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Armenia is the World Leader in Development and Extensive Application of Low-Cost Seismic Isolation For Construction of New and Retrofitting of Existing Buildings

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ABSTRACT

The paper provides a clear picture on how and why the seismic isolation technologies created/invented by the author bring Armenia, the developing and once a low-income country, to a leading position in the world in the application of low-cost seismic isolation. The first implementation of seismic isolation in the country started in 1994. Since then, every year more than two seismic (base or roof) isolated buildings in average were constructed/retrofitted in Armenia. Consequently, considerable number of real applications of the technology took place in the country where seismic isolation of the buildings proved to be cost-effective and affordable with a reduced construction cost. The paper illustrates seismic isolated newly constructed and retrofitted buildings and explains the reasons behind significant savings in consumption of concrete and steel and in the related cost of construction of various buildings due to implementation of the developed by the author seismic isolation strategies. It also emphasizes that the cost of seismic isolation laminated rubber-steel bearings (SILRSBs) manufactured in Armenia is noticeably lower than of the bearings manufactured elsewhere in the world. The paper states that the provisions of the progressive Armenian Seismic Code (Chapter 10 "Buildings and Structures with Seismic Isolation Systems" written by the author of this paper) substantially contribute to the design and construction of low-cost seismic isolated buildings.

Keywords: *seismic (base and roof) isolation, extensive experience, structural concepts, load-bearing systems, low-cost technologies, reduced consumption of construction materials, comparative analyses.*

INTRODUCTION

In recent years seismic isolation technologies in Armenia were extensively applied in construction of multi-story residential, medical, hotel, airport, and business center complexes with parking floors and with floors envisaged for offices, shopping centers, fitness clubs, etc.

Together with that seismic (base and roof) isolation technologies invented by the author of this paper were also applied for retrofitting of existing buildings without interruption of the use of these buildings.

To date there are 55 seismic isolated buildings in the country newly constructed or retrofitted by base or roof isolation systems.

Of this number of buildings 48 (Fig. 1) were erected thanks to the works of the author and in nowadays Armenia is well known as a country where seismic isolation systems are widely implemented in civil construction.

The number of seismically isolated buildings per capita in Armenia is one of the highest in the world – second after Japan.

In the paper of Martelli A., Forni M. & Clemente P (2012) it is stated that: "Armenia remains second, at the worldwide level, for the number of applications of such devices per number of residents, in spite of the fact that it is still a developing country".

What is the most important in the successful story of Armenia in application of seismic isolation technologies is that they bring to significant reduction of the cost of construction of new or retrofitting of existing buildings.

The SILRSBs different by their shape and dimensions, as well as by damping (low, medium, and high) were designed by the author and about 5200 SILRSBs were manufactured in the country, tested locally, and applied in construction (Fig. 2).

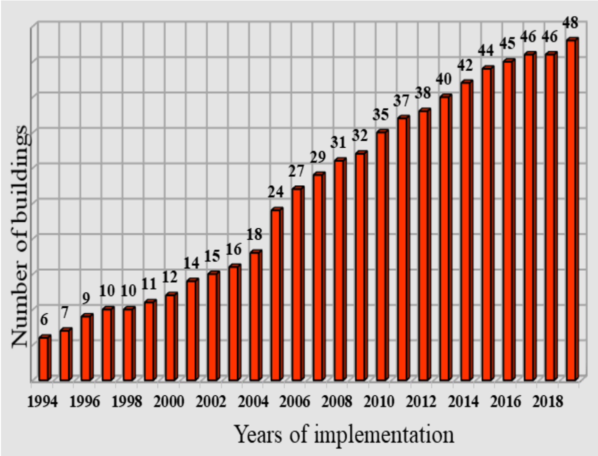

Figure1. *Number of seismic (base and roof) isolated buildings newly constructed or retrofitted in Armenia by years*

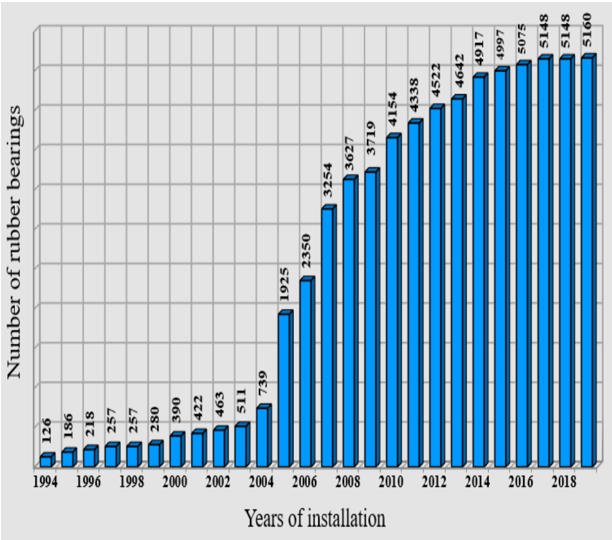

Figure2. *Number of rubber bearings installed in the newly constructed or retrofitted buildings in Armenia by years*

Several remarkable projects on construction of new base isolated buildings, as well as retrofitted by base or roof isolation existing buildings are mentioned to demonstrate the experience accumulated in Armenia.

Based on the gained experience further developments take place and unique seismic isolation structural concepts and technologies created by the author are applied more and more in civil construction utilizing his approach on installation at the isolation plane the clusters of small rubber bearings instead of a single large bearing under the columns or walls (Melkumyan, 2013a).

