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METHODS OF CREATION OF BASE ISOLATION SYSTEMS FOR RETROFITTING OF EXISTING REINFORCED CONCRETE FRAME BUILDINGS

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Abstract. *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. Methods of retrofitting by base isolation of existing frame buildings were developed by the author of this paper and they are described for two buildings: 4-story Armenian-American Wellness Center (AAWC) and 8-story Hematology Center Hospital Building (HCHB). These buildings were constructed about 40-50 years ago in Yerevan, the capital of Armenia. The bearing structure of AAWC existing building represents the moment resisting reinforced concrete (R/C) frames in both longitudinal and transverse directions. There are also stone bearing walls in some parts at the level of basement and the first floor. In the development of the structural concept of retrofitting of this building the objective was pursued to equip it with base isolation at the level of basement without interruption of the Center's operations. There was also a task to increase the number of floors from 4 to 6 with creation of a conference hall in the top two floors. The bearing structure of HCHB, however, represents the R/C frames with shear walls in longitudinal direction and the moment resisting frames in transverse direction. For this building the objective was to create a base isolation system again at the level of basement and to carry out reconstruction/ renovation works in superstructure simultaneously. Paper describes in detail the new structural concepts of retrofitting by base isolation and the results of analyses of these buildings in accordance with the provisions of Armenian Seismic Code and also time history analyses. The created solutions are proposed for the first time and envisage gradual cutting the structural elements and placing simultaneously the seismic isolators. Operations are designed to be performed in several stages for the columns and for the shear walls.*

1 INTRODUCTION

The retrofitting technique using base isolation has great potential for rehabilitation of ordinary civil structures such as apartment blocks and critical facilities such as schools, hospitals. It is well known that in this case the first dynamic mode of the isolated building involves deformation only in the isolation system, the building above being to all intents and purposes rigid. The higher modes do not participate in the motion so that the high energy in the ground motion at these higher frequencies cannot be transmitted into the building [1].

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

Then by the end of nineties, another project 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 [3]. For retrofitting of this building by base isolation the author of this paper provided to Russian and Chinese colleagues all the needed drawings, photos, video film related to the retrofitting works carried out in Armenia.

The other project is retrofitting of the 60 years old non-engineered 3-story stone school building which has historical meaning as well as a great architectural value. Unique operations were carried out in order to install the isolation system within the basement of this building and to preserve its architectural appearance. The project was implemented in Vanadzor (Armenia) in 2002 [4].

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 3-story historical building of the Iasi City Hall by base isolation. The structural concept, including the new approach on installation of seismic isolation rubber bearings was developed and the design of retrofitting was accomplished in cooperation with the Romanian company MIHUL S.R.L. The design was finally approved by the Technical Committee for Seismic Risk Reduction (a body especially created by the Government of Romania) on June 1, 2009 [5].

By given above the brief description of several projects an objective is pursued to demonstrate experience accumulated in Armenia in the field of retrofitting by base isolation of existing buildings with stone bearing walls. Later on the author of this paper has developed and proposed principally new structural approaches for seismic isolation of the existing buildings with R/C moment resisting frames, as well as with R/C frames which include the shear walls. One of them is a new structural concept on seismic isolation of the 4-story industrial R/C frame building located in the city of Yerevan (Armenia) and its simultaneous reconstruction into a 6-story hotel building [6].

The other new structural concepts are described in this paper for two buildings: 4-story Armenian-American Wellness Center (AAWC) [7] and 8-story Hematology Center Hospital Building (HCHB) [8] both constructed in Yerevan about 40-50 years ago. The seismic isolation of the buildings in these projects is planned to implement at the basement level. Seismic isolation laminated rubber-steel bearings (SILRSBs) with medium damping of about 10% were used. Their sizes and physical/mechanical parameters together with the detailed description of all phases for cutting the columns and shear walls and placing the seismic isolators are given in the paper. Results of analysis of these retrofitted buildings by the Armenian Seismic Code and the time histories are also given and discussed.

2 BASE ISOLATION RETROFITTING DESIGN FOR AN EXISTING 4-STORY R/C ARMENIAN-AMERICAN WELLNESS CENTER FRAME BUILDING

Retrofitting technology using seismic isolation rubber bearings was developed for the existing R/C frame building of the AAWC [9]. It is a 4-story building with a bearing structure mainly in the form of R/C frames, as well as with stone bearing walls in some parts on the level of basement and the first floor. In the development of the structural concept the objective was pursued to equip this building with base isolation without interruption of the use of AAWC. There was also a task to increase the number of floors from 4 to 6 with creation of a conference hall on the top two floors. The design view of the retrofitted AAWC building with already increased number of floors and its vertical elevation are shown in Figure 1.

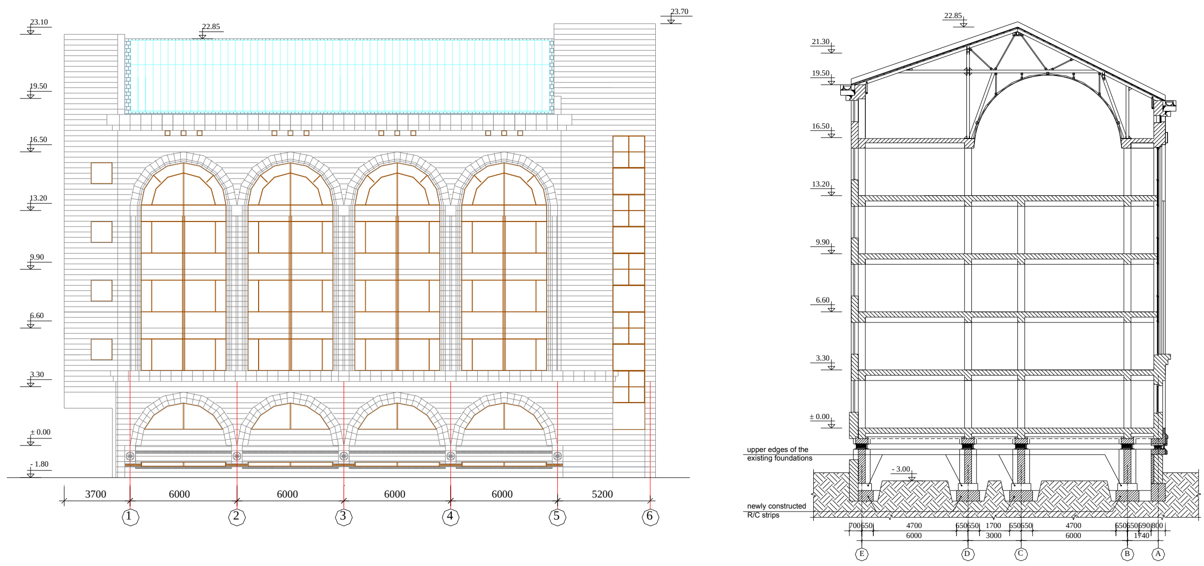


Figure 1: Design view of the retrofitted AAWC and its vertical elevation.

2.1 Structural concept of retrofitting by base isolation of the R/C frame building

The medium damping rubber bearings (MDRBs) from neoprene for seismic isolation of AAWC building were designed to provide for a horizontal displacement of 170 mm. Analysis of the isolation system for the design level earthquake was carried out based on spectral curves of Armenian Seismic Code and Spitak earthquake accelerogram recorded at Ashotsk station in 1988, scaled to 0.4g and digitized at the laboratory of Prof. Okada and Nakano of the Institute of Industrial Science, University of Tokyo [10], as well as accelerograms of Imperial Valley earthquake recorded at El Centro station (0.448g) and those of Northridge earthquake recorded at Arleta, Nordhoff Ave. fire station (0.444g).

Two types of seismic isolators were proposed for this project. The first one, with a diameter of 580 mm and height of 300 mm, was designed for placing in the columns of the basement, simultaneously with their strengthening. The second type, with a diameter of 380 mm and height of 202 mm, was envisaged for placing in the basement’s bearing walls. This type of smaller size isolators with horizontal stiffness equal to 0.81 kN/mm was designed earlier [11] and widely used for retrofitting of existing and construction of new buildings in Armenia.

