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New Application of Base Isolation Technology for Construction Of 9-Story Large-Panel Residential Building with The First Business Floor in Armenia

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***Abstract**: Seismic (base and roof) isolation technologies are well developed in Armenia due to the research, experimental and design works carried out by the author starting from 1993. Several International institutions, as well as local companies (developers) and private individuals have financed design works and construction of new and retrofitting of existing buildings. Currently Armenia is the second country in the world by the number of various base and roof isolated buildings per the number of residents. Also, this country is the world leader in large implementation of low-cost seismic isolation. This was achieved by application of the progressive normative documents, codes and standards written by the author and adopted by the government in 2006-2020. Using these documents many unique base and roof isolated buildings were realized in Armenia and briefly described in the paper. This year for the first time a 9-story large-panel base isolated residential building with the first business floor was designed by the author for construction in different regions of Armenia. The given paper is focused on the description of the structural concept and analysis of the mentioned building. Received results have confirmed the high reliability of the large- panel base isolated building with the superstructure moving practically as a rigid body and working in elastic stage. This brings to significant reduction of the consumption of steel in structural elements.*

***Keywords**: achievements in seismic isolation, newly constructed base isolated buildings, large-panel base isolated residential building, structural solution, design model, earthquake response analysis, results of analysis.*

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I. INTRODUCTION

Base isolation of multistory buildings in Armenia at its early stage was generally implemented due to financial support of an International Institutions: World Bank, Huntsman Corporation, Caritas Switzerland, Hayastan All-Armenian Fund, "Tufenkian Hospitality" LLC. Further development and application of base isolation technology in construction of new medium- and high-rise buildings took place owing to projects financed or by private companies (developers): "Elite Group" CJSC, "ITARKO Construction" CJSC, "Fredex Services" CJSC, etc. Also, some projects were financed by the Governmental program for providing apartments for young families, and the Healthcare Project Implementation Unit of the Ministry of Health, as well as by the private individuals who were constructing their own houses. Unique and innovative seismic isolation structural concepts for low-story and multi- story buildings were developed and designed by the author and they were widely applied during the last 25 years. Tables 1-5 are presenting statistics on some of the newly constructed base isolated buildings in different regions of Armenia. The bearing structures of these buildings were designed with application of the R/C bearing frames and shear walls, while single-family houses are representing the structures where only stone load-bearing walls are used (Table 6).

New technologies, using seismic isolation systems for construction of new buildings developed by the author have attracted attention of the international professional community. As it is mentioned in [1] "…the number of new applications of innovative anti-seismic techniques, especially seismic isolation, is particularly large in Japan, P.R. China and Armenia…"; "Some other countries are beginning to follow the excellent example of Armenia (…where seismic isolators are locally manufactured also for foreign markets…)".

Table 1. Statistics on newly constructed base isolated buildings from 1996 to 2003

Building	Apartment building with R/C bearing walls [2]	Apartment building with R/C masonry bearing walls [3]	Clinic building with R/C frames and shear walls [4]
Dimensions (m) of buildings in plan	33×14	34×20	47×20
Number of stories	4	4	3
Years of design	1996	1999-2000	2002
Years of implementation	1997-1998	2000-2001	2003
Number of buildings	1	2	1
Place of implementation	Spitak	Huntsman Village, Gyumri	Stepanakert
Buildings' views			
Number and type of rubber bearings	39, HDRB*	110, MDRB**	48, MDRB
Manufacturer of rubber bearings	Min Rubber Products, Malaysia	YFRTA, Armenia	YFRTA, Armenia

*HDRB - High damping rubber bearing (15%), **MDRB - Medium damping rubber bearing (8-10%)

Table 2. Statistics on newly constructed base isolated buildings from 2005 to 2006

Building	Apartment building in "Our Yard" complex [5]	Apartment building in "Our Yard" complex	Apartment building "Cascade" [6]
Dimensions (m) of buildings in plan	58×21	32×23	45×17
Number of stories	10	16	11
Years of design	2004-2005	2004-2005	2005
Years of implementation	2005	2005	2006
Number of buildings	2	1	1
Place of implementation	Yerevan	Yerevan	Yerevan
Buildings' views			
Number and type of rubber bearings	304, MDRB	160, MDRB	128, MDRB
Manufacturer of rubber bearings	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia

Table 2. Statistics on newly constructed base isolated buildings from 2005 to 2006 (Continued)