Exceptional features of the seismic isolation systems give the opportunity to apply them to steel, stone, reinforced masonry, reinforced concrete (R/C) frame, and braced-frame buildings, as well as to buildings, the bearing systems of which consist of R/C monolithic load-bearing walls, and asymmetric buildings with the number of stories from 1 to 20.

It is stated that suggested seismic isolation strategy reduces the cost of construction of medium- and high-rise buildings from 30% to 40% in comparison with the cost of conventional construction of fixed base buildings (Melkumyan, 2017, 2018). At the same time, retrofitting of the 3-9-story existing buildings by the invented seismic isolation technologies cost from 3 to 5 times less in comparison with the cost of the conventional strengthening of existing buildings (Melkumyan, 2020).

More importantly, the technologies, which create an excellent possibility to successfully implement retrofitting of existing buildings by seismic isolation without interruption of the use of these buildings, are further adding to the reduction of the costs that would have otherwise been needed for the temporary relocation of the occupants of the buildings.

Analyses of all the base isolated buildings carried out by the Armenian Seismic Code and the groups of the time histories are showing that structural elements below and above the seismic isolation planes are working mainly in the elastic phase.

Input accelerations of 0.4g-0.5g at the foundation bed get damped about 2.5-3.0 times in the superstructures. Almost uniform distribution of the vertical loads (not exceeding 1500 kN) upon the rubber bearings could be easily achieved. Obtained results indicate the high effectiveness of the created structural concepts of isolation systems. Comparative analyses have shown that suggested seismic isolation strategies are reducing the consumption of concrete by about 2 times and steel – 2.7 times. Also, reduction of the strength of the concrete on one grade takes place bringing to decreasing of the consumption of cement. The mentioned above magnitudes of the cost reduction of course include the cost of manufacturing, testing, and installation of SILRSBs. Development and application of seismic (base and roof) isolation unique technologies in construction of new and retrofitting of existing medium- and high-rise buildings in Armenia took place owing to projects financed by the international institutions like the World Bank, Huntsman Corporation, Caritas Switzerland, Hayastan All-Armenian Fund, as well as by local companies: “Tufenkian Hospitality” LLC, “Elite Group” CJSC, “ITARKO Construction” CJSC, and “Fredex Services” LLC. Two projects were financed by the Governmental program for providing apartments for young families and the Healthcare Project Implementation Unit of the Ministry of Health, and finally, three projects were financed by the private individuals who were constructing their own houses (Melkumyan, 2011, 2014a, 2015a).

Construction of New Base Isolated Buildings from 1997 To 2020

The original and innovative structural concepts were developed and implemented in construction of new buildings during the last 24 years. These buildings were analyzed using the provisions of the Armenian Seismic Code (RABC II-6.02-2006), as well as using different time histories. Development of the design drawings was carried out based on the mentioned in the Abstract Chapter 10 “Buildings and Structures with Seismic Isolation Systems” of the Code.

Together with that the following normative documents also written by the author and approved by the corresponding Governmental bodies were used during the design works: (i) “Guidelines for Design and Construction of Buildings with Application of Laminated Rubber Steel Bearings”, and (ii) “Standard of the Republic of Armenia AST 261-2007 - Seismic Isolation Laminated Rubber Steel Bearing”.

Construction of the Medium-Rise Base Isolated Buildings

Below in Figures 3-7 the views and the brief information on some of the medium-rise base isolated buildings are given (Melkumyan, 2004, 2011, 2015b).

Figure3. *4-story apartment building in the city of Spitak and fragment of its isolation system*

The building with monolithic R/C load-bearing walls was constructed in 1997. Dimensions of the building - 33×14 m. 39 high damping rubber bearings were manufactured by MIN RUBBER PRODUCTS (Malaysia), and were used to create the base isolation system within the building’s basement.

Figure4. *Two 4-story apartment buildings in the Huntsman Village of the city of Gyumri and fragment of its isolation system*

The buildings with R/C masonry load-bearing walls were constructed in 2001. Dimensions of each building - 34×20 m. 110 medium damping rubber bearings were manufactured by YFRTA (Armenia) for both buildings and were used to create the base isolation systems within the buildings' basement.

Figure5. *3-story clinic building in the city of Stepanakert and fragment of its isolation system*

The building with R/C bearing frames and shear walls was constructed in 2003. Dimensions of the building - 47×20 m. 48 medium damping rubber bearings were manufactured by YFRTA (Armenia), and were used to create the base isolation system within the building's basement.

Figure6. *7-story commercial center/hotel building in the city of Yerevan and its design model*

The building of L-shape in plan with R/C bearing frames and shear walls was constructed in 2007. Dimensions of the building - 45×37 m. 113 medium damping rubber bearings were manufactured by KHACHVAR (Armenia), and were used to create the base isolation system within the building's basement/parking floor

Figure7. *4-story building of medical center in the city of Vanadzor and fragment of its isolation system*

The building of □-shape in plan with R/C bearing frames and shear walls was constructed in 2016. Dimensions of the building - 86×69 m. 260 high damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation systems within the building's basement

Construction of the High-Rise Base Isolated Buildings

Below in Figures 8-16 the views and the brief information on some of the high-rise base isolated buildings are given. Seismic isolation systems are located at different levels above one, two or three parking floors, although there are the cases (Fig. 10, 12) where there are four floors below the isolation plane, of which two parking floors are underground and two commercial floors are above ground.

Figure8. *11-story building of the multifunctional residential complex "Cascade" in the city of Yerevan and its design model (Melkumyan, 2002)*

The building with R/C bearing frames and shear walls was constructed in 2005. Dimensions of the building - 45×17 m. 128 medium damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation system above one parking and one commercial floor.

