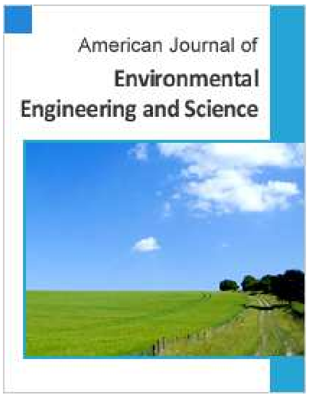
American Journal of Environmental Engineering and Science
2015; 2(5): 44-52
Published online October 20, 2015 (http://www.aascit.org/journal/ajees)
ISSN: 2381-1153 (Print); ISSN: 2381-1161 (Online)

American Association for Science and Technology



Keywords
Base Isolation,
Structural Concept,
Reinforced Concrete Structures,
Horizontal Stiffness,
Location of Isolators by Clusters,
Design Model,
Results of Analyses

Received: September 10, 2015
Revised: September 25, 2015
Accepted: September 27, 2015

Structural Concept and Analysis of the 4 - story Base Isolated Hospital Building "Vanadzor"

Mikayel Melkumyan

Center of New Construction Technologies, Armproject OJSC, Yerevan, Armenia

Email address

mmelkumi@yahoo.com

Citation

Mikayel Melkumyan. Structural Concept and Analysis of the 4 - story Base Isolated Hospital Building "Vanadzor". *American Journal of Environmental Engineering and Science.* Vol. 2, No. 5, 2015, pp. 44-52.

Abstract

Currently, using the developed by the author of this paper seismic base and roof isolation technologies, the number of already constructed and retrofitted buildings in Armenia has reached to 46. The number of base isolated buildings that are under construction is 3. Thus, the number of seismic isolated buildings per capita in Armenia is one of the highest in the world. In recent years seismic isolation technologies were extensively applied in construction of multi - story residential and business center complexes, as well as of schools, hotels and hospitals. They are briefly mentioned in the paper, which is, however, mainly dedicated to a 4 - story base isolated hospital building "Vanadzor" designed recently. Considered building has complicated architectural solution in plan and along its height. Construction of this hospital building is currently going on in the city of Vanadzor, the third biggest city in Armenia. The structural concept, including the new approach on installation of seismic isolation rubber bearings in this building by clusters, is described and some results of the earthquake response analyses are given. The building was analyzed using several time histories and also according to the requirements of the Armenian Seismic Code. Comparison of the obtained results indicates the high effectiveness of the proposed structural concept of isolation system and the need for further improvement of Seismic Code provisions regarding the values of the reduction factors for isolation systems.

1. Introduction

Base isolation of multistory buildings in Armenia is developing mainly through the projects financed by private companies. However, the projects on seismic isolation of schools and hospitals are implemented through the programs of the government of Armenia. Some of them are financed by the World Bank. The original and innovative structural concepts were developed during the last 15 years. The seismic isolation plane in all multistory buildings is designed above two or three parking floors, although there is a case where there are four floors below the isolation plane, of which two floors are underground and two floors are above ground. But in schools and hospitals the seismic isolation plane is designed within the limits of a one story basement. All the mentioned buildings (Fig. 1) 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 0.6 sec. Calculations were carried out by SAP 2000 and LIRA - SAPR2013 R2 software.

The results of the analyses of some of these buildings based on the Code were presented and discussed earlier (Melkumyan 2005, 2013). 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. 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 1.75 times in average (Melkumyan 2009). This means that some further measures should be taken in order to more realistically reflect characteristics 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 analysis carried out for the mentioned complexes and buildings 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.