Seismic isolation method for an existing building with R/C bearing frames is illustrated by Figure 2. Before starting the works on strengthening the existing columns, their surfaces should be cleaned from plaster and thoroughly washed. This is needed to ensure a good contact between the fresh concrete of the jackets and the concrete surfaces of the existing columns. The R/C jackets around the existing columns, which have cross-sections of 400×400 mm, are constructed using angles of 100×100×16 mm and steel plates of 10×100 mm, as well as reinforcing steel bars with diameter of 28 mm. Then immediately below the beams the parts of the columns with the height of about 200 mm are cleaned from the concrete cover layers and the steel plates of 20×200 mm are welded to the existing reinforcing bars of the columns. Created by these operations, the steel boxes right under the existing beams have four angles of 100×100×16 mm with short steel bars of 84×84 mm welded to them, which, in their turn, have bolts screwed into their body. The lower parts of these bolts are spherical and they rest on the spherical surfaces in the similar short steel bars of 84×84 mm welded to the angles of the jackets. Cross-section of the strengthened columns in the basement is 950×950 mm.

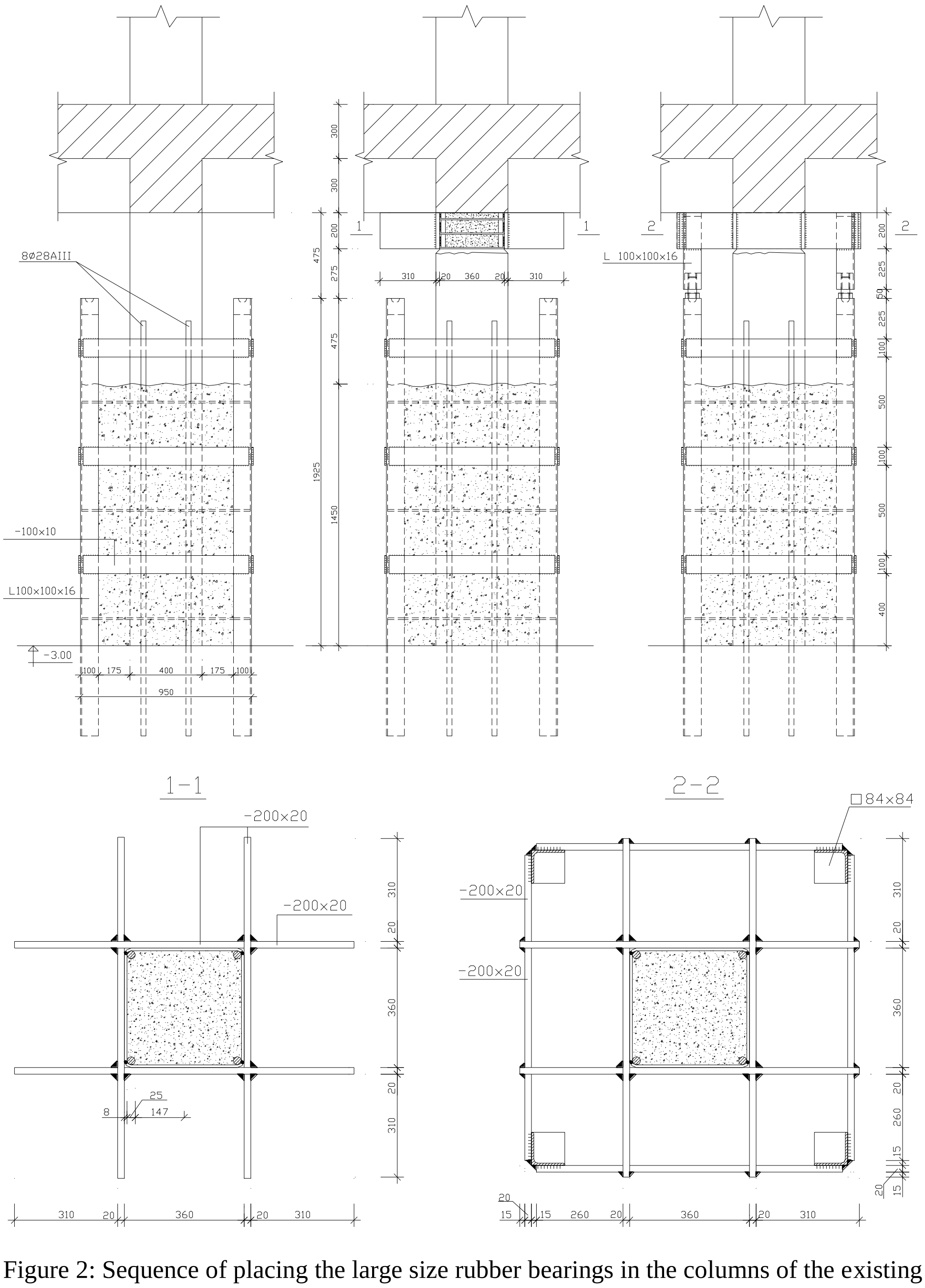


Figure 2: Sequence of placing the large size rubber bearings in the columns of the existing R/C frame building of the AAWC.

