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PERFORMANCE EVALUATION OF BASE ISOLATED HOSPITAL BUILDINGS AFTER KAHRAMANMARAS EARTHQUAKES

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Abstract. The devastating effects of February 6^{th}, 2023 earthquakes have been documented for many types of building systems located in the disaster region. Another important aspect of the region is that there are several seismic base-isolated hospital buildings that were constructed or is under construction. In this study, the performance evaluation of the base-isolated hospital buildings is discussed based on the data gathered from a field study conducted after the earthquakes. Several conclusions regarding the seismic performance of the isolator devices and behaviour of the isolated superstructure are made from these observations.
Keywords: seismic base isolation, performance-based earthquake engineering, structural dynamics, friction pendulum

Introduction. Seismic base-isolation is a widely employed technology to mitigate response of building structures during earthquake excitation. Application of seismic-base isolators has been mandatory in new hospital building constructions in Turkey and base-isolated design structural design guidelines are included in the latest edition of Turkish Earthquake Code [1] similar to other contemporary standards [2-4]. Therefore, there is an important base-isolated hospital building stock in all regions of Turkey. The area affected by February 6^{th}, 2023 Kahramanmaraş earthquakes is no exception. Base-isolated hospital buildings were constructed in Malatya, Hatay, Adana in recent years and several are under construction in Adıyaman, Kahramanmaraş and Osmaniye, the cities all of which have been severely affected from the earthquakes.

There are various analysis procedures to compute the design displacement of seismic base isolators. Equivalent linear procedures are widely employed for this purpose. The accuracy of the method was investigated by several researchers previously [5-8] and it has been determined that the estimation performance of the method depends on isolator properties and earthquake characteristics [9-11]. Due to being simple and practical, the equivalent linear procedures had been utilized to determine isolator design displacements of the base-isolated hospital buildings in the earthquake-stricken cities. The isolator dimensions had been determined accordingly by considering the performance objectives given by the seismic codes [1]. This study is devised to measure the actual displacements on seismic base isolators and to make observations on whether the design displacements had been exceeded in any of the hospital buildings.

A field study that has been conducted by the authors after the earthquakes documented the performance of the base-isolated hospital buildings. The buildings that have been inspected in the study are given in Table 1. The measured isolator displacements as well as residual displacements, if present, are also given. Friction pendulum type isolators were employed in all inspected hospital projects. The friction material that is used in this type of devices leaves some residual material during earthquake action, therefore it is possible to compute the maximum displacement demand by measuring the maximum distance of leftover friction material from the core on one side of the isolator plate. Due to symmetric behaviour, the same displacement demand is also present at the top plate. By multiplying the measured distance by two, the total displacement demand is calculated. The distance between top and bottom isolator plates is measured to compute the residual displacements. The computed isolator displacements are found to be less than the design displacement of seismic base isolators at all hospital buildings. The detailed observations and findings for each hospital project given in Table 1 are discussed in the following sections.

Table 1. Inspected Hospital Buildings [1]

Hospital	Measured Displacement (mm)	Residual Displacement (mm)
Elbistan State Hospital	30	25
Malatya Battalgazi State Hospital	160	10
Malatya Maternity and Children Hospital	30	~ 0
Hatay Dörtyol State Hospital	40	~ 0
Osmaniye State Hospital	60	25

Base-isolated building performance. Elbistan State Hospital. The distance of Teflon slider markings from the isolator core was measured as 15 mm on one plate of friction pendulum isolator. In total, isolator displacement is computed as 30 mm. It has been observed that seismic isolators which are located at the basement story of the hospital are covered with gypsum boards to provide insulation from fire (Fig.1). Limited damage in these gypsum boards were observed in all column axes due to isolator movement. Upon closer inspection of a friction pendulum by removing the damaged boards, a residual displacement of 20 mm was measured between top and bottom plates of the isolator (Fig. 2).

Figure 1. Cracking and slight damage in gypsum boards covering the seismic isolators due to displacement during the earthquakes [10]

Figure 2. One of the friction pendulum type seismic isolators of Elbistan State Hospital [10]

Malatya Battalgazi State Hospital. Battalgazi State Hospital, which is located in Malatya city center experienced both earthquakes and the seismic isolators were activated on both occasions. The maximum displacement was computed as 160mm by measuring the slider marks farthest (80 mm) from the core of the friction pendulum on one side (Fig.3). A residual displacement of 10 mm was also measured.

Figure 3. Maximum distance of the Teflon markings on one plate of the isolator (80 mm) [10]

Seismic isolators are located at the parking story of the hospital building. Accurate measurements were taken from the elevator core isolators which are located at a lower elevation than the rest of the isolators. A very rigid framing is present at the isolator interface both for the superstructure and fixed portion. Upon closer inspection of the parking story, a well-designed seismic detailing for mechanical and electrical installations was observed (Fig.4). No apparent deformation or damage was noted in these installations.

Figure 4. Seismic detailing of mechanical and electrical installation at the parking story [10]

Malatya Maternity and Children Hospital. The hospital building is in Yeşilyurt district of Malatya city center. The displacement capacity of the isolators installed in the project is ±360 mm. The maximum displacement computed from the slider marks on the isolator surfaces is 30 mm. No residual displacement is observed. Several issues have been detected in and around the hospital building constraining the movement of the isolated superstructure, hence the reason for low measured displacement.