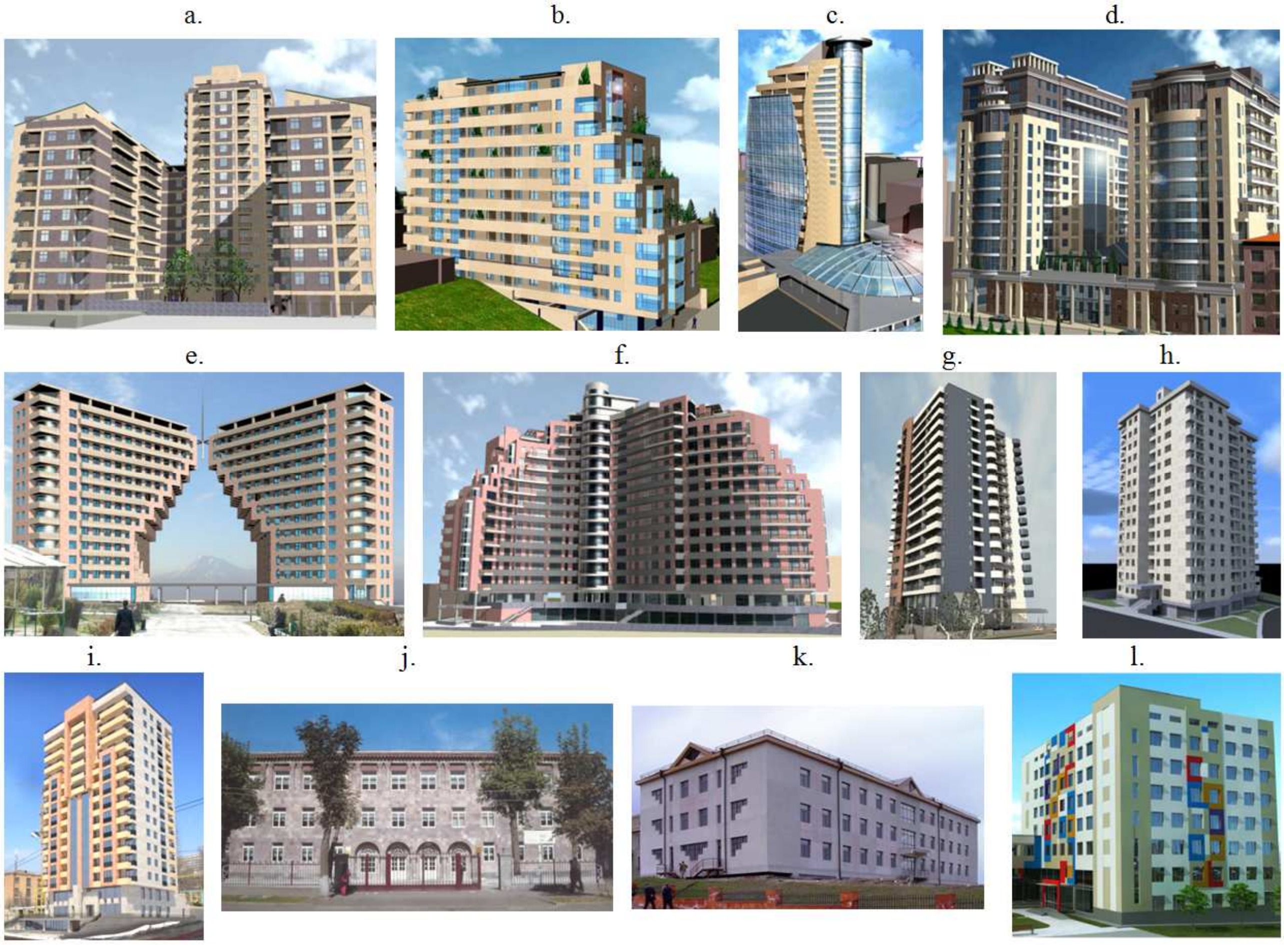


Fig. 1. *Views of the base isolated newly constructed or retrofitted buildings in the city of Yerevan (except items "j" and "k").*

a – 16 - and 10 - story buildings of the multifunctional residential complex "Our Yard" (Melkumyan 2005), b – 11 - story building of the multifunctional residential complex "Cascade" (Melkumyan et al. 2005), c – 20 - story business center "Elite Plaza" (Melkumyan 2011), d – 16 - and 14 - story buildings of the multifunctional residential complex "Arami" (Melkumyan & Hovhannisyan 2006, Melkumyan 2006), e – 18 - story buildings of the multifunctional residential complex "Northern Ray" (Melkumyan & Gevorgyan 2010), f – 16 - and 13 - story buildings of the multifunctional residential complex "Dzorap" (Melkumyan 2009), g – 17 - story building of the multifunctional residential complex "Baghramian" (Melkumyan & Gevorgyan 2008), h – 15 - story building of the multifunctional residential complex "Avan" (Melkumyan 2014), i – 17 - story building of the multifunctional residential complex "Sevak" (Melkumyan 2014), j – 3 - story #4 school building retrofitted by base isolation in the city of Vanadzor (Melkumyan et al. 2003), k – 3 - story base isolated Clinic Building in the city of Stepanakert (Melkumyan 2004), l – 8 - story Hematology Center Hospital Building retrofitted by base isolation (Melkumyan 2014)

2. Structural Concept of the 4 - story Base Isolated Hospital Building "Vanadzor"

One of the recent projects financed by the government of Armenia (Healthcare Project Implementation Unit, Ministry of Health, the World Bank credit) on analysis and design of 4 - story base isolated hospital building "Vanadzor" (Fig. 2) was accomplished in 2013. Construction of this building is currently going on in the city of Vanadzor.