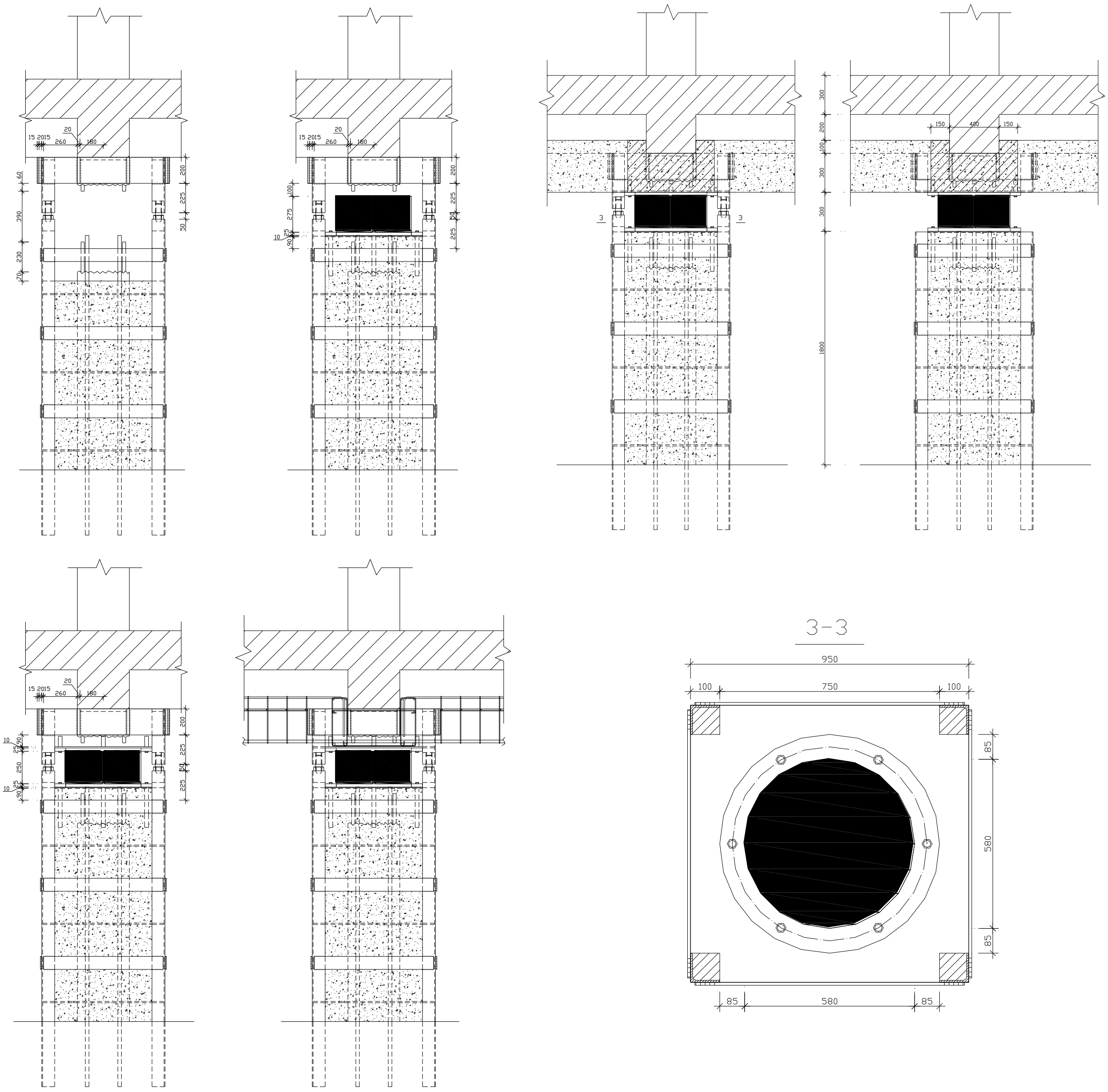


Figure 2: Sequence of placing the large size rubber bearings in the columns of the existing R/C frame building of the AAWC (continued).

In the next step the bolts should be unscrewed to a certain extent so that after cutting the existing columns the vertical loads could be reliably passed to the jackets without causing any damage to the existing beams. Operations of cutting of the columns should be performed in a special order stipulated in the design, and columns located next to each other should not be cut simultaneously. When any column is cut then immediately the following operations have to be implemented: placement of the isolator lower socket; placement of the isolator itself and its upper socket. The next step is the installation of the reinforcement frames above the isolators. These reinforcement frames are needed in order to strengthen the existing beams, creating a strong base for the whole superstructure. Actually, these frames serve as jackets for existing beams and when the concrete placed in the jackets gets to 70% of its design strength, the bolts are loosened. This operation should be done very carefully, slowly and gradually until all bolts get out from the spherical surfaces of the lower jackets and the building is settled on rubber bearings.

2.2 Design of the large-size isolator for retrofitting of the R/C frame building

For the AAWC building the frequency of the first mode of oscillations was chosen equal to 0.48 Hz. The total weight of the building W=37800 kN. Maximum vertical load on a single isolator w=2268 kN. Consequently, the total horizontal stiffness of isolation system is equal to:

$$K_{ht} = \frac{4\pi^2 m}{T^2} = \frac{4 \times 3.14^2 \times 37800}{2.08^2 \times 9.81} = 35125 \, {}^{kN}\!/_{m} \tag{1}$$

The plan of the seismic isolators' location is shown in Figure 3, which demonstrates that 20 isolators of a larger size are intended for placing in the columns and 8 isolators of a smaller size – for placing in the load bearing walls. The total horizontal stiffness of the 8 small-size isolators with a diameter of 380 mm is equal to:

$$K_{hs} = 0.81 \times 8 = 6.48 \, {}^{kN}\!/_{mm} = 6480 \, {}^{kN}\!/_{m}, \tag{2}$$

and the total horizontal stiffness of the 20 large-size isolators is equal to:

$$K_{hb} = 35125 - 6480 = 28645 \, {}^{kN}\!/_{m} \tag{3}$$

Using the value of total design displacement $D_t = 170$ mm and taking into account that the shear strain of rubber for this application was assumed $\gamma = 1.5$, the total thickness of the rubber t_r was defined from the expression $D_t = \gamma t_r$.

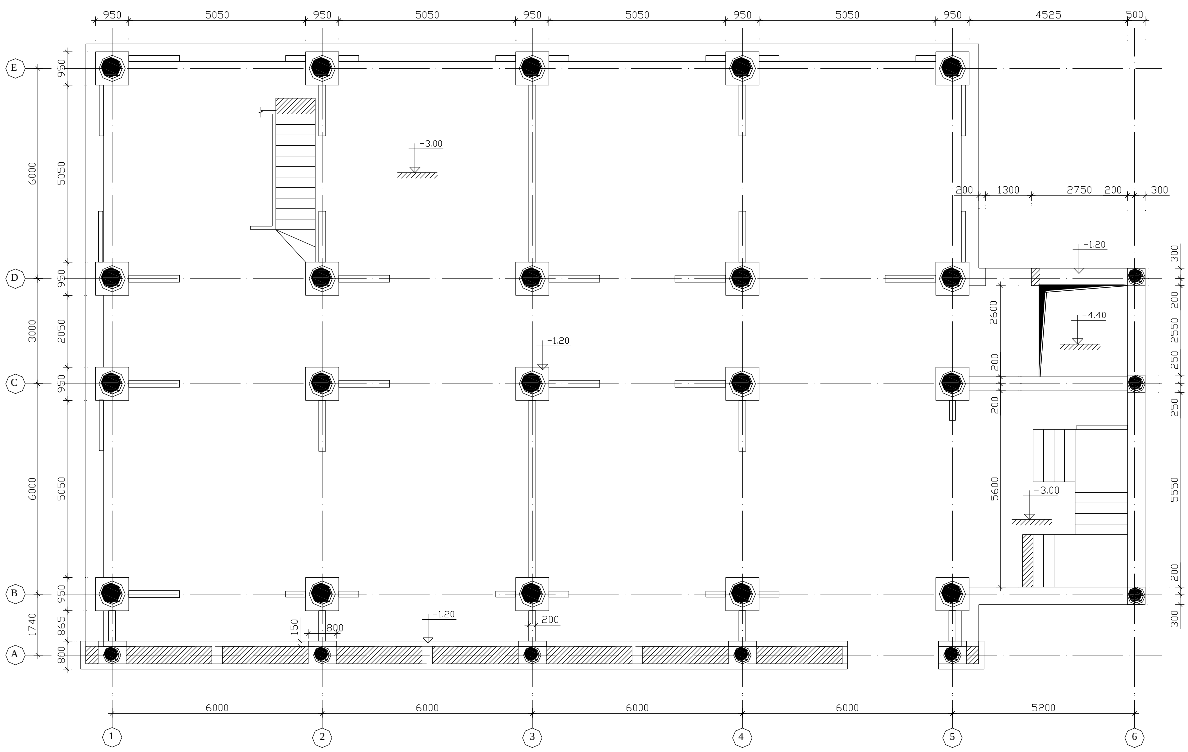


Figure 3: Plan of the seismic isolation MDRBs' location in the basement of the AAWC building.

Thus, the total thickness of the rubber is t_r=17.0:1.5=11.3 cm. The full cross-sectional area of the large-size rubber bearing was calculated by the formula:

$$A = \frac{K_{hb}}{20} \times \frac{t_r}{G} = \frac{28645}{20} \times \frac{0.113}{1000} = 0.1618\,m^2, \tag{4}$$

where G is the shear modulus of rubber.

In this case the diameter of large-size isolator Φ is equal to 0.454 m. The shape factor S is taken equal to 10 and the thickness of a single rubber layer is equal to:

$$t = \frac{\Phi}{4S} = \frac{0.454}{4 \times 10} = 0.0144m = 11.4mm. \tag{5}$$

This means the number of the rubber layers is $n_r = t_r/t$=113÷11.4≈10. Let us assume the thickness of a single steel sheet equal to 3 mm, the thickness of the steel end-plates equal to 25 mm and the thickness of the end cover layer equal to 2.5 mm. Then the total height of the bearing comes to h_t=2×25+10×11+9×3+2.5×2=192 mm (h=137mm). The safety factor SF against buckling, which is defined by the expression SF= P_{crit}/w has to be checked. For most types of bearings where S≥5, the Euler buckling load P_E is much higher than the shear stiffness per unit length P_S, and the critical load can be approximated as follows [1, 7]:

$$P_{crit} = \sqrt{P_S \times P_E}\ , \tag{6}$$

where $P_S = GA\frac{h}{t_r}$ and $P_E = \frac{\pi^2}{h^2}\frac{1}{3}E_c I\frac{h}{t_r}$, E_c=507 MPa, I≅0.05×0.4544=0.0021 m^4.

