SEISMIC ISOLATION EXPERIENCE ACCUMULATED IN ARMENIA

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ABSTRACT :

Since 1994 the total number of base and roof isolated buildings, which are already constructed, retrofitted or are under construction in Armenia, has reached to 32. The number of base isolated buildings per capita in Armenia is the one of the highest in the world. The construction of ordinary (apartment) buildings and critical facilities using seismic isolation costs 30-35% cheaper in comparison with the conventionally designed buildings. Much bigger savings were obtained in retrofitting of an apartment building and a school building. For the first time in the world retrofitting of these buildings by base isolation in Armenia was carried out without interruption of the use of the buildings. In these cases due to seismic isolation the cost of retrofitting was about 1.5-2.0 times less in comparison with the cost of conventional retrofitting. The original and innovative structural concepts of seven residential complexes, three hotels and of a business center were developed in 2004 - 2008. Under different columns of RC frames and different shear walls of these buildings different quantities of MDRB are envisaged. This is new approach on installation of the group of small rubber bearings instead of one big bearing. The advantages of this approach are listed in the paper. Based on the carried out analysis a conclusion was made that some further measures should be taken in order to more realistically describe the behavior of seismic isolated buildings in the design models during the calculations by the Seismic Code of Armenia.

KEYWORDS: Seismic isolation, new technologies, structural concepts, retrofitting, new design approach, multistory buildings

1. STATISTICS ON SEISMIC ISOLATED BUILDINGS

It should be mentioned that seismic isolation in Armenia is developing mainly through the projects financed by the international institutions (World Bank, Swiss CARITAS), “Hayastan” All Armenian Fund, private companies (“Elite Group” CJSC (Armenia), “PCG International” LLC (USA), “Tufenkian Hospitality” LLC (Armenia) or individual investors (Mr. John Huntsman) or persons, constructing their own houses. The matter is that seismic isolation techniques developed in Armenia, taking into account local manufacturing of rubber bearings, are leading to significant savings in construction costs. This fact is attracting the attention of financial institutions and private investors [1]. Table 1 gives statistics on application of seismic isolation techniques in Armenia for the last 14 years.

Presently several four factories in Armenia capable to manufacture high quality rubber bearings. Since the year 2000 they are producing bearings from neoprene with medium damping of about 9-10%. These bearings were designed and tested locally [2] and were used in construction of new buildings as well as for retrofitting of a school building.

The retrofitting of existing or construction of new buildings using seismic isolation costs much cheaper in comparison with the conventionally designed buildings [3, 4]. Accumulated experience shows that due to seismic isolation 30-35% of the cost of bearing structures of buildings can be saved. Much bigger savings were obtained in retrofitting of an apartment building and a school building. In these cases the cost of retrofitting was about 1.5-2.0 times less in comparison with the cost of conventional retrofitting. Also seismic isolation made it possible to speed up the whole construction process.

Table 1 Statistics on buildings in Armenia with application of seismic isolation techniques from 1994 to 2008

Name of building	Bath-houses with two 10-t water tanks on the attic floor	Existing apartment building with stone bearing walls	Existing apartment buildings with RC bearing frames and shear walls	Apartment building with RC bearing walls	Apartment buildings with reinforced masonry bearing walls
Type of seismic isolation	Base isolation	Base isolation	Additional Isolated Upper Floor (AIUF, roof isolation)	Base isolation	Base isolation
Dimensions of buildings in plan (m)	21x12	52x15	19x19	33x14	34x20
Number of stories	1	5	9	4	4
Years of design	1994	1994-1995	1995	1996	1999-2000
Years of implementation	1994-1995	1995-1996	1996-1997	1997-1998	2000-2001
Number of buildings	6	1	2	1	2
Newly constructed or retrofitted	Newly constructed	Retrofitted	Retrofitted	Newly constructed	Newly constructed
Place of implementation	Spitak(2); Gyumri (2); Vanadzor (2)	Vanadzor	Vanadzor	Spitak	Huntsman Village, Gyumri
Number and type of rubber bearings	126, LDRB*	60, HDRB**	32, HDRB	39, HDRB	110, MDRB***
Manufacturer of rubber bearings	NAIRIT, Armenia	TARRC, UK; Min Rubber Products, Malaysia; Sime Engineering Rubber Products, Malaysia	NAIRIT, Armenia; Min Rubber Products, Malaysia	Min Rubber Products, Malaysia	YFRTA, Armenia