Fig. 2. *Design view of the 4 - story base isolated hospital building "Vanadzor".*

Similarly to the hospital buildings briefly mentioned above, the considered building has a basement floor where the isolation system is designed. There are strong and rigid reinforced concrete (R/C) structural elements designed within the limits of the basement. The cross section of the foundation strips (Fig. 3) is T - shaped with the area of its bottom flange equal to 1400×400 (h) mm and of its web – 800×700 (h) mm. The cross section of most of the columns is also T - shaped so that the area of its flange is equal to 1800×600 mm and of its web – 900×600 mm. Some of the columns are designed with the L - shaped cross section. Consequently, the central core of all columns has a cross section equal to 600×600 mm. The height of the columns is equal to 2850 mm and the seismic isolators are installed just on top of them. The cross section of beams above the seismic isolators is equal to 600×650 (h) mm. The shear walls are designed with the thickness equal to 300 mm and they are located along the all exterior axes of the basement (see Fig. 3). Some of the shear walls are solid and others have door or window openings.

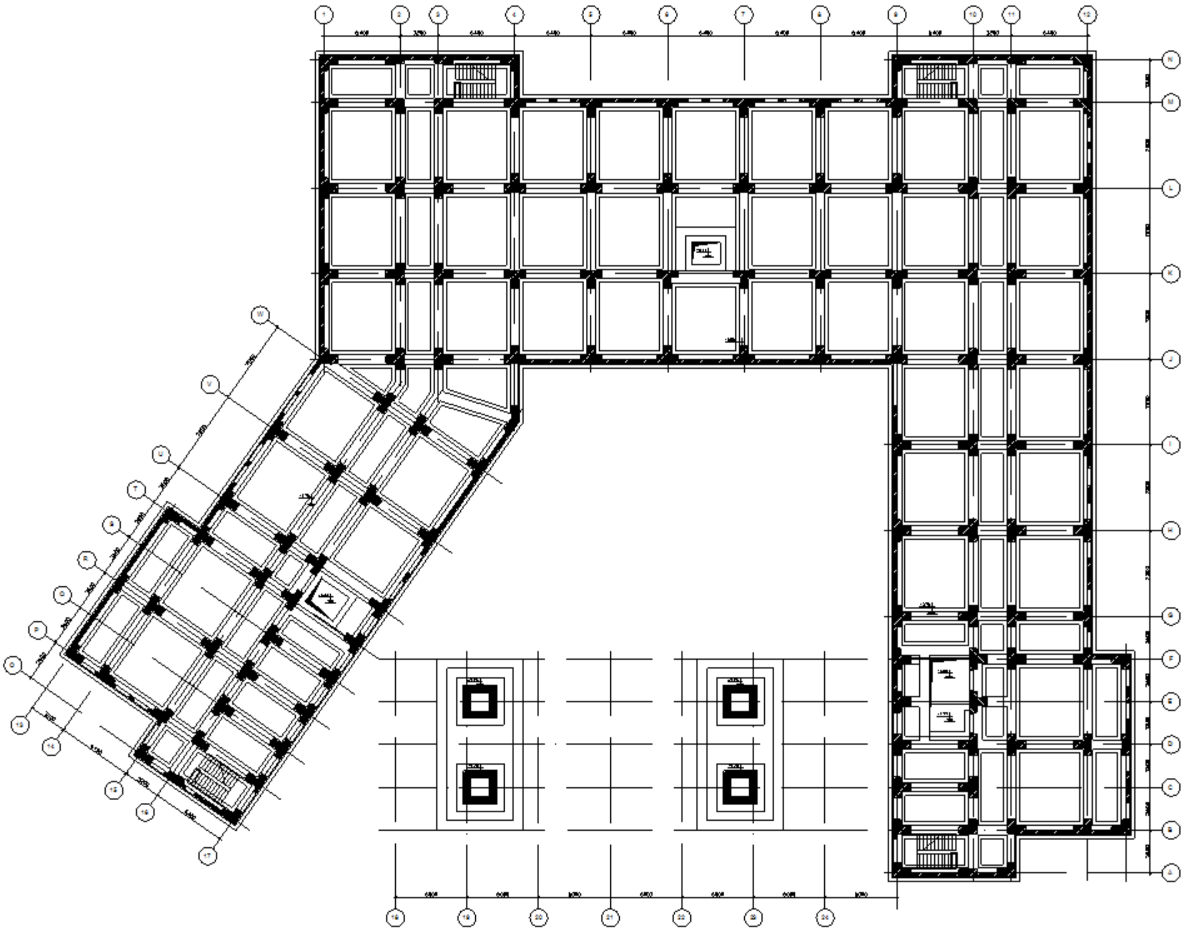


Fig. 3. *Plan of foundation strips and location of columns and shear walls at the mark of –3.70 in the 4 - story base isolated hospital building "Vanadzor".*

The accepted structural solution allowed obtaining a rigid system below the isolation plane.