Building	Business center "Elite Plaza" [7]	Apartment building in "Arami" complex	Apartment building in "Arami" complex [8]
Dimensions (m) of buildings in plan	42×36	33×32	52×33
Number of stories	20	14	16
Years of design	2005	2005	2006
Years of implementation	2005	2005	2006
Number of buildings	1	1	1
Place of implementation	Yerevan	Yerevan	Yerevan
Buildings' views			
Number and type of rubber bearings	246, MDRB	147, MDRB	128, MDRB
Manufacturer of rubber bearings	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia

Table 3. Statistics on newly constructed base isolated buildings from 2006 to 2007

Building	Apartment building in "Dzorap" complex [9]	Apartment building in "Dzorap" complex	Apartment buildings in "Northern Ray" complex [10]
Dimensions (m) of buildings in plan	32×33	67×29	74×39
Number of stories	13	16	18
Years of design	2005-2006	2005-2006	2005-2007
Years of implementation	2006	2006	2007
Number of buildings	1	1	2
Place of implementation	Yerevan	Yerevan	Yerevan
Buildings' views			
Number and type of rubber bearings	73, MDRB	239, MDRB	904, MDRB
Manufacturer of rubber bearings	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia

In [11] Armenia is mentioned among the few of developing countries where projects that apply low-cost base isolation systems for public housing have been completed. Finally, in [12] it is stated that "In the developing countries, base isolation technique has rarely been used due to non-existence of domestic production of bearings and high cost of the bearings produced in the developed countries…"; "A greater success in application of base isolation (with isolation of a large number of buildings) was achieved in Armenia where, in addition to placement of isolators in buildings, their production was also adopted".

Table 4. Statistics on newly constructed base isolated buildings from 2007 to 2011

Building	Commercial center/hotel "Tufenkian" [13]	Apartment building "Baghramian" [14]	Apartment building "Avan" [15]
Dimensions (m) of buildings in plan	45×37	41×36	40×28
Number of stories	7	17	15
Years of design	2007-2008	2007-2008	2010
Years of implementation	2007	2008	2011
Number of buildings	1	1	1
Place of implementation	Yerevan	Yerevan	Yerevan
Buildings' views			
Number and type of rubber bearings	113, MDRB	271, MDRB	247, MDRB
Manufacturer of rubber bearings	Khachvar, Armenia	Retine Noruyt, Armenia	R.M.I.A, Retine Noruyt, Armenia

Table 5. Statistics on newly constructed base isolated buildings from 2011 to 2014

Building	Apartment building "Sevak" [16]	Medical center "Vanadzor" [17]
Dimensions (m) of buildings in plan	30×30	86×69
Number of stories	17	4
Years of design	2011	2013
Years of implementation	2012	2014
Number of buildings	1	1
Place of implementation	Yerevan	Yerevan
Buildings' views		
Number and type of rubber bearings	184, MDRB	260, HDRB
Manufacturer of rubber bearings	R.M.I.A, Armenia	Retine Noruyt, Armenia

The given above information shows that different types of base isolated buildings were constructed in Armenia. Among them there are private residences, school buildings, clinic and hospital buildings, business and commercial centers, apartment buildings, and hotels. Also, Zvartnots International airport base isolated buildings, designed outside Armenia, were successfully implemented in the country. The total number of seismically isolated buildings (including those designed not only by the author of this paper) per capita in Armenia is one of the highest in the world [18].

Table 6. Statistics on newly constructed base isolated buildings from 2002 to 2020

Building	Single-family house with stone bearing walls	Single-family house with stone bearing walls [19]	Single-family town-house with stone bearing walls [20]
Dimensions (m) of buildings in plan	15×15	14×14	22×10
Number of stories	2	2	3
Years of design	2001	2003-2004	2017-2018
Years of implementation	2001-2002	2004-2005	2019-2020
Number of buildings	1	1	1
Place of implementation	Proshyan Village	Jrvezh	Jrvezh
Buildings' views			
Number and type of rubber bearings	16, MDRB	16, MDRB	12, HDRB
Manufacturer of rubber bearings	YFRTA, Armenia	GTMC, Armenia	Shahnazaryans LLC, Armenia

1 STRUCTURAL CONCEPT OF BASE ISOLATED 9-STORY LARGE-PANEL RESIDENTIAL BUILDING WITH THE FIRST BUSINESS FLOOR

The building under consideration (Figure 1) actually consists of 10 floors of which the first floor is below outside ground surface and serves as a parking. The next floor, which is above outside ground surface, is a so-called business floor envisaged for different business purposes (shops, offices, etc.). Seismic isolation system is designed at the upper level of this business floor and supports the superstructure that consists of 8 residential floors. These floors are going to be constructed using prefabricated R/C large-panels, while the floors below the seismic isolation interface are frame structures with shear walls.

