building. In the case of the school building the lower continuous beams were structurally connected to the bearing walls of the basement. This afforded a possibility to strengthen the bearing walls by lower continuous beams before cutting the building and passing its weight through the seismic isolators to the bearing walls of the basement. Such structural solution permits the bearing walls of the basement to reliably carry the concentrated vertical loads and does not worsen their behavior and stress-strain state compared to other known solutions mentioned above [5]. The unique operations were carried out to install seismic isolation bearings and the technique of installation is especially important for the considered building, which has a historical and architectural value. First, the building's external appearance should not be disfigured under any circumstances. Second, not a single stone of the façade should fall down when making openings in the bearing walls. One may have to deal with three different situations in making openings in the existing walls of the basement [11]. The relatively simple case is when the opening has the part of existing wall above it. In this case there is no need to use any additional supports, as the strength of the wall above the opening is sufficient to avoid collapse. A more complicated situation for making openings arises when any of the existing beams or girders is crossing the space of the opening. In this case one of the ends of the existing beam loses its support and it is necessary to create temporary supports in order to carry the dead load of the existing building. The operation should be performed very carefully in order to avoid any damages in the superstructure after making openings in the existing walls. The most complicated case is when the opening does not have any part of the existing wall above it. For the subject matter school building such situations occurred at the entrance, where openings had to be made just beneath the columns and the arches. The arches had to be temporarily supported before starting to make the openings. Then the opening under the column should have been gradually made using temporary mechanical jacks. During every step of implementation in such complicated cases of retrofitting it is necessary to take care of the condition of the existing structures to prevent development of any damages, as these structures are part of the valuable architectural appearance of the building.

Then the project on retrofitting of about 100 years old existing stone bank building was implemented in the city of Irkutsk, Russia[12]. It was emphasized that for retrofitting the bank building by base isolation the Russian colleagues have used the method developed in [8] by the author of this paper, who also provided them with all the needed drawings, photos, video film related to the retrofitting works carried out in Armenia. Together with the retrofitting by base isolation of various stone buildings retrofitting technology using seismic isolation rubber bearings was developed also for the existing R/C frame building of the Armenian-American Wellness Center (AAWC) [13, 14]. Finally, experience accumulated in Armenia in retrofitting of existing buildings including those of historical and architectural value created a good basis for participation in the international competition announced by the Government of Romania for development of the design on retrofitting of about 180 years old historical building of the Iasi City Hall by base isolation. It is considered a cultural heritage building and used to be the Romanian Royal Family residence [15]. The retrofitting design was to be implemented within the framework of the Romania Hazard Risk Mitigation and Emergency Preparedness Project. The structural concept, including the new approach on installation of seismic isolation rubber bearings [6] was developed by the author of this paper and the design of retrofitting the Iasi City Hall building was accomplished in cooperation with the Romanian company MIHUL S.R.L. The design was approved by the Technical Committee for Seismic Rick Reduction (a body especially created by the Government of Romania) in 2009. According to the developed design the seismic isolation system was to be implemented within the limits of the building's basement. However, only a partial basement existed under some part of the building and, therefore, it was proposed to extend the basement throughout the whole built surface of the building. This requires to excavate the soil inside of the building and to bare the existing foundation walls. Obviously, before creation of the isolation system these walls must be thoroughly cleaned and washed from the remainders of soil and then adequately strengthened. The proposed structural solution provides for jacketing of the natural stone walls of the foundations with the thickness of concrete for jacketing equal to 5 cm.

For the above mentioned projects the medium damping rubber bearings (MDRBs) with the damping of about 8-9% and the high damping rubber bearings (HDRBs) with the damping of about 13-15% from neoprene have been designed by the author of this paper. Medium or high damping rubber bearings are a simple, economical means of providing isolation. They have the low horizontal stiffness required to provide a long vibration period (typically 2 sec) to a structure mounted on such bearings. Their vertical stiffness is high, which minimizes rocking of the structure during an earthquake. The damping needed to limit the displacement of the structure and reduce the response at the isolation frequency is incorporated into the rubber compound, and so generally no auxiliary dissipation devices are needed. The service life of the bearings is expected to be several decades [16], and they should require no maintenance. Many projects throughout the world have installed seismic isolation systems based on such type of bearings [17, 18, 19].

Retrofitting Design for the Existing Four-Story Stone Damaged Building of School #68

School #68 after M. Mkhoyan consists of four buildings and the oldest one among them was constructed in 1959 (Fig. 1a). This building has damages concentrated mainly within the limits of the first floor (Fig. 1b) and also there are damages in the form of incline cracks (Fig. 1c) in the walls of the upper floors. Retrofitting design of the mentioned old building was developed in accordance with the contract between the “Save the Yerevan Schools from Earthquakes (SYSE)” Foundation (Client) and the “Armproject” OJSC (Design Institution) in 2015. The structural concept of retrofitting using base isolation technology together with strengthening by R/C jackets of the damaged load-bearing walls and results of earthquake response analysis of the considered building are described below.

a.

b.

c.

Figure 1: General view of the 4-story old damaged stone building of the school #68 to be retrofitted by base isolation and strengthened by the R/C jackets (a) and fragments of its damaged parts within the limits of the first (b) and upper floors (c)

Structural Approach on Strengthening of Load-Bearing Walls of the Old Damaged Building of School #68 usingR/C Jackets

The 4-story old building of school #68 has thick load-bearing walls made of tuff stones. The thickness of bearing walls varies from 700 mm in the basement to 600 mm in the floors above the ground. The building has symmetric rectangular plan with dimensions of about 52×17 m and has two exterior and two interior longitudinal load-bearing walls and the same number of exterior and interior transverse load-bearing walls. The floors' slabs consist of precast reinforced concrete hollow-core panels. Before starting implementation of base isolation system the developed design envisages strengthening of the existing load-bearing walls by R/C jackets. This is actually the first attempt to combine base isolation with R/C jacketing providing the needed earthquake resistance to an existing building. Figure 2 shows all four façades of the building with indication of the damages and the different types of R/C jackets designed for local strengthening of the existing walls. Obviously, there was an intention to make the jackets as symmetric as it is possible.