This provides a good basis for effective and reliable behavior of isolators during the seismic impacts. Of course the superstructure (the part of building above the isolation plane, which consists of 3 floors) should have substantial rigidity for the same purpose. This was achieved by using R/C columns with cross section of 400×400 mm and 200 mm thick shear walls around the staircases and elevators' shafts. The thickness of R/C slabs was set at 150 mm for all floors. Plan of location of seismic isolators is shown in Fig. 4.

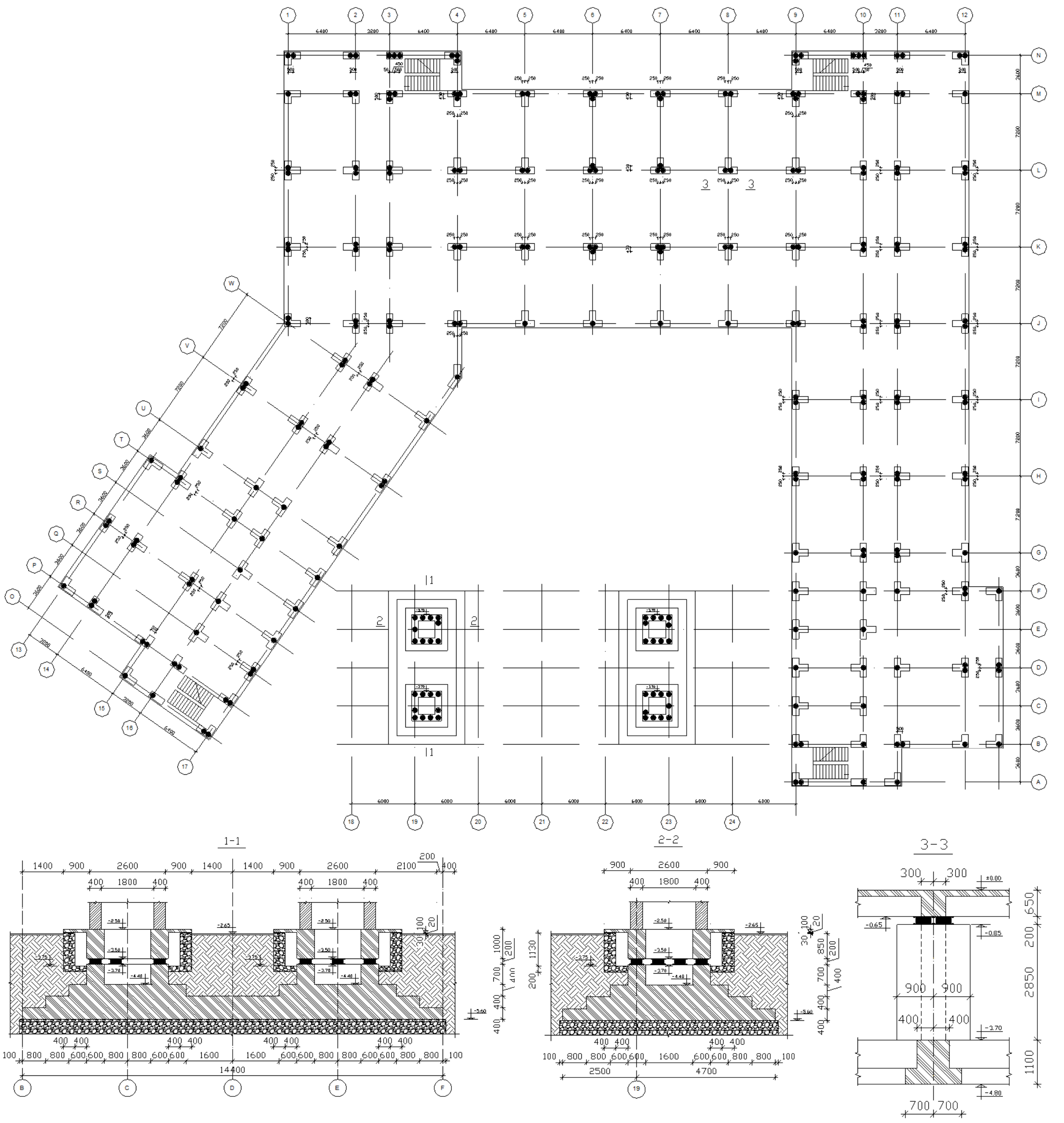


Fig. 4. *Plan of location of seismic isolation rubber bearings at different marks in the 4 - story base isolated hospital building "Vanadzor".*