Figure 1. Architectural design view of the of 9-story large-panel residential building with the first business floor

There are two types of R/C columns in the parking and business floors. The first type has a rectangular cross-section with the dimensions of 1600×600 mm to place on top of them three seismic isolation laminated rubber-steel bearings (SILRSBs) and the second type – 1100×600 mm to place on top of them two SILRSBs. The plan of location of the bearings by clusters
[21] in seismic isolation system of the considered building is shown in Figure 2 and its vertical elevation – in Figure 3.

Along the exterior perimeter of the parking floor all the columns are connected by the shear walls with the thickness of 200 mm. Columns and the shear walls along the all axes of the parking floor are supported by strip foundation beams of rectangular cross-section with the dimensions equal to 800×1200(h) mm. At the top of the parking floor columns are connected by rectangular beams of 400×650(h) mm and a slab with the thickness of 150 mm. There is also a car slop designed for the parking floor.

The both types of R/C columns of the parking floor are continued to the business floor with the same cross-sections. On top of all the columns in the business floor SILRSBs are located and at this level columns are connected to each other by the lower beams also of rectangular cross-section 400×400(h) mm. However, lower beams at this level do not have slab. Immediately above the SILRSBs the upper beams are designed with cross-section 400×650(h) mm and a slab with the thickness of 150 mm at their top. Thus, the lower and upper beams together with the SILRSBs between them are forming the seismic isolation system of the given building. The upper beams are supporting the whole superstructure, namely, the 8 residential floors which will be constructed using R/C large-panel structures.

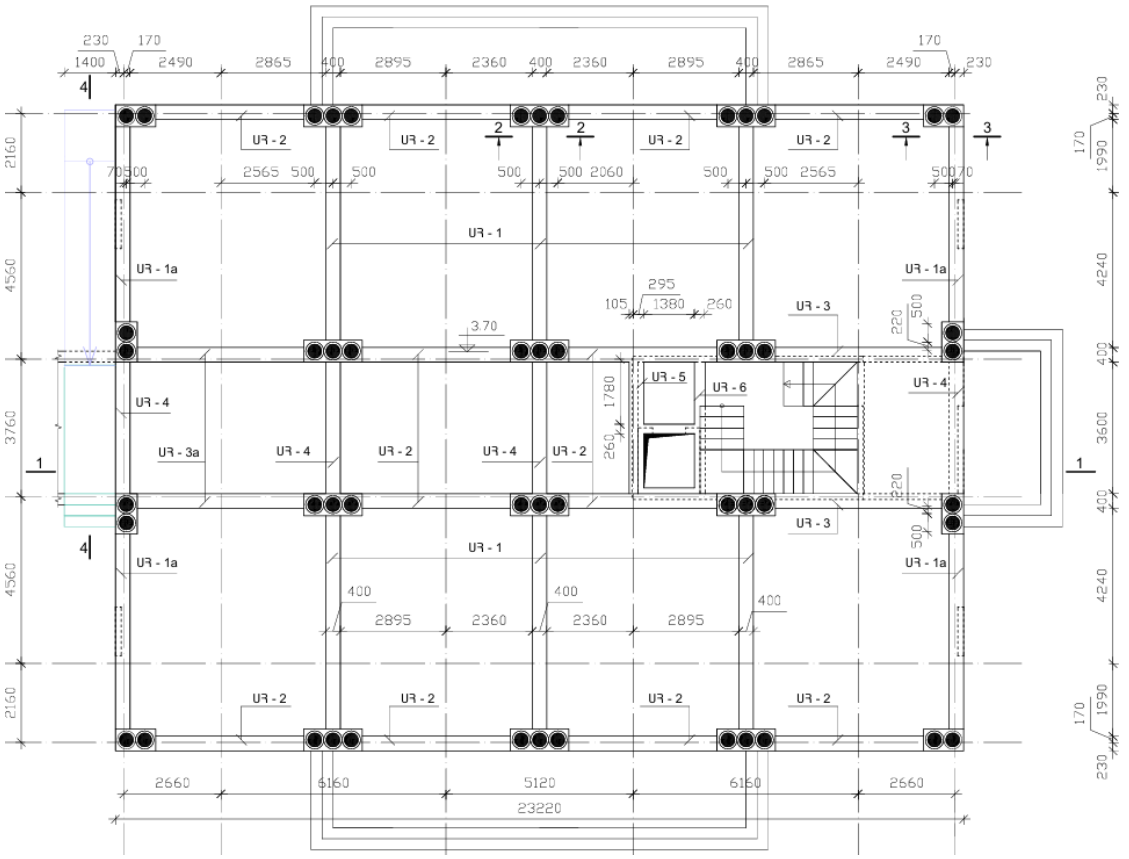


Figure 2. Plan of location of SILRSBs in the seismic isolation system of 9-story large-panel apartment building

