International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 11, Issue 9 [September. 2022] PP: 28-42

Overview of the Unique Seismic Isolation Technologies Developed in Armenia for New and Existing Buildings Providing their High Sustainability

Mikayel G. Melkumyan
Professor, Doctor of Sciences (Engineering), Academician
President of the Armenian Association for Earthquake Engineering
Director of the "Melkumyan Seismic Technologies" LLC

Abstract

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

Date of Submission: 01-09-2022 Date of Acceptance: 13-09-2022

The paper provides a clear picture on how and why did 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 for different types of buildings.
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.
To date there are 56 seismic isolated buildings in the country newly constructed or retrofitted by base or roof isolation systems. The number of seismically isolated buildings per capita in Armenia is one of the highest in the world – second after Japan. 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.
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. SILRSBs different by their shape and dimensions, as well as by damping (low, medium, and high) were designed by the author and about 5500 SILRSBs were manufactured in the country, tested locally, and applied in construction. The paper also 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.
Various 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.
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. 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. 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.

1. INTRODUCTION

This Chapter is a retrospective of author's work since 1993 on creation, development, and application of seismic isolation systems in construction of different types of new 1-20 story buildings, as well as strengthening and retrofitting of existing 3-9 story buildings.

Due to these works, Armenia is currently at the top level in the field of seismic isolation and being small and developing country Armenia stands side by side with powerful and advanced countries. I am proud of that! By the number of already constructed and retrofitted seismic isolated buildings per capita Armenia is second in the world after Japan. This fact is widely recognized by the international professional community. At the 15th World Conference on Earthquake Engineering in 2012 Prof. Martelli, Dr. Forni, and Dr. Clemente (Italy) have stated: "*It is worthwhile stressing that Armenia remains second, at worldwide level, and has the largest number of building applications of seismic isolation per number of residents, in spite of the fact that it is a still developing country*".

What is the most important in this successful story of my country on 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 Chapter provides a clear picture on how and why the created/invented by the author seismic isolation technologies make Armenia, the developing and once a low-income country, the world leader in the application of low-cost seismic isolation.

Below are some other views of prominent experts in the field of seismic isolation about our achievements. In the letter to the President of the republic of Armenia in 1995 Dr. Baker and Dr. Fuller (UK) have affirmed: "…*The project that particularly deserves commendation involves the rehabilitation of an existing five-story apartment block in the town of Vanadzor by cutting away the present foundation and inserting rubber mounts that will isolate the building from future earthquake ground motions. This is the first apartment building in the world to be so retrofitted… The design for this unique project was carried out by Dr. Mikayel Melkumyan and our institute wishes to offer heartiest congratulations to those leading this important work… Wide use of the technique for the rehabilitation of existing buildings developed in the project offers great potential benefit to countries with a high seismic risk such as Armenia… We can say with confidence that the rehabilitation project in Armenia is making an important addition to the technology of earthquake protection and will provide an example not only to Armenia but also to other earthquake-prone countries*".

Having visited Armenia, Prof. Kelly (USA) after seeing designed by the author buildings expressed his admiration for the works performed, and in his interview to the newspaper Republic of Armenia in 1997 said the following: "*I was impressed by innovative approach of Prof. Melkumyan, whom I have known for several years. He quickly developed and implemented the project of a seismically isolated building. Mikayel managed everything in the shortest possible time, even faster than it is done in America. In other countries, seismic isolation is usually applied in newly constructed buildings. But he took a bold step and has become the first in the world, implementing seismic isolation in the existing building*".

In his opinion sent to the All-Armenian Fund for the Award of the President of the Republic of Armenia in 2001 Prof. Kelly also declares: "*Dr. Mikayel Melkumyan, is a well-known specialist in the field of earthquake engineering. As a scientist and engineer he has an extraordinary capacity in identifying, stating, and solving scientific/engineering problems. His professional skills go beyond theoretical boundaries, and he is notable for this ability to apply and implement the scientific solutions in the practice of earthquake-resistant construction. Significance of his works is represented by large-scale implementation of base isolation and other advanced technologies in construction practice. The most important thing is that under the leadership of Dr. Melkumyan, the seismic isolation systems and the isolators themselves were designed, produced, and tested locally. It is also significant that these structures are much less expensive than conventional buildings. All these factors create a good basis for further implementation of base isolation in Armenia*".