Consequently, the shear stiffness per unit length is equal to:

$$P_S = 1000 \times 0.1618 \times \frac{0.137}{0.113} \cong 196\,kN, \tag{7}$$

and the Euler buckling load is equal to:

$$P_E = \frac{3.14^2 \times 507000 \times 0.0021}{0.137 \times 3 \times 0.113} \cong 226030kN. \tag{8}$$

Thus, the critical load is P_{crit}=6656 kN and the safety factor is SF=6656/2268=2.93<3. From this it follows that the size of bearings should be reconsidered. The static compressive stress in the above designed bearing is about 14 MPa. Now let us assume this value is not more than 9 MPa, as it was taken for the small-size isolator. In this case the full cross-sectional area and diameter of the large-size bearing will increase:

$$A = \frac{226800}{90} = 2520\,cm^2,\ \ \Phi = 56.65\,cm. \tag{9}$$

Let us finally accept Φ=58 cm and A=2641 cm^2. Then the total thickness of the rubber will be equal to t_r=18.4 cm, the thickness of a single rubber layer t=15 mm and the number of the rubber layers n_r=184÷15≅13.

Assuming the thickness of the end cover layer equal to 2.5 mm and the thickness of the steel end-plates equal to 32 mm, the total height of the bearing will comprise h_t=32×2+15×13+3×12+2.5×2=300 mm (h=231 mm). With these new recalculated values the shear stiffness per unit length is equal to:

$$P_S = 1000 \times 0.2641 \times \frac{0.231}{0.195} \cong 313\,kN. \tag{10}$$

Taking into account that for the accepted diameter of the bearing I≅0.05×0.584=0.0057 m^4, the Euler buckling load is equal to:

$$P_E = \frac{3.14^2 \times 507000 \times 0.0057}{0.231 \times 3 \times 0.195} \cong 210850 kN, \tag{11}$$

and the critical load and the safety factor are respectively equal to:

$$P_{crit} = \sqrt{210850 \times 313} \cong 8124 kN, \text{ and } SF = \frac{8124}{2268} = 3.58 > 3. \tag{12}$$

This means the designed bearing is acceptable and satisfies the requirement related to the safety factor. Its geometrical dimensions are shown in Figure 4 where the picture of the manufactured large-size bearing is given as well.

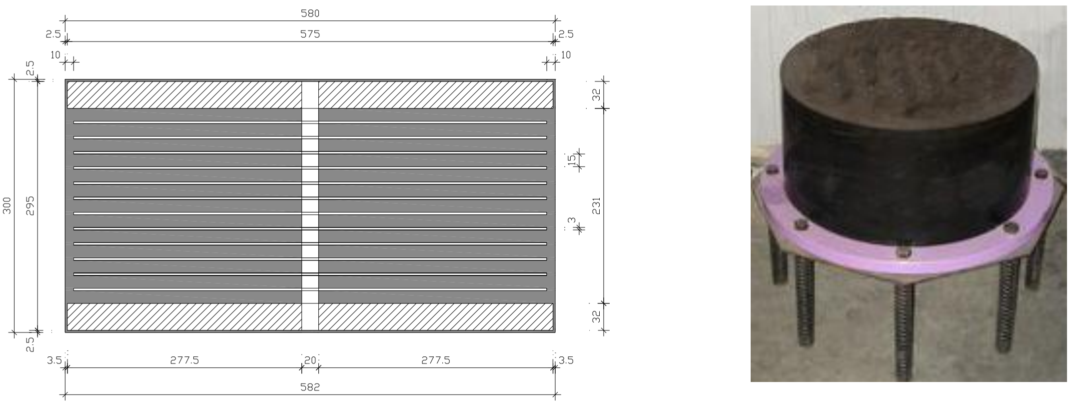


Figure 4: Geometrical dimensions and the view of the manufactured large-size bearing (seismic isolator) designed for retrofitting of the AAWC building.

3 BASE ISOLATION RETROFITTING DESIGN FOR AN EXISTING 8-STORY R/C HEMATOLOGY CENTER HOSPITAL FRAME BUILDING WITH SHEAR WALLS

Implementation of the project of seismic isolation and reconstruction of the 8-story (plus a basement) HCHB (Fig. 5) has started in 2014.

a. b.

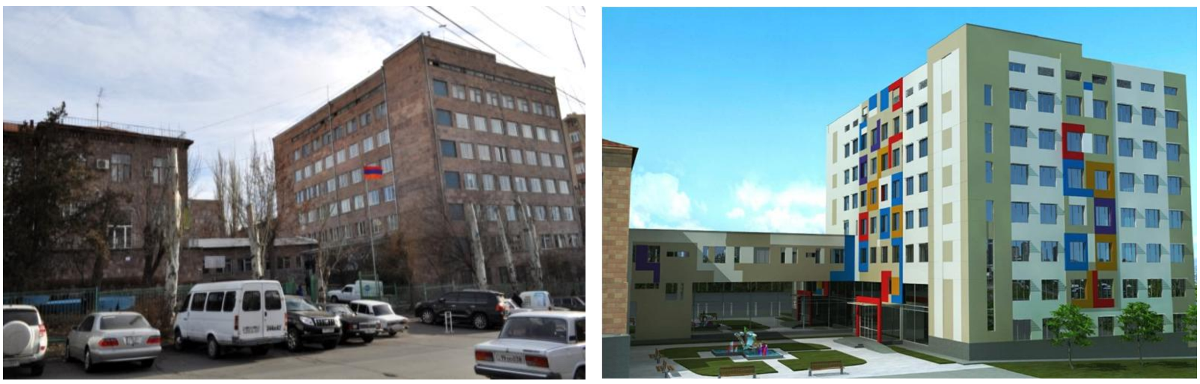


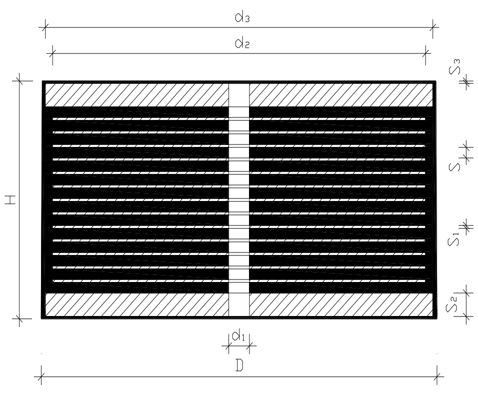
Figure 5: View of the existing HCHB before (a) and its design view after renovation and retrofitting by base isolation (b)

During the development of the project design, principally new structural approaches have been proposed by the author of this paper for seismic isolation of the building's R/C bearing frames and shear walls. The existing building has rectangular plan with dimensions of 36.4×24.4 m, six spans of 6 m each in longitudinal direction and four spans of 6 m each in transverse direction. The bearing (moment resisting) frames with strong beams of cross section 400x520(h) mm are located in transverse direction, while in longitudinal direction, there are frames with the interior weak beams of cross section 1200x250(h) mm and exterior weak beams of cross section 800x250(h) mm and with shear walls of the thickness equal to 140 mm. Cross section of all the columns is equal to 400x400 mm. The height of floors from 1-st to 7-th is equal to 3.3 m, of 8-th (technical) floor – 2.5 m.

3.1 The set objectives and parameters of the used SILRSBs

The seismic isolation of the building in this project is planned to be implemented at the basement level. The main objective is to implement the proposed structural solution for seismic isolation of the existing building in parallel with its full renovation. This is one of the advantages of retrofitting by base isolation when superstructure can be renovated immediately with the implementation of the works on retrofitting. Obviously, this will significantly shorten the whole construction process. Such an approach becomes possible as due to application of base isolation to this existing building there is no need to strengthen the structural elements of the superstructure. Along with providing the high reliability to the building, seismic isolation also allows considerable savings in construction cost. The experience in seismic isolation of existing buildings in Armenia has shown that compared to other methods for improving the earthquake resistance of the buildings, seismic isolation is several times less expensive [5].