Table 1 (Continuation)

Name of building	Single-family house with stone bearing walls	Existing school #4 with stone bearing walls	Clinic building with RC bearing frames and shear walls	Multistory multifunctional complex with RC bearing frames and shear walls on Sayat Nova Ave.	Apartment building with RC bearing frames and shear walls in the multi-functional complex “Our Yard”
1	2	3	4	5	6
Type of seismic isolation	Base isolation	Base isolation	Base isolation	Base isolation	Base isolation
Dimensions of buildings in plan (m)	15x15	38x21	47x20	55x27	58x21

1	2	3	4	5	6
Number of stories	2	3	3	17	10
Years of design	2001	2001	2002	2003-2004	2004-2005
Years of implementation	2001-2002	2002	2003	2004	2005
Number of buildings	2	1	1	1	2
Newly constructed or retrofitted	Newly constructed	Retrofitted	Newly constructed	Under construction	Newly constructed
Place of implementation	Proshyan Village (1); Yerevan (1)	Vanadzor	Stepanakert	Yerevan	Yerevan
Number and type of rubber bearings	32, MDRB	41, MDRB	48, MDRB	228, MDRB	304, MDRB
Manufacturer of rubber bearings	YFRTA, Armenia; GTMC, Armenia	YFRTA, Armenia	YFRTA, Armenia	GTMC, Armenia	Retine Noruyt, Armenia

Table 1 (Continuation)

Name of building	Apartment building with RC bearing frames and shear walls in the multi-functional complex “Our Yard”	Multistory multifunctional complex “Cascade” with RC bearing frames and shear walls	Business center “Elite Plaza” with RC bearing frames and shear walls	Apartment building with RC bearing frames and shear walls in the multi-functional complex on Arami str.	Apartment building with RC bearing frames and shear walls in the multi-functional complex on Arami str.
Type of seismic isolation	Base isolation	Base isolation	Base isolation	Base isolation	Base isolation
Dimensions of buildings in plan (m)	32x23	45x17	42x36	33x32	52x33
Number of stories	16	11	20	11	13
Years of design	2004-2005	2005	2005	2005	2005
Years of implementation	2005	2005	2005	2005	2005
Number of buildings	1	1	1	1	1
Newly constructed or retrofitted	Newly constructed	Newly constructed	Under construction	Under construction	Under construction
Place of implementation	Yerevan	Yerevan	Yerevan	Yerevan	Yerevan
Number and type of rubber bearings	160, MDRB	128, MDRB	246, MDRB	147, MDRB	224, MDRB
Manufacturer of rubber bearings	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia

Table 1 (Continuation)

Name of building	Multistory apartment complex "Dzorap"	Multistory apartment complex "Northern Ray"	Commercial center-hotel on Hanrapetutyan Str.	Multistory apartment building on Baghramian Ave.	Hotel complex in Stepanakert	Hotel complex in Dilijan
Type of seismic isolation	Base Isolation	Base Isolation	Base Isolation	Base Isolation	Base Isolation	Base Isolation
Dimensions of buildings in plan (m)	99×33	74×39	45×37	41×36	46×26	56×26
Number of stories	15	15	7	17	5	6
Years of design	2005-2006	2005-2007	2006-2008	2006-2008	2007-2008	2007-2008
Years of implementation	2006	2007	2006	2008	2008	2008
Number of buildings	2	2	1	1	1	1
Newly constructed or retrofitted	Under construction	Under construction	Under construction	Under construction	Under construction	Under construction
Place of implementation	Yerevan	Yerevan	Yerevan	Yerevan	Stepanakert	Dilijan
Number and type of rubber bearings	312, MDRB	904, MDRB	113, MDRB	271, MDRB	97, MDRB	102, MDRB
Manufacturer of rubber bearings	Retine Noruyt, Armena	Retine Noruyt, Armena	Khachvar, Armenia	Retine Noruyt, Armena	Khachvar, Armenia	Khachvar, Armenia

*LDRB - Low damping rubber bearing (5%)
**HDRB - High damping rubber bearing (>10%)
***MDRB - Medium damping rubber bearing (8-10%)

2. SHORT DESCRIPTION OF THE PRINCIPAL SEISMIC ISOLATION PROJECTS IMPLEMENTED IN ARMENIA FROM 1995 TO 2003

New technologies using seismic isolation systems for upgrading of the earthquake resistance of existing buildings as well as for construction of new buildings were developed in Armenia after the 1988 Spitak Earthquake [5]. Research works in the field of seismic isolation started in 1993 with the support of AUA and National Survey for Seismic Protection (NSSP).