In the Chapter 17 of the book "Earthquake Engineering in Europe" in 2010 Prof. Garevski (North Macedonia) has specified: "*In the developing countries, base isolation technique has rarely been used due to non-existence of domestic production of bearings and high cost of the bearings produced in the developed countries. There have been some attempts to popularize this technique through development of low-cost bearings and their installation in demonstration structures, but no attempt for production has been made and hence there has not been any mass application of such bearings. A greater success in application of base isolation (with isolation of a large number of buildings) was achieved in Armenia where, in addition to placement of isolators in buildings, their production was also adopted*".

In his interview to the Journal of the Builders Union of Armenia – Architecture and Construction, #6(64) of 2011 Prof. Anagnostopoulos (Greece) said the following: "*Prof. Mikayel Melkumyan is a very well-known* *worldwide for his pioneering works on this technique, base isolation, which is probably the future of the earthquake protection. Prof. Melkumyan published a book with his contributions in earthquake engineering in Armenia and with all the pioneering works of isolated buildings that he has designed here in Armenia. Now, from my international experience I do not really know anyone else and anywhere else in the world who has made so many designs of base isolated buildings. In this respect, I think that Prof. Melkumyan has placed Armenia in one of the top countries in the world as far as application of base isolation is concerned. As the matter of fact, if you take into account the size of Armenia, I would imagine that maybe Armenia is in the top two to three countries where base isolation has been used so extensively. I can tell you now that among many people in the world who worked and carry our research on base isolation Mikayel is unique in the fact that he is not only doing research in base isolation but he applies it as an engineer and you cannot find that many people worldwide who combine this – generating the knowledge and also applying the knowledge; and I am in the unique position to appreciate the difficulties in taking some theoretical research results and apply them into practice and making them practically useful. This is where Mikayel has to be congratulated. I am sure that his book will be extremely useful not just in Armenia but worldwide in many countries because it is a combination of theory and practice, and most of the books that you will find in the literature on base isolation are mainly theoretical*".

This Chapter will allow the reader to become acquainted with a number of unique, modern and cost-effective seismic isolation strategies, which can be easily, and in very short periods of time, implemented with high efficiency in newly constructed, as well as in existing buildings, making them earthquake proof without interruption of the use of the existing buildings. An important aspect here is that the Chapter's seismic isolation strategies are demonstrated on real examples of buildings with different structural systems, such as reinforced concrete (R/C) frame buildings with shear walls, stone, and R/C buildings with load-bearing walls, as well as buildings with asymmetric plans (Tables 1 and 2). The cost-effectiveness of the suggested strategies is further proved by comparative analyses carried out for buildings both with and without seismic isolation systems.

Table 1. Some of the existing buildings retrofitted in Armenia by base or roof isolation technologies

Buildings retrofitted by base isolation technology (Patent №579)	
Stone apartment	Stone school
	
R/C braced-frame hospital	R/C frame hotel
	
R/C braced-frame buildings retrofitted by roof isolation technology	

However, the main purpose of the Chapter is a call upon young engineers and scientists. The author wants them to know after reading this Chapter that even without support of the government and influential sponsors it is possible to achieve significant results in the science and practice of earthquake resistant construction. Achieving success in any area requires a frontrunner who will push forward his/her brainchild regardless of the barriers, provided that this brainchild brings a benefit to the country. Therefore, I would like to wish championship to young engineers and scientists, who could become frontrunners only through a vast sense of purpose, hard work, meticulous mind, constant quest and by never being content with what has already been achieved. Only this way we can bring glory and prosperity to our beloved Armenia.

Table 2. Some of newly constructed base isolated buildings in Armenia

STATISTICS ON BUILDINGS WITH APPLICATION OF SEISMIC ISOLATION TECHNOLOGIES IN ARMENIA

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. Furthermore, worldwide experience proves that seismic isolation is the most reliable technology. Excellent examples demonstrating the effectiveness and high reliability of seismically isolated buildings during the destructive Hanshin-Awaji earthquake in 1995 (Japan) [1] and the Great Sichuan Earthquake in 2008 (China) [2] are well known.