Seismic isolators of same type and sizes were used to make the seismic isolation system. Total 117 SILRSBs were used with aggregate horizontal stiffness of 94,770 kN/m. These were manufactured according to the Republic of Armenia Standard HST 261-2007 with the sizes and physical/mechanical parameters given in Figure 6.



External diameter of the bearing (D): (380 ± 2.0) mm;
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;
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 this 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: (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 6: Dimensions and physical/mechanical parameters of SILRSB

At the same time, an objective is set to determine the dynamic characteristics of the building after completing the seismic isolation and reconstruction works, and to compare displacements during micro-oscillations for the superstructure and part of the building below the seismic isolation plane level. It is decided to thoroughly follow/record all activities in all phases of seismic isolation system construction by photo and video cameras, to archive the obtained materials, as well as to place seismic sensors with identical specifications at all levels of the building, including the basement floor, in order to record accelerations, displacements and dynamic characteristics during seismic impacts in mutually perpendicular directions.

3.2 Proposed structural solution of retrofitting by base isolation of the R/C frame building with shear walls

The seismic isolation system is constructed at the basement floor level, between marks -0.9 and -1.1. The seismic isolators are placed under all columns of the superstructure, grouped in two or three isolators. They are placed also within the limits of shear walls. The given structural solution developed for cutting the columns and shear walls and placing the seismic isolators is proposed for the first time ever and it is performed in 11 stages for the columns (Fig. 7), and 12 stages for shear walls (Fig. 8).

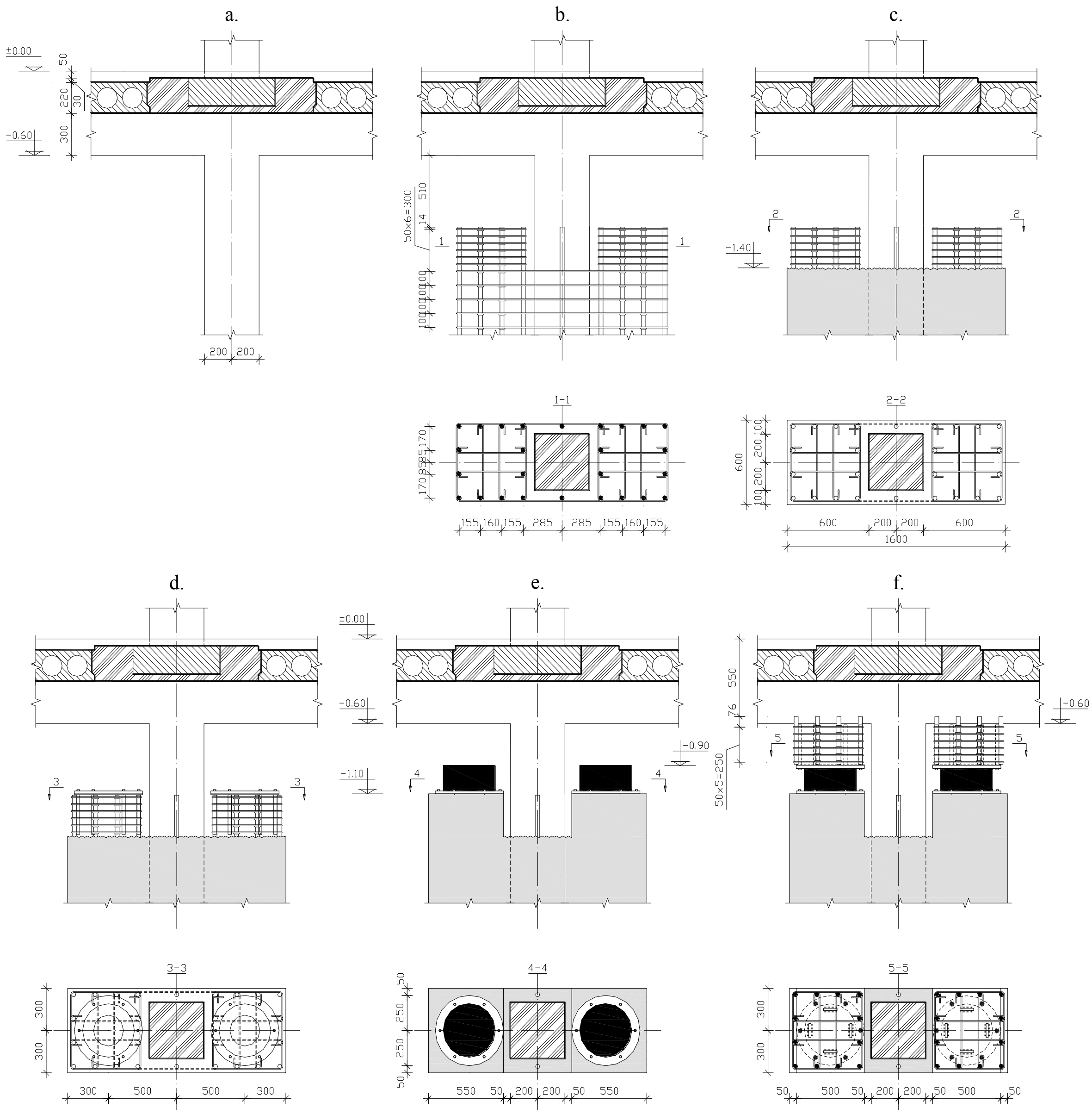


Figure 7: Stages of installation of the seismic isolation rubber bearings under the existing interior columns of HCHB

