Retrofiting by Base Isolation of the Existing Stone Kindergarten Building with Increasing its Area by Newly Constructed Seismic Isolated Extension

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Abstract—**The author of this paper has donated funds to carry out the base isolation retrofitting design for the existing 1-story kindergarten building with stone bearing walls including design of a new base isolated extension for this kindergarten. In the given case the task was pursued to increase the earthquake resistance of the old kindergarten building in the village Khndzoresk of the Syunik Marz of Armenia by application of seismic isolation at the level of the building's basement. In the same time the purpose was to enlarge the area of the existing kindergarten by the base isolated extension to be newly constructed and rigidly connected to the old building. The author have put a lot of efforts to make possible recognition of Armenia as a country where seismic (base and roof) isolation systems are widely implemented in construction of new and retrofitting of existing buildings. The number of seismically isolated buildings per capita in Armenia is one of the highest in the world – second after Japan. The paper given below emphasizes that Armenia achieved significant results also in local manufacturing/testing of seismic isolation laminated rubber-steel bearings (SILRSBs) in accordance with the international standards. Several remarkable projects on retrofitting by base isolation of the existing buildings like apartment, bank, school, hospital, hotel, and kindergarten buildings are briefly mentioned in the paper. Based on the gained experience further developments take place and unique base isolation structural concepts and technologies created by the author are applied more and more to the existing buildings. In this paper base isolation retrofitting design and analysis by the Armenian Seismic Code for the 1-story kindergarten building with stone bearing walls is described. This will be a first application of base isolation retrofitting technology to an existing stone building with simultaneous increase of its area by the newly constructed base isolated extension. The other important factor is that applied structural concept allows retrofitting by base isolation without interruption of the use of kindergarten building.**

Keywords—base isolation strategy; existing buildings; seismic protection; seismic retrofitting; structural concepts;, low-cost technology; no interruption of the buildings' use; Seismic Code analysis; SILRSBs' testing results

I. Introduction

The retrofitting technique using base or roof isolation has great potential for rehabilitation of ordinary civil structures such as apartment blocks, banks, hotels, and critical facilities such as schools, kindergartens, and hospitals. The works on development and research of seismic isolation technologies were initiated by the author in 1993. Since then and up to the end of 2022, during a period of 29 years about 64 buildings and structures have been designed with application of base or roof isolation systems. Of these designed buildings the total number of already constructed and retrofitted buildings or those currently under construction and retrofitting in Armenia and Nagorno-Karabakh (Artsakh) has reached 56 (Fig. 1). Among them there are bathhouses, private residences, school buildings, clinic and hospital buildings, business and commercial centers, hotels, apartment buildings and International Airport "Zvartnots". In [1] it is stated that: "Armenia remains second, at the worldwide level, for the number of applications of such devices per number of residents, in spite of the fact that it is still a developing country".

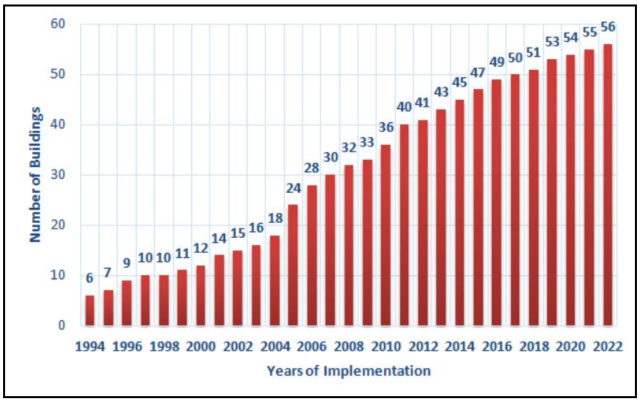


Fig. 1. *Number of seismic (base and roof) isolated buildings newly constructed or retrofitted in Armenia and Nagorno-Karabakh (Artsakh) by years.*

Together with that SILRSBs different by their shape and dimensions, as well as by damping (low, medium and high) were designed and about 5500 SILRSBs were manufactured in the country, tested locally and applied in construction (Fig. 2).

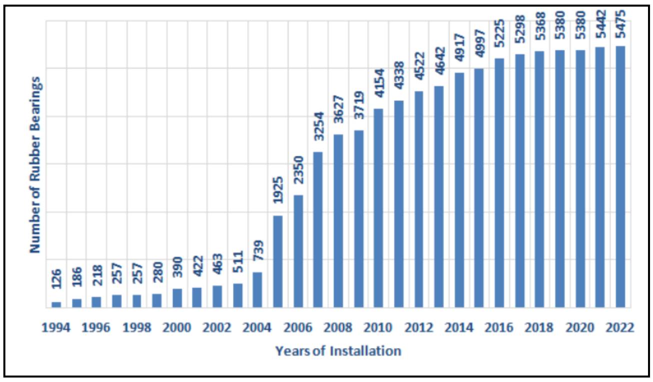


Fig. 2. *Number of rubber bearings installed in the newly constructed or retrofitted buildings in Armenia and Nagorno-Karabakh (Artsakh) by years.*

Several remarkable projects on retrofitting by base and roof isolation were developed and implemented using technologies created by the author of this paper. One of them is retrofitting by base isolation of a 5-story stone apartment building (Fig. 3a) in the city of Vanadzor (Armenia). The operation was made in 1996 [2] without resettlements of the occupants. World practice provides no similar precedent in retrofitting of apartment buildings.

The next technology was utilizing the developed method of an additional isolated upper floor (AIUF) acting as a vibration damper. This technology of roof isolation was used in earthquake protection design and implementation for two existing reinforced concrete (R/C) 9-story standard design frame buildings (Fig. 3b) also in the city of Vanadzor. The projects were implemented in 1996-1997 [3].