It is also known that the growth in the number of seismically isolated buildings is still quite slow, with the exception of some countries such as Japan, Italy, China, and currently Armenia. A serious reason for this is the lack of provisions in the seismic codes for analysis and design of such type of buildings [3]. This problem, however, was solved in Armenia and, thus, successful application of seismic isolation in the country is also conditioned by availability of relevant legal and technical documentation, including: a Chapter on "Buildings and Structures with Seismic Isolation Systems" in the National Design Code for Earthquake Resistant Construction, the "Guidelines for Design and Construction of Buildings with Application of Laminated Rubber-Steel Bearings", and the "Standards (Specifications) on Manufacturing of Seismic Isolation Laminated Rubber-Steel Bearings". All these documents were developed by the order of the Ministry of Urban Development, adopted by the Government of Armenia and are in force since 2006 [4].

It should be emphasized that Armenia was experiencing extremely hard times in 1993 when the works on development and research of seismic isolation technologies were initiated by the author of this Chapter. Since then, during a period of 28 years about 63 buildings and structures have been designed with application of base or roof isolation systems. Of these designed buildings the total number of already constructed and retrofitted buildings or those currently under construction and retrofitting has reached 56 (Fig. 1).

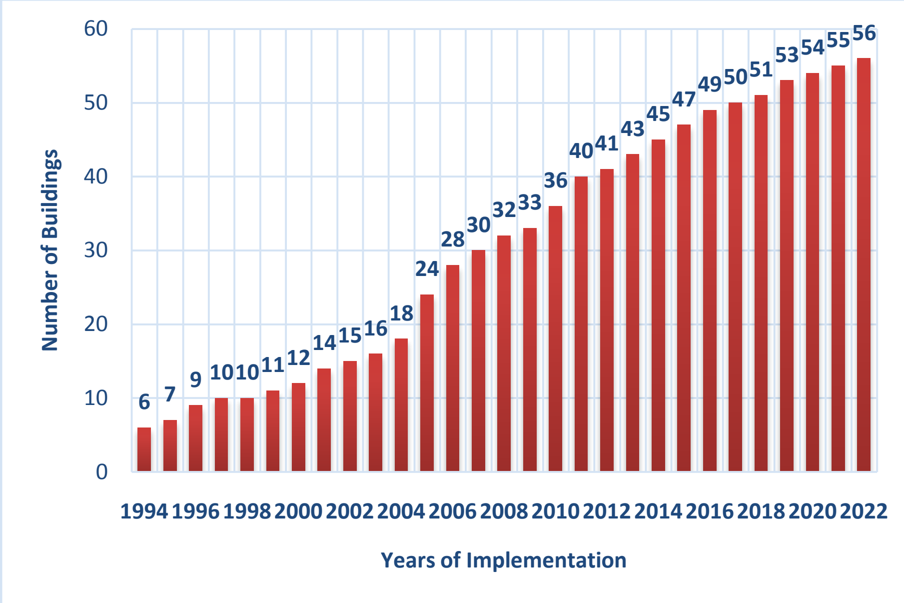


Figure 1. Number of seismic (base and roof) isolated buildings newly constructed or retrofitted in Armenia by years

Among them there are bathhouses, private residences, school buildings, clinic and hospital buildings, business and commercial centers, apartment buildings, hotels, and "Zvartnots" International Airport buildings. Corresponding number of rubber bearings manufactured and installed in Armenia by years is given in Figure 2. Detailed statistics on constructed and retrofitted buildings in Armenia designed by the author of this Chapter with application of seismic isolation technologies for the mentioned period of time is given below in the Tables 3-7 [5, 6].