Figure9. *16- and 10-story buildings of the multifunctional residential complex "Our Yard" in the city of Yerevan and their design models (Melkumyan, Gevorgyan & Hovhannisyan, 2005)*

The buildings with R/C bearing frames and shear walls were constructed in 2005. Dimensions of two 10-story buildings - 58×21 m and of 16-story building - 32×23 m. Total 464 medium damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation systems above the two parking floors.

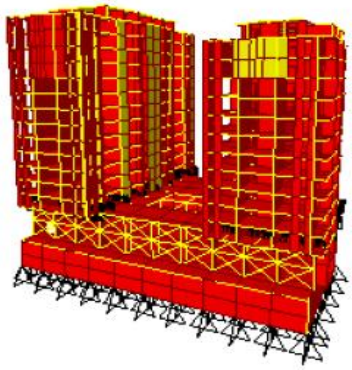

Figure10. *16- and 14-story buildings of the multifunctional residential complex "Arami" in the city of Yerevan and their design models (Melkumyan, 2006b)*

The buildings with R/C bearing frames and shear walls were constructed in 2006. Dimensions of 14-story building - 33×32 m and of 16-story building - 52×33 m. Total 371 medium damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation systems on top of four floors (two underground parking and two above ground commercial floors).

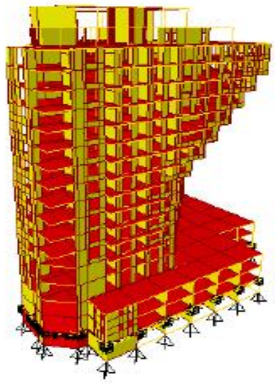

Figure11. *18-story buildings/twins of the multifunctional residential complex "Northern Ray" in the city of Yerevan and the design model of one building (Melkumyan & Gevorgyan, 2010)*

The buildings with R/C bearing frames and shear walls were constructed in 2007. Dimensions of each building - 74×39 m. Total 904 medium damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation system on top of the first parking floor.

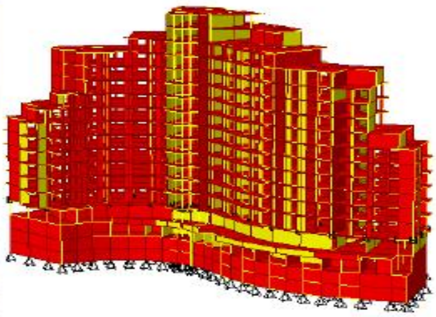

Figure12. *Multifunctional residential complex "Dzorap" in the city of Yerevan consists of 16- and 13-story parts divided by the anti-seismic vertical gap and their design models (Melkumyan, 2011a)*

The buildings with R/C bearing frames and shear walls were constructed in 2007. Dimensions of 13-story part - 32×33 m and of 16-story part - 67×29 m. Total 312 medium damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation system on top of four floors (two underground parking and two above ground commercial floors).

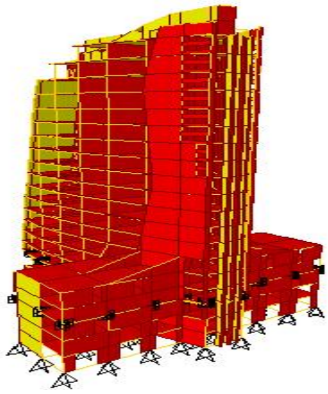

Figure13. *20-story building of business center "Elite Plaza" in the city of Yerevan and its design model (Melkumyan & Gevorgyan, 2011b)*

The building with R/C bearing frames and shear walls was constructed in 2007. Dimensions of the building - 42×36 m. 246 medium damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation system above the two parking and one commercial floors.

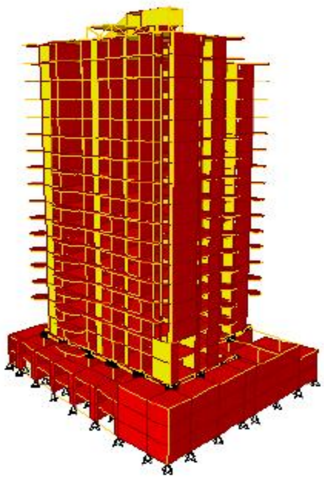

Figure14. *17-story building of the multifunctional residential complex "Baghramian" in the city of Yerevan and its design model(Melkumyan & Gevorgyan, 2008)*

The building with R/C bearing frames and shear walls was constructed in 2008. Dimensions of the building - 41×36 m. 271 medium damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation system above the two parking and one commercial floors.

The soil conditions for all the above presented buildings are good and according to the RABC II-6.02-2006 the soils here are of category II with the predominant period of vibrations of not more than 0.6 sec. Dynamic analyses were carried out by SAP 2000. The results of the analyses of some of these buildings based on the Code were presented and discussed earlier (Melkumyan, 2005, 2013b). 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 0.5-0.6 sec (Melkumyan, 2009).

Figure15. *15-story building of the multifunctional residential complex "Avan" in the city of Yerevan and its design model(Melkumyan, 2014b)*

The building with R/C bearing frames and shear walls was constructed in 2011. Dimensions of the building - 40×28 m. 247 medium damping rubber bearings were manufactured by R.M.I.A. (Armenia), and were used to create the base isolation system above the ground commercial floor.

Figure16. *17-story building of the multifunctional residential complex "Sevak" in the city of Yerevan and its design model (Melkumyan, 2014c)*

The building with R/C bearing frames and shear walls was constructed in 2012. Dimensions of the building - 30×30 m. 184 medium damping rubber bearings were manufactured by R.M.I.A. (Armenia), and were used to create the base isolation system above the two parking and one commercial floors. 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. They prove that if professionally designed seismic isolation brings to cost effective and rational structural solutions of high reliability (Fujita, 1999).