In the considered building the approach suggested earlier (Melkumyan & Hovhannisyan 2006, Melkumyan 2007, 2009) on installation of the clusters of small rubber bearings instead of a single large bearing under the columns was used. Corresponding examples of installed isolators are shown in Fig. 5.

Fig. 5. *Examples on installation of rubber bearings' clusters in the 4 - story base isolated hospital building "Vanadzor" in the course of construction.*

From Figures 4 and 5 it can be seen that different numbers of rubber bearings are installed under the different structural elements. However, all of them are of the same size (diameter 380 mm, height 202 mm) and characteristics. They have horizontal stiffness equal to 0.81 kN/mm, a damping factor of about 13 - 15%, can develop horizontal displacement of up to 280 mm (about 220% of shear strain), and can carry a vertical design load of up to 1500 kN. They are made from neoprene and were designed and tested locally (Melkumyan 2001, Melkumyan & Hakobyan 2005).

The approach on installation of the cluster of small rubber bearings instead of a single large bearing is not a typical one for the buildings with isolation systems. The advantages of this approach are the following: increased seismic stability of the building; more uniform distribution of the vertical dead and life loads as well as additional vertical seismic loads on the rubber bearings; small bearings can be installed by hand without using any mechanisms; easy replacement of small bearings, if necessary, without using any expensive equipment; easy casting of concrete under the steel plates with anchors and recess rings of small diameter for installation of bearings; neutralization of rotation of buildings by manipulation of the number and location of bearings in the seismic isolation plane, etc. (Foti and Mongelli 2011, Melkumyan 2011). 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 (Melkumyan 2014). Thus, thanks to the suggested approach, more rational solution can be achieved, which is increasing the effectiveness of isolation system in general.

3. Results of Analysis of the 4 - story Base Isolated Hospital Building "Vanadzor"

Earthquake response analysis of the considered building was carried out using LIRA - SAPR2013 R2 software as well as SAP 2000 non - linear program and 8 selected time histories recorded in Armenia (7.12.88 Spitak, EW and NS directions), Iran (20.06.90 Manjil, NE direction), Japan (17.12.87 Chiba, NS direction), USA (09.03.49 Hollister, 20.12.54 Eureka, NE direction and 17.10.89 Loma Prieta), and former Yugoslavia (15.04.79 Bar, EW direction) and scaled to 0.52g acceleration. Also the building was analyzed based on the provisions of the Armenian Seismic Code. The design model (Fig. 6) was developed by application of different types of finite elements for shear walls, floor slabs, columns and beams, as well as for seismic isolators.

Calculations were carried out taking into account the non - linear behavior of seismic isolation rubber bearings with the following input parameters: yield strength – 56 kN; yield displacement – 19mm; effective horizontal stiffness – 0.81 kN/mm. As for the above mentioned buildings the soil conditions of the site where the considered building was going to be constructed correspond to category II, for which the soil conditions coefficient k_0=1 and the site prevailing period of vibrations 0.3≤T0≤0.6 sec. Armenian Seismic Code specifies several types of soils related to category II: (i) rocks with uniaxial ultimate compression strength of less than 15 MPa; (ii) gravelly sands of high and medium coarseness, high and medium density, with low moisture content; (iii) fine and pulverescent sands of high and medium density, with low moisture content. The site is located in zone 3, where the expected maximum acceleration is equal to a=400 cm/sec2 (0.4g).

There are different allowable damage coefficients envisaged in the Code. For this particular case of R/C frame building with shear walls it is required to apply for superstructure the allowable damage coefficient (reduction factor) k_1=0.4 but for seismic isolators and the structures below the isolation plane – k_1=0.8. Actually, the Code requires that any base isolated building of the mentioned type should be analyzed twice: first, by applying k_1=0.8 and the obtained results will serve as a basis to design the isolation system and structures below it, and then the second analysis should be carried out by applying k_1=0.4 and the derived results will serve as a basis to design the superstructure.