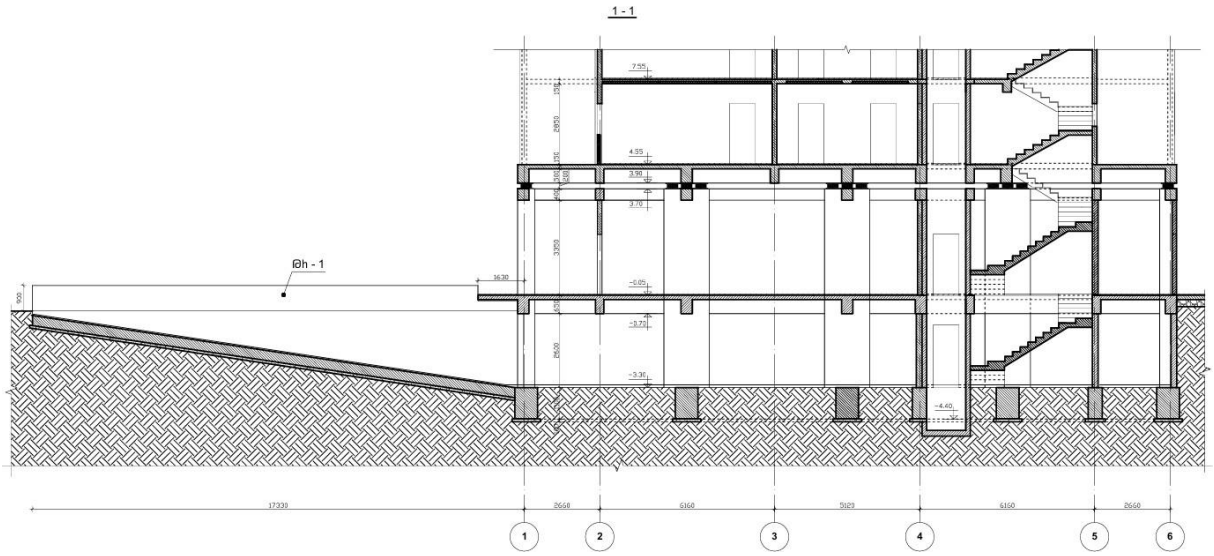
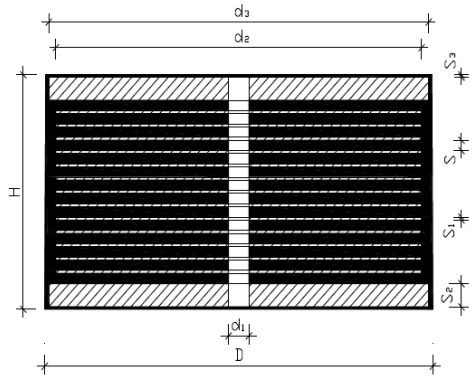


Figure 3. Vertical elevation of the lower part of 9-story large-panel apartment building showing location of the seismic isolation system between the lower and upper beams

From Figure 3 one can see that seismic isolation system of the considered building is designed at the upper level of its first business floor. SILRSBs of the same type and sizes were used to form the seismic isolation system. Total 52 SILRSBs were used with aggregate horizontal stiffness equal to K_{eff} = 0.81×52=42.12 kN/mm. These are manufactured in Armenia according to the Republic of Armenia Standard HST 261-2007 with the sizes and physical/mechanical parameters given in Figure 4.



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: 13-15%.

Figure 4. Dimensions and physical/mechanical parameters of the seismic isolation laminated rubber-steel bearing

The slab right above the seismic isolation system includes the embedded steel parts (Figure 5) to weld to them the R/C large-panel structures. Location of the R/C large-panel structures at this level is shown in Figure 6 and the section a-a in Figure 7 gives imagination on how these structures are connected to the slab and to each other.

The slabs of the parking and business floors were designed as monolithic homogenous structures while the slabs of the residential floors are consisting of two layers. The lower layer with the thickness of 80 mm was designed in the form of different prefabricated R/C elements with the width of 2180 mm and various spans (Figure 8). Upper monolithic layer with the thickness of 70 mm provided the needed horizontal rigidity to the slabs of superstructure. The developed structural solution gives the possibility to significantly speed up the whole construction process.