Retrofitting By Base and Roof Isolation of Existing Buildings from 1996 To 2015

Below in Figures 17-22 the views and the brief information on some of the retrofitted by base or roof isolation buildings are given.

Unique structural concepts and technologies to implement them were developed by the author for each of the described buildings.

Figure17. *First existing 5-story stone apartment building in Armenia retrofitted by base isolation (technology invented by the author) in the city of Vanadzor and fragments of its isolation system. This building was retrofitted for the first time in the world without interruption of its use, so, that during retrofitting works people were not moved out of the building (Melkumyan, 1994, 2002, 2006b, 2009)*

The building with stone load-bearing walls was retrofitted in 1996. Dimensions of the building - 52×15 m. 60 high damping rubber bearings were manufactured by TARRC (UK), MIN RUBBER PRODUCTS (Malaysia), and Sime Engineering Rubber Products (Malaysia), and were used to create the base isolation system within the building's basement.

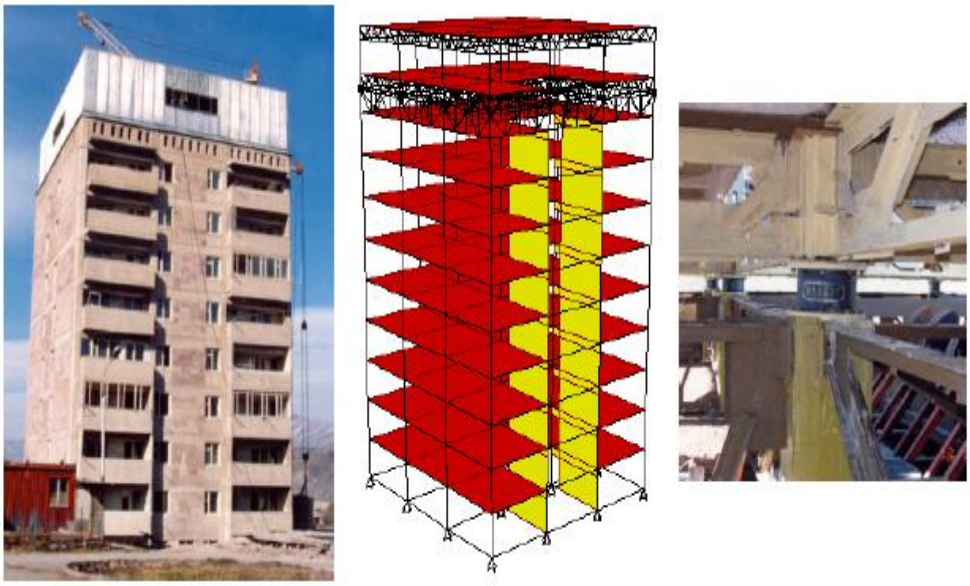

Figure18. *9-story existing apartment building retrofitted by roof isolation (invented by the author method of Additional Isolated Upper Floor - AIUF) in the city of Vanadzor, its design model and fragment of its isolation system. This building was retrofitted in parallel with reconstruction works going on in all floors (Melkumyan, 2007, 2009, 2011)*

The building with R/C bearing frames and shear walls was retrofitted in 1997. Dimensions of the building - 19×19 m. 16 medium damping rubber bearings were manufactured by NAIRIT (Armenia), and were used to create the roof isolation system between the AIUF and the main building.

Figure19. *9-story existing apartment building retrofitted by roof isolation (also by the method of AIUF) in the city of Vanadzor, its design model and fragment of its isolation system. This building was also retrofitted in parallel with reconstruction works going on in all floors (Melkumyan, 2007, 2009, 2011)*

The building with R/C bearing frames and shear walls was retrofitted in 1997. Dimensions of the building - 19×19 m. 16 high damping rubber bearings were manufactured by MIN RUBBER PRODUCTS (Malaysia), and were used to create the roof isolation system between the AIUF and the main building.

Figure20. *3-story existing school building retrofitted by base isolation in the city of Vanadzor and fragments of its isolation system. At the time of retrofitting the building was 60 years old. This building, which has historical and architectural value, was also retrofitted without interruption of its use (Melkumyan, 2005, 2011, Melkumyan & Hakobyan, 2005)*

The building with stone load-bearing walls was retrofitted in 2002. Dimensions of the building - 38×21 m. 41 medium damping rubber bearings were manufactured by YFRTA (Armenia), and were used to create the base isolation system within the building’s basement.

Figure21. *9-story existing Hematology Center Hospital building retrofitted by base isolation in the city of Yerevan and fragment of its isolation system. This building was retrofitted in parallel with reconstruction works going on in all floors (Melkumyan, 2014d, 2015a, 2019)*

The building with R/C bearing frames and shear walls was retrofitted in 2014. Dimensions of the building - 38×26 m. 117 high damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation system within the building's basement

Figure22. *4-story existing industrial building with R/C bearing frames retrofitted by base isolation in the city of Yerevan and fragment of its isolation system. This building was converted into hotel and was retrofitted in parallel with reconstruction works going on in all floors (Melkumyan, 2014a, 2019)*

The building with R/C bearing frames was retrofitted in 2015. Dimensions of the building - 81×18 m. 158 high damping rubber bearings were manufactured by RETINE NORUYT (Armenia), and were used to create the base isolation system within the building's basement.

Why Seismic Isolation Brings To Significant Reduction of the Cost of Construction of New Or Retrofitting of Existing Buildings In Armenia?