Then by the end of nineties, another project initiated by Prof. Eisenberg and Dr. Smirnov [4] on retrofitting of about 100 years old 3-story stone bank building was implemented in the city of Irkutsk (Russia) with increasing of the number of stories up to 4 (Fig. 3c). It was emphasized by them that for retrofitting the existing bank building using base isolation they have implemented the method developed in [2] by the author of this paper who provided Russian and Chinese colleagues with all the needed drawings, photos, video films related to the retrofitting works carried out in Armenia.

The other project is retrofitting of the 60-year-old 3-story stone school building which has historical meaning as well as a great architectural value (Fig. 3d). Unique operations were carried out to install the isolation system within the basement of this building and to preserve its architectural appearance. The project was implemented in the city of Vanadzor in 2002 [5, 6].

Fig. 3. *Projects on retrofitting by base and roof isolation utilizing different seismic isolation strategies developed by the author of this paper and implemented in Armenia, Russia, and Nagorno-Karabakh (Artsakh).*

By given above brief information on several projects an objective is pursued to demonstrate experience in the field of retrofitting by base isolation of existing buildings with stone bearing walls, as well as of earthquake protection by roof isolation of existing R/C frame buildings. Later, the author has developed and proposed principally new structural approaches for base isolation of the existing R/C frame buildings with and without shear walls. Thus, further developments have taken place for retrofitting by base isolation and unique operations on retrofitting of the 8-story Hematology Center Hospital Building (Fig. 3e), constructed in Yerevan about 45 years ago, were accomplished in 2015. The seismic isolation of this existing building was created at the basement level. Detailed description of all phases for cutting the columns and shear walls and placing SILRSBs of the same sizes and physical/mechanical parameters are given in [7]. Results of analysis of this retrofitted building by the Armenian Seismic Code and the time histories are presented in [8].

The next strategy is retrofitting by base isolation of about 55-year-old 4-story R/C industrial frame building with its simultaneous reconstruction into a 6-story hotel building (Fig. 3f). This building is also located in Yerevan. New original technology on retrofitting by base isolation was developed and applied to this building and the results of its analysis in accordance with the provisions of Armenian Seismic Code and also time history analysis are discussed in [9]. SILRSBs with high damping of about 15% were used. Created solution is proposed for the first time and envisages placing the seismic isolators around the existing columns and then gradual cutting these structural elements. Operations are designed to be performed for the existing columns in several stages. This project was accomplished in 2016.

Recently, in 2020-2022, two projects on retrofitting of existing buildings by base isolation were carried out in the city of Stepanakert the capital of Nagorno-Karabakh. One of them, which is almost finished, is retrofitting of the existing 9-story large-panel apartment building (Fig. 3g). Actually, this is the first of such kind of existing buildings in the world retrofitted by base isolation without eviction of tenants [10, 11]. In retrofitting design and its application to the mentioned building the approach suggested by the author for retrofitting of existing buildings with the load-bearing walls (Patent of the Republic of Armenia №579) was used. The same approach was applied for the second existing 2-story stone building. Retrofitting design for this building envisages its simultaneous conversion into a 3-story kindergarten (Fig. 3h). This building is currently in the process of retrofitting [12]. Architectural design for this building was carried out by "Storaket" Architectural Studio.

The given paper focused on retrofitting design of the existing 1-story building with stone bearing walls. This is an old kindergarten building in the village Khndzoresk of the Syunik Marz of Armenia, which is going to be retrofitted by application of seismic isolation at the level of the building's basement. Structural concept of retrofitting was developed for this building based on the acquired experience briefly described above. The building is analyzed based on the provisions of the Armenian Seismic Code. The area of the existing kindergarten will be enlarged by the base isolated extension to be newly constructed and rigidly connected to the old building.

II. Structural Concept of Retrofitting by Base Isolation of the Existing 1-story Kindergarten Building with Stone Bearing Walls

Retrofitting design of the 1-story building under consideration (Fig. 4) was developed by the author of this paper in 2023. This project will be implemented in the village Khndzoresk. The building has rectangular plan with main dimensions of 11.1×10.4 m and with non-symmetric layout of the interior load-bearing walls. All walls have a thickness equal to 500 mm. The building has two exterior and one interior longitudinal load-bearing wall, as well as two exterior and two interior transverse load-bearing walls. The building has a basement under its whole built area (Fig. 5). The basement slab as well as the slabs of the ground floor was made of the precast reinforced concrete hollow-core panels, which have the thickness equal to 220 mm.

Fig. 4. *View of the existing 1-story kindergarten old building with stone bearing walls to be retrofitted by base isolation at the level of its basement.*

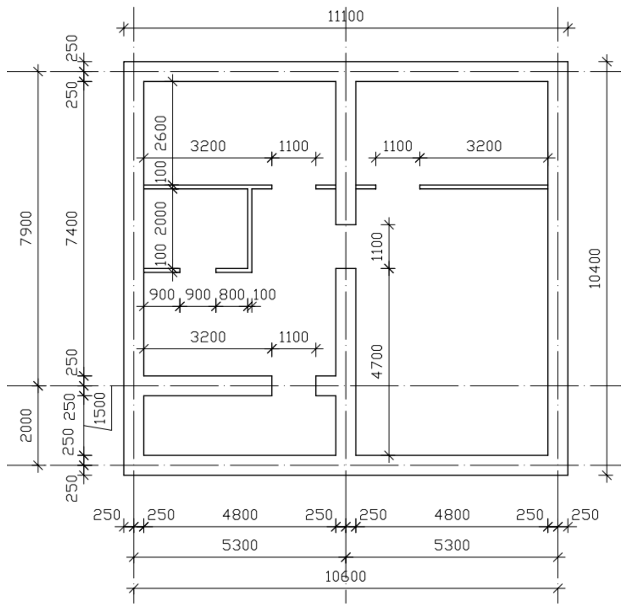


Fig. 5. *Plan of the basement under the existing 1-story kindergarten old building with stone bearing walls.*