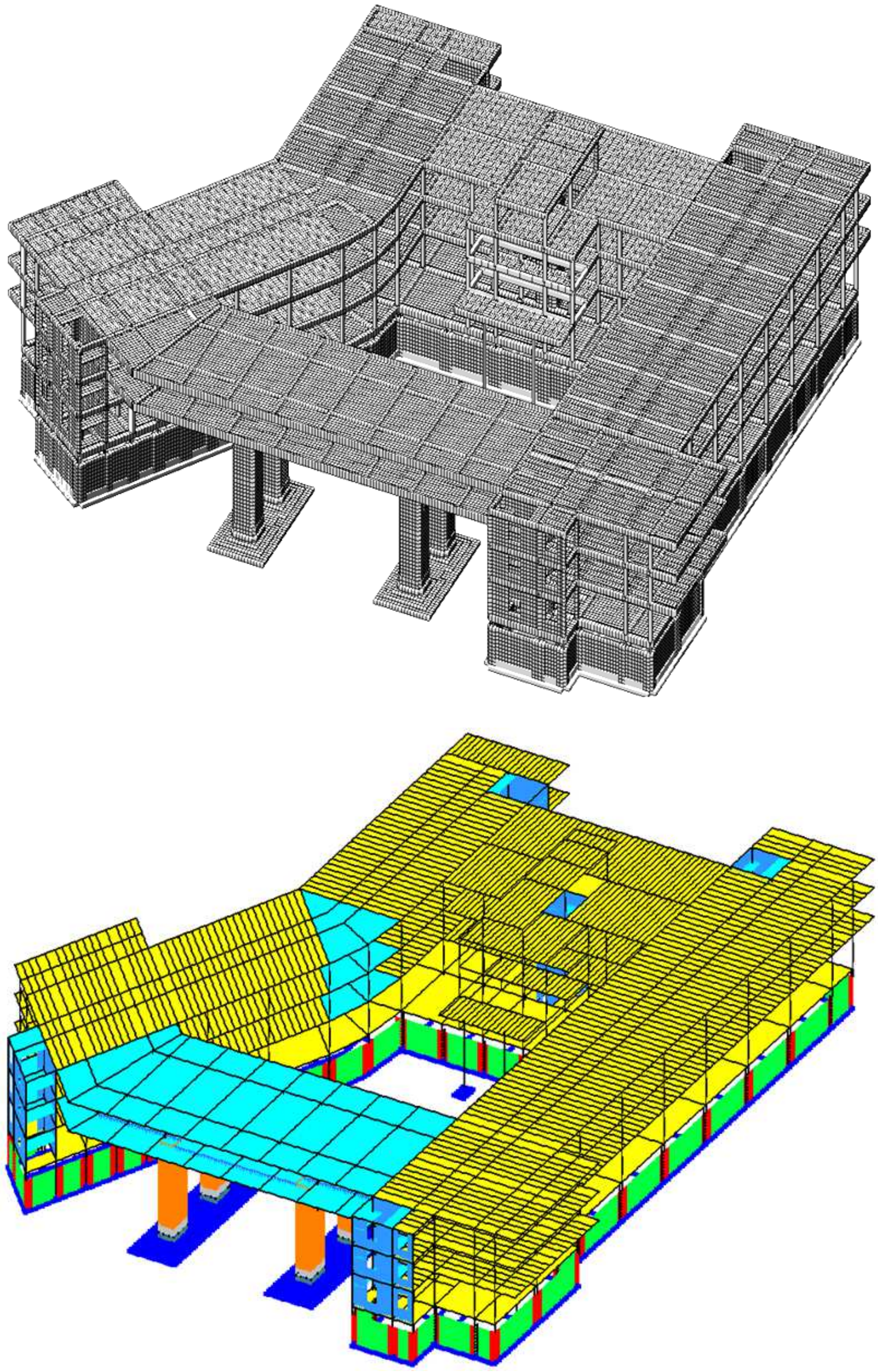


Fig. 6. *Design model of the 4 - story base isolated hospital building "Vanadzor". The model is given in two versions for better understanding.*

Importance coefficient of the building – k_2=1.3 and taking this into account the building was analyzed under the seismic impact of 0.52g (0.4g×1.3). Some results of the analyses by the Armenian Seismic Code and time histories are given in Tab. 1.