Figure 2: Main, side, and back façades of the 4-story old damaged stone building of the school #68 indicating damages and the designed R/C jackets

Those jackets which are designed to cover the damaged parts of the walls (such R/C jackets are shown by the inclined hatching) have the thickness of 80 mm and will be constructed from both sides of the load-bearing walls. Reinforcement in these jackets consists of 200×200 mm steel meshes with horizontal reinforcing bars having a diameter of 14 mm and vertical reinforcing bars with diameter of 12 mm. The vertical bars are anchored in the upper beams to be constructed above the seismic isolation plane. The jackets from both sides of the load-bearing walls are connected to each other by the reinforcing bars of diameter 8 mm which are placed in the holes of diameter 10 mm drilled with the spacing of 600 mm in the load-bearing walls. In order to provide reliable connection of the mentioned reinforcing bars with the tuff stones design requires the use of the epoxy glue. The both sides of these bars have to be reliably connected to the steel meshes of the R/C jackets. Before constructing the mentioned jackets the cement injection in the walls' cracks must be performed.

Based on the carried out analysis and on the technical condition of the walls within the limits of the first floor it was also decided to cover/strengthen the rest surface of these walls by the other type of the R/C jackets. These jackets (shown by hatching of shading type) will be constructed only from the exterior sides of the load-bearing walls and have the thickness of 40 mm. Their reinforcement consists of 200×200 mm steel meshes with horizontal and vertical reinforcing bars of diameter 6 mm. Such type of jackets connected to the load-bearing walls by the reinforcing bars of diameter also 6 mm which are placed using epoxy glue in the holes of diameter 8 mm and the deepness of 200 mm drilled with the spacing of 600 mm in the load-bearing walls. However, design envisages construction of the same type 40 mm thick jackets also for two interior transverse load-bearing walls again within the limits of the first floor. In this case the R/C jackets will be constructed from both sides of the mentioned walls.

Structural Concept of Retrofitting by Base Isolation of the Old Damaged Building of School #68

For design of isolation system along all exterior and interior load-bearing walls of the school building the method of retrofitting by base isolation according to the above mentioned Patent of the Republic of Armenia #579 was used. This base isolation method for existing buildings with bearing walls that involves placing of seismic isolators at the level of the foundation or the basement solves the problem in the following manner (Fig. 3). According to the innovative technology, openings with certain spacing are made in the basement bearing walls to accommodate lower reinforcement frames with seismic isolator sockets. Binding reinforcement lower frames are passed along both sides of the bearing walls through already installed reinforcement frames of the lower pedestals. Then the latter are concreted after placing of seismic isolators in the lower sockets to form lower pedestals. In this particular case of the school building the dimensions of the openings are equal to 1000×1150(h) mm or 1060×1150(h) mm and the spacing between the centers of the openings (or between the seismic isolators) varies and comprises 2650 mm, 2800 mm, 2950 mm, 3200 mm, 3350 mm, 3500 mm, and 4275 mm.

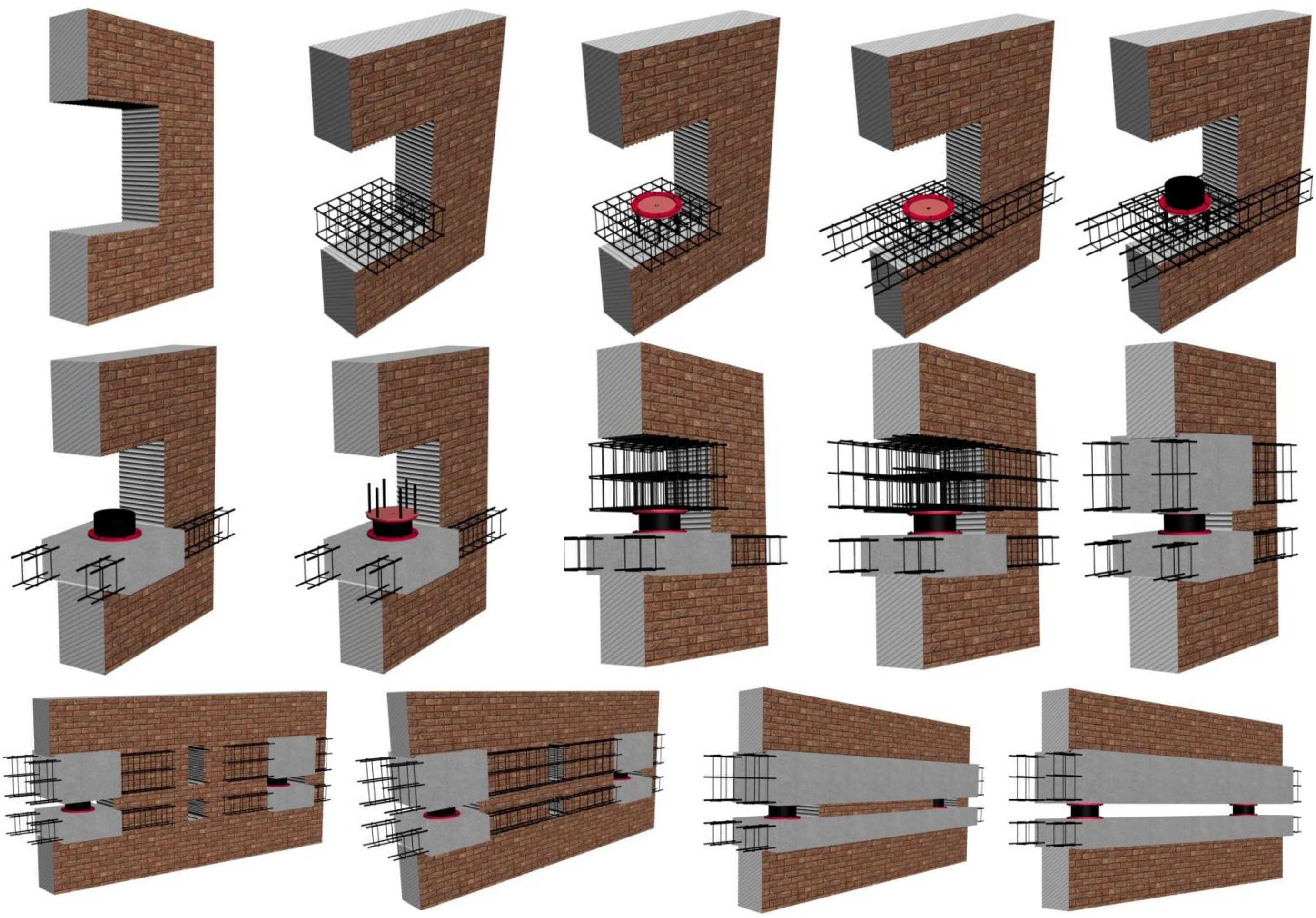
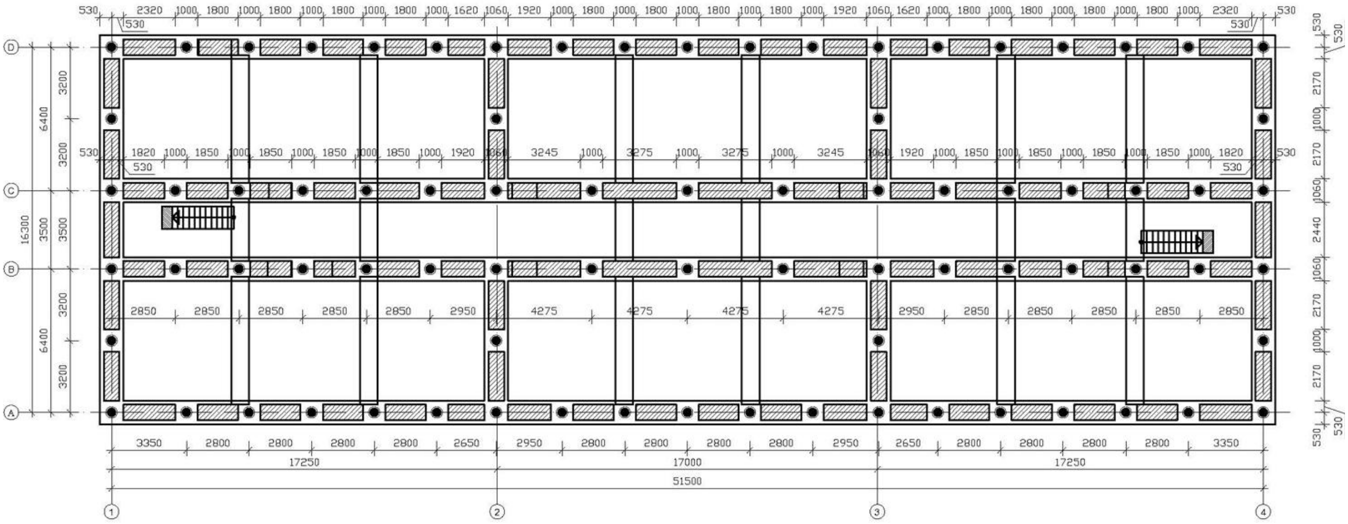