For design of isolation system along all the exterior and interior load-bearing stone walls of the old kindergarten building the method of retrofitting by base isolation according to the above-mentioned Patent of the Republic of Armenia #579 was used [13]. The developed base isolation method for existing buildings involves placing of seismic isolators at the level of basement in the middle part along the height of its load-bearing walls solves the problem in the following manner (Fig. 6). According to the developed by the author innovative technology, openings with certain spacing are made in the basement load-bearing walls to accommodate lower reinforcement frames with seismic isolator sockets. It is very important that two adjacent openings in the walls are not made simultaneously. 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. 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 of pedestals, ends of the binding reinforcement frames are left free beneath and above the seismic isolators. These free ends of reinforcing bars are tied to each other by the additional reinforcement frames of the adjacent lower and upper pedestals of seismic isolators.

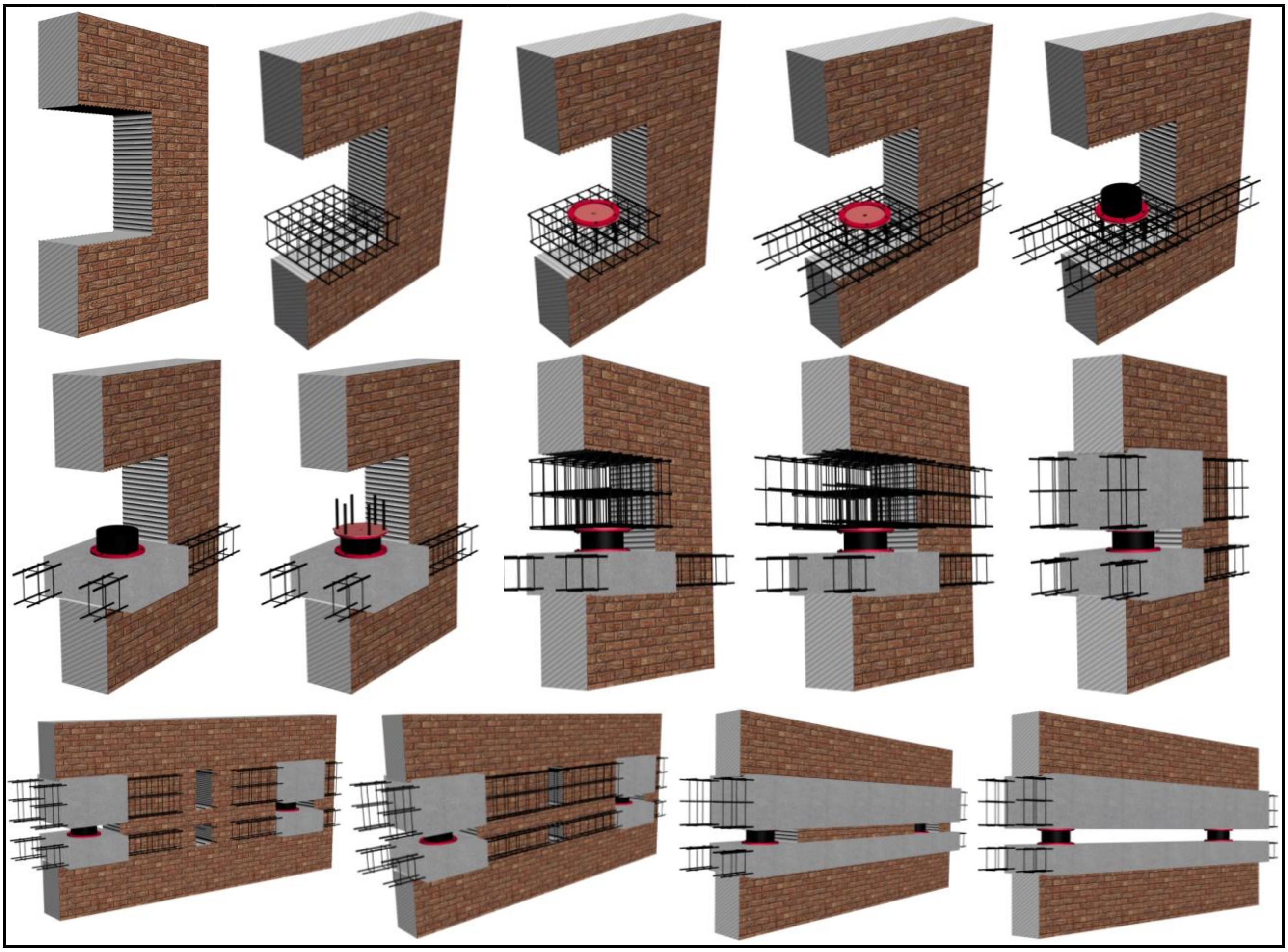


Fig. 6. *3D views of the seismic isolation system installation stages in the existing building with stone load-bearing walls.*

Then the parts between pedestals are concreted thus forming lower and upper continuous beams along all load-bearing walls of the building's basement (see Fig. 6). The parts of the existing walls, which at this point remain between seismic isolators, must be then removed creating gaps and the building is hence separated from its foundation, being linked to it only by the seismic isolators. Parts of walls existing between seismic isolators should be cut off beginning from the middle of the building plan and continuing to its periphery. This will allow avoiding cracks at the top of the building considering the vertical deformations in SILRSBs during cutting of the walls.

