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Base Isolated 5-Story Residential Building for Construction in the Devastated Zone of 2023 Turkey–Syria Earthquake

Mikayel Melkumyan
President, Armenian Association for Earthquake Engineering
CEO, "Melkumyan Seismic Technologies" LLC

Abstract
The article provides information on development and application of the created by the author seismic isolation systems in Armenia and on the country's leading position in the world in implementation of the low-cost seismic isolation for construction of new and retrofitting of existing buildings. Based on the extensive experience and having in mind the terrible situation in the devastated zone of the 2023 Turkey-Syria earthquake, the author has decided to develop a structural design of base isolated residential building for its multiple implementations in the suffered regions.
The author suggested to the Turkish colleagues to consider this design as his gift (the gift from his company "Melkumyan Seismic Technologies" LLC) to Turkish people and people of other nationalities who are living in the affected area. Earlier the author has already developed seismic isolation designs also for the other countries, namely, retrofitting designs for Russia, Romania and Kazakhstan, as well as design for construction of new building in Peru. These projects are briefly described below in the paper. However, the given paper is focused on the structural solution and some details of analysis of base isolated 5-story residential building for construction in the Turkey-Syria earthquake zone.

Keywords: *low-cost seismic isolation in Armenia, development and application, 2023 Turkey-Syria earthquake, devastated area, transfer of the experience, seismic isolated building, structural solution, design and analysis, gift from the author.*

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I. Introduction

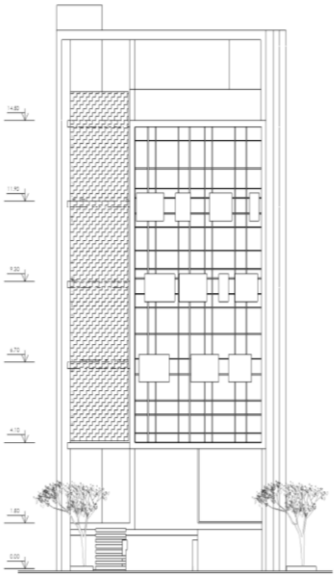
After the devastating Turkey-Syria earthquake many other strong earthquakes occurred in different countries, including the last strongest one in Japan, where 90% of buildings in the affected area were destroyed. These, as well as many previously occurred strong earthquakes, are testifying that we must pay special attention to construction of highly reliable buildings which use modern anti-seismic technologies. In this regard the author has decided to develop a design of base isolated building and submit it to the Turkish colleagues to consider this design as his gift (the gift from his company "Melkumyan Seismic Technologies" LLC) to Turkish people and people of other nationalities who are living in the affected area.

Starting from 1993 revolutionary transformations in the field of earthquake engineering in Armenia have been found [1, 2]. These solutions are based on the application of seismic isolation systems using chloroprene rubber produced locally. As a result, the new technologies for upgrading earthquake resistance and retrofitting the existing buildings, as well as for construction of new buildings with application of seismic isolation systems were developed, and these technologies represented new directions of earthquake engineering in the country.

Currently created by the author seismic (base and roof) isolation technologies are applied in Armenia for construction of new and retrofitting of existing buildings. These are buildings with different structural solutions from 1 to 20 stories. In [3] the leading role of the country is mentioned: "*It is worthwhile stressing that Armenia remains second, at worldwide level, and has the largest number of building applications of seismic isolation per number of residents, in spite of the fact that it is a still developing country*". Thus, by his achievements in the field of seismic isolation the author brought Armenia to the second place in the world, after

Japan. Recognizing these achievements several states, namely, Russia, Romania, Peru, and Kazakhstan were interested in application of the author's seismic isolation technologies (Figure 1) in their countries.

(a)



(b) (c) (d)

Figure 1. Retrofitting of existing buildings in Russia, Romania and Kazakhstan and construction of new building in Peru using developed by the author base isolation technologies
(a) 4-story existing stone bank building retrofitted in the city of Irkutsk (Russia) by base isolation; (b) 2-story existing stone Iasi City Hall building in Romania designed for retrofitting by base isolation; (c) 7-story residential building on Chullo str. in the city of Arequipa (Peru) designed for new construction using base isolation system; (d) 19-story (including two basement floors) existing apartment building on Dostyk ave. in the city of Almaty (Kazakhstan) designed for retrofitting by base isolation

Particularly, regarding the project in Russia the main points of its implementation described in the paper [4] were presented at the 12th WCEE. It was emphasized in the mentioned paper that for retrofitting by base isolation of the existing bank building in the city of Irkutsk the author's method developed in [5] was implemented. All the needed drawings, photos, video film related to the retrofitting works carried out in Armenia and designed for the project in Irkutsk were provided by the author of this paper.

