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RECENT APPLICATIONS OF SEISMIC ISOLATION IN CIVIL BUILDINGS IN ARMENIA

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SUMMARY

At the end of 2001 the "Caritas Switzerland" started a project in Armenia in the city of Vanadzor, Armenia on retrofitting of the school #4 building. The school building with very nice architectural view is 50 years old and represents a 3-story stone building with pretty complicated structural concept, which does not meet the modern requirements of earthquake resistant construction. The conventional retrofitting of such building would bring to infringement of the architectural view, would require bigger investments and longer duration of the whole construction process. Taking above into account it was proposed to retrofit the school #4 building based on innovative technology (Patent of the Republic of Armenia #579). This proposal was first accepted by Dr. G. Käppeli, responsible for the project from "Caritas Switzerland", and then by local authorities. The project was implemented by "Kanaka" OJSC. The seismic isolation system at the level of the basement of the building was created in 3.5 months. Thanks to the proposed technology significant savings were achieved in comparison with the initially proposed conventional retrofitting.

In 2002 for the first time in Armenia base isolation was designed for construction of a critical facility like a clinic building. Previously, base isolation in Armenia was designed for different buildings with stone, masonry or R/C bearing walls (Melkumyan [1], Melkumyan et al. [2], Melkumyan [3]). This time base isolation was applied to a building, the bearing structure of which is represented by R/C frames with shear walls. This project was initiated by Armenian Fund USA (AFUSA) and is being implemented through Hayastan All-Armenian Fund. Currently the base isolated clinic building is under construction in the city of Stepanakert, Nagorno Karabakh. An original structural concept was developed and designed for creation of base isolation system and for superstructure of the 3-story clinic building. The period of vibrations of the building is taken as 2 s. The building was analyzed under the requirements of the Seismic Code of Armenia and also acceleration time history analysis was carried out using a group of different records selected from the existing database of strong ground motions. For the ground motion of 0.3 g the design displacement for isolation system 145 mm was obtained. The analysis of the building, including formation of its design model, is also described in the paper. It is shown that due to seismic isolation the savings in comparison with conventionally designed building (with a fixed base) amount to US$ 97,120, which is about 30-35% of the cost of the bearing structure.

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INTRODUCTION

In 2001 the project on retrofitting the school #4 in the city of Vanadzor, Armenia was initiated by the "Caritas Switzerland". The school is a 3-story 50 years old building with pretty thick bearing walls constructed using tuff stones. Actually the school building is a non-engineered structure with wooden floors. During the 1988 Spitak earthquake the building got some not heavy damages. These had local characters and were mainly concentrated in the staircases.
In 2000 a design was developed for conventional retrofitting of this school, which envisaged strengthening of bearing walls by reinforced concrete (R/C) jackets and by construction of R/C frames in addition to the existing walls in order to decrease the distance between the existing walls. Also it was envisaged to replace the wooden floors by the R/C slabs. However, having no funds the local government could not realize this project. Only after involvement of "Caritas Switzerland", which expressed its good will in order to help Armenian people, the retrofitting of the school #4 in Vanadzor became possible.

After carrying out the feasibility study in 2001 the "Caritas Switzerland" was supposed to start the project using the mentioned conventional design. At that time the donor was approached with a new proposal to use base isolation for retrofitting of the school instead of conventional retrofitting. The following advantages were presented: high reliability, lower cost and reduced duration of construction in comparison with conventional approach as well as preservation of the architectural view of the building. Also the experience in Armenia on retrofitting of existing building by base isolation was considered (Melkumyan [4]). Based on that proposal and after getting the agreements with the local authorities and the Ministry of Urban Development of Armenia a decision was made by "Caritas Switzerland" to retrofit the school #4 in Vanadzor by base isolation. That was in September 2001 and then in a very short period of time the design on seismic isolation was accomplished and in December 2001 was submitted to the construction company "KANAKA" OJSC, which was selected to carry out the job and which is one of the best construction companies in Armenia. This company has realized several unique base and roof isolation projects in the country.

