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# Structural Concept and Analysis of Base-Isolated Multiple Building Structure

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**ABSTRACT:** *This paper presents an overview of the present state of base isolation techniques with special emphasis and a brief on other techniques developed world over for mitigating earthquake forces on the structures. The dynamic analysis procedure for isolated structures is briefly explained. In the paper, which is, however, mainly dedicated to a 17-story base isolated apartment building "Sevak" 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 some results of the earthquake response analyses are given.*

**Keywords:** Seismic code analysis; seismic isolation; structural concept

## I. INTRODUCTION

Base isolation is nowadays a well-established and viable antiseismic design strategy for new buildings and bridges, as well as for the retrofit of existing ones, with several thousand applications in over 30 earthquake-prone countries worldwide. The use of this technology, originally restricted to massive and stiff structures, has been progressively extended in the past decade to include slender and high-rise buildings, as well as groups of structures built on a single platform (also labelled as "artificial ground") [1]. This is a consequence of the increase in the fundamental vibration period targeted in base-isolated conditions, following the incorporation of the latest generation of isolators, characterized by very low translational stiffness. The period, normally fixed at 2–2.5 s in early designs, was subsequently raised to 3–3.5 s, for standard buildings, and to over 4 s, for special structures. This allowed extending the benefits of seismic isolation to wider classes of applications, that is, the new structural configurations above and other notably demanding conditions, and, namely, significant geometrical irregularities in plan and/or elevation [2]; possible effects of near-fault earthquake components in the construction site [3–6]; a trend towards marked reductions in width of the separation gaps between adjacent structures built on one mobile platform [7] and towards simplified details of any installations crossing the isolation plan [3]; null or very limited structural and nonstructural damage to buildings [4] and total recentering capacity of the isolation systems, also for the highest levels of normative design earthquakes [8, 9]; and progressive cuts in costs, which aimed at improving the competitiveness of base isolation with respect to other seismic protection strategies [10]

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

a – 16- and 10-story buildings of the multifunctional residential complex "Our Yard" [1], b – 11-story building of the multifunctional residential complex "Cascade" [4], c – 20-story business center "Elite Plaza" [5], d –16- and 14-story buildings of the multifunctional residential complex "Arami" [6], [7], e – 18-story buildings of the multifunctional residential complex "Northern Ray" [8], f – 16- and 13-story buildings of the multifunctional residential complex "Dzorap" [3], g – 17-story building of the multifunctional residential complex "Baghramian" [9], h – 15-story building of the multifunctional residential complex "Avan" [10]

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 (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.

## II. STRUCTURAL CONCEPT OF THE DESIGN BASE ISOLATED APARTMENT BUILDING

One of the recent projects financed by ITARCO Construction, CJSC on analysis and design of 17-story base isolated building “Sevak” (Fig. 2) was accomplished in 2011. Construction of this building in Yerevan was completed in 2014.

Fig. 2. Design view of the 17-story base isolated apartment building “Sevak” constructed in Yerevan and its current view

Similarly to the buildings briefly described above, the considered building has three floors (envisaged for parking and 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 650X650 mm and of beams below the seismic isolators – 650X500(h) mm and above them – 650X700(h) mm. The thickness of shear walls in the lowest underground floor is equal to 500mm and in the next two floors is equal to 300 mm. The foundation is designed in the form of R/C slab with the thickness of 1300 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 400X400 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 Fig. 3 presents the vertical elevation of the building. Plan of location of seismic isolators is shown in Fig. 4.

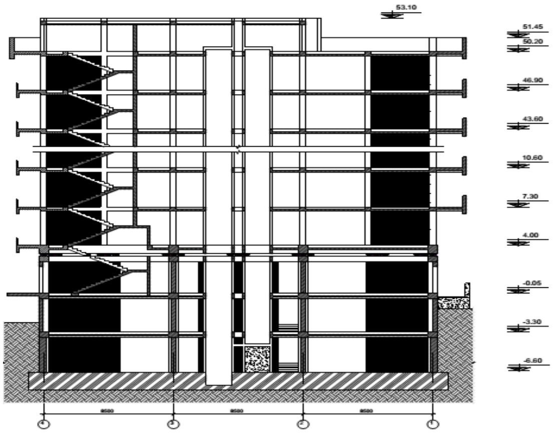

Fig. 3. Vertical elevation of the 17-story base isolated apartment building “Sevak” in the direction along the letters axes (between the axes “B” and “C”)

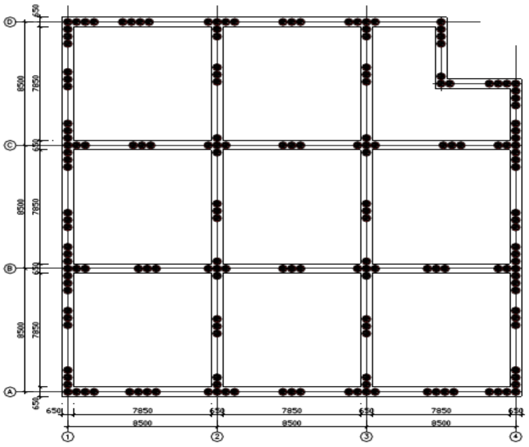

Fig. 4. Plan of location of seismic isolation rubber bearings at the mark of -3.10 in the 17-story apartment building “Sevak”

In the considered building the approach suggested earlier [3], [6], [11] 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, where a gap in stairway is also shown. 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 is placement 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 [12], [13].