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 at least 179 years old (at the time of the competitive bidding) historical building of the Iasi City Hall by base isolation [6]. The structural concept of retrofitting, including the new approach on installation of seismic isolation rubber bearings, and detailed results of the earthquake response analysis for two cases, i.e. when building is base isolated and when it has a fixed base, are described in [7].

In the same way, as for the Russian colleagues, the Peruvian specialists were also familiarized in detail with the author's seismic isolation technologies and received all the necessary explanations and comments. This was done during the author's visit to the city of Arequipa (Peru) by the invitation of the San Pablo Catholic University where, as one of the results, the author developed structural design for construction of the new base isolated 7-story "Chullo" residential building [8].

And finally, after the earthquake of magnitude 7.0 in January 2024 along the China-Kyrgyzstan border the scared residents of a 19-story apartment building located on the Dostyk ave. 138 in the City of Almaty have contacted the author of this paper being aware about his achievements in retrofitting of different types of existing buildings. The request was to consider upgrading the earthquake resistance of the mentioned building by implementation of the author's technology on retrofitting using base isolation systems. In response to the request of the dwellers the retrofitting design was elaborated and delivered to the clients. Its structural concept is described in [9].

Examples, briefly described above, point out on the successful international cooperation of the author's company "Melkumyan Seismic Technologies" LLC with various institutions in different countries. This cooperation and the author's huge experience as director of the Earthquake Zone Reconstruction Project Preparation and Implementation Unit (the World Bank Project) in Armenia [10, 11] brought him to the idea on development of the design of base isolated 5-story residential building for construction in the devastated zone of 2023 Turkey-Syria earthquake. After completion of the design it was delivered to the well-known Turkish company "Parlar Mühendislik Müşavirlik Limited Şirketi". Previously this company was interested by the seismic isolation technologies created by the author of the given paper. The developed and delivered design has received the high appreciation by the mentioned company which was expressed in their letter of January 22, 2024:

Dear Professor Melkumyan

Thank you for sharing, we were able to open the files. We thank you. Thank you for your hard work. Our work is to continue to be able to use your design… Hope we will be able to design like this as a team.
It would be a great pleasure for us to partner with an outstanding scientist and engineer like you.
We would like to use your design in the first appropriate structure in consultation with you.
Apart from this, there are requests for seismically isolated buildings in the wealthy districts of Istanbul…
Istanbul Municipality will build a building with isolators, we are following it. We have built other buildings of the municipality. They trust us very much.
Hoping to work together in the first opportunity…

Best Regards
Niyazi Parlar
Alen Diran Nergis

1. Design of the 5-Story Residential Building for Multiple Implementation in the Devastated Zone of 2023 Turkey-Syria Earthquake

Seismic isolation is generally not widely implemented in Turkey. It should be noted that here the seismic isolation systems are implemented mainly to health care facilities [12]. In the area affected by the magnitude 7.8 and magnitude 7.5 earthquakes on February 6, 2023 in Turkey the base-isolated hospital buildings generally exhibited superior performance of achieving the goal of immediate occupancy and provided better protection for nonstructural elements than fixed-base counterparts did [13]. This explains the current demand in Turkey to widely implement the seismic isolation systems in construction of new and retrofitting of existing buildings. Such a situation was usual for many countries like, for example, Japan [14], Chile [15], Italy, China, etc. Seismic isolation started its rapid implementation exactly after strong earthquakes, when people saw by their own eyes all the advantages of these brilliant systems.

Structural concept of base isolation was developed for a building under consideration taking into account the already acquired extensive experience on construction of new seismic isolated buildings. Foundation of the building consists of strips in longitudinal and transverse directions with the cross section of all the foundation beams (FBs) equal to 600×800(h) mm (Figure 2). Seismic isolation interface for this building is designed at the upper level of basement floor between the reinforced concrete (R/C) beams envisaged below and above the seismic isolation laminated rubber-steel bearings (SILRSBs).