As it was mentioned above the area of the existing old kindergarten must be enlarged in accordance with the request of the local authorities of Khndzoresk village. Therefore, suggested structural concept envisages creation of the base isolation system under the extension to be newly constructed and rigidly connected to the old building. To create the seismic isolation system under the old and new parts of the kindergarten (according to the described above technology) it was proposed to excavate the soil under the new part and, thus, to provide the additional space throughout the whole surface of the extension. From Fig. 7 one can see that after excavating the soil up to mark -1.60 the underlayer consisting of 50 mm thick layer of rubble and 50 mm thick layer of concrete are envisaged around the old building and under the foundation beams of the extension to be newly constructed.

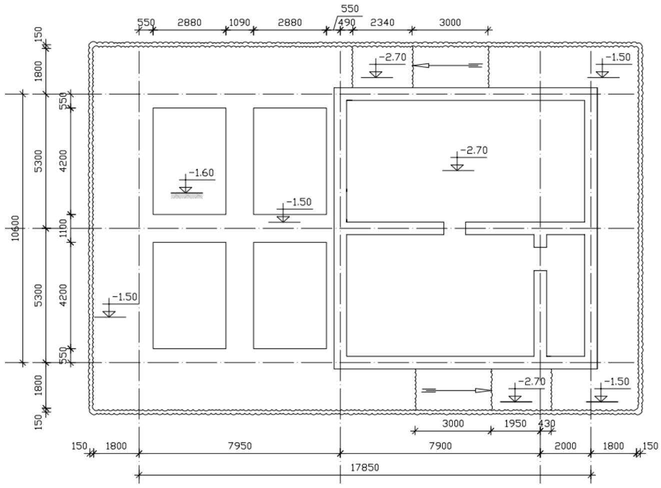
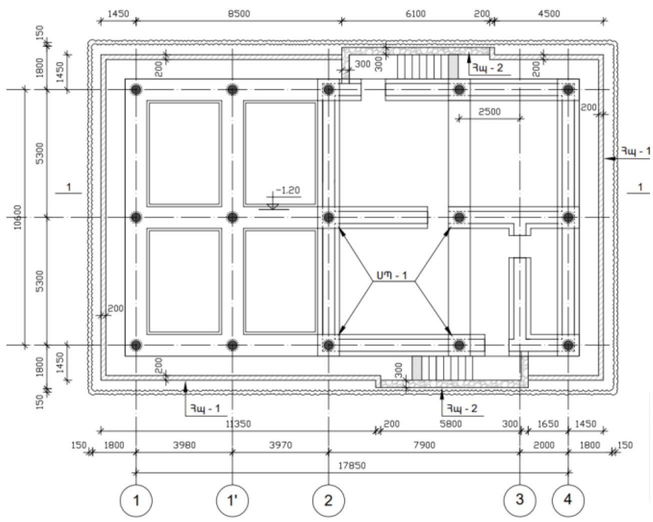


Fig. 7. *Plan of the 100 mm thick underlayer envisaged around the old building and under the foundation beams of the extension to be newly constructed.*

According to the above-described technology the following sequence of creation of seismic isolation system for the whole structure is envisaged. First of all the openings in the existing basement walls must be made. Then the reinforcement frames of the lower pedestals are installed together with the seismic isolator's lower sockets. After that the strip foundation beams must be made making sure that their reinforcement bars are passing through the reinforcement frames of the lower pedestals already installed in the existing wall along the axis "2". It is assumed that at this stage all the SILRSBs are installed in the lower sockets on the strip foundation beams of the extension to be newly constructed.

Also, the SILRSBs are installed along all the load-bearing walls of the old existing building (Fig. 8).



ՍՊ-1 – Lower Pedestal LP-1;
Յպ-1 and Յպ-2 – Retaining walls RW-1 and RW-2, respectively

Fig. 8. *Plan of location of SILRSBs at the level of the basement of existing kindergarten old building and at the mark -1.20 of its extension to be newly constructed between the axes "1" and "2".*

Fig. 8 shows that seismic isolation interface of the building under consideration consists of 15 SILRSBs. In this particular case of the 1-story kindergarten old existing building the dimensions of the openings to accommodate the lower and upper pedestals with the seismic isolator between them are equal to 900×1000(h) mm. The spacing between the centers of the openings (or between the seismic isolators) varies and comprises 3970 mm, 3980 mm, 4500 mm, 5300 mm, 5400 mm (see Fig. 8). Vertical elevation 1-1 of the isolated structure in longitudinal direction is shown in Fig. 9.