APPLICATION OF SEISMIC ISOLATION FOR RETROFITTING OF EXISTING 3-STORY STONE BUILDING OF THE SCHOOL #4 IN THE CITY OF VANADZOR, ARMENIA

Structural concept of retrofitting of school building by base isolation

The developed structural concept aims to retrofit an existing building by means of seismic isolation using simple working technology. Before this project only one time in Armenia a unique pioneering seismic isolation project was introduced in 1995-1996 for an existing 5-story stone apartment building (Melkumyan [1, 5]). The idea is to supply the building with seismic isolation by gradually cutting it from foundation and installing the isolators at the level of upper edge of foundation between a two-stage system of R/C beams. The operation is made without re-settlement of the dwellers. The world practice has had no similar precedent in retrofitting of apartment buildings. In the given case of school building the isolation system was designed on the level of basement where thickness of walls was 60-110 cm.

The medium damping rubber bearings (MDRB) for seismic isolation were designed in the Engineering Research Center of the American University of Armenia to give a horizontal displacement of 14 cm. As the range of the static vertical loads on each bearing is quite high (700 kN-1200 kN) it was decided to have two types of bearings (Soft -"S" and Hard -"H"), differing only in the shear modulus of the rubber similarly as was suggested by Fuller et al. [6]. All together 41 MDRBs have been manufactured by the Yerevan factory of rubber technical articles (YFRTA). The plan of bearings' location is shown on Fig. 1.

Seismic isolation method for an existing building with bearing walls that envisions placing of seismic isolators at the level of basement solves the problem as follows (Fig. 2). According to the innovative technology (Melkumyan [1]), in the basement bearing walls 1 openings 2 with certain spacing are made to accommodate lower reinforcement frames 3 with seismic isolator sockets 4.

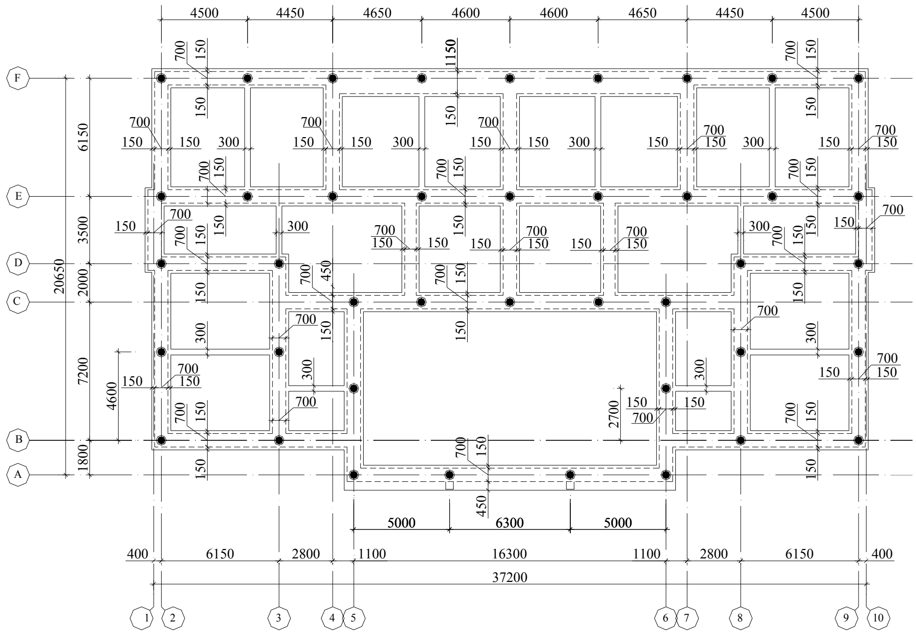


Figure 1. The plan of MDRB's location on the level of basement of the school building