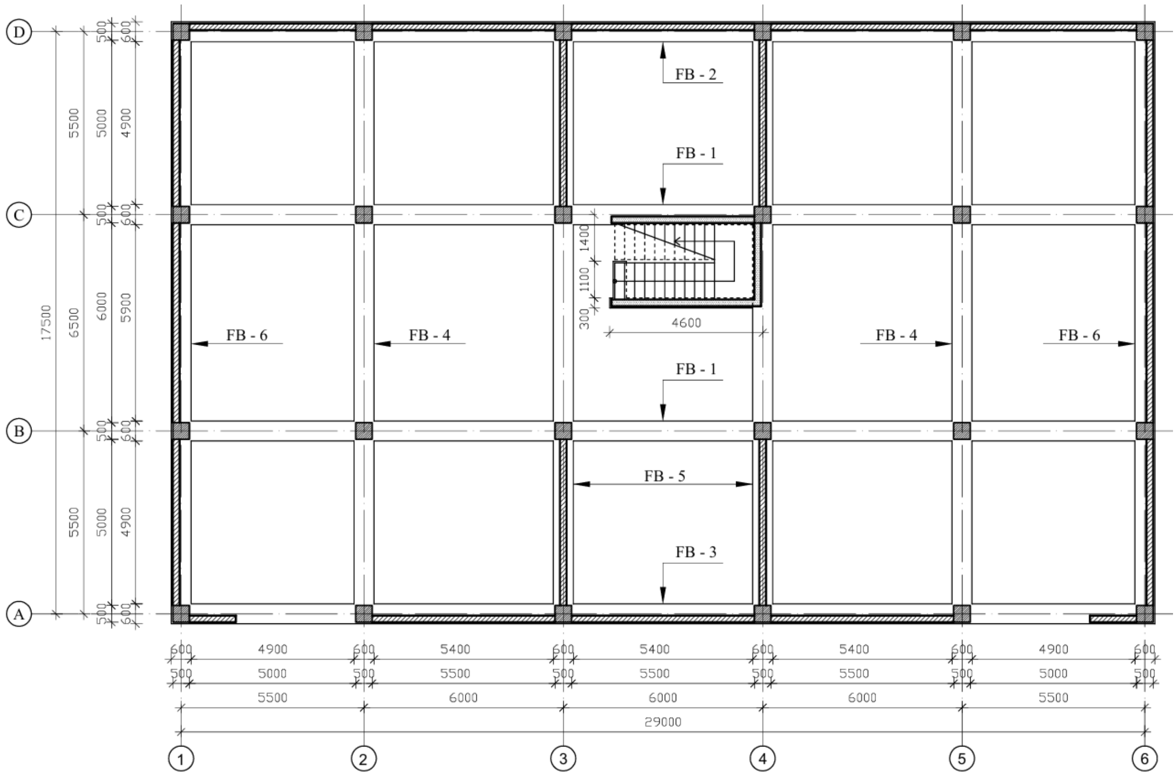


Figure 2. Plan of the foundation strip beams of 5-story residential building designed for multiple implementations in the devastated zone of 2023 Turkey-Syria Earthquake

From Figure 2 one can see that considered building has symmetric rectangular plan with main dimensions of 29.6×18.1 m. Plan of the lower beams (LBs) with the location right above them of 36 SILRSBs is shown in Figure 3. Here the vertical section 1-1 of the basement where seismic isolation system is located is also shown. From these drawings it follows that LBs have the cross section equal to 600×300(h) mm. Then the 200 mm thick seismic isolation vertical gap is envisaged and above this gap the upper beams (UBs) are designed. They are supported by the SILRSBs (Figure 4). At the mark of -0.05 the UBs are unified by the R/C slabs which have a thickness equal to 120 mm. This mark corresponds to the upper surface of UBs and the upper surface of the monolithic R/C slabs between them.