Figure 3: 3D views of the seismic isolation system installation stages in the existing building with bearing walls

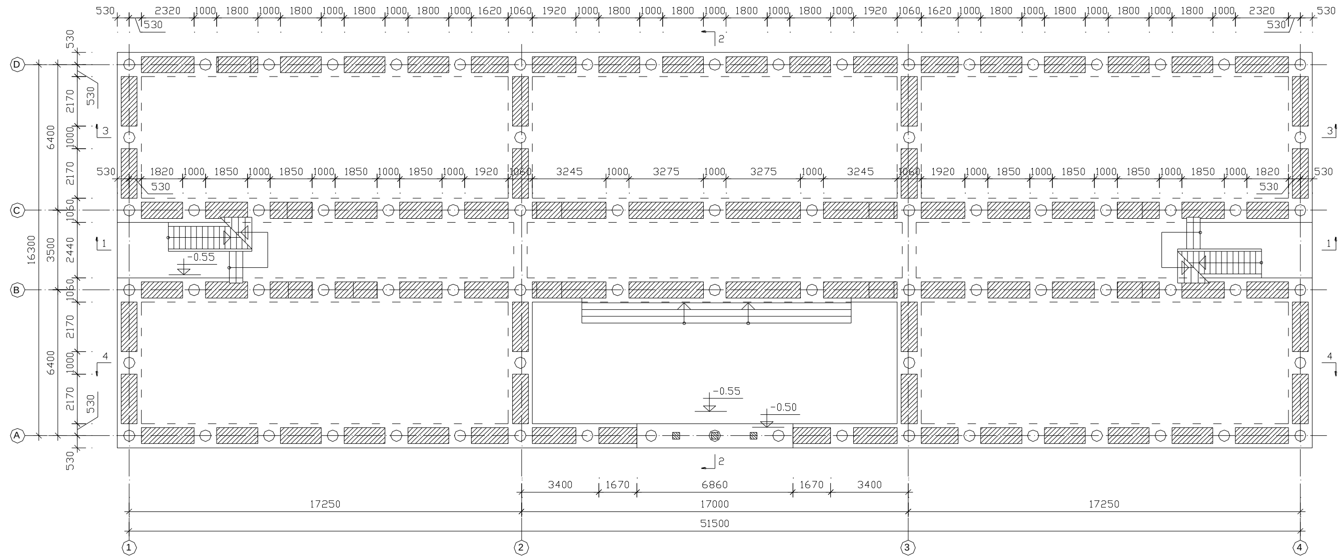
Upper sockets and upper reinforcement frames are placed on the isolators passing along both sides of the bearing walls upper binding reinforcement frames, through already installed upper reinforcement frames of the upper pedestals. Then the latter are concreted to form the upper pedestals. When concreting the frames, ends of the binding reinforcement frames are left free beneath and above the seismic isolators. In the parts of walls between the seismic isolators, openings are made and short binding reinforcement frames are placed through them. The latter tie additional reinforcement frames of the adjacent seismic isolators (usually these small openings and the short binding reinforcement frames are needed in case if the spacing between the seismic isolators exceeds 5000 mm, and, therefore, for the considered school building they were not done). Then the parts between pedestals are concreted thus forming lower and upper continuous beams along all bearing walls of the building. The parts of the existing walls, which at this point still remain between seismic isolators, are removed creating gaps and the building is hence separated from its foundation, being linked to it only by the seismic isolators. It is very important that two adjacent openings in the walls are not made simultaneously; parts of walls existing between seismic isolators should be cut off beginning from the middle of the building plan.