Here a simple recess connection detail was chosen. Binding reinforcement lower frames 5 are passed along both sides of bearing walls 1 through reinforcement frames 3. Then the latter are concreted forming lower pedestals 6. The next step is to place seismic isolators 7 in the lower sockets 4. Upper sockets 8 and upper reinforcement frames 9 are placed on the isolators 7 passing along both sides of bearing walls 1 upper binding reinforcement frames 10 through the upper reinforcement frames 9. Then the latter are concreted forming upper pedestals 11. In concreting the frames, ends of binding reinforcement frames 5 and 10 are left free beneath and above seismic isolators 7. In the parts of walls between seismic isolators, openings 12 are made where short binding reinforcement frames 13 and 14 are placed through them. The latter tie additional reinforcement frames 15 and 16 of neighboring seismic isolators. Then the parts between pedestals are concreted forming thus lower 17 and upper 18 continuous beams along all bearing walls of the building. The parts 19 of existing walls 1 between seismic isolators 7 are removed creating gaps 20 and the building appears separated from its foundation and linked to it only by seismic isolators. It is very important that openings in walls are made so that two adjacent openings are not made simultaneously; parts of walls existing between seismic isolators should be cut off beginning from the middle of building in plan. It is obvious that the suggested working technology is rather facilitated and supervision of working performance simplified.

Testing of seismic isolation rubber bearings for base isolated school building

In order to test seismic isolation rubber bearings special testing facilities were designed and manufactured (Melkumyan [7]). The loading system was envisaged to test simultaneously two rubber bearings under horizontal and vertical loadings and could produce up to 1000 kN force on the bearings in both directions. It consists of two side columns, upper and lower beams, movable in the horizontal direction steel plate and horizontally immovable upper plate. The horizontal immovability of this steel plate in the direction of bearings' shear was provided through cylindrical elements welded to both opposite sides of this plate. For fixing the bearings in the loading frame four recess rings were bolted to the lower and upper immovable plates as well as to the internal movable plate. The bearings were compressed by vertical force, through hydrojack, which was located in the frame and the axis of which coincided with longitudinal axis of the frame and bearings. The actuator was positioned in such a way that its longitudinal axis was in one horizontal plane with the internal movable plate (Fig. 3).

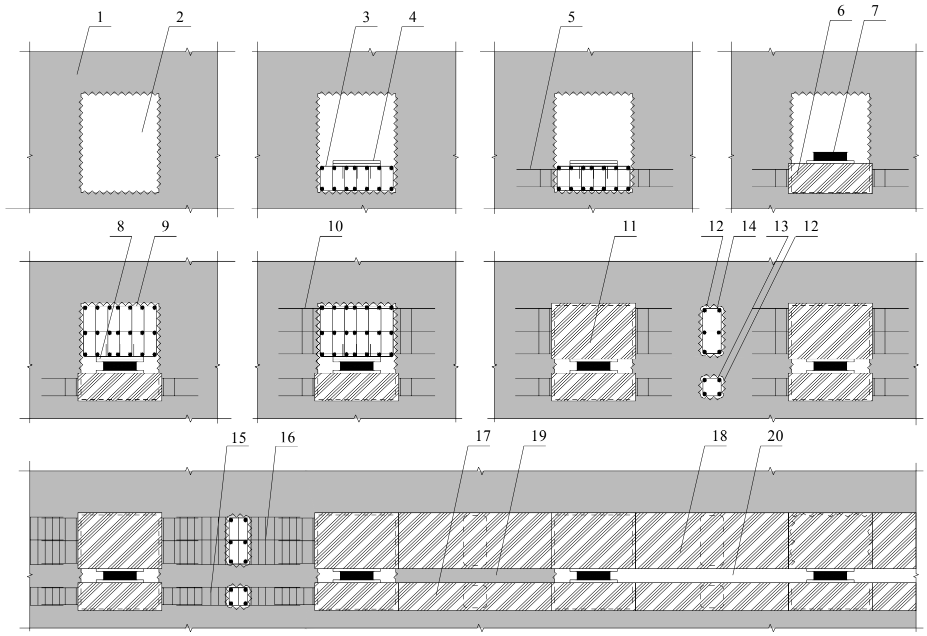


Figure 2. Stages of installation of seismic isolation in the existing 3-story school building