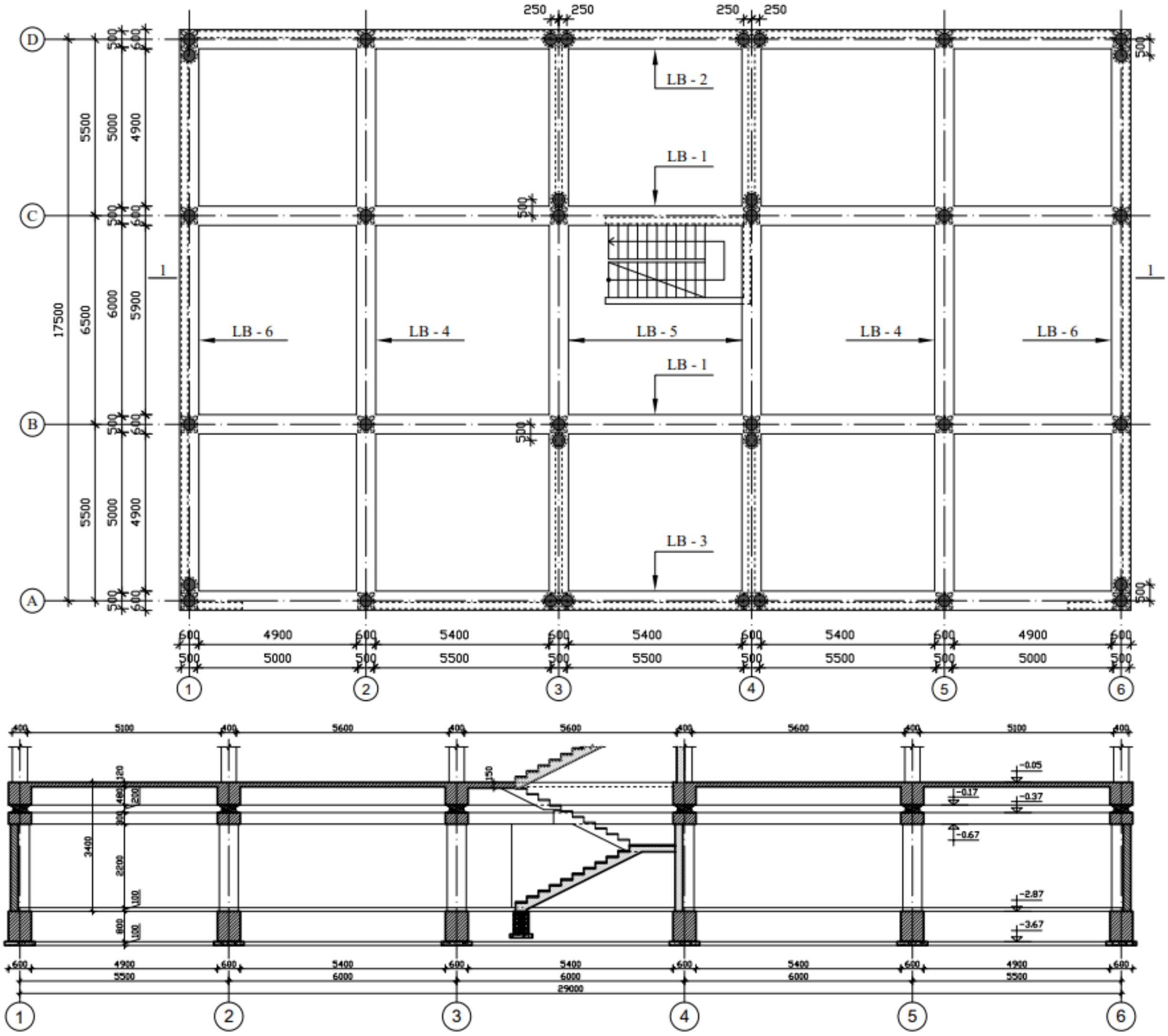


Figure 3. Plan of the lower beams envisaged below the seismic isolators and vertical section of the basement floor of 5-story residential building designed for multiple implementations in the devastated zone of 2023 Turkey-Syria Earthquake

The cross section of the UBs along the longitudinal and transverse axes of the building is equal to 600×600(h) mm. These beams support the whole superstructure of the building. The superstructure is the part of the building above the seismic isolation system. Thus, the latter has the total thickness equal to 1100 mm and consists of the lower and upper beams with the SILRSBs between them. There are no slabs at the level of the lower beams. The cross section of all the columns in the basement is equal to 500×500 mm.

It is necessary to mention the designed shear walls for the considered building. As it follows from Figure 2 the shear walls in the basement are located mainly along the exterior axes and also along the axes "3" and "4". The walls around the staircase are not the structural elements. All the mentioned shear walls have the thickness equal to 200 mm. They will provide the needed rigidity to the part of the basement below the seismic isolation system. The basement will serve as the parking floor for about 14 cars. In the superstructure the shear walls of the same thickness as in the basement are envisaged only along the axes "3" and "4" and around the staircase as it is shown in Figure 4.

Besides the monolithic slabs (MSs) at the level of the UBs there are also three cantilever slabs (CSs) of which two slabs are located along the axes "1" and "6" and one slab is designed along the axis "A". The thickness of the CSs is equal to 150 mm. Similar structural solution is accepted for the all five floors of the superstructure with the differences related to the cross sections of columns and collar beams. Columns in superstructure have the cross section equal to 400×400 mm and the collar beams (CBs) - 400×350 (h) mm (Figure 5).