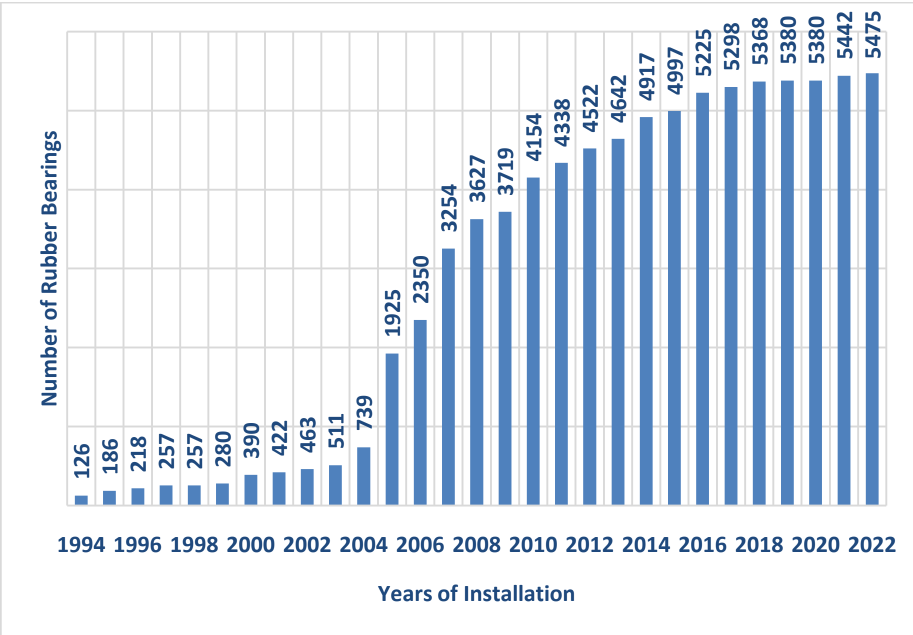


Figure 2. Number of rubber bearings installed in the newly constructed or retrofitted buildings in Armenia by years

Table 3. Statistics on buildings with application of seismic isolation technologies from 1994 to 2003

Building	Bathhouse with two 10 t water tanks in the attic space	Existing apartment building with stone bearing walls	Existing apartment building with R/C bearing frames and shear walls	Apartment building with R/C bearing walls
Type of seismic isolation	Base isolation	Base isolation	Additional Isolated Upper Floor (AIUF, roof isolation)	Base isolation
Dimensions of buildings in plan, (m)	21×12	52×15	19×19	33×14
Number of stories	1	5	9	4
Years of design	1994	1994-1995	1995	1996
Years of implementation	1994-1995	1995-1996	1996-1997	1997-1998
Number of buildings	6	1	2	1
Newly constructed or retrofitted	Newly constructed	Retrofitted	Retrofitted	Newly constructed
Place of implementation	Spitak (2), Gyumri (2), Vanadzor (2)	Vanadzor	Vanadzor	Spitak
Number and type of rubber bearings	126, LDRB*	60, HDRB**	32, HDRB	39, HDRB
Manufacturer of rubber bearings	NAIRIT, Armenia	TARRC, UK; Min Rubber and Sime Engineering Products, Malaysia	NAIRIT, Armenia; Min Rubber Products, Malaysia	Min Rubber Products, Malaysia

Table 3. Continued

Building	Apartment building with R/C masonry bearing walls	Single-family house with stone bearing walls	Existing school building No.4 with stone bearing walls	Clinic building with R/C bearing frames and shear walls
Type of seismic isolation	Base isolation	Base isolation	Base isolation	Base isolation
Dimensions of buildings in plan, (m)	34×20	15×15	38×21	47×20
Number of stories	4	2	3	3
Years of design	1999-2000	2001	2001	2002
Years of implementation	2000-2001	2001-2002	2002	2003
Number of buildings	2	1	1	1
Newly constructed or retrofitted	Newly constructed	Newly constructed	Retrofitted	Newly constructed
Place of implementation	Huntsman Village, Gyumri	Proshyan Village	Vanadzor	Stepanakert
Number and type of rubber bearings	110, MDRB***	16, MDRB	41, MDRB	48, MDRB
Manufacturer of rubber bearings	YFRTA, Armenia	YFRTA, Armenia	YFRTA, Armenia	YFRTA, Armenia

*LDRB - Low damping rubber bearing (5%-8%), **HDRB - High damping rubber bearing (10%-15%)
***MDRB - Medium damping rubber bearing (8-10%)

Table 4. Statistics on buildings with R/C bearing frames and shear walls with application of seismic isolation technologies from 2003 to 2006