Armenia is a success story in developing and implementing cost-effective and affordable seismic isolation systems for almost three decades despite being a developing middle-income country. As it is shown below in Section 6, due to application of the developed by the author seismic isolation technologies, in Armenia construction of the bearing structures of new seismic isolated buildings costs from 30% to 40% less in comparison with the cost of construction of fixed base buildings. At the same time retrofitting of existing buildings applying invented by the author seismic isolation technologies costs from 3 to 5 times less in comparison with the cost of the conventional strengthening of existing buildings. More importantly, from Section 3 it follows that the developed technologies have allowed to successfully implement retrofitting of existing buildings by seismic isolation without interruption of the use of these buildings, which is further adding to the reduction of the costs that would have otherwise been needed for the temporary relocation of the occupants of the buildings. There are several reasons for the mentioned savings. One of them is that rubber bearings manufactured in Armenia cost significantly less than bearings manufactured elsewhere in the world. This is conditioned by the lower labor cost and the cost of utilities, availability of rubber components in the country, as well as existence of several competing factories capable of manufacturing high quality rubber bearings with low (LDRB), medium (MDRB) and high (HDRB) damping. Also, the provisions of the Armenian Seismic Code for seismically isolated structures are much more progressive in comparison with, for example, the USA Code in terms of analysis and design of superstructures of base isolated buildings. The Code of USA on Seismic Isolation is extremely conservative. This is the reason why seismic isolation is actually dying in this country. That is why seismic isolation is not applied as extensively in USA, as it could. As a result of progressive provisions of the Armenian Seismic Code for seismically isolated buildings, a huge amount of reinforcement could be reduced in superstructures of newly constructed R/C base isolated buildings. In addition, cross-sections of the bearing structures (columns, beams, shear walls, floor slabs) are smaller, and there is no need to apply high strength concrete for them. Therefore, large amounts of concrete and cement may also be saved insuper structures. In case of retrofitting of existing buildings applying base isolation technologies there is no need to strengthen the superstructures. This was proved by numerous analyses based on the Code and time histories. Superstructures could be renovated/ reconstructed if needed, but not strengthened. This gives large flexibility to architects when they are developing their designs.

Thus, successful implementation of seismic isolation technologies in the last 28 years, the presence of industry capable of local manufacture of seismic isolators, the presence of capable scientific and engineering brainpower for local development and design of seismic isolation systems, the possibility of retrofitting by seismic isolation without interruption of the use of the facilities, the low cost of retrofitting and new construction with seismic isolation, and the possibility of speeding up the retrofitting process fully justify further practical application of the advanced seismic isolation technologies in Armenia.

Brief Information on the Author's Approach on Application of Clusters of Small Rubber Bearings

In the considered buildings the approach suggested earlier (Melkumyan & Hovhannisyan, 2006a, Melkumyan, 2007, 2009) on installation of the cluster of small rubber bearings instead of a single large bearing was used. Figure 23 shows that different numbers of SILRSBs are installed at different locations of the seismic isolation systems. However, all of them are of the same size and characteristics given in (Melkumyan, 2011, 2013a). They are made in Armenia from neoprene and were designed and tested locally (Melkumyan 2001, Melkumyan & Hakobyan, 2005).

The advantages of the approach on installation of the clusters of small rubber bearings instead of a single large bearing 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 and location of bearings in the seismic isolation plane, etc.

One more advantage was pointed out by Prof. Kelly during the 11th World Conference on Seismic Isolation in Guangzhou, China. Positively evaluating the suggested approach he mentioned that in the course of decades the stiffness of neoprene bearings may increase, and in order to keep the initial dynamic properties of the isolated buildings the needed number of rubber bearings can be dismantled from the relevant clusters.

Thus, thanks to the suggested approach, more rational solution can be achieved, which is increasing the effectiveness of isolation system in general.

This approach has attracted attention of many researchers, designers, and engineers (Foti & Mongelli, 2011).

Demonstration of the Cost-Effectiveness of Seismic Isolation Strategies on the Examples of Multistory Reinforced Concrete Frame Buildings with Shear Walls

To demonstrate and prove that developed seismic isolation strategies are leading to the low-cost construction, the author has decided not to bring in this Section textual clarifications, but, for greater visibility, to present the relevant comparative data for some buildings with and without seismic isolation in table forms.

However, there is a key point, which deserving attention, is that all the buildings with fixed base were designed before they were given to the author with the request to redesign them applying seismic isolation systems. This gave the possibility to directly compare data on consumption of concrete and steel in new innovative and previous conventional designs.

Expenditures Of Construction Materials In The 16- And 10-Story Base Isolated Buildings Of The Multifunctional Residential Complex “Our Yard” And Their Comparison With Expenditures In The Fixed Base Buildings Of The Same Architectural Solutions

Foundations of the fixed base buildings were designed as a solid slab with the thickness of 1500 mm. Cross section of columns in the parking floors was 700x700 mm and in superstructures – 600x600 mm. Cross section of beams in the parking floors was 700x600(h) mm and in superstructures – 600x520(h) mm. Thickness of the floors’ slabs at all levels of fixed base buildings was 200 mm.

Thickness of shear walls in the parking floors was 400 mm and in superstructures – 300 mm. However, in the base isolated buildings the concept of foundations was changed to the strip beams with the cross-section of 900×1500(h) mm.

Cross-section of columns in the parking floors was not changed, but in superstructures it was changed to 500x500 mm. Cross-section of beams in the parking floors was changed to 700x500(h) mm and in superstructures – to 500x350(h) mm.