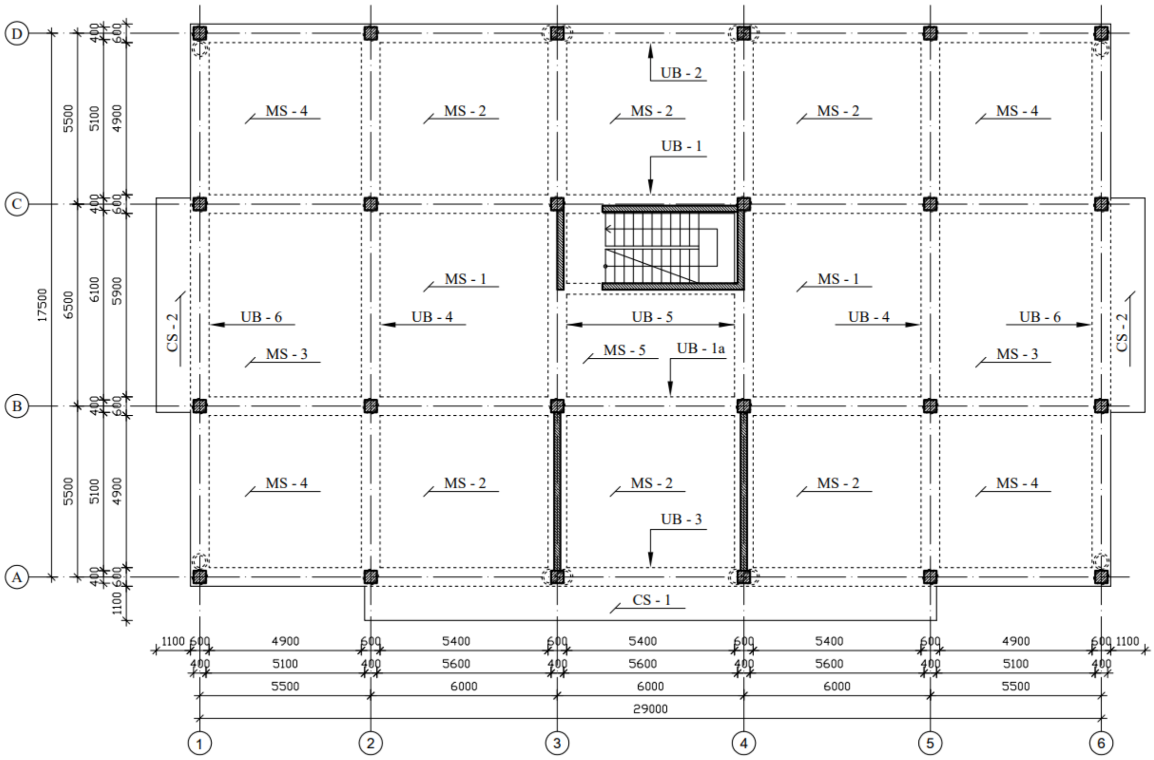


Figure 4. Plan of the upper beams located immediately above the seismic isolators of 5-story residential building designed for multiple implementations in the devastated zone of 2023 Turkey-Syria Earthquake