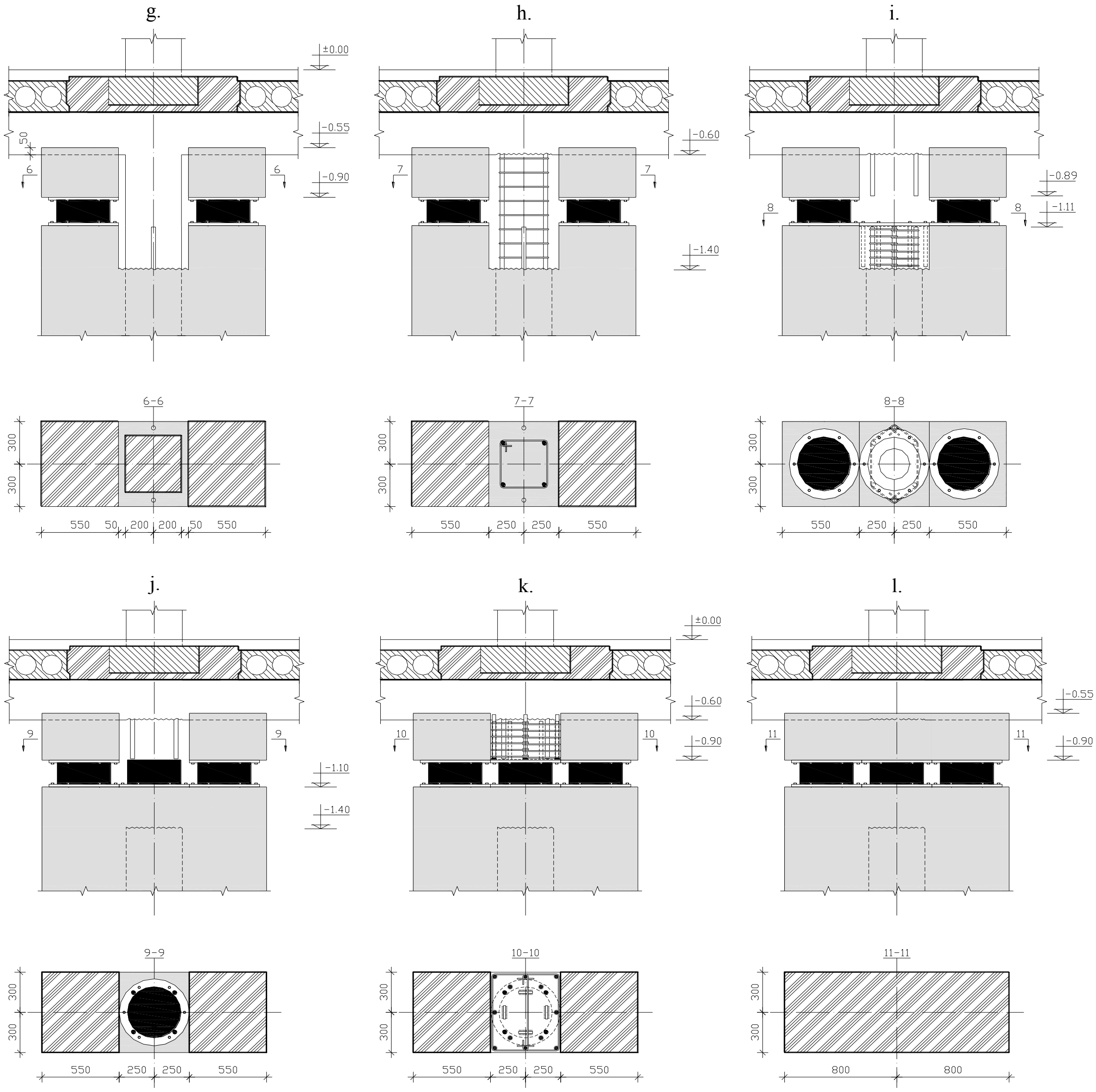


Figure 7: Stages of installation (Continued)

Additional reinforcement around existing columns of the basement is anchored both to the existing spread footings and newly designed beams that connect the spread footings to each other. The mentioned additional parts increase cross-sections of the columns and ensure their required stiffness. Only after placing the reinforcement cages for these parts, concrete can be cast to make the designed mutually perpendicular strap beams that will connect the existing spread footings.

As concrete is casted on the parts containing additional reinforcement around basement columns, it is necessary to follow that the lower sockets of seismic isolators are in strictly horizontal position. The same applies to concreting of the lower pedestals in sheer walls of the basement. All operations related to cutting the columns till the stage 6 can be performed simultaneously. However, after cutting a first column, all remaining stages up to stage 11 inclusive have to be performed for it, by concreting the part above the seismic isolator. Afterwards, the next column can be dealt with and so on.

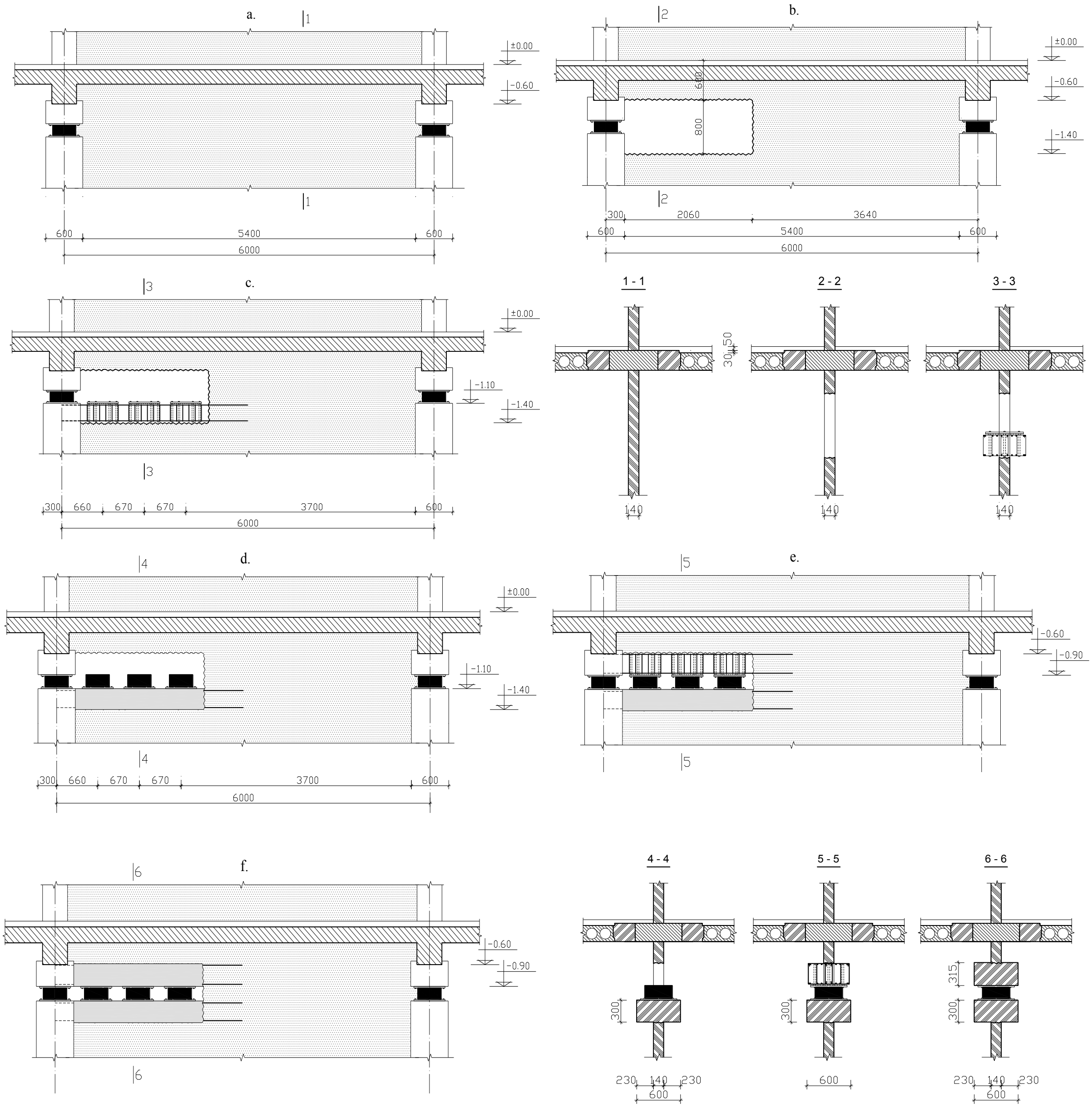


Figure 8: Stages of installation of the seismic isolation rubber bearings within the limits of the existing shear walls of HCHB

In parallel to the above-mentioned operations, the shear wall cutting can be performed up to the stage 5 inclusive. It is not allowed to make openings in the shear walls next to each other simultaneously. Special attention needs to be paid to the stairs to be built near the building's back entrance and those leading to the basement. All these structures have gaps between them and superstructure. These gaps ensure unhindered movement of the superstructure and displacement of the seismic isolation system during design earthquakes. In the basement floor limits, the elevator shafts have metallic carcasses, which are hung on new beams designed at the mark ±0.00. There are 100 mm gaps between the lower parts of the mentioned metallic shafts and bottoms of the elevator pits. The sizes of pits are chosen in such way that during design earthquakes they allow free movement of elevator shafts, without touching the pit walls.

Placing all isolators of the seismic isolation system brings in separating of the building's superstructure from its base (Fig. 9). Consequently, the mass of the building and horizontal seismic loads are passed to vertical structures and footings of the basement floor only through seismic isolators.