Thickness of the floors’ slabs at all levels of base isolated buildings was changed to 150 mm. Thickness of shear walls in the parking floors was changed to 300 mm and in superstructures – to 160 mm. The base isolation system is designed within the parking floors (basements). All columns of this floors at the level immediately below the seismic isolators located by clusters are connected by so-called lower beams with the cross-section 700×400(h) mm. No slab envisaged at this level.

Then immediately above the seismic isolators so-called upper beams with the cross-section 700×750(h) mm are designed and structurally connected in horizontal direction by a 150 mm thick slab.

For comparison, detailed data on consumption and cost of the construction materials in the different structural elements (including seismic isolators and the beams below and above them) are presented in Table 1.

Table1. *Comparison of consumption and cost of the concrete and steel in the structural elements of the 16- and 10-story R/C frame buildings with shear walls of the multifunctional residential complex "Our Yard" for two cases: when buildings are fixed base and base isolated*

Structural elements		Fixed base buildings	Base isolated buildings
Consumption of concrete	Foundation	3131(25)	1648 m^3 (B25)
	Columns	3148 m^3 (B25)	1499 m^3 (B20)
	Beams	4254 m^3 (B25)	2488 m^3 (B20)
	Shear walls	2715 m^3 (B25)	1939 m^3 (B20)
	Slabs	4308 m^3 (B25)	3282 m^3 (B20)
	Beams below seismic isolators	-	334 m^3 (B25)
	Beams above seismic isolators	-	705 m^3 (B25)
Total consumption of concrete		17556 m^3	11895 m^3
Total consumption of steel		2635 t (150kg/m^3)	1071 t (90kg/m^3)
Total cost	of concrete	$ 1,773,156	$ 1,179,500
	of steel	$ 2,239,750	$ 910,350
	of seismic isolators	-	$ 270,200
Total cost of construction materials for the whole building		$ 4,012,906	$ 2,360,050
Savings comprise			41%

Consequently, due to application of base isolation strategy the volume of concrete in structural elements of the considered residential complex was reduced by a factor of 1.5 on average. At the same time the amount of steel was reduced by about 2.5 times.

Expenditures of Construction Materials in the 17-Story Base Isolated Building of the Multifunctional Residential Complex "Sevak" And Their Comparison with Expenditures in the Fixed Base Building of the Same Architectural Solution

Foundation of the fixed base building was designed as a solid slab with the thickness of 1500 mm. Unlike the buildings described above, at the time when the author started redesigning of this building applying seismic isolation system, the mentioned foundation of the fixed base building was almost constructed.

That is why practically no changes were applied to the previously designed foundation. Cross-section of columns in the parking and ground floors was 750x750 mm and in superstructure – 600x600 mm.

Cross-section of beams in the parking and ground floors was 700x600(h) mm and in superstructure – 600x520(h) mm. Thickness of the floors' slabs at all levels of fixed base building was 200 mm.

Thickness of shear walls in the parking and ground floors was 400 mm and in superstructure – 300 mm.

However, in the base isolated building cross section of columns in the parking and ground floors was changed to 650x650 mm, but in superstructure it was changed to 400x400 mm. Cross section of beams in the parking and ground floors was changed to 600x500(h) mm and in superstructure – to 400x350(h) mm.

Thickness of the floors' slabs at all levels of base isolated building was changed to 120 mm. Thickness of shear walls in the parking and ground floors was changed to 300 mm and in superstructure – to 160 mm.

The base isolation system is designed above the two parking and one commercial floors. All columns of the commercial floor at the level immediately below the seismic isolators are connected by lower beams with the cross-section 650×500(h) mm. Then immediately above the seismic isolators upper beams with the cross-section 650×700(h) mm are designed and structurally connected in horizontal direction by a 150 mm thick slab.

For comparison, detailed data on consumption and cost of the construction materials in the different structural elements (including seismic isolators and the beams below and above them) are presented in Table 2.From the presented data it follows that due to application of base isolation strategy the volume of concrete in structural elements of the considered residential complex was reduced by a factor of 1.3 on average. At the same time the amount of steel was reduced by about 2.0 times.

Table2. *Comparison of consumption and cost of the concrete and steel in the structural elements of the 17-story R/C frame building with shear walls of the multifunctional residential complex "Sevak" for two cases: when building is fixed base and base isolated*

Structural elements		Fixed base building	Base isolated building
Consumption of concrete	Foundation	910 m^3 (B25)	865 m^3 (B25)
	Columns	474 m^3 (B25)	360 m^3 (B20)
	Beams	1074 m^3 (B25)	579 m^3 (B20)
	Shear walls	1108 m^3 (B25)	857 m^3 (B20)
	Slabs	2258 m^3 (B25)	1768 m^3 (B20)
	Beams below seismic isolators	-	60 m^3 (B25)
	Beams above seismic isolators	-	102 m^3 (B25)
Total consumption of concrete		5824 m^3	4591 m^3
Total consumption of steel		943 t (162kg/m^3)	468 t (102 kg/m^3)
Total cost	of concrete	$ 582,420	$ 436,145
	of steel	$ 848,700	$ 421,200
	of seismic isolators	-	$ 112,240
Total cost of construction materials for the whole building		$ 1,431,120	$ 969,585
Savings comprise			32%

Expenditures Of Construction Materials In The 15-Story Base Isolated Building Of The Multifunctional Residential Complex "Avan" And Their Comparison With Expenditures In The Fixed Base Building Of The Same Architectural Solution

Foundation of the fixed base building was designed as a solid slab with the thickness of 1500 mm. Cross section of columns in the ground floor was 700x700 mm and in superstructure – 600x600 mm. Cross section of beams in the ground floor was 700x600(h) mm and in superstructure – 600x520(h) mm. Thickness of the floors' slabs at all levels of fixed base building was 200 mm. Thickness of shear walls in the ground floor was 400 mm and in superstructure – 300 mm. However, in the base isolated building the concept of foundation was changed to the strip beams with the cross section of 800×1500(h) mm. Cross section of columns in the ground was changed to 600x600 mm, but in superstructure it was changed to 400x400 mm. Cross section of beams in the ground floor was changed to 600x500(h) mm and in superstructure – to 400x350(h) mm. Thickness of the floors' slabs at all levels of base isolated building was changed to 120 mm. Thickness of shear walls in the ground floor was changed to 200 mm and in superstructure – to 160 mm.