Actually the basement in the considered building exists only under a part of it between the axes “A”-“D” and “1”-“2”. Therefore, in order to implement an isolation system the suggested solution envisages extension of the basement throughout the whole built surface of the building and, accordingly, all existing walls of the newly created basements must be treated in the same way as it was described in Introduction for the Iasi City Hall building. Figure 4 shows the designed plan of location of seismic isolators and the plan of the slab above the isolation system as well as the longitudinal vertical elevation of the school building. Transverse vertical elevation of the isolated building and longitudinal vertical elevations of the building’s basement together with the corresponding joints are shown in Figure 5.

a.



b.



c.

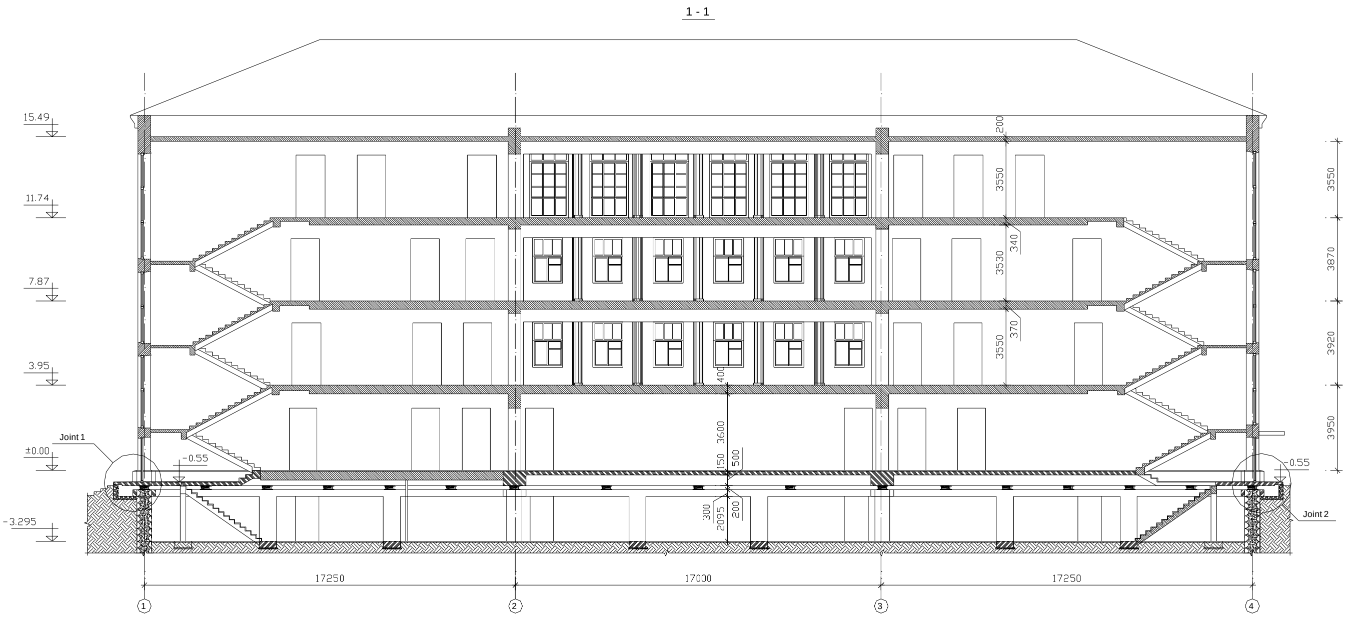
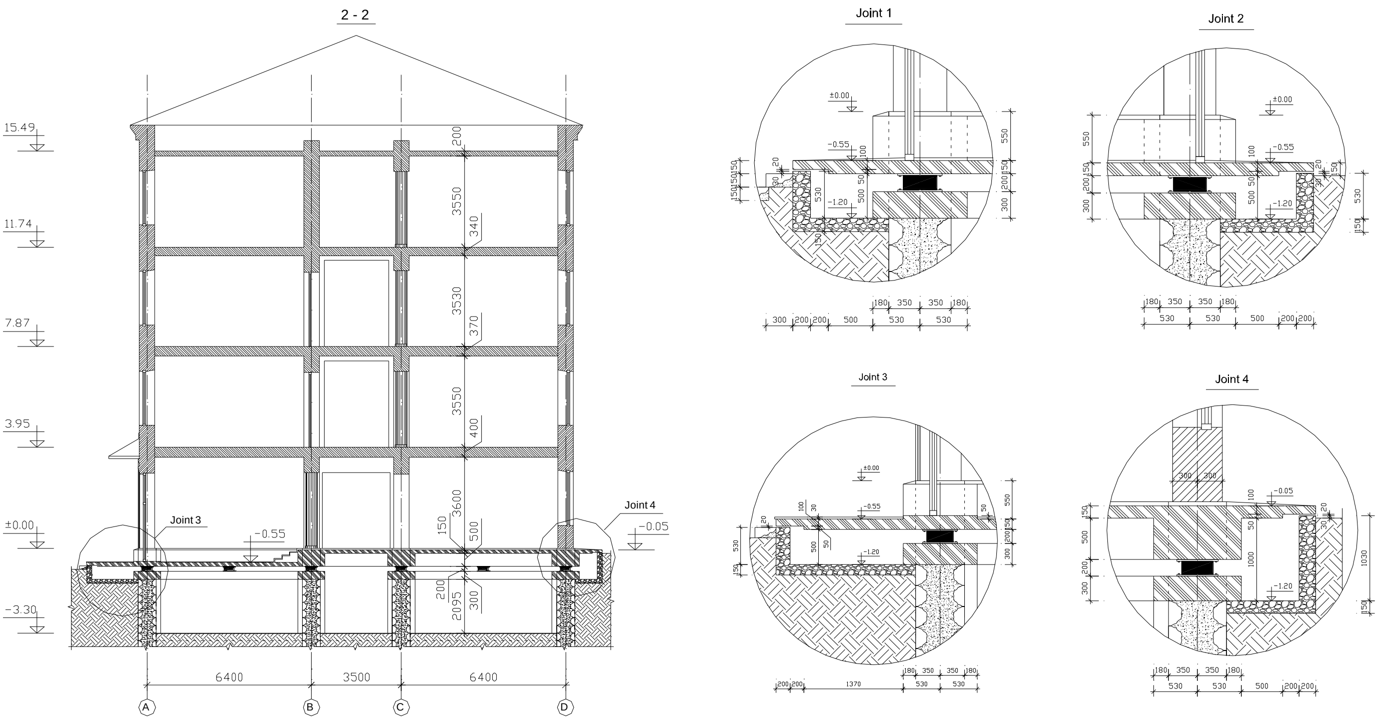