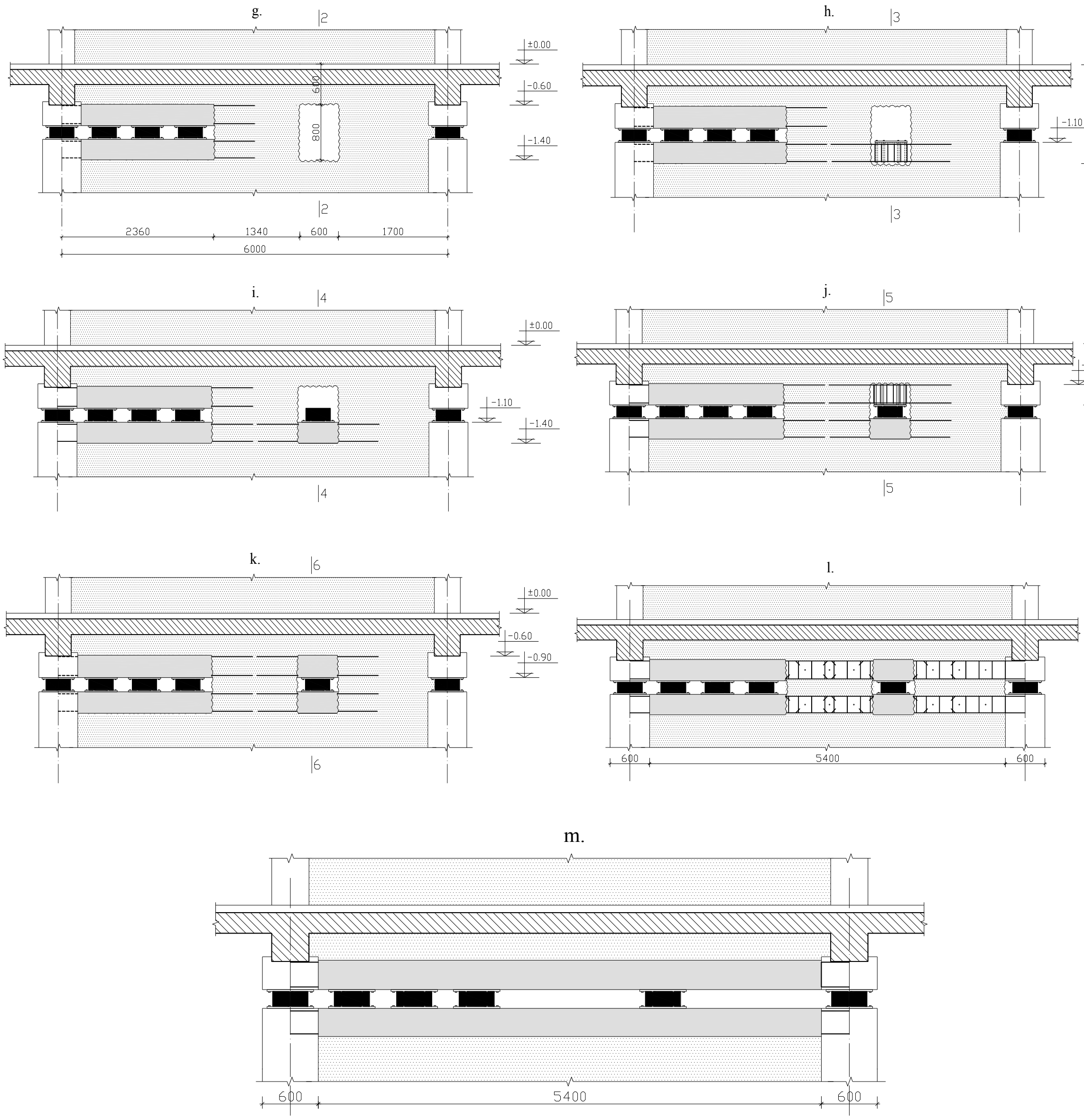


Figure 8: Stages of installation (Continued)

The seismic isolation works around the perimeter of the building are performed in a specific sequence. First, earthworks are implemented. According to the design, trenches are dug along the outer perimeter of the building. Then, the self-supporting walls at the first floor level and part of the walls encasing the basement down to the mark -1.10 are dismantled, and all façade beams along the outer perimeter of the building are constructed. Afterwards, around the basement's outer perimeter retaining walls are built, which are covered by cantilever slabs, in order to protect the formed gap from precipitation and avoid possible accumulation of trash. However, the main purpose of this gap is to ensure effective action of the seismic isolation system during a seismic impact.

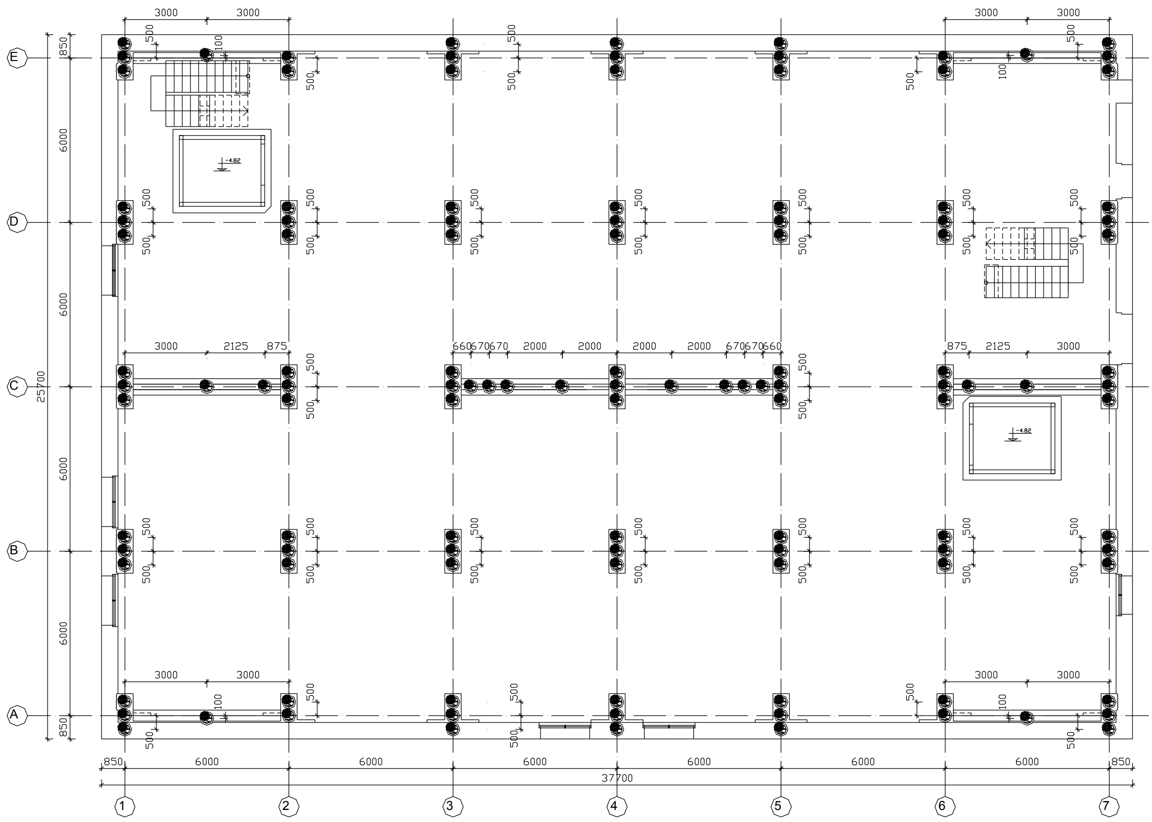


Figure 9: Plan of location of seismic isolators on the level of the existing basement of HCHB

Once the seismic isolation system is completed, all partitions of the basement have to be built, with gaps ensuring unhindered movement of bearing structures above and below the seismic isolation plane relative to each other. The sizes of the gaps are determined by displacement values obtained by calculations. The design involves constructing 50 mm thick R/C layers on all inter-storey floor slabs of the building. For this purpose, top surfaces of all prefab floor slabs and connecting cross-beams have to be bared, whereas the joints between these structural elements have to be cleaned from debris. Before making the R/C layers, all surfaces and joints must be thoroughly washed. After that, 300 mm long rebars with diameter of 8 mm have to be placed in joints with a spacing of 900 mm and concrete has to be cast. The rebars are necessary for creating reliable connection between reinforcement meshes of R/C layers and existing prefab slabs. Given the extremely low quality of connection between existing sheer walls and columns, it is also planned to strengthen these joints with R/C coatings. The areas to be coated must be cleaned beforehand from plaster and washed.