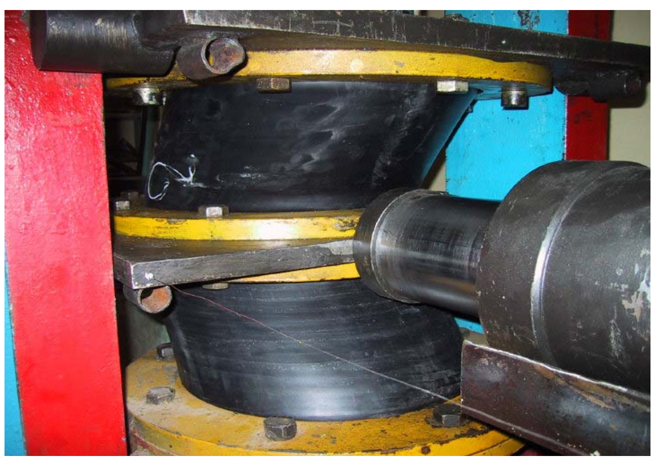


Figure 3. Testing of seismic isolation bearings for retrofitting of the existing school building

All together 18 pairs of seismic isolation bearings manufactured in the YFRTA were tested and sent to the construction site in Vanadzor. On the Fig. 4 and 5, as an example, the relationships “vertical force - displacement” and “horizontal force - displacement” for one pair are given, respectively. During the displacement control shear test isolators were subject to constant vertical force of 800 kN and gradual increasing of horizontal displacement with bringing it to the maximum value of the design displacement - 140 mm.

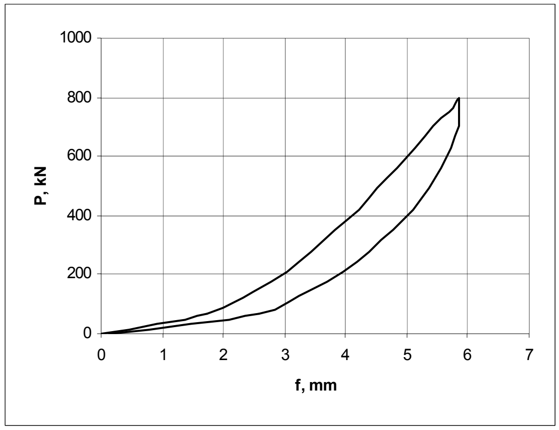


Figure 4. "Vertical force - displacement" loop for School # 4 seismic isolation bearing

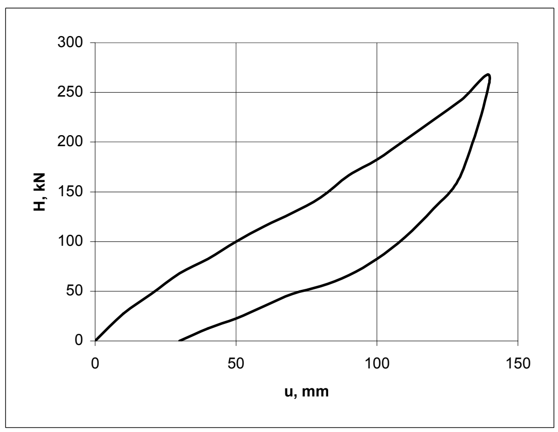


Figure 5. "Horizontal force - displacement" loop for School # 4 seismic isolation bearing

Illustration of the process of creation of seismic isolation system

For the considered building, which has historical and architectural value the technique of installation of seismic isolators has especially important meaning. First of all an infringement of the external view of the building should not take place under any circumstances. Secondly, no one stone of the façade should fall down during making openings in the bearing walls.