The seismic isolators are located in the parking story of the structure. Upon inspection of the story, it has been discovered that infill walls were constructed to create rooms. There was no seismic detailing in these walls, as they were connected to the bottom slab of the isolated superstructure. Consequently, isolator movement has been severely constrained during earthquake response due to pounding effects between the bottom floor beams of the superstructure and the infill walls. Significant damage has been observed in these walls (Fig.5).

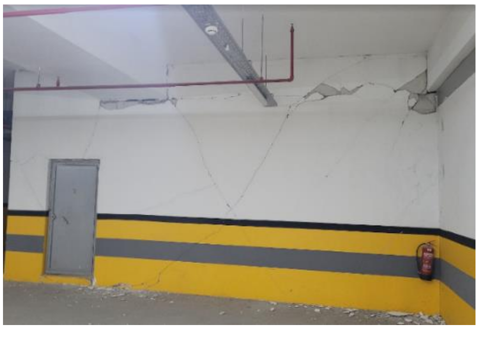

Figure 5. Infill walls at the isolator (parking) story, constraining the movement of the isolated superstructure [10]

Several access ramps were constructed around the building perimeter, further constraining the displacement of the superstructure. The ramps were built using cast-in-place concrete with asphalt overlay. They provided a rigid connection between the isolated superstructure and ground, resulting in a limited isolator displacement response (Fig.6).

Figure 6. The access ramps of the hospital building cracked and deformed in places where the seismic gap would have been [11]

Hatay Dörtyol State Hospital. The hospital is in Dörtyol district of Hatay province. The design displacement of seismic isolators of the Hatay Dörtyol Hospital building ±400 mm. The maximum isolator displacement has been computed as 40 mm (Fig.7), with no residual displacement Although the hospital is in close proximity to the fault rupture of the first earthquake occurred on February 6th, evidence of minimal isolator displacement has been observed. A significant factor for reduced demand could be that the hospital along with Dörtyol district is located on stiff soil. The structure has well- constructed seismic gaps detailing along its perimeter (Fig.8). The gap is covered by hinged platforms that are connected to the isolated superstructure. The free end of the platforms has an angled detail that allows for sliding movement along the contact points to the pavement around the structure. No major damage has been observed in the seismic gaps apart from one corner that collided with the pavement during the earthquake action. It is determined that the resulting superficial damage did not constrain the isolator displacements (Fig. 9).

Figure 7. Measured isolator bottom plate displacement at Hatay Dörtyol Hospital [11]

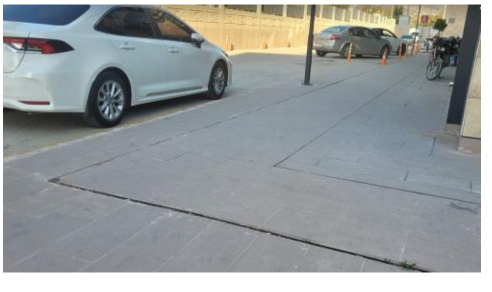

Figure 8. The hinged platform covers of the seismic gaps along the perimeter [11]

Figure 9. Minor collision damage between a corner of the isolated structure and the pavement [11]

Osmaniye State Hospital. The hospital complex which was due to open one week after the February 6th earthquakes is in Osmaniye city center. The maximum isolator displacement has been computed as 60 mm. The isolators, which have a design displacement of ±450mm, exhibited 25 mm of residual displacement (Figure 10). No significant issues were detected at seismic gaps surrounding the structure and the isolation story. Hence, seismic isolators were not constrained during the earthquake response. A passive displacement measuring device composed of a marked plate and a needle was present at the isolation story (Figure 11). However, it did not measure the displacement demands of the earthquakes correctly.

Figure 10. Residual isolator displacement in Osmaniye State Hospital [12]

Some nonstructural damage in stairwells of the isolated superstructure was determined. More importantly, the fire suppression system has failed due to seismic action flooding several floors (Fig. 12). Due to inappropriate seismic detailing, the plumbing could not resist the earthquake induced displacement. Hanged ceilings and electrical components were found to be damaged due to flooding. If the hospital had been operational at the time of the earthquakes, it would have been out of service for several days due to flood damage.

Figure 11. Displacement measuring device located at the isolation story of Osmaniye State Hospital [12]

Figure 12. Flood damage at upper stories of isolated superstructure and resulting red (rust) residue at Osmaniye State Hospital [12]

Summary and conclusions. In this study, seismic performance of the base-isolated hospital buildings at the Kahramanmaraş earthquakes was evaluated. Several base-isolated hospitals located in the cities affected by the earthquakes were inspected in a field study. Isolator displacements as well as structural damage if present were documented. Following conclusions were reached:

• Landscaping applications that include filling or closing the seismic gaps around the isolated structure affect the isolator performance negatively such that it yields to damage which could leave the hospital out of service.

• A proper seismic detailing of electrical network and plumbing at the isolation story is of significant importance so no interruption of service occurs after the earthquakes due to failure in these installments.

• The nonstructural wall damage occurring in the isolated superstructure is mainly due to providing insufficient connection between constructed walls and structural frames. In addition, heavy wall construction material such as concrete bricks show inferior performance during seismic action of the superstructure in terms of cracking and out of plane failure.

• Appropriate seismic design of the installations at the isolated hospital building is necessary for uninterrupted service after an earthquake. Hanged ceiling components, electrical connections, fire suppression systems should be designed according to expected seismic demands of the superstructure. It has been documented that the hospital could be taken out of service due to failure in these systems even though the structure survives the earthquake with no or minor damage.

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