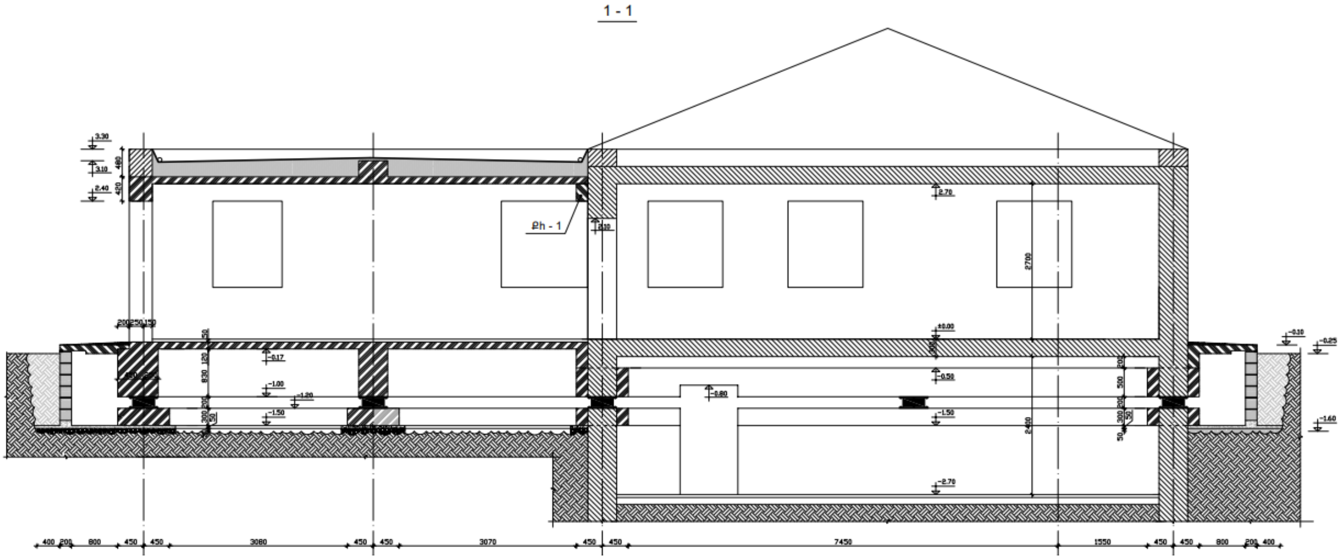
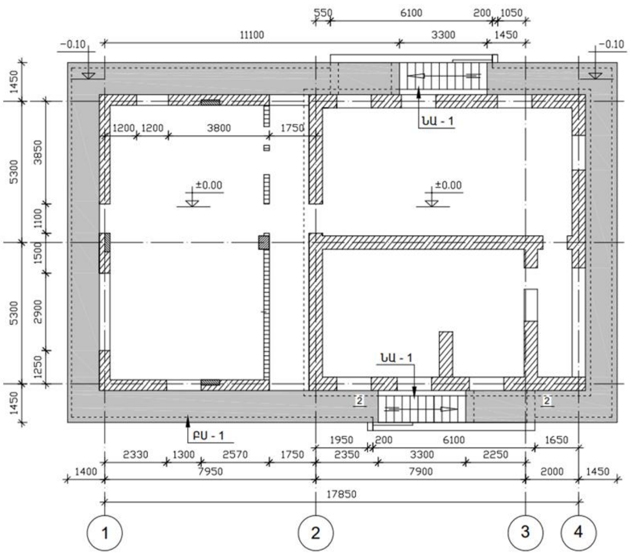


Fig. 9. *Vertical elevation 1-1 in longitudinal direction of the base isolated existing stone kindergarten building together with its extension to be newly constructed.*

From the vertical elevation 1-1 one can see that the base isolation system consists of the lower continuous beams with the height of 300 mm to be constructed below the isolation interface, the gap (200 mm) where the SILRSBs are located and the upper continuous beams with the height of 500 mm to be constructed above the isolation interface. Thus, base isolation system will be constructed between the marks -1.50 and -0.50. At the mark -0.05 between the axes "1"-"2" a new monolithic slab was designed, which have the thickness equal to 120 mm. The width of the lower and upper continuous beams from the both sides of the existing load-bearing walls is the same and equal to 200 mm. To tie these beams to the walls and to each other design envisages drilling holes of diameter 20 mm in the existing walls and placing reinforcing bars of diameter 16 mm in these holes (for lower beams in one level and for upper beams in two levels) using polymer-cement mortar.

Special attention needs to be paid to the stairs at both sides of the building leading from the level of the cantilever slab around the building to the basement (Fig. 10). These are the single-flight stairs which have 12 footsteps. The upper four of them designed as cantilever beams coming out from the upper continuous beams of seismic isolation system. The rest 8 footsteps are going to be made on the concrete underlayer prepared in advance on the soil. In the same way the stair landings must be made. There is a 50 mm gap envisaged in the design between the upper 4 stairs and lower 8 stairs (Fig. 11). The main purpose of this gap, as well as the 200 mm gap of isolation system 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.

From Figure 9 one can see that there are also large gaps with the width of 800 mm 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.



ԲՍ-1 – Cantilever slab CS-1; ՆԱ-1 – Basement stairs BS-1

Fig. 10. *Plan of location of the stairs at both sides of the old existing building leading from the level of the cantilever slab (colored in grey) around the building to its basement.*

Then, around the basement retaining walls are built, which are covered by cantilever slab coming out from the upper continuous beams in order to protect the formed gap from precipitation and avoid possible accumulation of trash. The cantilever slab serves also as a pavement around the building.

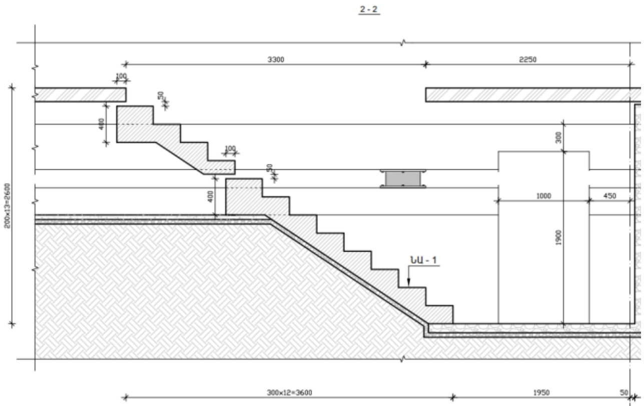


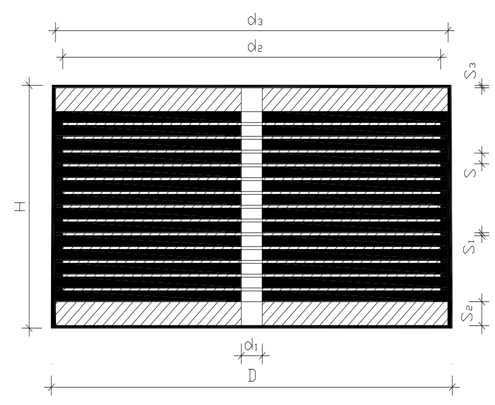
Fig. 11. *Vertical elevation 2-2 in longitudinal direction of the stairs leading to the building's basement.*