When the opening is made, the lower reinforcement frame of the lower pedestal with the isolator socket can be placed and after that binding reinforcement lower frames are passed along both sides of bearing wall through the frame of the lower pedestal (Fig. 6). At the next step the concrete of the lower pedestal is casted, the isolator is installed and above it the upper socket and the reinforcement frame of the upper pedestal are placed. Then the binding reinforcement upper frames are passed through the frame of the upper pedestal along both sides of existing bearing wall (Fig. 7). After casting the concrete of the upper pedestal all lower and upper pedestals should be connected to each other forming a two-stage system of R/C continuous beams (Fig. 8).

Figure 6. The view of the lower reinforcement frames installed in the opening together with the isolator socket

Most complicated case is the one when the opening does not have any part of existing wall above it. For school building such cases happened at the entrance when openings should be made just beneath the columns and the arches. The opening under the column should be made gradually. With this purpose, at the beginning the part of the foundation only under the one quarter of the column section should be taken out. This will allow to install under the column a mechanical jack. In cases like this the reinforcement frames of the lower and upper pedestals cannot be prepared in advance and should be made in situ (Fig. 9).

During every step of implementation of such complicated cases of retrofitting it is necessary to take care of the condition of the existing structures not permitting development of any damages as these structures are part of the valuable architectural appearance of the building. The general view of the retrofitted school building is shown on Fig. 10.

Figure 7. The view of the upper reinforcement frame installed in the opening together with the isolator upper socket after casting the concrete of the lower pedestal

Figure 8. The view of a two-stage system of R/C continuous beams, which separate the building from its foundation and create the seismic isolation system

Figure 9. Existing column and the wall behind it are supported temporarily and the reinforcement frame of the upper pedestal is installed

Figure 10. The general view of the retrofitted by base isolation 3-story School #4 building

MOST RECENT APPLICATION OF BASE ISOLATION TO A 3-STORY CLINIC BUILDING IN STEPANAKERT, NAGORNO KARABAKH

Structural concept of a new base isolated clinic building

One of the distinctive features of the building is that its edge parts are designed as cantilevers with the span of 3 m and therefore the shear walls here were envisaged also to provide safe performance of the cantilever parts. Such structural concept was dictated by the soil conditions and with the purpose to reach more savings, as there was no need for a big space in the basement. The clinic building has three floors above the ground and a basement. The isolation system is located on the level of the basement just under the floor slab of the first story (Fig. 11). The detail of the location of seismic isolatiors along the exterior axis is shown on Fig. 12.