Building	Residential house with dynamic damper	Apartment building in “Our Yard” complex	Apartment building in “Our Yard” complex	Apartment building “Cascade”
Type of seismic isolation	Base isolation	Base isolation	Base isolation	Base isolation
Dimensions of buildings in plan, (m)	14×14	58×21	32×23	45×17
Number of stories	2	10	16	11
Years of design	2003-2004	2004-2005	2004-2005	2005
Years of implementation	2004-2005	2005	2005	2005
Number of buildings	1	2	1	1
Newly constructed or retrofitted	Newly constructed	Newly constructed	Newly constructed	Newly constructed
Place of implementation	Jrvezh	Yerevan	Yerevan	Yerevan
Number and type of rubber bearings	16, MDRB	304, MDRB	160, MDRB	128, MDRB

Manufacturer of rubber bearings	GTMC, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia	Retine Noruyt, Armenia

Table 4. Continued

Building	Business center “Elite Plaza”	Apartment building in “Arami” complex	Apartment building in “Arami” complex	Apartment building in “Dzorap” complex	Apartment building in “Dzorap” complex
Type of seismic isolation	Base isolation	Base isolation	Base isolation	Base isolation	Base isolation
Dimensions of buildings in plan, (m)	42×36	33×32	52×33	32×33	67×29
Number of stories	20	14	16	13	16
Years of design	2005	2005	2005	2005-2006	2005-2006
Years of implementation	2005	2005	2005	2006	2006
Number of buildings	1	1	1	1	1
Newly constructed or retrofitted	Newly constructed	Newly constructed	Newly constructed	Newly constructed	Newly constructed
Place of implementation	Yerevan	Yerevan	Yerevan	Yerevan	Yerevan
Number and type of rubber bearings	246, MDRB	147, MDRB	224, MDRB	73, MDRB	239, MDRB
Manufacturer of rubber bearings	Retine Noruyt	Retine Noruyt	Retine Noruyt	Retine Noruyt	Retine Noruyt

Table 5. Statistics on buildings with R/C bearing frames and shear walls with application of seismic isolation technologies from 2006 to 2009

Building	Apartment building in “Northern Ray” complex	Commercial center/hotel	Apartment building “Baghramian”	Hotel building
Type of seismic isolation	Base isolation	Base isolation	Base isolation	Base isolation
Dimensions of buildings in plan, (m)	74×39	45×37	41×36	56×26
Number of stories	18	7	17	6
Years of design	2005-2007	2007-2008	2007-2008	2007-2008
Years of implementation	2007	2007	2008	2009
Number of buildings	2	1	1	1
Newly constructed or retrofitted	Newly constructed	Newly constructed	Newly constructed	Newly constructed
Place of implementation	Yerevan	Yerevan	Yerevan	Dilijan
Number and type of rubber bearings	904, MDRB	113, MDRB	271, MDRB	102, MDRB
Manufacturer of rubber bearings	Retine Noruyt, Armenia	Khachvar, Armenia	Retine Noruyt, Armenia	Khachvar, Armenia

Table 6. Statistics on buildings with application of seismic isolation technologies from 2010 to 2016

Building	Apartment building with R/C bearing frames and shear walls	School building with stone bearing walls	School building with stone bearing walls	Apartment building “Avan” with R/C bearing frames and shear walls
Type of seismic isolation	Base isolation	Base isolation	Base isolation	Base isolation
Dimensions of buildings in plan, (m)	23×25	33×15	37×16	40×28
Number of stories	13	2	2	15
Years of design	2010	2010	2010	2010
Years of implementation	2010	2010	2010	2011
Number of buildings	1	1	1	1
Newly constructed or retrofitted	Newly constructed	Newly constructed	Newly constructed	Newly constructed
Place of implementation	Yerevan	Vardakar Village	Akhurik Village	Yerevan
Number and type of rubber bearings	112, MDRB	36, MDRB	40, MDRB	247, MDRB
Manufacturer of rubber bearings	R.M.I.A, Armenia	R.M.I.A, Armenia	R.M.I.A, Armenia	R.M.I.A, Retine Noruyt