III. Parameters of the Used Seismic Isolation Laminated Rubber-Steel Bearings and Results of their Testing

As it was mentioned above the seismic isolation system of the considered old existing building and its extension is designed at the level of the basement (see Fig. 9). Total 15 SILRSBs of the same type and sizes with aggregate effective horizontal stiffness equal to K_{eff}=0.81×15=12.15 kN/mm were used to form the seismic isolation system. These are manufactured in Armenia by "Shahnazaryans" LLC according to the Republic of Armenia Standard HST 261-2007 with the sizes and physical/mechanical parameters given in [13, 14] (Fig. 12).

Testing of SILRSBs was carried out in accordance with the mentioned Standard. Different loading systems were designed by the author to test simultaneously two rubber bearings with diameters of up to 380 mm, or one rubber bearing with a diameter of 580 mm, under horizontal and vertical loadings. They were capable of producing up to 1000 kN of force on the bearings in horizontal direction and up to 2000 kN in vertical direction.

The system used for this particular project (Fig. 13) consisted of two columns, upper and lower beams, a steel platform movable in the horizontal direction and a horizontally immovable upper plate. The bearings were compressed by vertical force through a hydraulic jack, which was located in the frame and the axis of which coincided with longitudinal axes of the frame and bearings. The horizontal actuator was positioned in such a way that its longitudinal axis was in the same horizontal plane with the internal movable plate. The tests were carried out by "Melkumyan Seismic Technologies" LLC in conformity with the accepted methodology through application of alternating cyclic horizontal loading. During the displacement control shear test isolators were subjected to constant vertical force and gradually increasing horizontal displacement that reached the maximum value corresponding to the design displacement. Figure 13 also shows the deformed rubber bearings tested up to the displacement of 190 mm using a testing facility designed for the combined shear and compression tests of bearings with diameters of up to 380 mm. Results of the testing are presented in Table 1.



External diameter of the bearing (D): (380 ± 2.0) mm;
Internal diameter of the bearing's central hole (d_1): (19 ± 1.0) mm;
Height of the bearing (H): (202.5 ± 2.5) mm;
Thickness of the rubber layers (S): (9 ± 0.1) mm;
Diameter of the steel shim plates (d_2): (360 ± 0.5) mm;
Thickness of the steel shim plates (S_1): (2.5 ± 0.1) mm;
External diameter of the upper and lower flanges (d_3): (376 ± 0.5) mm;
Thickness of the upper and lower flanges (S_2): (20 ± 0.2) mm;
Thickness of the upper and lower flanges' protective layer (S_3): (2 ± 0.1) mm;
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 must be (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) mm;
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;
Shore A hardness of the bearing: 70 ± 5 points;
Damping coefficient of the bearing: 10-15%.

Fig. 12. *Dimensions and physical/mechanical parameters of the seismic isolation laminated rubber-steel bearing.*

Fig. 13. *Facilities in the laboratory named after the author of this paper and designed by him for testing of different types of the seismic isolation laminated rubber-steel bearings*

TABLE I. SOME RESULTS OF TESTING OF SILRSBS MANUFACTURED BY "SHAHNAZARYANS" LLC FOR THE PROJECT ON RETROFITTING BY BASE ISOLATION OF THE EXISTING STONE BUILDING AND ITS SEISMIC ISOLATED EXTENSION TO BE NEWLY CONSTRUCTED IN KHNDZORESK

Marking of SILRSBs	***Date of testing***	***Modulus of elasticity, Mpa***	***Vertical stiffness, kN/mm***	***Shear modulus, Mpa***	***Horizontal stiffness, kN/mm***
S43	01.03.23	462.1	415.7	0.857	0.771
S44-S45	02.03.23	464.2	417.6	0.901	0.811
S46-S47	02.03.23	579.9	521.7	0.890	0.801
S48-S49	10.03.23	543.7	489.1	0.923	0.831
S50-S51	10.03.23	465.3	418.6	0.894	0.804
S52-S53	13.03.23	592.0	532.5	0.988	0.889
S54-S55	15.03.23	797.1	717.1	0.944	0.849
S56-S57	15.03.23	604.5	543.8	1.001	0.901

After completion of testing all the SILRSBs were labeled and sent to construction site. These isolators will be 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 and lower continuous beams; the isolators themselves are not bolted to the structure (Fig. 14).

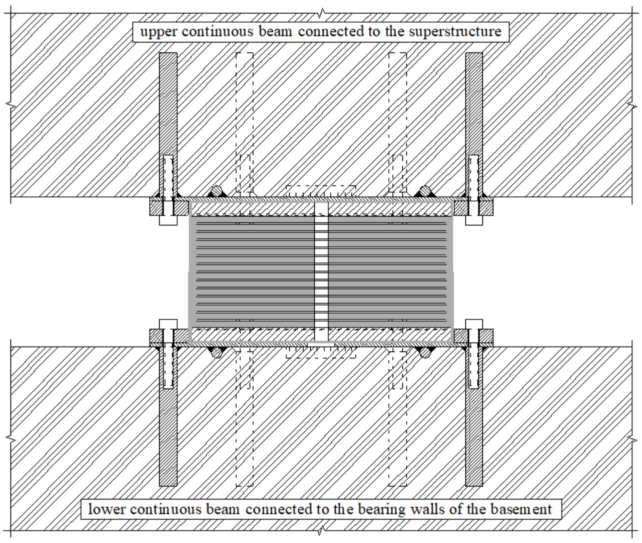


Fig. 14. *Location of SILRSBs by upper and lower recesses provided by annular steel rings.*