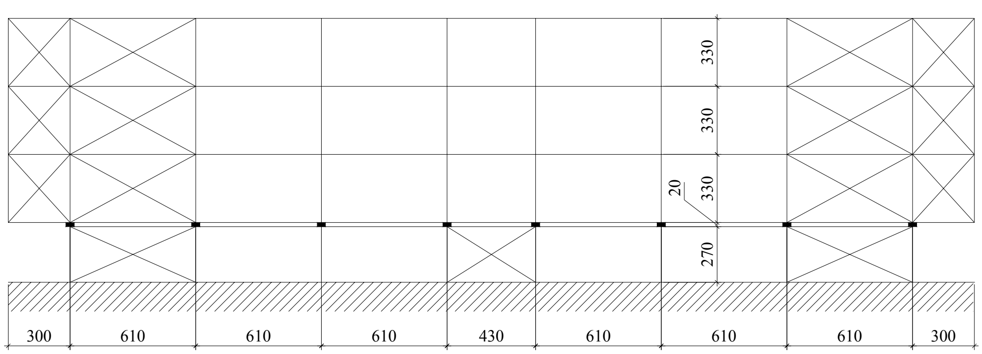


Figure 11. Schematical vertical elevation of the clinic building

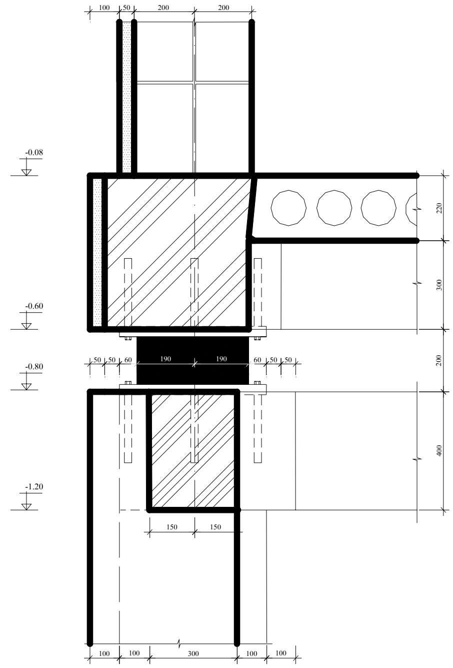


Figure 12. Location of seismic isolators between the basement and superstructure

Totally 48 seismic isolation MDRBs at a damping level of about 8% manufactured and tested locally were used in the isolation system. Under each of the exterior columns a single bearing was envisaged and under each of the interior columns a couple of bearings was envisaged (Fig. 13) in order to reliably carry the vertical static loads. The magnitude of these loads on the interior columns of the basement was equal to 1800 kN. The purpose of such an approach was to use the same type of bearings in the whole building. This was conditioned by the necessity to design building and to manufacture bearings in a very short time, thus avoiding the need of preparation of an extra mold.

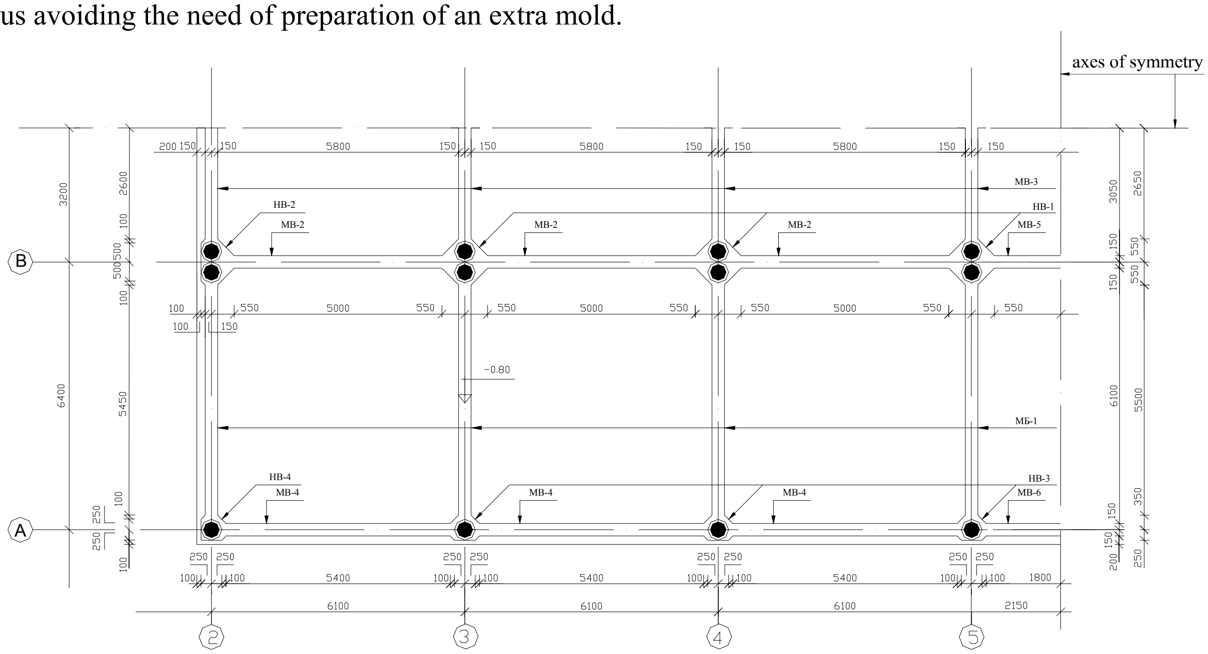


Figure 13. The plan of MDRBs location on the level of basement of the clinic building