Tab. 1. *Some results of the analyses of 4 - story base isolated hospital building "Vanadzor" by the Armenian Seismic Code and time histories.*

Parameters obtained by the analysis based on the Armenian Seismic Code		
Period of vibrations (sec)	T_x=1.85*	T_y=1.81**
Maximum inter - story drift (mm)	11.0 (k_1=0.4)	14.2 (k_1=0.4)
Horizontal shear force on the level of foundation (kN)	22640 (k_1=0.4) 40970 (k_1=0.8)	24630 (k_1=0.4) 43530 (k_1=0.8)
Maximum displacement of the isolation system (mm)	102.0 (k_1=0.4) 178.0 (k_1=0.8)	111.0 (k_1=0.4) 195.0 (k_1=0.8)
Average parameters obtained by the 8 time histories analyses		
Maximum inter - story drift (mm)	6.5	8.3
Horizontal shear force on the level of foundation (kN)	18360	19780
Maximum displacement of the isolation system (mm)	105.0	114.0

* Period of vibrations along the horizontal axes of the building
** Period of vibrations along the vertical axes of the building

The carried out earthquake response analyses have shown that in comparison with the fixed base buildings, seismic isolation significantly reduces the maximum spectral acceleration, proving to be cost effective for the isolated structures and ensuring high reliability of their behavior under seismic impacts (Naeim & Kelly 1999, Fujita 1999, Saito 2006, Martelli et al. 2008, Melkumyan 2011, Melkumyan 2014). From the obtained results it follows that the first mode vibrations' periods of base isolated building in longitudinal (X) and transverse (Y) directions are almost equal to each other. Thanks to the proposed approach of location of rubber bearings by clusters in seismic isolation system, in none of the isolators the vertical force exceeds 1500 kN. More or less uniform distribution of the vertical loads upon the rubber bearings was achieved and also no rotation in the building's isolation system and, consequently, in superstructure was observed.

It also can be noticed that the displacements of isolation system, inter - story drifts and horizontal shear forces obtained by calculations of the base isolated building by the Armenian Seismic Code are close to the same values obtained by the time history analysis when the applied allowable damage coefficient (reduction factor) k_1=0.4. But in case if k_1=0.8 then Code based results regarding the horizontal shear forces are higher by a factor of 2.2 and those regarding the maximum inter - story drifts and maximum displacements of the isolation system are higher by a factor of 1.75 in average. Therefore, the Code needs a more accurate designation of reduction factors for seismic isolation systems. At this stage it is suggested by the author of this paper to accept for zone 3 in calculations based on the Code k_1=0.6 for seismic isolators and the structures below the isolation plane in the next edition of the Code, as a compromise solution.