The base isolation system is designed within the ground floor. All columns of this floor at the level immediately below the seismic isolators located also by clusters are connected by lower beams with the cross-section 600×400(h) mm. No slab envisaged at this level. Then immediately above the seismic isolators upper beams with the cross-section 600×750(h) mm are designed and structurally connected in horizontal direction by a 120 mm thick slab. For comparison detailed data on consumption and cost of the construction materials in the different structural elements (including seismic isolators and the beams below and above them) are presented in Table 3. From the presented data it follows that due to application of base isolation strategy the volume of concrete in structural elements of the considered residential complex was reduced by a factor of 1.5 on average. At the same time the amount of steel was reduced by about 2.4 times.

Table3. *Comparison of consumption and cost of the concrete and steel in the structural elements of the 15-story R/C frame building with shear walls of the multifunctional residential complex "Avan" for two cases: when building is fixed base and base isolated*

Structural elements		Fixed base building	Base isolated building
	Foundation	825 m^3 (B25)	450 m^3 (B25)
	Columns	567 m^3 (B25)	363 m^3 (B20)
	Beams	1387 m^3 (B25)	853 m^3 (B20)
	Shear walls	747 m^3 (B25)	534 m^3 (B20)

Consumption of concrete	Slabs	1940 m^3 (B25)	1212 m^3 (B20)
	Beams below seismic isolators	-	76 m^3 (B25)
	Beams above seismic isolators	-	149 m^3 (B25)
Total consumption of concrete		5466 m^3	3637 m^3
Total consumption of steel		765 t (140kg/m^3)	346 t (95 kg/m^3)
Total cost	of concrete	$ 546,600	$ 345,515
	of steel	$ 688,500	$ 311,400
	of seismic isolators	-	$ 148,200
Total cost of construction materials for the whole building		$ 1,235,100	$ 805,515
Savings comprise			35%

Conclusions

Several remarkable projects are mentioned in the paper to demonstrate the leading role of Armenia in the world in construction of new and retrofitting of existing base or roof isolated buildings of different types applying seismic isolation technologies, approaches, and strategies developed by the author of this paper.

Progressive provisions of the Chapter 10 “Buildings and Structures with Seismic Isolation Systems” of Armenian Seismic Code substantially contribute to the design and construction of low-cost seismic isolated buildings. Input accelerations of 0.4g-0.5g at the foundation bed get damped due to seismic isolation about 2.5-3.0 times in the superstructures. Comparative analyses have shown that huge amount of reinforcement could be reduced in superstructures of seismic isolated buildings. In addition, cross-sections of the bearing structures (columns, beams, shear walls, floor slabs) are smaller, and there is no need to apply high strength concrete for them. Therefore, large amounts of concrete and cement may also be saved in superstructures. In case of retrofitting of existing buildings applying seismic isolation technologies there is no need to strengthen the superstructures. Thus, in Armenia seismic isolation decreases the cost of construction of medium- and high-rise buildings from 30% to 40% in comparison with the cost of conventional construction of fixed base buildings. Also, seismic isolation decreases the cost of retrofitting of the 3-9-story existing buildings from 3 to 5 times in comparison with the cost of conventional strengthening of existing buildings. These magnitudes of the cost reduction consider the cost of manufacturing, testing, and installation of SILRSBs.

References

[1] Foti D. and Mongelli M. (2011). Isolatori sismici per edifice esistenti e di nuova costruzione, Dario Flaccovio Editore, (in Italian).

[2] Fujita T. (1999). Demonstration of Effectiveness of Seismic Isolation in the Hanshin-Awaji Earthquake and Progress of Applications of Base-Isolated Buildings. Report on 1995 Kobe Earthquake by INCEDE, ERC and KOBEnet. Institute of Industrial Science, University of Tokyo - Voluntary Information Network for Earthquake Disaster Mitigation. Serial No. 15: pp. 197-216.

[3] Martelli A., Forni M. & Clemente P. (2012) Recent Worldwide Application of Seismic Isolation and Energy Dissipation and Conditions for Their Correct Use, Proceedings of the 15th WCEE, Lisbon, Portugal.

[4] Melkumyan M. (1994) Base Isolation Retrofit Project in Armenia, Proceedings of the UNIDO Workshop on Use of Natural Rubber Based Bearings for Earthquake Protection of Small Buildings. Jakarta, Indonesia, 1994.

[5] Melkumyan M. (2002). Seismic Isolation of Civil Buildings in Armenia. Journal of Progress in Structural Engineering and Materials, Vol.4 No.4, pp. 344-352.

[6] Melkumyan M. (2004). Recent Applications of Seismic Isolation in Civil Buildings in Armenia. Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, British Columbia, Canada, paper No.3318.

[7] Melkumyan M., Gevorgyan E. and Hovhannisyan H. (2005). Application of base isolation to multifunctional multistory buildings in Yerevan, Armenia. Proceedings 9th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Kobe, Japan, Vol. 2: pp. 119-127.