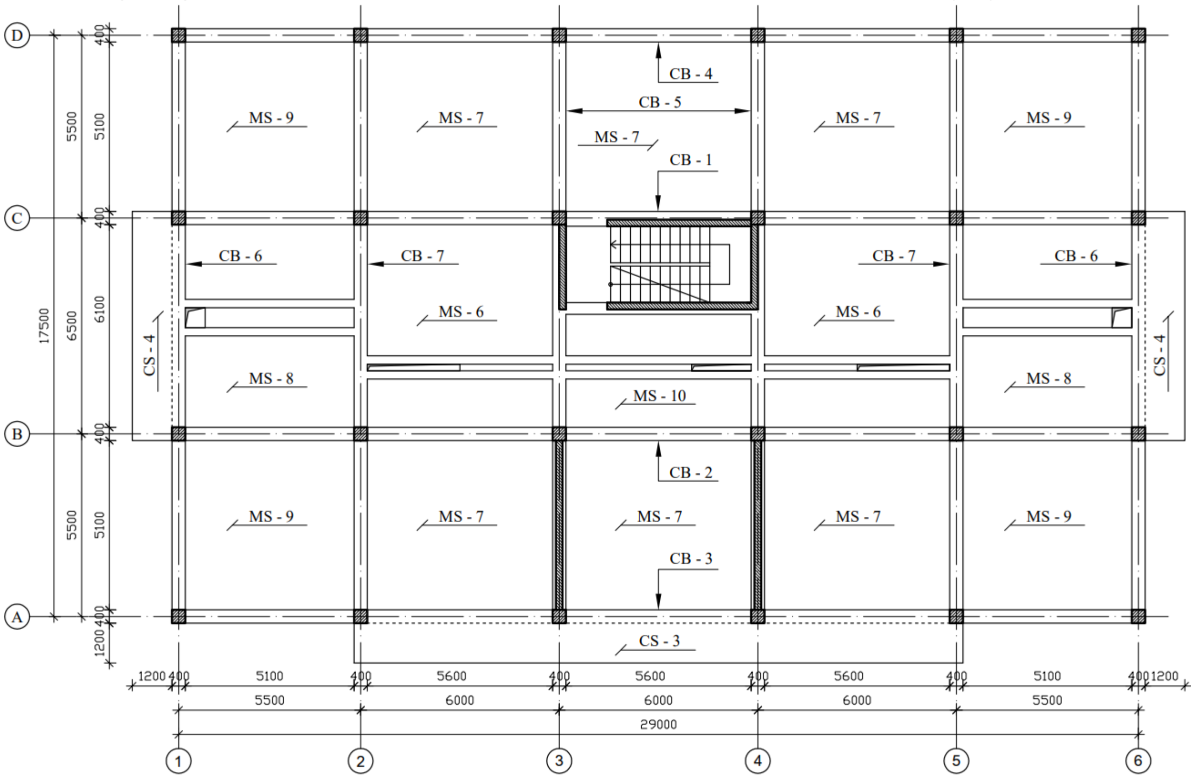


Figure 5. Plan of the typical floor of superstructure of the 5-story residential building designed for multiple implementations in the devastated zone of 2023 Turkey-Syria Earthquake

Fragment of the vertical elevation of the building's staircase that includes the parts of the basement, and the first living floor is shown in Figure 6, where the gaps of the seismic isolation system and of stairs are clearly seen. Special attention needs to be paid to the stair leading to the basement. There is a gap envisaged in the design for this structural element, namely, for the stair flight SF-3. 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.

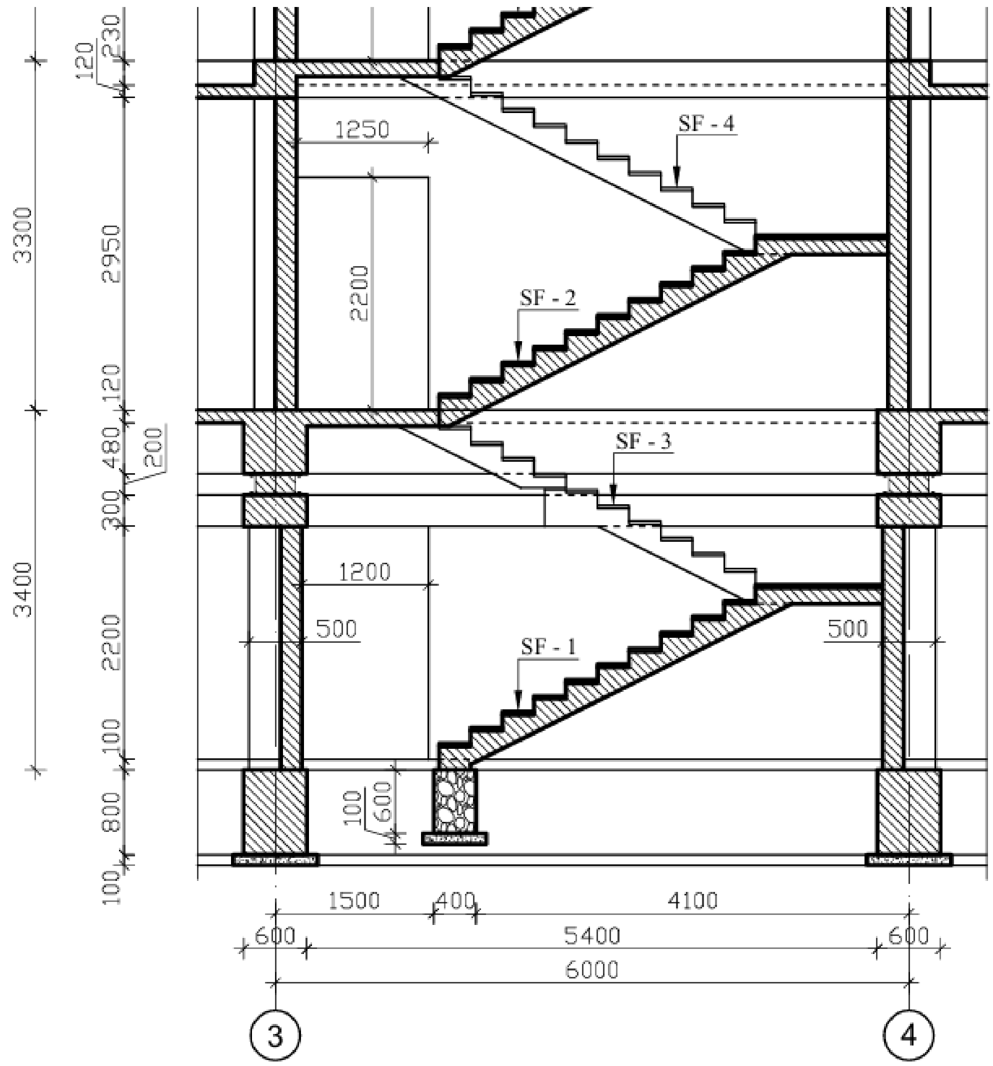


Figure 6. Fragment of the vertical elevation of the building's staircase showing the gaps of the seismic isolation system and of stair flight SF-3

High damping SILRSBs are applied in the considered building. They 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 bearings can be designed to withstand safely the large horizontal displacements imposed on them during an earthquake. The service life of the bearings is expected to be several decades [16], and they should require no maintenance. In accordance with the Armenian standards the service life of SILRSBs manufactured in the country is not less than 150 years [17].