In 1995 the seismic isolation rubber bearings, which were implemented in the first unique project, envisaged the use of high damping natural rubber. At the damping of 10% and more this type of bearings was designed in collaboration with Tun Abdul Razak Research Center (TARRC, UK) and was manufactured and tested in UK and Malaysia [6, 7]. Under the design vertical load and the maximum horizontal displacement of 195 mm there was no sign of an approach to the displacement capacity of the isolators. Bearings had 14 rubber layers with diameter of 380 mm and thickness of 9 mm each and 13 steel layers with diameter of 360 mm and thickness of 2.5 mm each. The soft type bearings shear stiffness was equal to 0.58 kN/mm, vertical stiffness - 310 kN/mm, and they were designed to carry out 585 kN vertical load. For hard type bearing these values were equal to 0.81 kN/mm, 400 kN/mm and 820 kN, respectively. The design horizontal displacement comprised 130 mm. These high damping rubber bearings (HDRB) were used for retrofitting of an existing 5-story stone apartment building. The idea was to supply this 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 was made without re-settlement of the dwellers. The world practice has had no similar precedent in retrofitting

of apartment buildings. The project was financed by the World Bank.

The other project on upgrading seismic resistance of two 9-story existing R/C frame buildings by means of additional isolated upper floor (AIUF) pioneered in applying seismic isolation to the top (roof isolation) part of the buildings [8]. The connection of AIUF to the building was designed by means of bolted type of rubber bearings manufactured in "NAIRIT" plant (Fig. 1). Under the earthquake impact AIUF, acting as a vibration damper, reduces stress-deformed state of the building and increases earthquake resistance for the latter in average by a factor of 1.6 [9]. It is worth noting that the isolated upper floor allows not only upgrading the earthquake resistance of a building, but enlarging its useful space as well. The most distinctive feature of this earthquake resistance upgrading method, however, is that there is no need to re-settle residents from the building during construction works.

a. b.

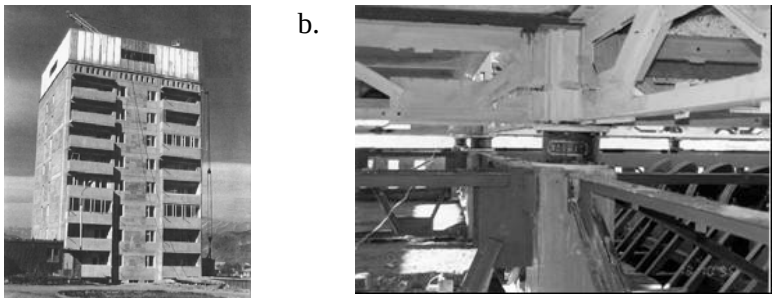

Figure 1 General view of a nine-story apartment building protected with AIUF (roof isolation) in Vanadzor (a) and a fragment of its connection with the building (b)

Figure 2 Fragment of base isolation system of four-story newly constructed apartment building in Spitak

In the next project for the first time in Armenia a seismic isolation system was designed for the construction of a new building in the center of the old Spitak, which was almost completely destroyed during the 1988 Spitak earthquake. After this tragedy buildings with more than two stories were not erected here. In the given case, thanks to the base isolation, for the first time after the mentioned earthquake, a building was designed two times higher, i.e. four story. In this project the same hard type of HDRB were used (Fig. 2). This and the previous two projects were also financed by the World Bank. In 1997 two unique tests were carried out, when the construction of the building was almost completed. The purpose of the first one was the trial of the technology of replacement of seismic isolators. The purpose of the other one was to check the correlation of the design and actual parameters of the isolation system [10].

