Armenia is the one of the world leaders in development and application of base isolation technologies

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INTRODUCTION

During the last 12 years 33 buildings and structures have been designed in Armenia using seismic isolation technologies. The total number of base and roof isolated buildings, which are already constructed, retrofitted or are under construction, has reached 28. Among them there are bathhouses, private houses, a school building, a clinic building, a business center and apartment buildings. The last applications of seismic isolation took place in design and construction of 10-20-story multifunctional buildings, which include underground floors (garages) and above ground floors for offices, apartments, restaurants, fitness clubs, pools, etc. The number of base isolated buildings per capita in Armenia is the one of the highest in the world.

Construction of base isolated structures has started in Armenia in 1994. In 1995 the number of such structures reached 6. In 1998 there were already 10 buildings and structures where base or roof isolation systems were used. The larger application of base isolation has begun at the end of 1999 and at the beginning of the year 2000. At that time the design of 12 base isolated buildings has started. During 2001-2003 for the first time in Armenia base isolation was applied to a single-family house, to school and to clinic buildings [Melkumyan M.G. et al, 2004; Melkumyan M.G. and Gevorgyan E.L., 2004]. In 2004 till present base isolation was designed and applied for the first time to multistory multifunctional buildings.

STATISTICS AND EFFECTIVENESS OF APPLICATION OF SEISMIC BASE AND ROOF ISOLATION IN ARMENIA

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) 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 [Melkumyan M.G., 2001]. Table 1 gives statistics on application of seismic isolation techniques in Armenia for the last 12 years.

Presently there are four factories in Armenia, namely: NAIRIT plant, Yerevan Factory of Rubber Technical Articles (YFRTA), General Transworld Manufacturing Company (GTMC) and "Retine Noruyt" CJSC 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 [Melkumyan M.G., 2001] and were used in construction of new buildings as well as for retrofitting of a school building.

Consequently, one of the important factors for application of such technologies in Armenia is the presence of the chemical industry in the country capable to locally manufacture high quality isolators. Another factor is the presence of scientific and engineering resources capable to design, investigate, test and improve the seismic isolation technologies. Together with that the world experience proves that the seismic isolation technology is the most reliable. The excellent example of demonstration of the effectiveness of two seismic isolated buildings during the destructive Hanshin-Awaji earthquake in 1995 (Kobe, Japan) is well known [Fujita T., 1999].

Thanks to the above mentioned capabilities the retrofitting or construction of ordinary (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 apartment building 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 clinic building.

TABLE 1: Statistics on buildings and structures in Armenia with the application of seismic isolation techniques from 1994 to 2006

Name of building or structure	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	Apart-ment building with RC bearing walls	Apart-ment 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 implemen-tation	1994-1995	1995-1996	1996-1997	1997-1998	2000-2001
Number of buildings or structures	6	1	2	1	2
Newly constructed or retrofitted	Newly constructed	Retrofitted	Retrofitted	Newly constructed	Newly constructed
Place of implemen-tation	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***
Manufac-turer 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

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

TABLE 1: (Continuation)

Name of building or structure	Single-family house with stone bearing walls	Existing school #4 with stone bearing walls	Clinic building with RC bearing frames and shear walls	Multistory multi-functional 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"
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
Number of stories	2	3	3	17	10
Years of design	2001	2001	2002	2003-2004	2004-2005
Years of implemen-tation	2001-2002	2002	2003	2004	2005
Number of buildings or structures	2	1	1	1	2
Newly constructed or retrofitted	Newly constructed	Retrofitted	Newly constructed	Under construction	Under construction
Place of implemen-tation	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
Manufac-turer of rubber bearings	YFRTA, Armenia; GTMC, Armenia	YFRTA, Armenia	YFRTA, Armenia	GTMC, Armenia	Retine Noruyt, Armenia

TABLE 1: (Continuation)

Name of building or structure	Apartment building with RC bearing frames and shear walls in the multi-functional complex "Our Yard"	Multistory multi-functional 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 implemen-tation	2005	2005	2005	2005	2005
Number of buildings or structures	1	1	1	1	1
Newly constructed or retrofitted	Under construc-tion	Under construc-tion	Under construc-tion	Under construc-tion	Under construc tion
Place of implemen-tation	Yerevan	Yerevan	Yerevan	Yerevan	Yerevan
Number and type of rubber bearings	160, MDRB	128, MDRB	246, MDRB	147, MDRB	224, MDRB
Manufac-turer of rubber bearings	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia

The savings due to seismic isolation amounts to 92,360 USD for the apartment building and 97, 120 USD for the clinic building [Melkumyan M.G., 2002 and Melkumyan M.G., 2004]. Accumulated experience shows that thanks 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 Vanadzor. Here for the first time in the world retrofitting of these buildings by base isolation 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. Also seismic isolation made it possible to speed up the whole construction process.

Thus, successful implementation of new technologies in the last 12 years, the presence of industry capable of locally manufacturing seismic isolators, the presence of capable scientific and engineering resources locally developing and designing seismic isolation systems, the presence of the design codes and guidelines for seismic isolation of buildings and structures [Khachian E.E., 1992; Fuller K.N.G. & Melkumyan M.G., 1998; Melumyan M.G., 2002], the possibility of retrofitting by seismic isolation without interruption of the use of the facilities, the low cost of retrofitting and new construction using seismic isolation, the possibility to accelerate the whole construction process, and high reliability fully justify further practical application and effectiveness of the advanced seismic isolation technologies in Armenia.