Table 6. Continued

Building	Apartment building "Sevak" with R/C bearing frames and shear walls	Medical center "Vanadzor" with R/C bearing frames and shear walls	Existing building with R/C bearing frames and shear walls of Yeolyan Hematology center	Existing industrial building with R/C bearing frames to be converted into hotel
Type of seismic isolation	Base isolation	Base isolation	Base isolation	Base isolation
Dimensions of buildings in plan, (m)	30×30	86×69	38×26	81×18
Number of stories	17	4	9	6
Years of design	2011	2013	2013	2014
Years of implementation	2012	2014	2014	2016
Number of buildings	1	1	1	1
Newly constructed or retrofitted	Newly constructed	Newly constructed	Retrofitted	Retrofitted
Place of implementation	Yerevan	Vanadzor	Yerevan	Yerevan
Number and type of rubber bearings	184, MDRB	260, HDRB	117, HDRB	158, HDRB
Manufacturer of rubber bearings	R.M.I.A.	Retine Noruyt	Retine Noruyt	Retine Noruyt

Table 7. Statistics on buildings with application of seismic isolation technologies from 2017 to 2022

Building	Two residential town-houses with stone bearing walls unified by one rigid base isolated R/C slab		Existing apartment building with R/C large panel bearing walls	Existing building with stone bearing walls to be converted into kindergarten
	town-house №1	town-house №2		
Type of seismic isolation	Base isolation		Base isolation	Base isolation
Dimensions of buildings in plan, (m)	11×9.75	11×9.75	34.6×11.2	30.2×19.7
Number of stories	3	3	9	3
Years of design	2017-2018		2019	2022
Years of implementation	2019	2020	2021	2022
Number of buildings	1	1	1	1
Newly constructed or retrofitted	Under construction	Under construction	Under retrofitting	Under retrofitting
Place of implementation	Jrvezh		Stepanakert	Stepanakert
Number and type of rubber bearings	12, HDRB		62, HDRB	33, HDRB
Manufacturer of rubber bearings	Shahnazaryans, Armenia	Shahnazaryans, Armenia	Shahnazaryans, Armenia	Shahnazaryans, Armenia

Note: "Shahnazaryans" LLC is a successor of R.M.I.A. Ltd

BRIEF INFORMATION ON THE AUTHOR'S APPROACH ON APPLICATION OF CLUSTERS OF SMALL RUBBER BEARINGS IN SEISMIC ISOLATED BUILDINGS

In the considered buildings the approach suggested earlier [5, 7, 8] on installation of the cluster of small rubber bearings instead of a single large bearing was used. Figure 3 shows that different numbers of SILRSBs are installed at different locations of the seismic isolation systems.

Figure 3. Examples on installation of clusters with different numbers of rubber bearings

However, all of them are of the same size and characteristics given in [6, 9]. They are made in Armenia from neoprene and were designed and tested locally [10]. 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 [11].

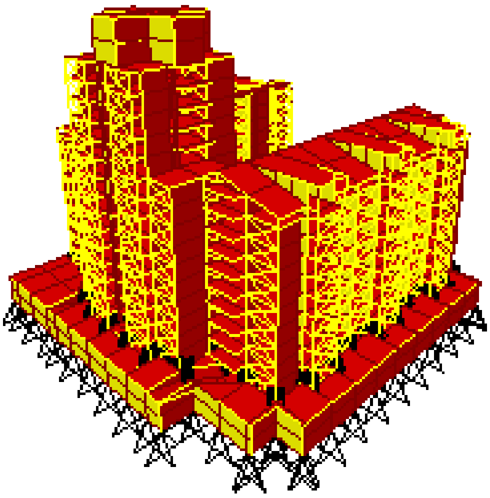
DEMONSTRATION OF THE COST-EFFECTIVENESS OF SEISMIC ISOLATION STRATEGIES ON THE EXAMPLES OF MULTISTORY REINFORCED CONCRETE FRAME BUILDINGS WITH SHEAR WALLS

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 [12].

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

Some data on this complex are given in Figure 4. 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 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.

Figure 4. 16- and 10-story buildings of the multifunctional residential complex "Our Yard" in the city of Yerevan and their design models

The base isolation system is designed within the parking floors (basements). All columns of these 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 8. 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.