From the Figures 8, 9, and 15 one can see that in plan of the old existing building and its extension to be newly constructed a retaining wall is envisaged along all the exterior axes. This was needed considering that ground level around the entire structure is higher than the level of seismic isolation interface. As it is mentioned above the distance between all the exterior walls and the retaining wall is equal to 800 mm and this gap is covered by the monolithic cantilever slab. Having all testing results and based on the carried out analysis on uniform distribution of the stiffness in seismic isolation interface a drawing was developed showing markings of SILRSBs to be placed at each location (Fig. 15). This strategy would lead to a somewhat more uniform distribution of the horizontal seismic forces and help ensure that the isolation system's center of stiffness is close in plan to the projection of the building's center of mass.

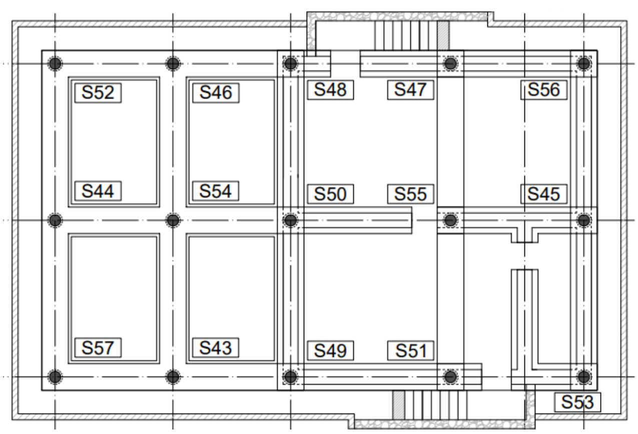


Fig. 15. *Plan of seismic isolation interface showing markings of SILRSBs to be placed at each location.*

This minimizes the excitation of torsion vibrations of the building on the isolators during an earthquake.

IV. Analysis of the Base Isolated Old Building with Stone Bearing Walls Together with its Newly Constructed and Rigidly Connected Extension

Analysis of the seismic isolation system and the whole structure was performed in accordance with the Armenian Seismic Code RABC 20.04.2020 assuming the following parameters:

- Seismic zone 1 and soil category II;
- Soil conditions coefficient is K_0=1.0 and the site prevailing period of vibrations 0.3≤T0≤0.6 sec;
- Permissible damage coefficient for determining displacements – K_{1z}=0.8;
- Permissible damage coefficient for analysis of the superstructure – K_1=0.7;
- Coefficient of seismicity – A=0.3.

After multiple criticisms by the author of this book of the former edition of the Armenian Seismic Code RABC II-6.02-2006 it was finally edited and converted into new edition RABC 20.04.2020 (the author was one of those who actively participated in preparation of this new edition by changing many of the provisions of the former edition). Namely, new edition now requires that any base isolated building should be analyzed applying the same permissible damage coefficient for analysis of the superstructure, as well as the isolation system and structures below it. In the given case permissible damage coefficient K_1=0.7 was used in analysis. It is also assumed that vibration period (T) of the base isolated building should be around 2 sec. According to the new RABC 20.04.2020 horizontal displacement of the base isolation system must be calculated by the formulas (5) and (32) of the Code:

$$D= K_{1z}\times(T/2\pi)^2\times A\times K_0\times[\beta(T)/B(n)]\times K_1, \qquad (1)$$

where dynamic coefficient β(T) depends on soil category and determined by the formulas given in the Code. In this case β(T)=0.81. B(n) depends on the damping of isolation system and for the value of 10% Code suggests this coefficient equal to 1.3. Thus:

$$D=0.8\times(2/6.28)^2\times300\times(0.81/1.3)\times0.7=10.08 \text{ cm}.$$

Based on the provision of item 349 of the RABC 20.04.2020 the obtained value of horizontal displacement must be multiplied by a factor 1.1. At the same time based on the provision of another item 345 to provide high reliability of seismic isolation system it is required to apply one more factor 1.1. Thus, the calculated value of horizontal displacement must be multiplied by a factor 1.21.

$$D_t=10.08\times1.21=12.2 \text{ cm}.$$

Obtained value of total horizontal displacement is smaller than the maximum permissible displacement suggested by the Armenian Standard HST 261-2007 (28 cm). This will provide high reliability of the designed seismic isolation system.

According to the RABC 20.04.2020 total seismic force on the top of isolation system (base of superstructure) must be calculated by the formula (35) of the Code:

$$S_t = K_{eff} \times D_t = 0.81 \times 15 \times 122 = 1482.3 \text{ kN}. \quad (2)$$

To calculate the vibration period of the base isolated kindergarten building the masses of its floors were computed and the total mass M_t of the building was equal to 1300 t. According to the RABC 20.04.2020 vibration period for the base isolated structure is determined by the formula (31) of the Code using the values of the total mass of this building (superstructure) and effective stiffness of isolation system:

$$T = 2\pi \times \sqrt{Q/(K_{eff} \times g)} = 6.28 \times \sqrt{1300/12150} = 2.05 \text{ sec}. \quad (3)$$

Using the obtained values, it is possible to calculate the magnitude of acceleration just above the seismic isolation interface:

$$a = S_t/M_t = 1482.3/1300 = 1.14 \text{ m/sec}^2. \quad (4)$$

From this it follows that due to application of base isolation acceleration at the level of the first floor of the superstructure decreases by 2.63 times in comparison with the input ground acceleration (3.0 m/sec^2). This is very typical result showing the high effectiveness and reliability of base isolated structures. Particularly, the superstructure of the kindergarten building will have no deformations due to moving during the earthquake as a rigid body. All the structural elements below and above the seismic isolation interface will work only in elastic stage. Analysis shows that the magnitudes of accelerations at the level of the slab just above the seismic isolation interface and at the top of the building are practically equal to each other.