Figure 4: Design plan of location of seismic isolators on the level of the existing and newly created basement highlighting the lower pedestals under the isolators and the lower continuous beams along the whole perimeter of the load-bearing walls (a), the plan of the slab designed above the seismic isolation interface and connected to the upper continuous beams (b), and the longitudinal 1-1 vertical elevations of the isolated building (c)



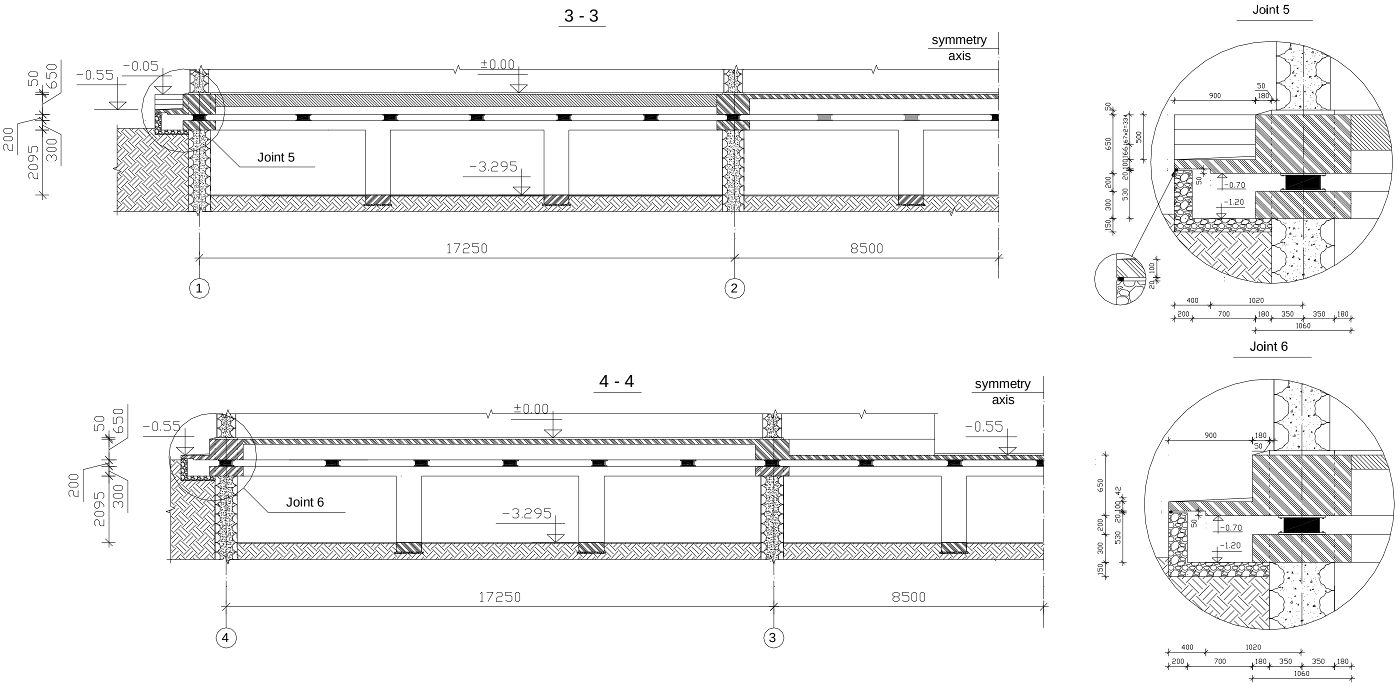


Figure 5: Transverse 2-2 vertical elevation of the isolated building and longitudinal 3-3 and 4-4 vertical elevations of the building's basement with the relevant joints detailed illustrating the structural concept of the designed seismic isolation system

Special attention needs to be paid to the stairs leading to the basement at both ends of the building. These are the single-flight stairs which have their own supports permitting to separate them from the stair landings, thus, providing the gaps between the stairs and superstructure. There are also gaps envisaged around the perimeter of the building where seismic isolation works are performed in a specific sequence. First, earthworks are implemented and according to the design, trenches are dug along the outer perimeter of the building. Afterwards, around the basement retaining walls are built, which are covered by cantilever slabs coming out from the upper continuous beams in order to protect the formed gap from precipitation and avoid possible accumulation of trash. However, the main purpose of this gap and the above mentioned gaps of the basement's stairs is to ensure unhindered movement of the superstructure, as well as effective action of the seismic isolation system and accommodation of its horizontal displacement during any seismic impact.

Earthquake Response Analysis of the Base Isolated Stone Damaged Building of School #68

Earthquake response analysis of the seismic isolation system and the whole structure was performed in accordance with the Armenian Seismic Code RABC II-6.02-2006 and by the acceleration time histories using LIRA-SAPR2014 R4 software. According to the mentioned Code, the following parameters were assumed for analysis:

- seismic zone 3 and soil category II;

-soil conditions coefficient is K_0=1.0 and the site prevailing period of vibrations $0.3 \leq T_0 \leq 0.6$ sec;

-coefficient of seismicity – A=0.4;

-permissible damage coefficient for determining displacements – K_1=0.8;

-permissible damage coefficient for analysis of seismic isolation system and reinforced concrete structures below it –K_{1z} = 0.8;

-permissible damage coefficient for analysis of the superstructure – K_1=0.6;