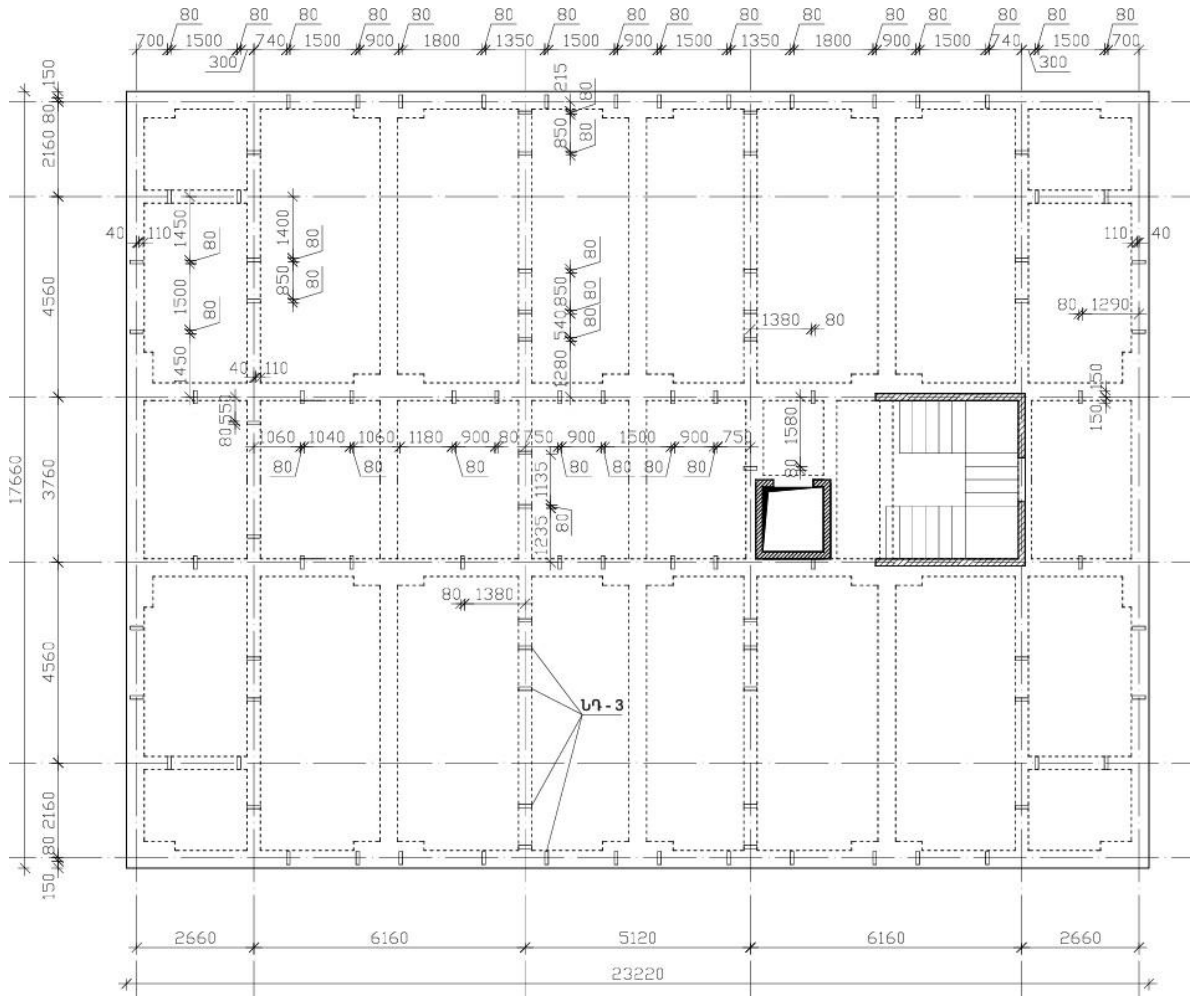


Figure 5. Location of the embedded steel parts in the slab above the seismic isolation system