V. Conclusions

Several remarkable projects on retrofitting by base isolation of the existing buildings like apartment, school, bank, hotel, hospital, and kindergarten buildings are briefly mentioned in the paper to demonstrate the retrofitting experience accumulated in Armenia.

Retrofitting design for another existing 1-story kindergarten building with the stone load-bearing walls is presented including extension of this building by newly constructed part rigidly connected to the old building. As a tool for retrofitting the base isolation technology is used. The innovative structural concept of retrofitting by base isolation is described in detail explaining retrofitting approaches for the existing buildings with load-bearing walls.

Total 15 SILRSBs were used in seismic isolation system. These are manufactured in Armenia according to the Republic of Armenia Standard HST 261-2007. Their dimensions and physical/mechanical parameters are given.

Some results of analysis of the base isolated 1-story building with the stone load-bearing walls by the Armenian Seismic Code are given showing that the structural elements below and above the seismic isolation plane will work only in the elastic phase. Total horizontal displacement comprises 12.2 cm, period of vibration – 2.05 sec and acceleration at the level above the seismic isolation interface – 1.14 m/sec^2. An input acceleration of 0.3g at the foundation bed gets damped about 2.63 times in the superstructure.

Obtained results prove the high effectiveness of the created base isolation system and reliability of the old building and its extension, which will suffer no damage under seismic impacts. Under the impact of the design level earthquake the inter-story drifts remain smaller than the permissible values.

Based on the extensive experience accumulated in Armenia it can be stated that comparison of the construction cost of retrofitting by the suggested design with the cost of conventional strengthening shows that significant cost savings (up to 5 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 of the use (exploitation) of the old 1-story kindergarten building.

References

[1] A. Martelli, M. Forni, & P. Clemente, Recent Worldwide Application of Seismic Isolation and Energy Dissipation and Conditions for Their Correct Use, Proceedings of the 15th WCEE, Lisbon, Portugal, 2012

[2] M. Melkumyan, The use of high damping rubber isolators to upgrade earthquake resistance of existing buildings in Armenia. 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.

[3] M. Melkumyan, Base and roof isolation for earthquake retrofitting and protection of existing buildings in Armenia, International Symposium on Seismic Risk Reduction (the JICA Cooperation Project in Romania), Bucharest, Romanian, 2007, pp.593-600.

[4] V. Smirnov, J. Eisenberg, F. Zhou, Y. Chung, A. Nikitin, Seismoisolation for upgrading of an existing historical building in Irkutsk-City, Siberia-Russia. 12th World Conference on Earthquake Engineering, Auckland, New Zealand, Paper No. 0962, 2000.

[5] M. Melkumyan, G. Käppeli, R. Khalatyan, H. Hovivyan, Application of seismic isolation for retrofitting of existing 3-story stone building of the

school #4 in the city of Vanadzor, Armenia, 8th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Yerevan, Armenia, 2003, pp.557-565.

[6] M. Melkumyan, H. Hovivyan, L. Movsessyan, and S. Terjanyan, Technique of installation of seismic isolation bearings in an existing building with historical and architectural value, 8th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Yerevan, Armenia, 2003, pp.629-641.

[7] M. Melkumyan, Seismic isolation retrofitting experience in Armenia and new structural concept for an existing 8-story reinforced concrete hospital building to be retrofitted by base isolation, Study of Civil Engineering and Architecture. J., vol.3, 2014, pp.78-92.

[8] M. Melkumyan, Unique retrofitting technology for base isolation of an existing 8-story R/C Hematology Center hospital frame building with shear walls, Journal of Civil Engineering and Architecture Research, vol.2, no.12, 2015, pp.1153-1162.

[9] M. Melkumyan, New structural concept for an existing 4-story reinforced concrete industrial frame building to be retrofitted by base isolation and simultaneously reconstructed into a 6-story hotel building, Engineering & Technology. J., vol.1, no.1, 2014, pp.1-12.

[10] M. Melkumyan, Base isolation retrofitting design for the existing 9-story large-panel apartment building, International Journal of Trend in Scientific Research and Development (IJTSRD), ISSN: 2456-6470, vol. 4, no. 4, 2020, pp.199-209.

[11] M. Melkumyan, Unique Concepts and Features of Seismic Isolation Systems, "B P International", First Edition, ISBN 978-81-959913-0-3 (Print), ISBN 978-81-959913-6-5 (eBook), DOI: 10.9734/bpi/mono/978-81-959913-0-3, 2022, 563 p.

[12] M. Melkumyan, Base isolation retrofitting design for the existing 2-story stone building and its conversion into a 3-story kindergarten, World Journal of Advanced Engineering Technology and Sciences (WJAETS), ISSN: 2582-8266, vol. 8, no. 1, 2023, pp.1-14.

[13] M. Melkumyan, New solutions in seismic isolation, Yerevan, LUSABATS, 2011, 264 p.

[14] K. Fuller, C. Lim, S. Loo, M. Melkumyan, K. Muniandy, Design and testing of high damping rubber earthquake bearings for retrofit project in Armenia, Earthquake Hazard and Seismic Risk Reduction, Kluwer Academic Publishers, The Netherlands, 2000, pp.379-385.