[8] Melkumyan M. (2005). Current situation in application of seismic isolation technologies in Armenia”. Proceedings International Conference dedicated to the 250th anniversary of the 1755 Lisbon Earthquake, Lisbon, Portugal, pp. 493-500.

[9] Melkumyan M. & Hakobyan A. (2005). Testing of seismic isolation rubber bearings for

different structures in Armenia. Proceedings 9th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Kobe, Japan, Vol. 2: pp. 439-446.

[10] Melkumyan M. & Hovhannisyan H. (2006a). New approaches in analysis and design of base isolated multistory multifunctional buildings. Proceedings 1st European Conference on Earthquake Engineering and Seismology (a joint event of the 13th ECEE & 30th General Assembly of the ESC), Geneva, Switzerland, Paper 194.

[11] Melkumyan M. (2006b). Armenia is the one of the world leaders in development and application of base isolation technologies. “MENSHIN” Journal of the Japan Society of Seismic Isolation, No. 54: pp. 38-41.

[12] Melkumyan M. (2007). Seismic isolation of civil structures in Armenia - development and application of innovative structural concepts. Proceedings ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Rethymno, Crete, Greece, Paper 1691.

[13] Melkumyan M. & Gevorgyan E. (2008). Structural concept and analysis of a 17-Story multifunctional residential complex with and without seismic isolation system. Proceedings 2008 Seismic Engineering Conference Commemorating the 1908 Messina and Reggio Calabria Earthquake, Reggio Calabria, Italy, Part Two: pp.1425 - 1432.

[14] Melkumyan M. (2009). Armenian seismic isolation technologies for civil structures - example on application of innovative structural concepts, R&D and design rules for developing countries. Proceedings 11th World Conference on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Guangzhou, China, Paper K01.

[15] Melkumyan M. & Gevorgyan E. (2010). Structural concept and analysis of 18-story residential complex “Northern Ray” with and without base isolation system. Proceedings of the 14th European Conference on Earthquake Engineering, Ohrid, Macedonia, Parer No. 480.

[16] Melkumyan M. (2011a). New solutions in seismic isolation. “LUSABATS”, Yerevan, ISBN 978-9939-808-76-5, 280p.

[17] Melkumyan M. & Gevorgyan E. (2011b). Structural Concept and Analysis of 20-Story Business Center “Elite Plaza” with and without Base Isolation System. Proceedings of the 12th World Conference on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Sochi, Russia, paper No.41.

[18] Melkumyan M. (2013a). New Approach in Design of Seismic Isolated Buildings Applying Clusters of Rubber Bearings in Isolation Systems. Earthquakes and Structures. An International Journal, Vol.4, No. 6, pp.587-606.

[19] Melkumyan M. (2013b). Comparison of the analyses results of seismic isolated buildings by the design code and time histories. Journal of Civil Engineering and Science, Vol.2, Issue 3: pp.184-192.

[20] Melkumyan M. (2014a). New Structural Concept for an Existing 4-story Reinforced Concrete Industrial Frame Building to be Retrofitted by Base Isolation and Simultaneously Reconstructed into a 6-story Hotel Building. Engineering and Technology, Vol.1, No.1, pp.1-12.

[21] Melkumyan M. (2014b). Structural Concept and Analysis of the 15-Story Base Isolated Apartment Building “Avan”. International Journal of Engineering Research and Management, Vol.1, Issue 7, 157-161.

[22] Melkumyan M. (2014c). Structural Concept and Analysis of the 17-Story Base Isolated Apartment Building “Sevak”. International Journal of Engineering and Applied Sciences, Vol.1, Issue 3, 13-17.

[23] Melkumyan M. (2014d). Seismic Isolation Retrofitting Experience in Armenia and New Structural Concept for an Existing 8-Story Reinforced Concrete Hospital Building to be Retrofitted by Base Isolation. Study of Civil Engineering and Architecture (SCEA), Vol.3, pp.78-92.

[24] Melkumyan M. (2015a). Unique Retrofitting Technology for Base Isolation of an Existing 8-story R/C Hematology Center Hospital Frame Building with Shear Walls. - Journal of Civil Engineering and Architecture Research (JCEAR), Ethan Publishing Company, CA, USA, Vol.2, No.12, pp.1153-1162.

[25] Melkumyan M. (2015b). Structural Concept and Analysis of the 4-story Base Isolated Hospital Building “Vanadzor”. - American Journal of Environmental Engineering and Science, Vol.2, No.5, pp.44-52.

[26] Melkumyan M. (2017). Demonstration of the Cost-Effectiveness of Base Isolation Strategy on the Example of the 16-Story Reinforced Concrete Frame Building with Shear Walls. Journal of Scientific and Engineering Research (JSAER), ISSN: 2394-2630, Vol.4, No.7, pp.317-326

[27] Melkumyan M. (2018). Savings in Consumption of Concrete and Steel and in the Related Cost of Various Reinforced Concrete Frame Buildings with Shear Walls Due to Implementation of Base Isolation Strategies. International Journal of Scientific Review (IJSR), Academic Research Publishing Group, ISSN(e): 2412-2599, ISSN(p): 2413-8835,

Vol.4, Issue 8, pp.68-73, DOI: https// doi.org/ 10.32861/sr.48.68.73.

[28] Melkumyan M. (2019). Seismic Isolation Strategies for Earthquake-Resistant Construction: Emerging Opportunities. “Cambridge Scholars Publishing”, UK, ISBN (10): 1-5275-1802-7, ISBN (13): 978-1-5275-1802-5, 2019, 268 p.

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