Table 8. 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

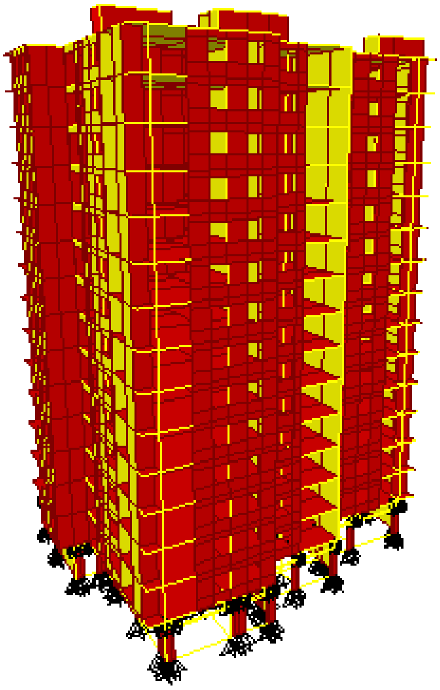
Structural elements		Fixed base buildings	Base isolated buildings
Consumption of concrete	Foundation	3131(25)	1648 m^3 (B25)
	Columns	3148 m^3 (B25)	1499 m^3 (B20)
	Beams	4254 m^3 (B25)	2488 m^3 (B20)
	Shear walls	2715 m^3 (B25)	1939 m^3 (B20)
	Slabs	4308 m^3 (B25)	3282 m^3 (B20)
	Beams below seismic 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%

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

Some data on this complex are given in Figure 5. 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.



The building with R/C bearing frames and shear walls was constructed in 2011.
Dimensions of the building - 40×28 m.
Total 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.

Figure 5. 15-story building of the multifunctional residential complex “Avan” in the city of Yerevan and its design model

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 9.
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.

Table 9. 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
Consumption of concrete	Foundation	825 m3 (B25)	450 m3 (B25)
	Columns	567 m3 (B25)	363 m3 (B20)
	Beams	1387 m3 (B25)	853 m3 (B20)
	Shear walls	747 m3 (B25)	534 m3 (B20)
	Slabs	1940 m3 (B25)	1212 m3 (B20)
	Beams below seismic isolators	-	76 m3 (B25)
	Beams above seismic isolators	-	149 m3 (B25)
Total consumption of concrete		5466 m3	3637 m3
Total consumption of steel		765 t (140kg/m3)	346 t (95 kg/m3)
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%

2. CONCLUSIONS

Detailed statistics on constructed and retrofitted buildings in Armenia designed by the author of this Chapter with application of the original seismic isolation technologies for the time period from 1994 to 2022 is given. Also the brief information on the author’s approach on application of clusters of small rubber bearings in seismic isolated buildings is mentioned.

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]. Fujita T. “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. IIS, University of Tokyo-Voluntary Information Network for Earthquake Disaster Mitigation. 1999, Serial No. 15, pp. 197-216.

[2]. Zhou F., Tan P., Heisha W., Huang X. “Recent Development and Application on Seismic Isolation in China”. - Proceedings of the JSSI 15th Anniversary International Symposium on Seismic Response Controlled Buildings for Sustainable Society. Tokyo, Japan, 2009, Paper No. OS-2.

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

[4]. Melkumyan M. “Achievements in Seismic Isolation in Armenia Determine Further Successful Development and Implementation of These Innovative Technologies”. - Proceedings of the JSSI 15th Anniversary International Symposium on Seismic Response Controlled Buildings for Sustainable Society. Tokyo, Japan, 2009, Paper No. OS-5, pp. 21-28.

[5]. Melkumyan M. “Armenian Seismic Isolation Technologies for Civil Structures - Example on Application of Innovative Structural Concepts, R&D and Design Rules for Developing Countries”. - Proceedings of the 11th World Conference on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures. Guangzhou, China, 2009, Paper No. K01.

[6]. Melkumyan M. "New Solutions on Seismic Isolation". - LUSABATS, Yerevan, Armenia, ISBN 978-9939-808-76-5, 2011, 280 p.

[7]. Melkumyan M. & Hovhannisyan H. "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, 2006, Paper No. 194.

[8]. Melkumyan M. "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, 2007, Paper No. 1691.

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

[10]. Melkumyan M. & Hakobyan A. "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, 2005, Vol. 2: pp. 439-446.

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

[12]. Melkumyan M. "Armenia is the World Leader in Development and Extensive Application of Low-Cost Seismic Isolation for Construction of New and Retrofitting of Existing Buildings". - Journal of Architecture and Construction (JAC), 2020, Volume 3, Issue 3, pp.43-60.