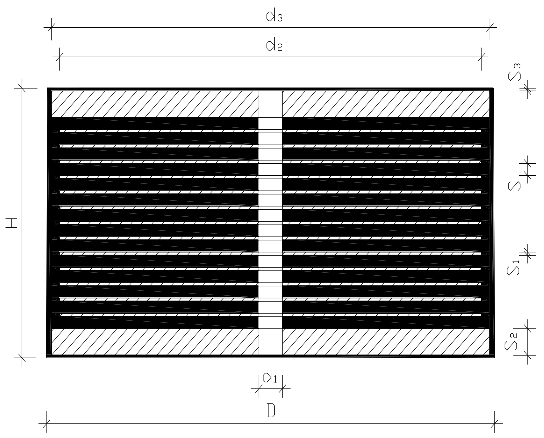
-importance coefficient of the building – K_2=1.3;

Actually, the Code requires that any base isolated building should be analyzed twice: first, by applying K_1=0.8 and the obtained results will serve as a basis to design the isolation system and structures below it, and then the second analysis should be carried out by applying K_1=0.6 and the derived results will serve as a basis to design the superstructure. This is, however, in general case if analysis is going on for a stone structure to be newly constructed. But in the given case when the existing structure is under consideration the analysis of its superstructure with application of K_1=0.6 is needed for designing of R/C jackets and for checking the values of the inter-story drifts, as well as receiving the values of floors' accelerations, inertial forces, etc. The following 7 acceleration time histories given in Table 1 were selected for calculations and their acceleration amplitudes were scaled to 0.52g (0.4g×1.3) taking into account the importance of the building.

Table 1: Acceleration time histories selected for earthquake response analysis of the 4-story old damaged building of school #68

Earthquake and Record Component	Date	Predominant Period, sec	Duration, sec
Eureka (USA) in horizontal NE direction	20.12.54	0.44	26
Bar (former Yugoslavia) in horizontal EW direction	15.04.79	0.55	15
Chiba (Japan) in horizontal NS direction	17.12.87	0.35	39
Spitak (Armenia) in horizontal EW direction	07.12.88	0.43	18
Spitak (Armenia) in horizontal NS direction	07.12.88	0.47	18
Loma Prieta (USA) in horizontal EW direction	17.10.89	0.34	10
Manjil (Iran) in horizontal NE direction	20.06.90	0.49	20

For this project the HDRBs from neoprene have been designed. Their main parameters and geometrical dimensions are given in Figure 6. As it is seen from Figure 4 altogether 80 HDRBs were used to create the seismic isolation system with total horizontal stiffness equal to 64.8 kN/mm. The 3D design model was developed using different types of finite elements for walls, floor slabs and seismic isolators, with due consideration of the structural solution of the superstructure (i.e. part of the building above the seismic isolation plane).



$D=380 \pm 2.0; d_1=19 \pm 1.0$;
$H=202.5 \pm 2.5; S=9 \pm 0.1$;
$d_2=360 \pm 0.5; S_1=2.5 \pm 0.1$;
$d_3=376 \pm 0.5; S_2=20 \pm 0.2$;
$S_3=2 \pm 0.1$;
Mass of the bearing: (77.5 ± 2.5) kg;
The bearing must withstand a maximum (design) permissible vertical loading of 1500 kN;
Shear modulus of the bearing's rubber: (0.97 ± 0.15) MPa;
Vertical stiffness of the bearing: no less than 300 kN/mm;
Horizontal stiffness of the bearing: (0.81± 0.1) kN/mm;
Shore A hardness of the bearing: 70 ± 5 points;
Damping coefficient of the bearing: 13-15%;
The bearing must withstand a maximum (design) permissible horizontal displacement of 280 mm, without causing cracks greater than 3 mm deep and 6 cm long

Figure 6: Dimensions and physical/mechanical parameters of HDRBs

Based on the presented input data and the developed design model the calculated periods of vibrations for the first oscillation mode were equal to T_{1long}=2.15 sec in longitudinal and T_{1trans}=2.21 sec in transverse directions. Some results of analyses of the base isolated 4-story old damaged building of school #68 by the Armenian Seismic Code and the average results by the acceleration time histories are given in Table 2. Floor accelerations along the height of superstructure in both directions are different. Figures 7 and 8 illustrate the front and back views of the developed design model and reduction of input acceleration in the superstructure of the base isolated school building both in longitudinal and transverse directions, respectively, under the impact of the 7.12.1988 Spitak Earthquake acceleration time history, X direction recorded at Ghukassian (Ashotsk) station.

Table 2: Some results of analyses of base isolated 4-story old damaged buildingof school #68

Design parameters	By the Armenian Seismic Code		Average by the time histories	
	in longitudinal direction	in transverse direction	in longitudinal direction	in transverse direction
Horizontal shearforces at the level of foundation (kN)	16520 (K_1=0.8)	16220 (K_1=0.8)	9840	9677
Displacements of the isolation system (mm)	199 (K_1=0.8)	204 (K_1=0.8)	126	132
Maxim minter-story drifts (mm)	2.0 (K_1=0.6)	7.0 (K_1=0.6)	1.0	4.8