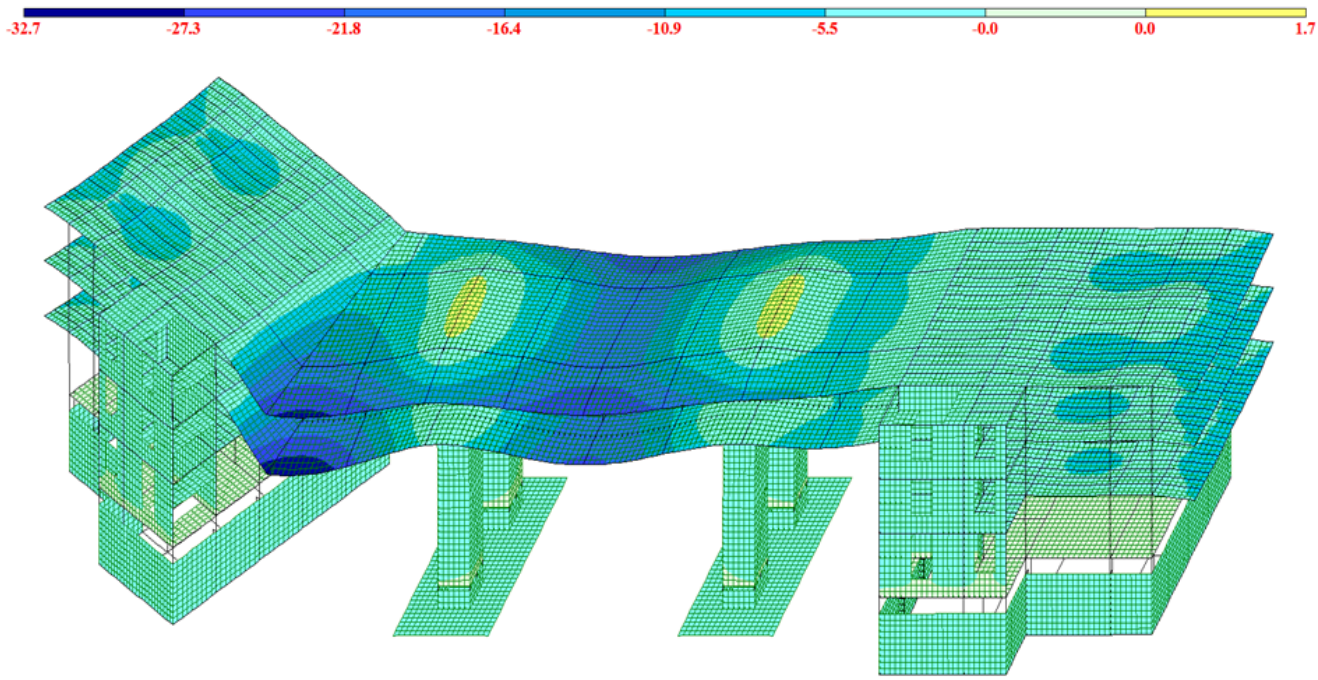


Fig. 7. *The deformed state of the front part of 4 - story base isolated hospital building "Vanadzor" under the action of the vertical static design loads.*

From the above given description of the hospital building "Vanadzor" and from Figures 2 and 6 it can noticed that the front of the building has a unique architectural and structural solution. In this part design envisages construction of only fourth floor which connects like a bridge the left and right wings of the building between the axes "17" and "9". Within the limits of its span this so called "bridge" is supported by four hollow columns with outside dimensions equal to 2600×2600 mm and inside dimensions – 1800×1800 mm (see section 1 - 1 in Fig. 4). Under each of such columns ten seismic isolation rubber bearings are installed with different location as it is shown in Fig. 4. Obviously, that the differences in location of rubber bearings were dictated by the results of analysis. The deformed view of this part of the building under the action of the vertical static design loads is shown in Fig. 7, from where it is seen that the maximum vertical displacement is not more than 33 mm, which is within the allowable range.

4. Conclusions

The conducted study confirms that base isolation is one of the most effective technologies in earthquake resistant construction. It brings to simultaneous reduction of floor accelerations and inter - story drifts and to significant reduction of shear forces in comparison with the fixed base buildings. The suggested structural concept of the 4 - story base isolated hospital building "Vanadzor" and the new approach on installation of clusters of seismic isolation rubber bearings brings to rational solution of the whole bearing structure. It increases overall stability of the building and effectiveness of the isolation system, neutralizing the rotation in the building's isolation system and, consequently, in its superstructure. In this case almost uniform distribution of the vertical loads upon the rubber bearings was achieved. The obtained results also indicate that first mode vibrations' periods of base isolated building in longitudinal and transverse directions are almost equal to each other. Comparison of the Code based analyses results with those obtained by the time history analyses indicates that the shear forces at the level of isolation systems, the maximum displacements of the isolators, and the maximum inter - story drifts in the superstructures calculated based on the Armenian Seismic Code provisions are considerably higher than the same values calculated by the time histories. Therefore, the Armenian Seismic Code needs a more accurate designation of reduction factors for seismic isolation systems.

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. and Rizzo S. (2008). Seismic isolation: present application and perspectives. Proceedings of the ASSISi International Workshop on Base Isolated High - Rise Buildings, Yerevan, Armenia, pp. 1 - 26.

[4] Melkumyan M. (2001). The state of the art in development of testing facilities and execution of tests on isolation and bridge bearings in Armenia. Proceedings 5th World Congress on Joints, Bearings and Seismic Systems for Concrete Structures, Rome, Italy, Paper 044.

[5] Melkumyan M., Käppeli G., Khalatyan R., Hovivyan H. (2003). Application of seismic isolation for retrofitting of existing 3 - story stone building of the school #4 in the city of Vanadzor, Armenia. Proceedings of the 8th World Seminar on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures, Yerevan, Armenia, pp. 557 - 565.

[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. and 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. and Hovhannisyan H. (2006). 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. (2006). 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. and 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. and 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. (2011). New solutions in seismic isolation. “LUSABATS”, Yerevan.

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

[18] Melkumyan M. (2014). 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.

[19] Melkumyan M. (2014). Structural concept and analysis of the 15 - story base isolated apartment building “Avan”. International Journal of Engineering Research and Management (IJERM), Vol.1, Issue 7: pp.157 - 161.

[20] Melkumyan M. (2014). Structural concept and analysis of the 17 - story base isolated apartment building “Sevak”. International Journal of Engineering and Applied Sciences (IJEAS), Vol.1, Issue 3: pp.13 - 17.

[21] Naeim F. & Kelly J. (1999). Design of Seismic Isolated Structures. From Theory to Practice. John Wiley & Sons Inc.

[22] Saito T. (2006). Observed Response of Seismically Isolated Buildings. In Response Control and Seismic Isolation of Buildings, Taylor & Francis, pp. 63 - 88.