A comparative analysis was carried out for a 3-story clinic building considering two cases: first, when the building is designed with fixed base (conventional design) and second, when the building is seismically isolated. Some average results of this analysis are given in Tab. 1. The savings due to seismic isolation amounts to: (140,000+20,000)-(32,400+13,200+17,280)=97,120 USD. If to take into account that the cost of the bearing structures of this building (defined through a tender) is around 270,000 USD, a conclusion can be made that thanks to the seismic isolation 30%-35% of the cost can be saved.

Table 1. Results of comparative analysis of seismic (base) isolated and fixed base (conventionally designed) buildings

Values compared	Clinic Project in Stepanakert (for a three-storey clinic building)	
	Fixed-base building	Seismic isolated building
Total shear fore (kN)	34350	6830
Required reinforcement (t)	350	81
Required reinforcement per 1m^2 of the area of the building (kg)	126	29
Distance (cm) between the reinforcing bars and their average diameter (mm) in the walls or in the columns	16, ∅36 (in the columns)	35, ∅18 (in the columns)
Required strength of the concrete (N/cm^2)	3500	2000
Required cement (t)	500	330
Required cement per 1m^2 of the area of the building (kg)	180	119
Cost of reinforcement (US$)	140,000	32,400
Cost of cement (US$)	20,000	13,200
Cost of seismic isolators (US$)	-	17.280

Analysis of the base isolated clinic building

The period of vibrations of the building is taken as 2 s. The building was analyzed under the requirements of the Seismic Code of Armenia and also time history analysis was carried out using two different records selected from the existing database of strong ground motions. In the analysis a three-dimensional design model using frame and shell elements represents the building (Fig. 14). The following acceleration time histories were used. Northridge Earthquake – Arleta and Nordhoff fire station with PGA 0.344g and Imperial Valley Earthquake – El Centro with PGA 0.348g .

Seismic isolation rubber bearings had the following structural properties obtained from the experimental results (Melkumyan [7]): initial stiffness 3500,0 kN/cm, strain hardening stiffness 332,1 kN/cm, structure yield strength 700,0 kN, yield displacement 0,2 cm. Structural weight of the building is 41940,000 kN. In the results of analyses the following average values were obtained: maximum inertial force 17374,15 kN, maximum computed displacement 14.85 cm. "Spring force – Displacement" relationships are shown on Fig. 15. Displacement responses of isolation system are shown on Fig. 16.

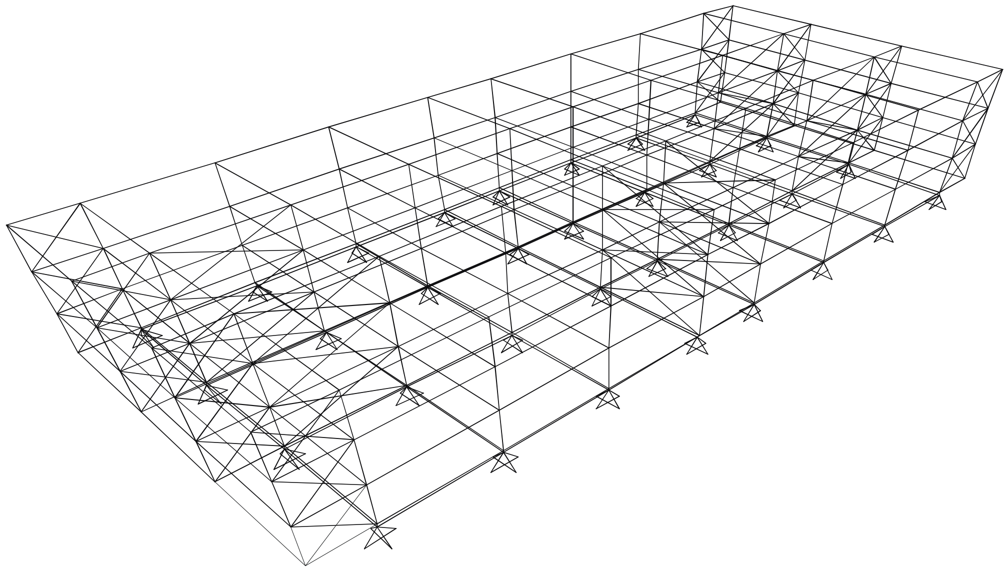
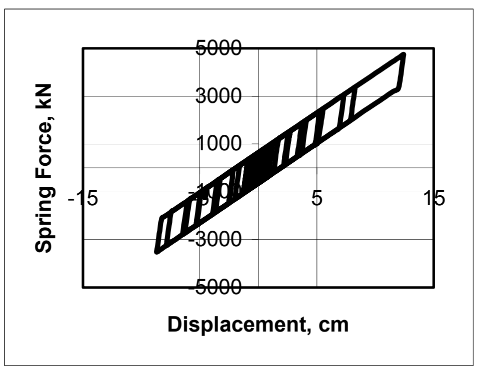