SILRSBs 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 UBs and LBs; the SILRSBs 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. Because the SILRSBs are simply located in a recess, no tapped holes for bolted connections are needed in the endplate. The side, top and bottom rubber cover layers ensure the steel plates are protected from corrosion (Figure 7).

Number of rubber layers: 14;
Number of internal metal plates: 13;
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 internal metal plates (d_2): (360 ± 0.5) mm;
Thickness of the internal metal 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. Critical vertical load is equal to 4500 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) kN/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%.

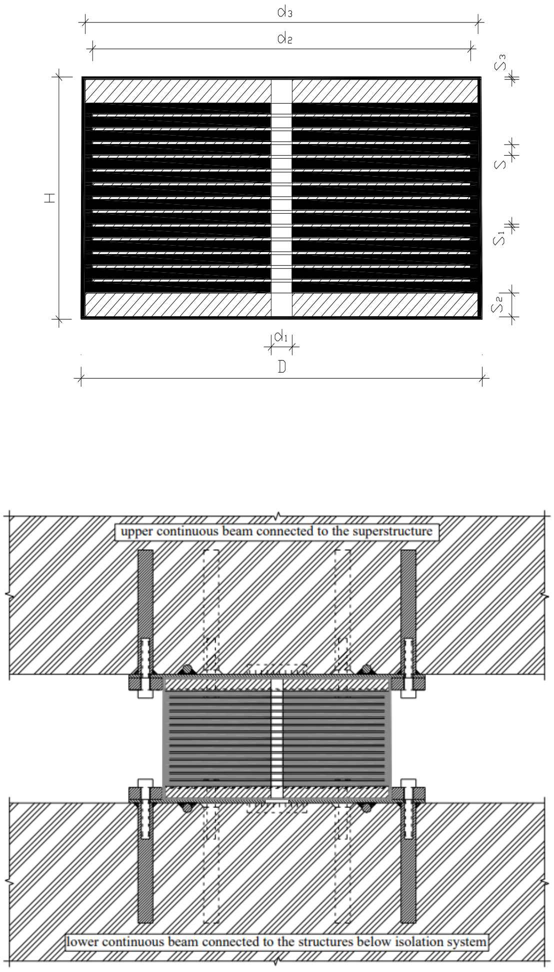


Figure 7. Dimensions and physical/mechanical parameters of SILRSBs to be applied in the seismic isolation system of the 5-story residential building designed for multiple implementations in the devastated zone of 2023 Turkey-Syria Earthquake

II. Analysis of the 5-Story Base Isolated Residential Building Designed for Multiple Implementation in the Devastated Zone of 2023 Turkey-Syria Earthquake

Analysis of the seismic isolation system and the whole structure was performed using the well-known program SAP2000 assuming that the building will be constructed in the seismic zone where the expected acceleration equal to 0.4g and the soils are hard with the site prevailing period of vibrations $0.3 \le T_0 \le 0.6$ sec. It is also assumed that vibration period T of the base isolated building should be around 2 sec. According to [18] in the absence of a site specific response spectrum the horizontal design displacement D of the base isolation system shall be calculated from the formula:

$$D(mm) = \frac{250 Z K_0 T}{B}, \qquad (1)$$

where T is the isolated structure's period, Z takes the value 0.4, B takes the value 1.3 according to the damping of 10% and K_0 takes the value 1.0 for the hard soil conditions. Thus, preliminary calculation of the horizontal design displacement gives the value equal to D=153.8 mm.

The total design displacement D_t shall include a contribution, D_r due to actual plus accidental eccentricity, **e**, between the center of stiffness of the isolation system and the projection of the center of mass of the structure on to the plane of the isolation system. D_r for an isolator a distance r′ from the center of stiffness shall be calculated from the relation:

$$D_r = \frac{Dr'e}{L_1^2 + L_2^2} \quad \text{or} \quad 0.1D, \qquad (2)$$

whichever is the greater. L_1 is the longest plan dimension of the structure and L_2 is the shortest plan dimension perpendicular to L_1. The minimum value allowed for the accidental eccentricity is $0.05L_1$. Thus, the total design displacement will be equal to:

$$D_t = 153.8 \times 1.1 = 169.18 \text{ mm}.$$

Obtained value of total horizontal displacement is smaller than the maximum permissible displacement suggested by the Armenian Standard HST261-2007 (280 mm). This will provide high reliability of the designed seismic isolation system. Based on the received value of total design displacement the total seismic force on the top of isolation system (base of superstructure) can be calculated by the formula:

$$S_t = K_{eff} \times D_t \qquad (3)$$

From Figure 7 it follows that effective horizontal stiffness of one SILRSB is equal to 0.81 kN/mm. As it was mentioned above and can be seen from Figure 3 there are 36 SILRSBs installed in seismic isolation system of the considered building and, therefore, total effective stiffness will comprise K_{eff}=0.81×36= 29.16 kN/mm. Using the obtained values of K_{eff} and D_t
the total seismic force on the top of isolation system (base of superstructure) can be calculated:

$$S_t = K_{eff} \times D_t = 29.16 \times 169.18 = 4933.3 \text{ kN}.$$

It is necessary to calculate the actual vibration period of the base isolated 5-story residential building using the values of the total effective stiffness and total weight of the building Q. This is needed to see how the calculated value of the building's vibration period close to the initially accepted value (2 sec). With this purpose the weights of the building's floors were computed, and the total weight of the building appeared to be equal to 30000 kN. Vibration period for the base isolated 5-story residential building is determined using the calculated value of total weight of this building (superstructure) and effective stiffness of isolation system:

$$T = 2\pi \times \sqrt{Q/(\ K_{eff} \times g)} = 6.28 \times \sqrt{3000/2916 \times 9.82} = 2.03 \text{ sec}.$$

Based on the received results, it is possible to calculate the magnitude of acceleration just above the seismic isolation interface:

$$a = S_t/M_t = 4933.3/3055 = 1.61 \text{ m/sec}^2,$$

where M_t is the total mass of the superstructure.
From this it follows that due to application of base isolation acceleration at the level of the first floor of the superstructure decreases by about 2.48 times in comparison with the input ground acceleration (4.0 m/sec^2). This is very typical result showing the high effectiveness and reliability of base isolated structures. Particularly, the superstructure of the 5-story residential 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.

III. Conclusions

Several remarkable projects on retrofitting by base isolation of the existing buildings like bank in Russia, Iasi City Hall – municipality building in Romania, and apartment building in Kazakhstan are briefly mentioned in the paper. Also, the project on construction of new base isolated apartment building in Peru is described and all these works are demonstrating the experience of the author in carrying out the projects on international level.

Following the gained experience the author has decided after the 2023 Turkey-Syria earthquake to develop a design of the base isolated 5-story residential building and submit it to the Turkish colleagues, particularly to the well-known Turkish company "Parlar Mühendislik Müşavirlik Limited Şirketi", for the multiple implementations of this design in the devastated zone. The author suggested them to consider this design as his gift (the gift from his company "Melkumyan Seismic Technologies" LLC) to Turkish people and people of other nationalities who are living in the affected area. The mentioned company highly appreciated the performed work and expressed its deep gratitude to the author in their letter of January 22, 2024, which is given in this paper.

Structural concept of base isolation was developed for a building under consideration, namely, the R/C frame structure with shear walls, taking into account the already acquired extensive experience on construction of new seismic isolated buildings in Armenia. The paper presents the structural solutions of the basement floor where seismic isolation system is located, as well as of the first and typical floors. Seismic isolation system consists of: lower beams which are connecting all the columns of the basement but do not have the R/C slab at their level; the gap where the 36 SILRSBs are located; and the upper beams right above the seismic isolators and unified by the R/C slab.

SILRSBs can be manufactured in Armenia according to the Republic of Armenia Standard HST 261-2007. Their dimensions and physical/mechanical parameters are given in the paper. This was done with the purpose that if the Turkish colleagues will not be able to export rubber bearings from Armenia, then the bearings with the given parameters can be ordered elsewhere, in Italy, China, Malaysia, etc. and shipped to Turkey.

Some results of analysis of the base isolated 5-story residential building designed for multiple implementations in the devastated zone of 2023 Turkey-Syria Earthquake are given showing that the structural elements below and above the seismic isolation plane will work only in the elastic phase. Total horizontal displacement of SILRSBs comprises 169.18 mm, period of vibration – 2.03 sec and acceleration just above the seismic isolation interface – 1.61 m/sec^2. An input acceleration of 0.4g at the foundation bed gets damped about 2.48 times in the superstructure.

Obtained results prove the high effectiveness of the created base isolation system and reliability of the building, 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 by the suggested design with the cost of conventional construction will show that significant cost savings will be achieved due to implementation of the developed design and created base isolation technology.

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