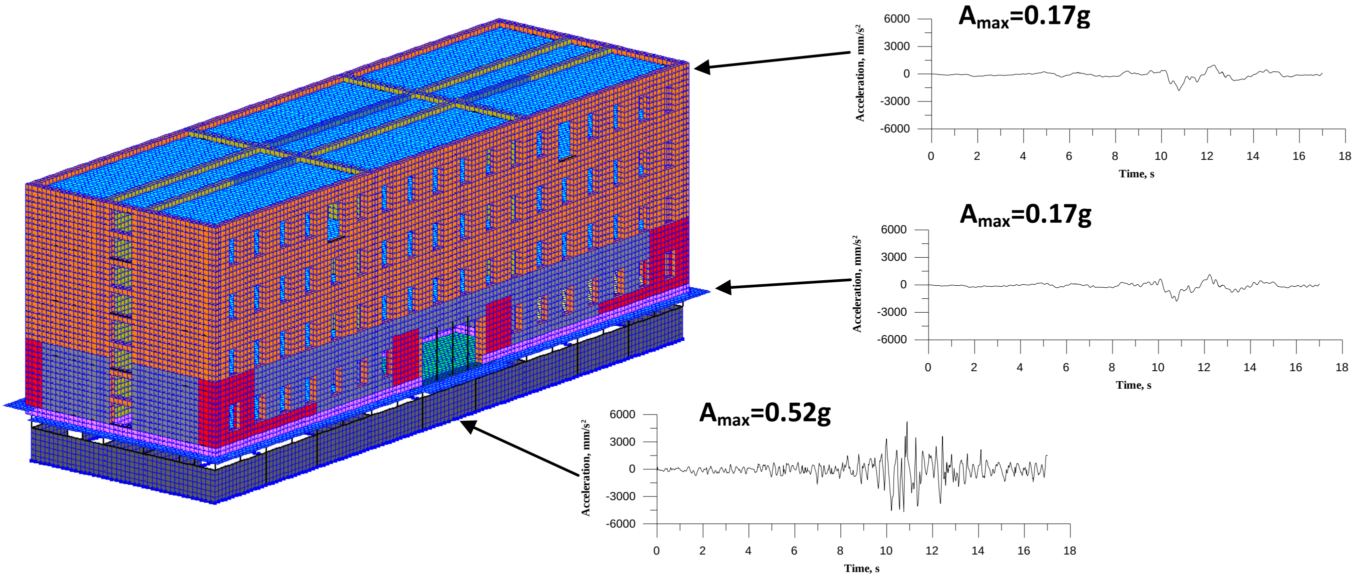


Figure 7: Design model (front view)of base isolated 4-story old damaged building of school #68 and comparison of the response accelerations at the levels of the top of isolators and the top of the building by the analysis in longitudinal direction using the 7.12.1988 Spitak Earthquake accelerogram

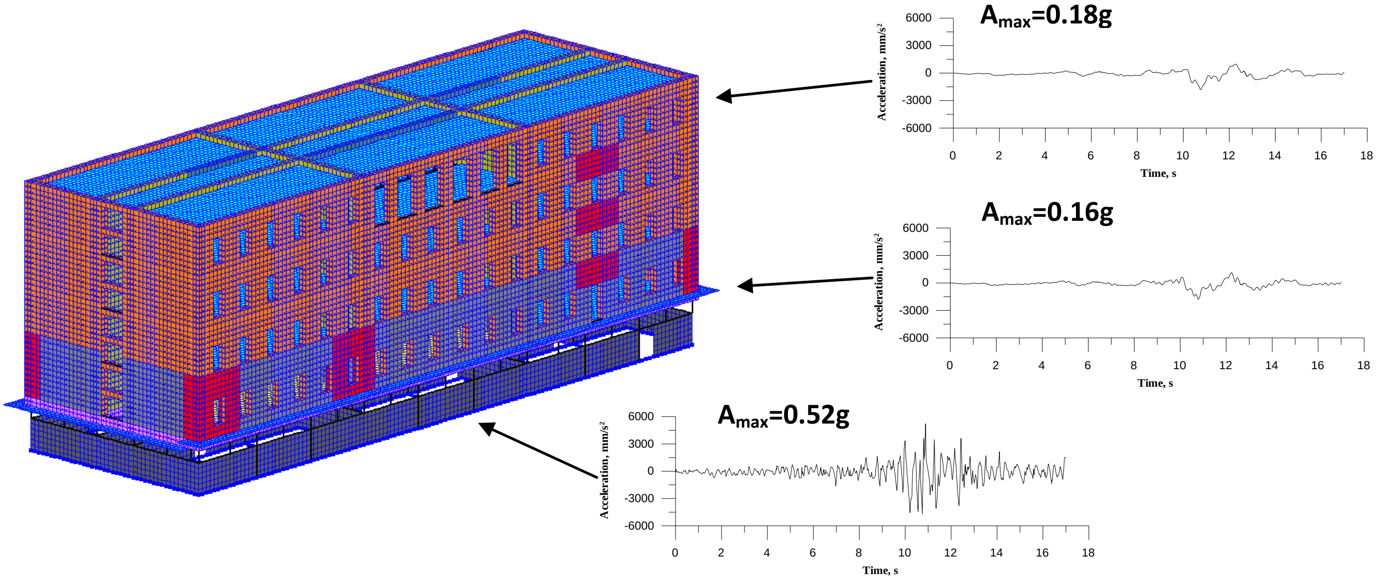


Figure 8: Design model (back view) of base isolated 4-story old damaged building of school #68 and comparison of the response accelerations at the levels of the top of isolators and the top of the building by the analysis in transverse direction using the 7.12.1988 Spitak Earthquake accelerogram

From these results it follows that maximum acceleration along the height of superstructure is equal to 0.18g, meaning that thanks to application of base isolation the input PGA of 0.52g decreases by about 2.9 times. Also it was obtained that in none of the isolators the vertical force exceeds 1500 kN. Superstructure is moving in horizontal direction as an almost rigid body without any overturning and consequently the obtained results prove the high effectiveness of the created base isolation system. This will ensure high reliability of the building, which will suffer no damage under seismic impacts, since the structural elements below and above the seismic isolation plane will work only in the elastic phase. Indeed, according to the RABC II-6.02-2006, the permissible inter-story drift for this type of the stone structure is equal to 1/550 of the floor height. The obtained results show that the maximum drift comprises 7.0 mm and occurs in transverse direction at the level of the first

floor which height is equal to 3950 mm. Therefore the value of the permissible inter-story drift for the first floor will be equal to Δ_{1trans}=7.2 mm and this value is bigger than the calculated one.
Also analysis revealed no rotation of the superstructure as there is practically no eccentricity between the horizontal stiffness center of the seismic isolation system and projection of the structure's mass center on isolation plane. This is proven and also can be well observed during the oscillations of the building in analysis by the time histories. It should be mentioned that for small deformations corresponding to the wind impact, the initial stiffness of rubber bearings is much higher than their effective stiffness and, thus, the ability of the system to provide an intrinsic restraint against wind loading is confirmed.