After that twelve 4-story apartment buildings with reinforced masonry bearing walls provided with seismic isolation were designed using medium damping rubber bearings (MDRB). At present time two buildings have already been constructed [4]. Calculation of isolation system for the design level earthquake was carried out for three cases: under availability of specific site response spectrum suggested by Gyumri Institute of Geophysics and Engineering Seismology; based on spectral curves of Armenian Seismic Code and based on earthquake accelerogram recorded at Ashotsk in 1988 and digitized at the laboratory of Prof. Okada of the Institute of Industrial Science University of Tokyo [11]. For these projects (Fig. 3), financed by Mr. John Huntsman, MDRBs were manufactured from neoprene in the Yerevan factory of rubber technical articles and were tested at NSSP. Their parameters were the same as described above for 5 story building but the design displacement was taken 190 mm with the 8-9% of damping [2, 3].

Above was mentioned that retrofitting or construction of apartment buildings and critical facilities using seismic isolation costs much cheaper in comparison with the conventionally designed buildings. For example, a comparative analysis was carried out for a 4-story building in Spitak considering two cases: first, when the building is designed with fixed base (conventional design) and second, when the building is seismically isolated. Similarly, a comparative analysis was carried out also for a 3-story base isolated clinic building (Fig. 4), construction of which was financed by "Hayastan" All Armenian Fund. The savings due to seismic isolation

amounts to 92,360 USD for the apartment building and 97,120 USD for the clinic building [3, 4]. If to take into account that the cost of the bearing structures of this buildings (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. Much bigger savings were obtained for retrofitting of a school building in Vanadzor (Fig. 5), financed by "Swiss CARITAS". In this case due to seismic isolation the cost of retrofitting was about 2.0 times less in comparison with the cost of conventional retrofitting.

Figure 3 Fragment of base isolation system of four-story newly constructed apartment building in Gyumri

Figure 4 General view of the three-story base isolated clinic building in Stepanakert

Figure 5 General view of the retrofitted by base isolation existing three-story stone building of school No 4 in Vanadzor

3. APPLICATION OF BASE ISOLATION IN CONSTRUCTION OF MULTISTORY MULTIFUNCTIONAL BUILDINGS

The original and innovative structural concepts of seven residential complexes, three hotels and of a business center and their designs were developed in 2004-2008. The seismic isolation plane in all buildings is designed above the two or three parking floors, although in one case of a residential complex there are four floors below the isolation plane, of which two floors are underground and two floors are above ground. Five residential complexes and a business center were described earlier [12]. Below on Fig. 6, 7 and 8 the base isolated buildings designed most recently are shown.

a. b.

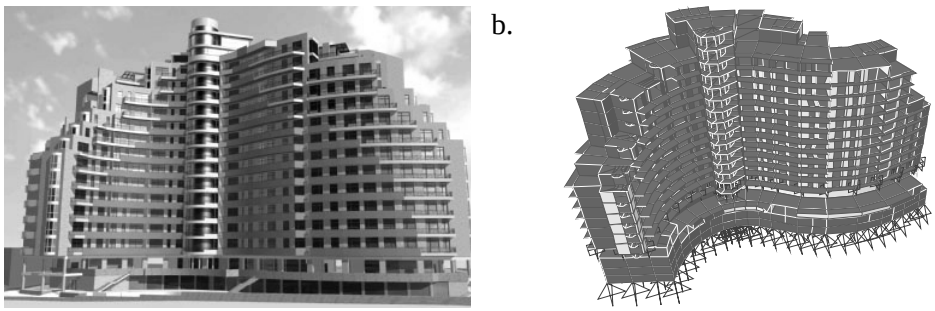

Figure 6 View of the15-story multifunctional residential complex "Dzorap" of "Elite Group" CJSC on Dzorap Street in Yerevan (a) and its design model (b)

a. b.