3.3 Analysis of the seismic isolated existing HCHB on the basis of the Armenian Building Code and acceleration time histories

According to a geological report, the site of the building is located in the Seismic Zone 3, and the site Soil Category is II corresponding to the Republic of Armenia Building Code (RABC II-6.02-2006). The report suggests an expected peak ground acceleration value of 0.4g. Vertical loading and seismic impact analysis of the seismic isolation system and the whole structure was performed in accordance with RABC II-6.02-2006 and by the acceleration time histories, using LIRA-SAPR2013 R2 software. The 3D design model (Fig. 10) was developed using bar frame finite elements, as well as membrane finite elements, with due consideration of the structural solution of the superstructure (i.e. part of the building above the seismic isolation plane).

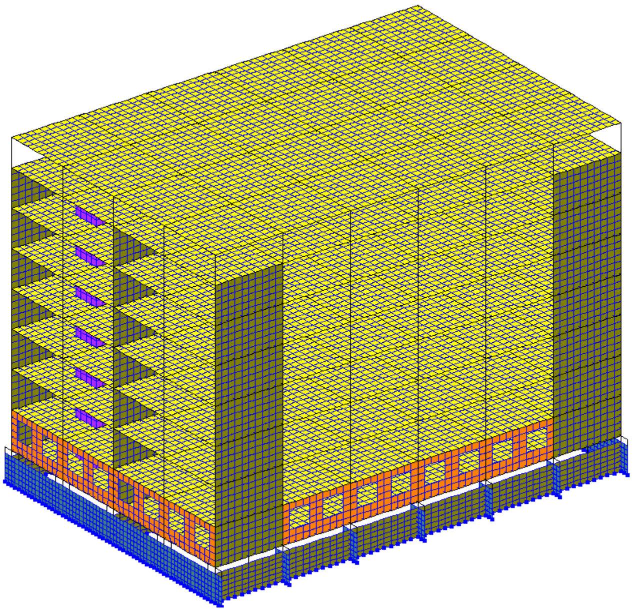


Figure 10: The 3D design model of the seismic isolated existing HCHB

According to the RABC II-6.02-2006, the following parameters were assumed for analysis:
- 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 seismic isolation system and reinforced concrete structures below it – K_{1z}=0.8;
-permissible damage coefficient for analysis of the superstructure – K_1=0.4;
-importance coefficient of the building – K_2=1.3;
-coefficient of seismicity – A=0.4.

The following 8 acceleration time histories given in Table 1 were selected for calculations and acceleration amplitude was scaled to 0.52g (0.4g×1.3) taking into account the importance of the building. The oscillations periods obtained for the building for the first oscillation mode were equal to T_{1long}=1.9 sec in longitudinal and T_{1trans}=2.0 sec in transverse directions. Maximum design displacements were equal to $D_{max,long}$=146 mm and $D_{max,trans}$=126 mm, respectively. As an example, Table 2 presents some results of calculations related to the middle axes of the building in mutually perpendicular directions. Here the shear forces impacting the seismic isolation system, horizontal displacements and accelerations of the seismic isolation system and all floors and maximum drifts of superstructure's floors, according to calculations by RABC II-6.02-2006 and respective average values by the time histories analysis are given.

The obtained results prove high effectiveness of the seismic isolation system, thanks to which the superstructure of the Hematology Center building practically will not deform during an earthquake and will act as a rigid body. 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 drift in longitudinal direction (for braced frames) is equal to 1/300 of the floor height, which comprises 8.3 mm for the technical floor and 11.0 mm for the other floors. These values are about 4.5 times in average bigger than the calculated drifts. Also in transverse direction (for moment resisting frames) permissible drift is equal to 1/200 of the floor height, which comprises 12.5 mm for the technical floor and 16.5 mm for the other floors and these values are about 1.8 times in average bigger than the calculated drifts. An input acceleration of 0.52g at the foundation bed gets damped in average up to

3.3 times in the superstructure, and accelerations induced at the first and last floor slabs of the structure differ only by around 28% in average.

Earthquake and record component	Date	Predominant period, sec	Duration, Sec
Hollister (USA)	09.03.49	0.30	9
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

Ttable 1: Acceleration time histories selected for earthquake response analysis of the seismic isolated HCHB

Calculated values		As per RABC II-6.02-2006		Average by the time histories	
		longitudinal direction along middle axis "C"	transverse direction along middle axis "4"	longitudinal direction along middle axis "C"	transverse direction along middle axis "4"
$S_{i.s.}$, kN		13050	12100	11200	9900
$D_{i.s.}$, mm		119.9	122.6	109.1	105.5
$A_{i.s.}$ in portion of "g"		0.137	0.119	0.125	0.103
D_n, mm/A_n in portion of "g"	1	121.0/0.138	128.5/0.125	110.0/0.126	110.6/0.108
	2	123.5/0.142	137.9/0.134	112.4/0.129	118.7/0.116
	3	125.8/0.144	147.7/0.144	114.5/0.131	127.1/0.124
	4	128.2/0.146	157.3/0.153	116.6/0.133	135.4/0.132
	5	130.6/0.150	166.7/0.162	118.8/0.136	143.4/0.140
	6	133.0/0.152	175.4/0.171	121.0/0.138	151.0/0.147
	7	135.5/0.155	183.1/0.178	123.2/0.141	157.6/0.153
	8	137.4/0.157	185.6/0.181	125.0/0.143	159.7/0.154
Δ, mm		2.5	9.8	2.4	8.4

$S_{i.s.}$ – Shear forces at the level of the seismic isolation system
$D_{i.s.}$ – Displacements of the seismic isolation system
$A_{i.s.}$ – Accelerations above the seismic isolation system
D_n – Displacements of the n^{th} floor of superstructure
A_n – Accelerations of the n^{th} floor of superstructure
Δ – Maximum drifts of the floors of superstructure

Ttable 2: Some results obtained by calculations in accordance with Armenian Building Code and average by the time histories for seismic isolated HCHB

The obtained results also show that vertical loads on seismic isolators do not exceed the stipulated value of 1500 kN, which is achieved through satisfying the requirements set in paragraphs 10.5.4 and 10.5.7 of the RABC II-6.02-2006. Consequently, there is practically no eccentricity between the horizontal stiffness center of the seismic isolation system and projection of the structure's mass center on SILRSBs' plane. This is proven and also can be well observed in analysis by the time histories during the oscillations of the building.

4 CONCLUSIONS

- Paper briefly describes seismic isolation technologies developed by the author for retrofitting of the different types of existing buildings. Five projects, where base isolation is applied, are mentioned, demonstrating retrofitting experience accumulated in Armenia.
- Paper dedicated to the further developments on retrofitting of existing buildings and is mainly focused on: (i) retrofitting by base isolation of the 4-story R/C frame building of Armenian-American Wellness Center with simultaneous increasing of the number of floors from 4 to 6, and (ii) retrofitting by base isolation of the 8-story R/C frame building of Hematology Center Hospital Building constructed 40-50 years ago.
- Methods of creation of base isolation systems in both existing buildings at the level of their basements with application of the newly developed different types of large-size (Φ=580 mm, h_t=300 mm) and small-size (Φ=380 mm, h_t=202.5 mm) seismic isolators are described.
- Details of the new and original structural concepts for retrofitting of the R/C frame hospital buildings are presented in the paper by stages of installation of the seismic isolation rubber bearings under the existing columns and within the limits of the existing shear walls.
- Retrofitting by base isolation of the existing 8-story Hematology Center Hospital Building is the most recent application in the city of Yerevan and the retrofitting process is currently going on in the mentioned building. Results of analysis of this building by the Armenian Seismic Code and the time histories have shown that the structural elements below and above the seismic isolation plane will work only in the elastic phase. The permissible floor drifts are about 2-4 times bigger than the calculated values. An input acceleration of 0.52g at the foundation bed gets damped in average up to 3.3 times in the superstructure.

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