RECENT APPLICATION OF BASE ISOLATION IN CONSTRUCTION OF MULTISTORY MULTIFUNCTIONAL BUILDINGS

The original and innovative structural concepts of five residential complexes and of a business center and their designs were developed in 2004 - 2006 (Fig. 1, 2, 3, 4 and 5). The seismic isolation plane in all cases is designed above the parking floors, although in case of the "Cascade" building the upper parking floor does not have a slab that makes the stiffness of this floor lower in comparison with the parking floors of the other complexes. The same is true for the residential complex on Arami str., which has four floors below the isolation plane, of which two floors are underground and two floors are above ground.

Fig. 1. The view of the 17-story multifunctional residential complex on Sayat-Nova Avenue in Yerevan

Different numbers of MDRBs are to be installed in these buildings. However, all of them are of the same size (diameter - 380 mm, and height - 202 mm) and characteristics. They have a damping factor of about 9-10%, can develop horizontal displacement of up to 280 mm (about 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. 6 and 7).

Fig. 2. The view of the 10- and 16-story buildings in the multifunctional residential complex “Our Yard” on Rostomi Street in Yerevan

Fig. 3. The view of the 11-story multifunctional residential complex “Cascade” on Demirchian Street in Yerevan

This is not a typical approach on installation of the group of small rubber bearings instead of one big bearing, which is conditioned from one side by the architectural solution in order to have a gap at the seismic isolation plane of about 200 mm. But from the structural point of view this approach is increasing the seismic stability of the buildings and is leading to a more uniform distribution of the vertical dead loads as well as of additional vertical seismic loads on the rubber bearings. Other advantages of this approach are the following:

- 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 soil conditions in all cases are good and the soils here are of category II with the predominant period of vibrations of not more than 0.5 sec. By the carried out calculations (using computer programs LIRA 9.2 and SAP 2000), for example, for the “Cascade” building, as one of the most complicated cases, the first mode vibrations’ period in longitudinal direction is equal to 1.90 sec and in transverse direction - 1.91 sec, while the corresponding periods for the non-isolated structure would be 0.83 sec and 0.86 sec. This means that seismic isolation has reduced the maximum spectral acceleration by a factor larger than 2. These figures prove the high effectiveness of seismic isolation and reliability of the buildings during strong seismic actions with the PGA equal to 0.4 g and even more.

Fig. 4. The view of the 20-story business center “Elite Plaza”on Khorenatsi Street in Yerevan

Fig. 5. The view of the 13-story and 11-story multifunctional residential complex on Arami Street in Yerevan

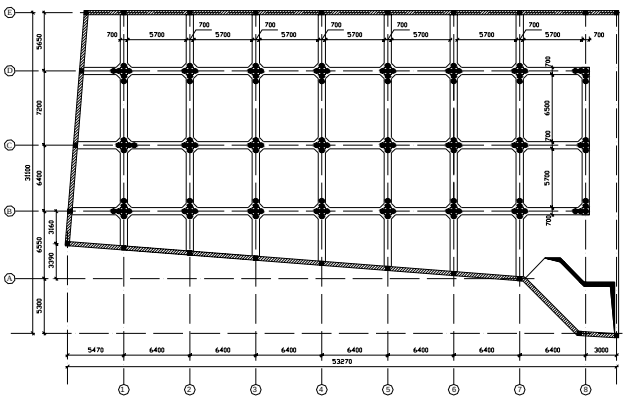

Fig. 6. Example of location of seismic isolators in “Cascade” building

Fig. 7. Example of installation of five rubber bearings under one of the columns of the 10-story building in “Our Yard” complex

For the time history non-linear earthquake response analysis a group of accelerograms was used including synthesized accelerograms. They were chosen so that the predominant periods of the Fourier spectra do not exceed 0.5-0.6sec. In this case the total shear forces on the level of isolation system, the maximum displacements of the isolators, and the maximum story drifts of the superstructure calculated based on the Code provisions are differing from the same values calculated by the time histories in about 2 times in average. This means 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 based on the Code. In other words further improvement of the Code provisions is needed regarding the reduction factors for seismic isolation systems.

The comparative analyses carried out for the considered residential as well as for the business center complexes for cases with and without application of seismic isolation clearly show the high efficiency of seismic isolation. They prove once again that if properly designed seismic isolation brings to rational structural solutions of high reliability. This is true also for the developed structural concepts and for the accomplished structural designs.

It should be mentioned that according to the Armenian law all designs must be evaluated by special licensed companies. Some of the designs of base isolated buildings have passed through the international expertise. The quality control of base isolation devices as well as of the construction of base isolated buildings is being carried out by the group of researchers and structural engineers at ERC of AUA under the leadership of Prof. Melkumyan. .

CONCLUSIONS

The effectiveness and application of seismic isolation systems in Armenia is justified. Detailed statistics on buildings where seismic isolation is applied and also on types of seismic isolation systems and on manufacturers of rubber bearings is presented. Various examples of applications of seismic isolation techniques in Armenia are described. It is shown that due to base isolation the savings in comparison with conventionally designed building (with a fixed base) is about 30-35% of the cost of the bearing structure of the building.

New structural concepts are proposed, designed and applied for the first time in Armenia for construction of 10-20 story multifunctional complexes, which include underground floors (garages) and above ground floors for offices, apartments, restaurants, fitness clubs, pools, etc. The new approach on installation of the group of small rubber bearings instead of one big bearing under the columns or shear walls is given and its advantages are mentioned.

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