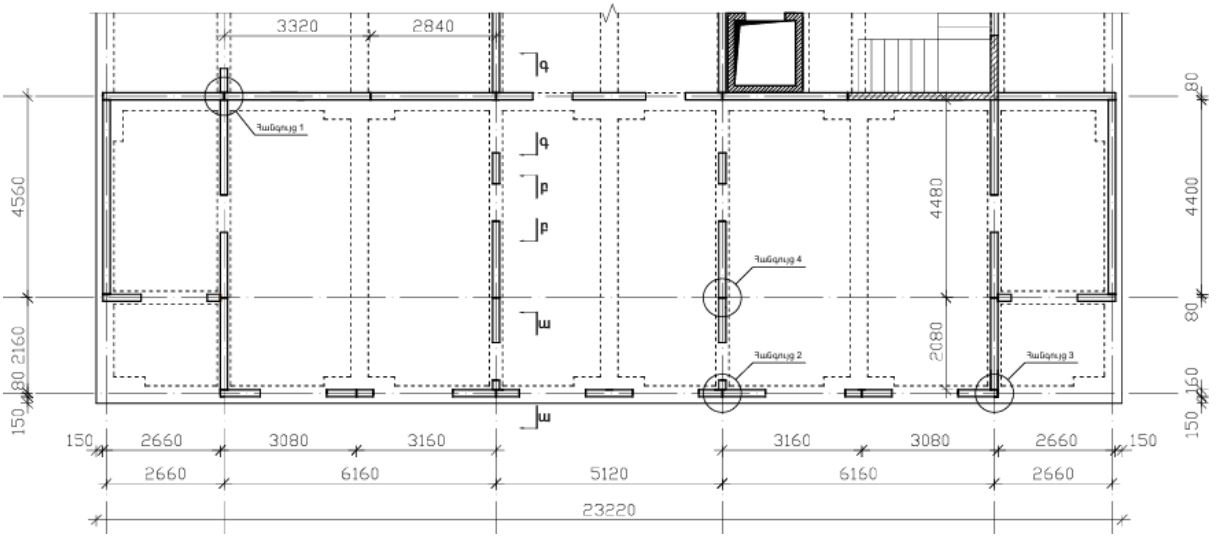


Figure 6. Location of the R/C large-panel structures on the slab above the seismic isolation system

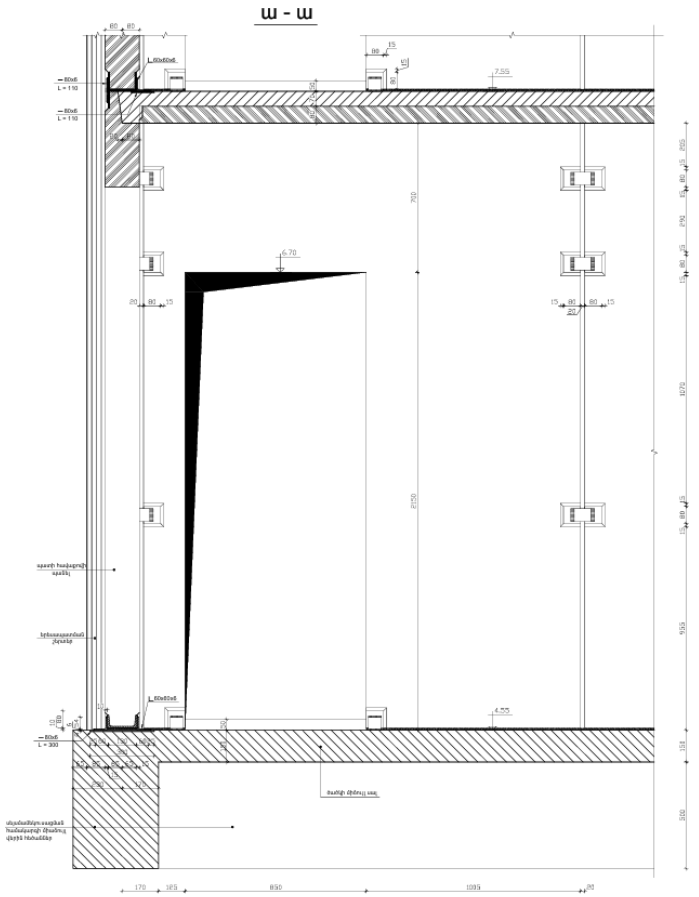


Figure 7. Welding of the R/C large-panel structures to the slab above the seismic isolation system and to each other

