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STRUCTURAL CONCEPT AND ANALYSIS OF THE 15-STORY BASE ISOLATED APARTENT BUILDING "AVAN"

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***Abstract*— In recent years seismic isolation technologies in Armenia were extensively applied in construction of multi-story residential and business center complexes with parking floors and with floors envisaged for offices, shopping centers, fitness clubs, etc. They are briefly described in the paper, which is, however, mainly dedicated to a 15-story base isolated apartment building "Avan" designed and constructed recently in the city of Yerevan. The structural concept, including the new approach on installation of seismic isolation rubber bearings in this building, is described and 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.**

***Index Terms*— Seismic isolation, structural concept, response analysis, time history, seismic code**

I. INTRODUCTION

Base isolation of multistory buildings in Armenia is developing mainly through the projects financed by private companies. The original and innovative structural concepts were developed during the last 13 years. The seismic isolation plane in all 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. All the mentioned buildings (Figure 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. 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 residential as well as for the business center complexes for cases with and without application of seismic isolation clearly show the high efficiency of seismic isolation. They prove once again that if properly designed seismic isolation brings to rational structural solutions of high reliability.

Fig. 1. Design views of the multi-storey base isolated buildings newly constructed in Yerevan

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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– 17-story building of the multifunctional residential complex “Sevak” (Melkumyan, 2011)

II. STRUCTURAL CONCEPT OF THE 15-STORY BASE ISOLATED APARTMENT BUILDING “AVAN”

One of the recent projects financed by the governmental program for providing apartments for young families on analysis and design of 15-story base isolated building “Avan” (Figure 2) was accomplished in 2011. Construction this building in Yerevan was completed in 2013.

Fig. 2. Design view of the 15-story base isolated apartment building “Avan” constructed in Yerevan and its current view

Similarly to the buildings briefly described above, the considered building also has a floor (envisaged for the offices) below the isolation plane designed using strong and rigid reinforced concrete (R/C) structural elements. The cross section of columns here is equal to 600×600 mm and of beams below the seismic isolators – 600×400(h) mm and above them – 600×650(h) mm. The thickness of shear walls is equal to 200 mm. The cross section of the foundation strips is equal to 800x1500(h) mm. The accepted structural solution allowed obtaining a rigid system below the isolation plane, which 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 consisted of 14 residential 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 160 mm thick shear walls between them. The thickness of R/C slabs was set at 120 mm for all floors. The drawing provided in Figure 3 presents the vertical elevation of the building. Plan of location of seismic isolators is shown in Figure 4.

In the considered building the approach suggested earlier (Melkumyan & Hovhannisyan, 2006, Melkumyan, 2007, 2009) on installation of the cluster of small rubber bearings instead of a single large bearing under the columns or shear walls was used. Corresponding examples of installed isolators are shown in Figure 5. From Figures 3, 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, and height - 202 mm) and characteristics. They have horizontal stiffness equal to 0.81 kN/mm, a damping factor of about 9-10%, can develop horizontal displacement of up to 280 mm (about 220% of shear strain), and can carry a vertical design load of up to 1500 kN. They are made from neoprene and were designed and tested locally (Melkumyan 2001, Melkumyan & Hakobyan, 2005).

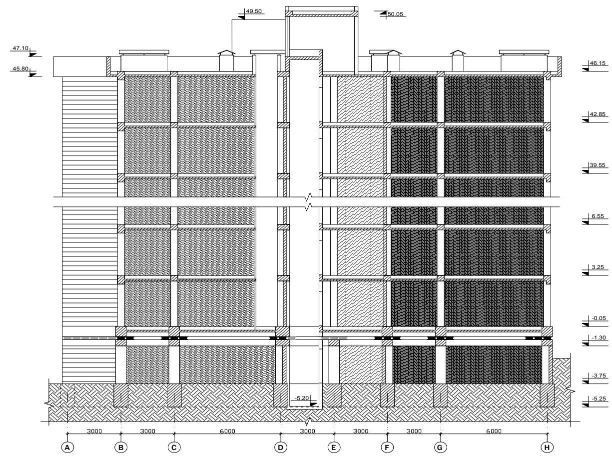

Fig. 3. Vertical elevation of the 15-story base isolated apartment building “Avan” in transverse directions along the axis “5”