Conclusions

Experience accumulated in Armenia is demonstrated in the paper briefly describing several remarkable projects on retrofitting by base isolation of the existing buildings like apartment, school and bank buildings, as well as hospital and city hall municipality buildings.
Based on the acquired experience the given paper presents the retrofitting design for the existing old damaged stone school building #68 constructed in the city of Yerevan in 1959 where as a tool for retrofitting the base isolation technology is used in combination with the R/C jackets for strengthening of the damaged parts of existing stone load-bearing walls.
Paper describes in detail the structural approach on application of the different types of R/C jackets mainly within the limits of the first floor of superstructure and innovative structural concept of retrofitting by base isolation. Preliminary cost estimations and comparison of the construction cost of retrofitting by the suggested design with the cost of conventional strengthening have shown that significant cost savings (up to 3-4 times) could be achieved due to implementation of the created base isolation technology.
The time needed for performing of the construction works by the given design could be shortened for about 5 times in comparison with the time for conventional strengthening. Implementation of the elaborated design will not require interrupting the use of the whole school building. Only the usage of the first floor will be interrupted. But, in contrary, the conventional strengthening will require interruption of the use of the whole building.
Some results of analysis of the base isolated school building #68 by the Armenian Seismic Code and the acceleration time histories are given in the paper showing that the structural elements below and above the seismic isolation plane will work only in the elastic phase. This proves the high effectiveness of the created base isolation system and reliability of the building, which will suffer no damage under seismic impacts as it will move in horizontal direction almost parallel to itself without development of any significant deformations in its body.Under the impact of the design level earthquake the inter-story drifts remain smaller than the permissible values. An input acceleration of 0.52g at the foundation bed gets damped about 3.0 times in the superstructure.

References

[1]. Fuller K., Lim C., Loo S., Melkumyan M., Muniandy K. *"Design and Testing of High Damping Rubber Earthquake Bearings for Retrofit Project in Armenia"*. - Earthquake Hazard and Seismic Risk Reduction. Editors – Serguei Balassanian, Armando Cistern as and Mikayel Melkumyan. Kluwer Academic Publishers. The Netherlands, 2000, pp. 379-385.

[2]. Walters M., Honeck B., Elsesser E. *"Use of Seismic Isolation in New and Retrofit Construction"*. - Proceedings of the Joint ASME/JSME Pressure Vessels and Piping Conference, Seismic, Shock and Vibration Isolation Vol. PVP319, Honolulu, HI, 1995, pp. 31-38.

[3]. Naaseh S., *"Seismic Retrofit of San Francisco City Hall: The Role of Masonry and Concrete"*. - Proceedings of the 3rd National Concrete Masonry Engineering Conference. San Francisco CA, 1995, Vol.2, pp. 769-795.

[4]. Skinner R., Robinson W., McVerry G. "An Introduction to Seismic Isolation". - John Willey & Sons, Ltd., 1993.

[5]. Report by the Ehrenkrantz Group, Burtch Beall, E.W. Allen and Associates, Forell/Elsesser Engineers and SSD, Inc. *"Base Isolation Study for the Renovation of the City and County Building, Salt Lake City, Utah"*, 1986.

[6]. Melkumyan M. "New Solutions in Seismic Isolation". - LUSABATS, Yerevan, 2011.

[7]. Melkumyan M. *"Seismic Isolation of Civil Buildings in Armenia"*. - Journal "Progress in Structural Engineering and Materials". 2002, Vol.4, No. 4, pp. 344-352.

[8]. Melkumyan M. *"The Use of High Damping Rubber Isolators to Upgrade Earthquake Resistance of Existing Buildings in Armenia"*. - Proceedings of the International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Seismic Vibrations of Structures, Taormina. Sicily, Italy, 1997, pp. 861-867.

[9]. Fuller K., Muhr A., Pond T. *"Current Base-isolation Research and Development at MRPRA and its Application to on Apartment Block in Indonesia"*. - Proceedings of International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Control of Vibration of Structures. Santiago, 1995.

[10]. Melkumyan M., Käppeli G., Khalatyan R., Hovivyan H. *"Application of Seismic Isolation for Retrofitting of Existing 3-story Stone Building of the School #4 in the City of Vanadzor, Armenia".* - Proceedings of the 8th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures. Yerevan, Armenia, 2003, pp. 557-565.

[11]. Melkumyan M., Hovivyan H., Movsessyan L., Terjanyan S. *"Technique of Installation of Seismic Isolation Bearings in an Existing Building with Historical and Architectural Value".* - Proceedings of the 8thWorld Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures. Yerevan, Armenia, 2003, pp. 629-641.

[12]. Smirnov V., Eisenberg J., Zhou F., Chung Y., Nikitin A. *"Seism isolation for Upgrading of an Existing Historical Building in Irkutsk-City, Siberia-Russia"*. - Proceedings of the 12th World Conference on Earthquake Engineering. Auckland, New Zealand. 2000, Paper No. 0962.

[13]. Melkumyan M. *"Retrofitting Experience from Armenia"*. - Proceedings of the Workshop "Hazard Risk Management in Europe and Central Asia". Istanbul, Turkey, 2004.

[14]. Melkumyan M. *"Base and Roof Isolation for Earthquake Retrofitting and Protection of Existing Buildings in Armenia"*. - Proceedings of the International Symposium on Seismic Risk Reduction (the JICA Cooperation Project in Romania). Bucharest, Romania, 2007, pp. 593-600.

[15]. Miyamoto K., Gilani A. *"Base Isolation for Seismic Retrofit of Structures: Application to a Historic Building in Romania"*. - Proceedings of the International Symposium on Seismic Risk Reduction (the JICA Cooperation Project in Romania). Bucharest, Romania, 2007, pp. 585-592.

[16]. Fuller K., Roberts, A. "Longevity of Natural Rubber Structural Bearings". - Proceedings IRC 97, Kuala Lumpur. 1997, pp. 777-87.

[17]. Kelly J. *"New Applications and R. & D. for Isolated Civil Buildings in USA".* - Proceedings of International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Control of Vibration of Structures. Santiago, 1995.

[18]. Akiyama H. *"State-of-the-Art in the World on Seismic Isolating of Bearings Based on the Results of the International Workshop Held in Tokyo in April 1992 - Most Recent Developments for Buildings and Bridges in Japan. Isolation, Energy Dissipation and Control of Vibration and Structures".* - Proceedings of International Post-SMiRT Conference, GLIS. Italy, 1993, pp. 3-26.

[19]. Melkumyan M. *"Base Isolation Retrofit Project In Armenia"*. - Proceedings of the UNIDO Workshop on Use of Natural Rubber Based Bearings for Earthquake Protection of Small Buildings. Jakarta, Indonesia, 1994.