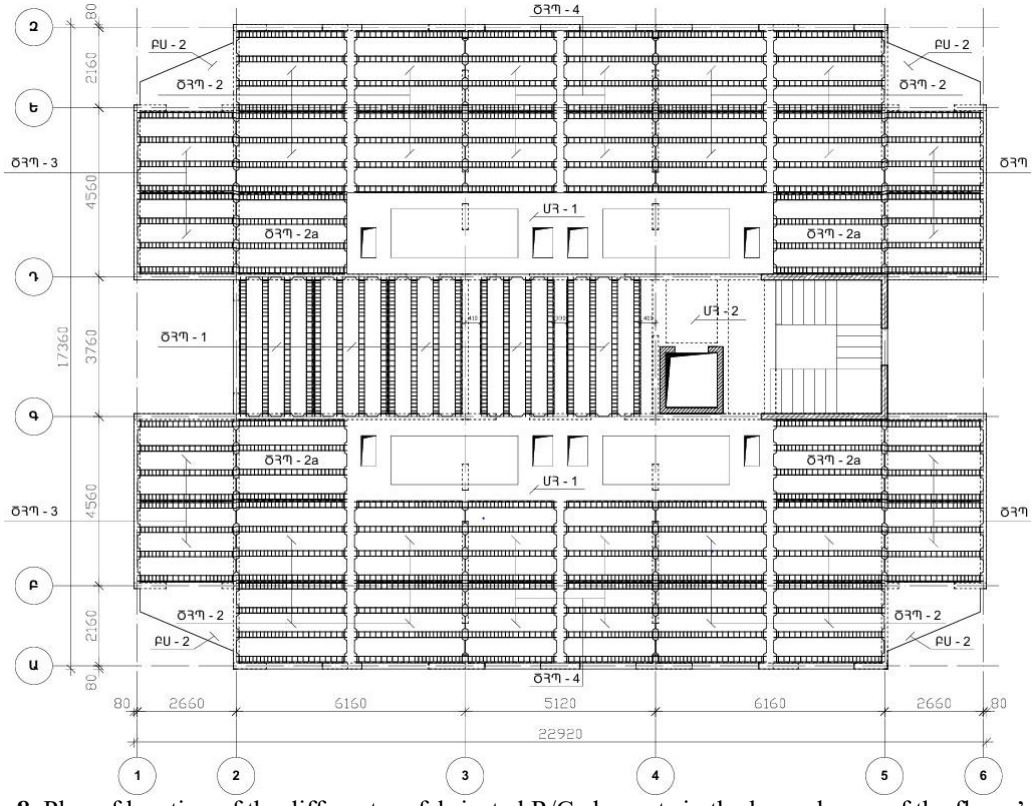


Figure 8. Plan of location of the different prefabricated R/C elements in the lower layers of the floors' slabs

II. SPATIAL ANALYSIS OF BASE ISOLATED 9-STORY LARGE-PANEL RESIDENTIAL BUILDING WITH THE FIRST BUSINESS FLOOR

Analysis of the seismic isolation system and the whole structure was performed in accordance with the Chapter X of the Armenian Seismic Code RABC 20.04 [22] 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_1=0.8;
- Permissible damage coefficient for analysis of the superstructure – K_1=0.4;
- Coefficient of seismicity – A=0.3.

Armenian Seismic Code RABC 20.04 requires that horizontal displacement of the seismic isolation system of any base isolated building should be calculated using the formulas (5) and
(32) of the Code. It is assumed that vibration period (T) of the base isolated building should be around 2 sec. Thus, horizontal displacement will be equal to:

$$D = 0.8\times(T/2\pi)^2\times A\times g\times K_0\times[\beta(T)/B(n)],$$

where dynamic coefficient β(T) depends on soil category and determined by the formulas given in the Code. In this case β(T) =0.95. B(n) depends on the damping of isolation system and for the value of 15% Code suggests this coefficient equal to 1.56. Consequently:

$$D = 0.8\times(2/6.28)^2\times 300\times(0.95/1.56)=14.62 \text{ cm.}$$

Obtained value of horizontal displacement is almost the same as was received based on the dynamic analysis using LIRA-SAPR 2013 R2 software. Formation of the design model (Figure 9) was done in accordance with the developed structural solution by application of several types of finite elements for large-panel walls (shear walls), floor slabs, columns and beams, as well as for seismic isolators.

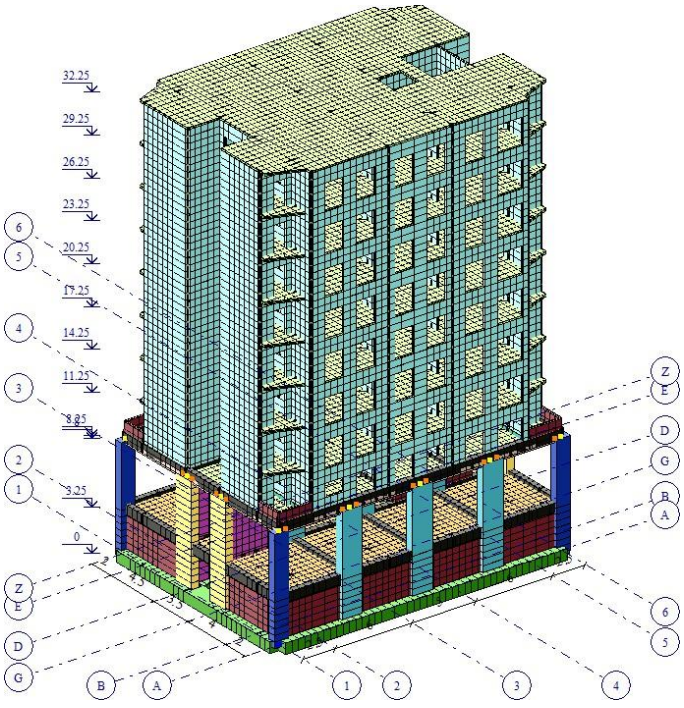


Figure 9. Design model of the base isolated 9-story large-panel apartment building with the first business floor