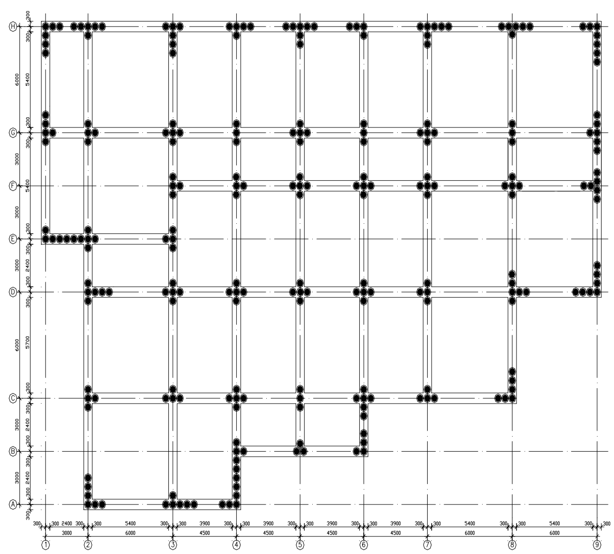

Fig. 4. Plan of location of seismic isolation rubber bearings at the mark of -0.90 in the 15-story apartment building “Avan”

Fig. 5. Examples on installation of rubber bearings' clusters in the 15-story base isolated apartment building "Avan"

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

III. RESULTS OF ANALYSIS OF THE 15-STORY BASE ISOLATED APARTMENT BUILDING "AVAN"

Earthquake response analysis of the considered building was carried out using 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 0.4g acceleration. Also the building was analyzed based on the provisions of the Armenian Seismic Code. The design model (Figure 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.

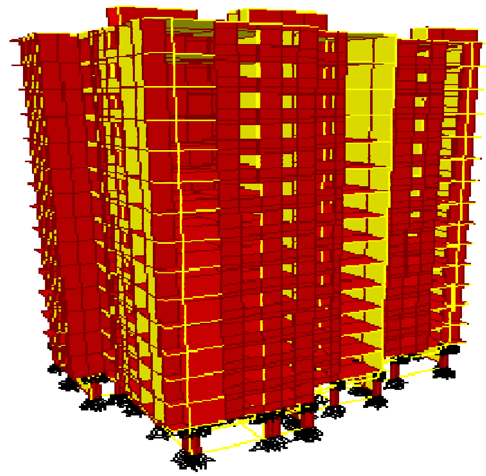

Fig. 6. Design model of the 15-story base isolated apartment building "Avan"

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 – 19 mm; 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. The site is located in zone 3, where the expected maximum acceleration is equal to a=400 cm/sec^2. There are different allowable damage coefficients envisaged in the Code. For this particular case of R/C building with shear walls it is required to apply for superstructure the allowable damage coefficient (reduction factor) k_1=0.4 and 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.

Some results of the analyses by the Armenian Seismic Code and time histories are given in Table 1. 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). 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.

Table 1: Some results of the analyses of 15-story base isolated apartment building "Avan" 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=2.03	T_y=2.06

Inter-story drift (mm)	1.2 (k_1=0.4) 2.3 (k_1=0.8)	1.8 (k_1=0.4) 3.5 (k_1=0.8)
Horizontal shear force on the level of foundation (kN)	22175 (k_1=0.4) 44341 (k_1=0.8)	22590 (k_1=0.4) 45175 (k_1=0.8)
Displacement of the isolation system (mm)	111.0 (k_1=0.4) 222.0 (k_1=0.8)	113.0 (k_1=0.4) 226.0 (k_1=0.8)
Average parameters obtained by the 8 time histories analyses		
Inter-story drift (mm)	0.9	1.5
Horizontal shear force on the level of foundation (kN)	24068	25130
Displacement of the isolation system (mm)	106.0	104.0

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. Differences in these values are in the range of 5-30%. But in case if k_1=0.8 the Code based results are higher by a factor of 2.1 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 k_1=0.6 for zone 3 in the next edition of the Code, as a compromise solution.

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 15-story base isolated apartment building "Avan" 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 actually 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 (by a factor of 2.1 in average) 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.

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