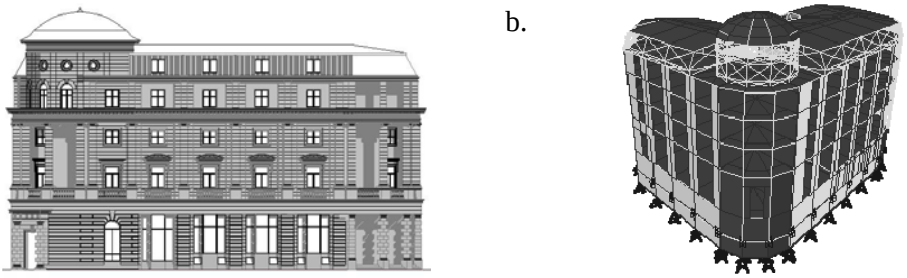

Figure 7 View of 6-story base isolated commercial center-hotel of "Tufenkian Hospitality" LLC on Hanrapetutyan Street in Yerevan (a) and its design model (b)

a. b.

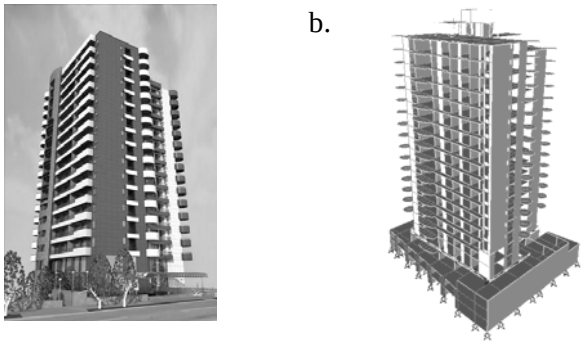

Figure 8 View of the 17-story base isolated multifunctional residential complex of “Elite Group” CJSC on Baghramian Avenue in Yerevan (a) and its design model (b)

Different numbers of MDRB are installed in these buildings. They can develop horizontal displacement of up to 280 mm (220% of shear strain) and can carry a vertical load of up to 1,500 kN. Under different columns of RC frames and different shear walls of these buildings different quantities of MDRBs are envisaged (Fig. 9).

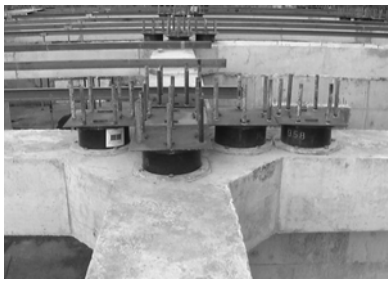

Figure 9 Example of installation of six rubber bearings under one of the columns of the 17-story base isolated building

The suggested approach on installation of the group of small rubber bearings instead of one big bearing is not a typical for the buildings with isolation systems. The advantages of this approach are the following: increased seismic stability of the building; more uniform distribution of the vertical dead and life loads as well as additional vertical seismic loads on the rubber bearings; small bearings can be installed by hand without using any mechanisms; easy replacement of small bearings, if necessary, without using any expensive equipment; easy casting of concrete under the steel plates with anchors and recess rings of small diameter for installation of bearings; neutralization of rotation of buildings by manipulation of the number of bearings in the seismic isolation plane, etc.

All complexes were analyzed using the provisions of the Armenian Seismic Code, as well as using different time histories. The results of the analyses of these buildings based on the Code were presented and discussed earlier [12]. For the time history non-linear earthquake response analysis a group of accelerograms was used including synthesized accelerograms. The comparative analyses carried out for the mentioned complexes for cases with and without application of seismic isolation clearly show the high efficiency of seismic isolation and also show that further improvement of the Code provisions is needed regarding the reduction factors for seismic isolation systems.

5. CONCLUSIONS

- Statistics on seismic isolated buildings in Armenia retrofitted or constructed from 1994 to 2008 is given.
- Principal seismic isolation projects implemented in Armenia and Nagorno Karabakh from 1995 to 2003 are described.
- The cost-effectiveness of retrofitting of existing or construction of new buildings using base isolation technologies in comparison with the conventionally designed fixed base buildings is proved.

- The original and innovative structural concepts of seven base isolated residential complexes, three hotels and of a business center implemented in the cities of Yerevan, Dilijan and Stepanakert from 2004 to 2008 are described.
- The new approach in analysis and design of base isolated multistory multifunctional buildings is suggested. The idea is to install under the columns and shear walls not one big rubber bearing but a group of small bearings in order to increase the overall effectiveness of isolation system. The advantages of this approach are listed in the paper.
- Further improvement of the Armenian Seismic Code provisions is needed regarding the reduction factors for seismic isolation systems.

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