The value of horizontal displacement of the seismic isolation system is much smaller than the maximum permissible displacement suggested by the Standard HST 261-2007 (28 cm). This will provide high reliability of the designed seismic isolation system. According to the RABC
20.04 total seismic force on the top of isolation system (base of superstructure) must be calculated by the formula (35) of the Code:

$$S = K_{eff} \times D = 42.12 \times 146.2 = 6157.9 \text{ kN}.$$

To calculate the vibration period of the base isolated 9-story large-panel building the mass M of its superstructure was computed: M = 4080 t. According to the RABC 20.04 vibration period for the base isolated 9-story large-panel building 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:

$$T = 2\pi \times \sqrt{M/(K_{eff} \times g)} = 6.28 \times \sqrt{4080/42120} = 1.95 \text{ sec}.$$

This value differs from the initially assumed period on only 2.5%. Using the obtained values, it is possible to calculate the magnitude of acceleration just above the seismic isolation interface:

$$a = S/M = 6157.9/4080 = 1.51 \text{ m/sec}^2.$$

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 times in comparison with the input ground acceleration (3.0 m/sec^2). This is very typical result showing the high effectiveness of base isolated structures.

In accordance with the RABC 20.04 the values of inter-story drifts for the large-panel buildings must be no bigger than 1/350 of the floor height if building is located in seismic zone 1. This means that if floors' height in this building is equal to 3.0 m, then inter-story drifts must be no bigger than 8.57 mm. Carried out analysis have shown that due to application of seismic isolation the maximum inter-story drift for the considered large-panel building do not exceed 3.65 mm, which is about 2.3 times smaller than allowable drift. Also, analysis shows that superstructure of this building being supported by seismic isolation system is actually moving in mutually perpendicular horizontal directions as a rigid body. Received results are fully corresponding to the worldwide experience which proves that seismic isolation is the most reliable technology. Excellent examples demonstrating the effectiveness and high reliability of seismically isolated buildings during the destructive Hanshin-Awaji earthquake in 1995 (Japan) [23] and the Great Sichuan Earthquake in 2008 (China) [24] are well known.

III. CONCLUSIONS

Statistics on some of the newly constructed base isolated buildings in different regions of Armenia is given and many unique base isolated buildings which were realized in Armenia are briefly described in the paper. The bearing structures of these buildings were designed with application of the R/C bearing frames and shear walls, while single-family houses are representing the structures where only stone load-bearing walls are used.

For the first time world wide the base isolation technology was developed and then designed by the author for construction of 9-story large-panel residential buildings to be implemented in Armenia. Structural concept of the mentioned building is described in detail by several drawings presented in the corresponding figures. The building's design model is given together with analysis carried out in accordance with the Chapter X of the Armenian Seismic Code RABC 20.04.

Suggested unique building actually consists of 10 floors of which the first floor is below outside ground surface and serves as a parking. The next floor, which is above outside ground surface, is a so-called business floor envisaged for different business purposes like shops, offices, etc. Seismic isolation system is designed at the upper level of this business floor and supports the superstructure that consists of 8 residential floors to be constructed using developed by the author R/C prefabricated large-panels. Total 52 SILRSBs were used in seismic isolation interface with aggregate horizontal stiffness equal to K_{eff} = 42.12 kN/mm. For seismic isolated buildings SILRSBs are manufactured in Armenia according to the Republic of Armenia Standard HST 261-2007.

Received results of analysis are very promising showing high reliability of the developed structural concept and effective behavior of its base isolation system. Actually, the superstructure being supported by seismic isolation system is moving in mutually perpendicular horizontal directions as a rigid body. Period of vibrations of the considered base isolated building is equal to T = 1.95 sec. The value of obtained horizontal

displacement of seismic isolation system is equal to D = 14.62 cm, which is almost 2 times smaller than the magnitude of the allowable displacement by the above mentioned Standard. Also, maximum inter-story drift for the considered large-panel building do not exceed Δ = 3.65 mm, which is about 2.3 times smaller than allowable drift given in the Code RABC 20.04. This confirms that superstructure of the base isolated building will demonstrate only elastic behavior during design level earthquake.

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