Figure 14. Three-dimensional design model of the 3-story base isolated clinic building

a.



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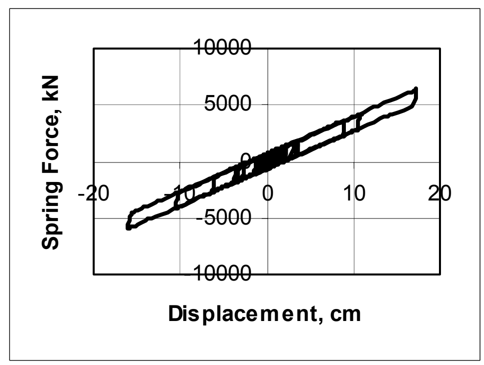
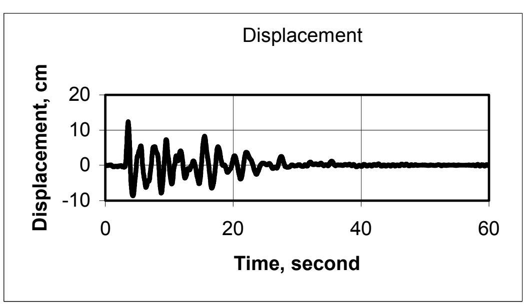


Figure 15. "Spring force – Displacement" relationships obtained from the analyzing by Northridge Earthquake (a) and El Centro Earthquake (b)

a.



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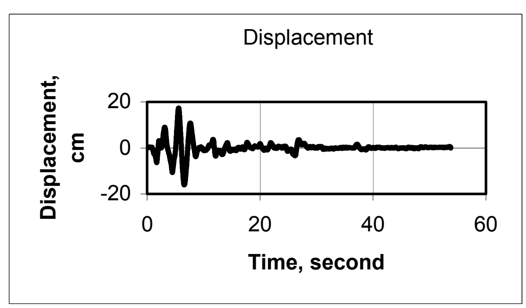

Figure 16. Displacement response of isolation system obtained from the analysis by Northridge Earthquake (a) and El Centro Earthquake (b)

CONCLUSIONS

The paper describes remarkable examples of recent applications of the innovative base isolation technology to the existing school building in the city of Vanadzor and to the new clinic building in the city of Stepanakert. The structural concept of retrofitting of the scool building on the level of its basement is given in detail. Every step of retrofitting is explained and illustrated. Some results of testing of seismic isolation rubber bearings together with the description of testing facilities are also given in the paper.

An original structural concept was developed and designed for creation of base isolation system and for superstructure of the 3-story clinic building. For the ground motion of 0.3 g the design displacement for isolation system 145 mm was obtained. It is also shown that due to seismic isolation the savings in comparison with conventionally designed building (with a fixed base) amount to US$ 97,120 which is about 30-35% of the cost of the bearing structure of the building.

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