Fig. 5. Examples on installation of rubber bearings' clusters in the 17-story base isolated apartment building “Sevak” in the course of construction

## III. DESIGN WITH BASE ISOLATION

When checking the aseismic design of a base isolated reinforced-concrete building a normal overcapacity factor of 1.25 times is assumed. If the design is controlled by beam-end moments it may still be desirable to proportion the members for an inverted triangle distribution of loads despite the actual uniform distribution. This will give a further reserve of 20% to 30% and hence the overall reserve may be taken as 50%. Further the provision for triangular loads will increase the effective bilinear stiffness ratio for moderate ductility factors.

Consider as an example a reinforced concrete building of 3 storeys with a fundamental period of 0.25 seconds, and with an overall viscous damping of 0.05. If the design base shear is for a yield level of 0.12W, and if the members are designed for a triangular load distribution, then the elastic reserve may be taken as 50% and the effective base yield level as 0.18W. From Figs. it is found that the building remains elastic until the ground accelerations reach 1, 2 times those of the El Centro earthquake. For 1.5 and 2.0 times the El Centro earthquake the ductility demands are 1.5 and 3.7 respectively, assuming a bilinear stiffness ratio of 0.15. For comparison with the base-isolated building, the ductility demands are given for the building without base isolation, with a design base share of 0.16W, and with a viscous damping of 0.05. For an overcapacity factor of 1.25 the yield load is 0.2W.

The equivalent weight W p of a single mass system may be taken as 90£ of the building weight, so that the yield load is 0.22 W e . From Figs it is found that the building reaches its yield level for accelerations of 0.25 times the El Centro earthquake and that the ductility demands for 1.0, 1.5 and 2.0 times the El Centro accelerations are 6.2, 11.5 and 18.5 respectively. The ratio of maximum member ductility to the above overall ductilities will be much higher and more variable for a range of earthquakes than the corresponding ratio for base-isolated buildings, for the reasons enumerated earlier.

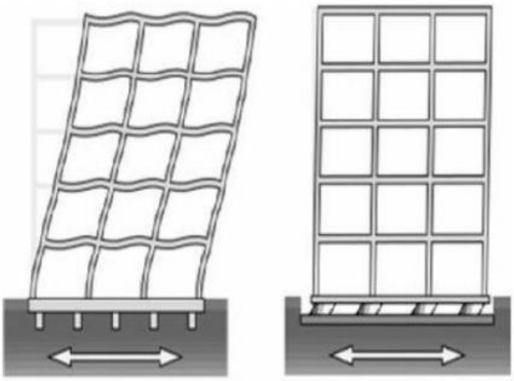

Fig.6 The behavior change of structure without isolator and with isolator incorporation.

The high ductility demands on the no isolated building, when under severe earthquake attack, would lead rapidly to lower yield levels and to negative bilinear slope ratios which would further increase ductility demands and lead to rapid failure. The ductility demands for the isolated and the nonisolated buildings are given in Fig. Base isolation is defined as a flexible material which is provided at base to reduce the seismic forces of any structure. Fig.6 illustrates the behavior change of structure without isolator and with isolator incorporation.

Base Isolation Technique is the process of de-coupling a sub-structure and a super-structure by various techniques.

- Protection of Building Frame
- Protection of Life – Current Code
- Protection of Non-Structural Components and Contents
- Protection of Processes and Function
- Provide for an operational facility after the earthquake

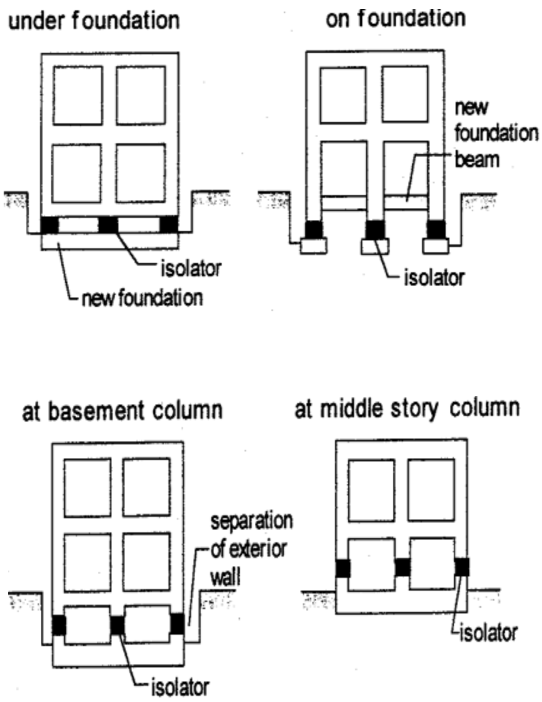

Fig.7 Isolator Components between the Foundation and Superstructure

## V. CONCLUSION

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 17-story base isolated apartment building "Sevak" and the new approach on installation of clusters of seismic isolation rubber bearings brings to rational solution of the whole bearing structure. Finally we conclude that the design of short-period buildings is much more accurate and controlled with base isolation than without isolation.

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