A Comparative Study on Seismic Isolation Applications in Turkey

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ABSTRACT: Design of seismically isolated hospital structures have become popular in Turkey within last five years especially after Ministry of Health's policy change. The new hospital complexes of about twenty campuses has been either under design or scheduled for planning for the next five years. The Ministry strictly requires use of seismic isolation systems for high risk seismic regions not only to mitigate the adverse effect of earthquakes on structures but also to keep operating expensive medical devices just immediately after the earthquake. Since the technology has been very new to Turkish market, a flux of manufacturers promoting different products were inevitable that have created some richness of education that also sometimes ended up in confusions. Therefore, the selection of seismic isolation systems for different geometries of structures over different soil conditions have become a hurdle for the engineers who has started learning this new technology. In this study, seismic isolation systems used at some of the hospital designs have been compared in terms of types, sizes, mechanical properties, expected performances. The case study includes five hospitals in which two of the complexes have almost been completed and three of them are still under construction. In many cases, friction pendulum based systems and lead rubber bearings have been selected based on the detailed analytical studies. It shall also be noted that two of the hospitals are very close to an active fault that required a comprehensive study of near fault effects in seismic hazard computations.

1 INTRODUCTION

1.1 Current State of Seismic Isolation Technology in Turkey

In Turkey as milestone moment, application of seismic isolation technology to new hospital designs at high seismic regions become mandatory in the technical memorandum published by the Ministry of Health. Per the memorandum, no project specific or site specific technical criteria can be found to select the type of seismic isolation application intended to be used for hospital buildings [Ozdemir 2016]. In this study, five different seismically isolated reinforced concrete hospital buildings at high seismic zones being first and second seismic zones are presented in a comparative way regarding seismic isolation design considerations.

1.2 Design Philosophy

The hospitals with seismic isolation have been designed at DBE (design basis earthquake) level with 475 years return period. The structural design forces have obtained from multimode response spectra analysis. The base shear forces for this level of earthquake have been ranging from 0.08W to 0.15W based on the differences in hospital structures.

The seismic isolation design has been conducted at MCE (maximum credible earthquake) level with 2475 years return period. The isolation design displacement has been performed thru equivalent lateral force procedure (ASCE 2010). The non-linear time history analysis conducted thru selected seven ground motions have been used to verify this simple method. Ground motion selection and calibration

is a very complex problem (Burks et al 2015) and is not within the focus of this paper. The equivalent static procedure (Koshnoudian and Mehrparvar 2008) can be used in preliminary design of structures with seismic isolation and also be used to limit the design forces not to fall under a certain value even if the non-linear time history analysis can lead to significantly low level forces than the limited values.

Modelling of inelastic response of the buildings is a very complex problem (Cardone et al 2013) and sometimes can lead to converges problems under non-linear time history analysis. In such cases, new sets of earthquake records can be selected or properties of hysteretic elements can be revised. Therefore, using such limits as mentioned above can be considered to be an insurance to ignore some unreliable results of non-linear time history analyses.

Comfort level limits are usually checked at DBE level and in such cases non-linear time history analysis have been utilized to determine if any one of the floor excitations are in exceedance of 0.2g. Such a check of comfort level is very unique and can result in increasing stiffness of the stories with braces as happened in some cases. At MCE level, the ratio of total base shear to total weight of the structure is usually set to 0.15 to 0.20.

The isolation system has been usually placed under a monolithic slab connecting separate blocks of the hospital complex. The expansion joints of the blocks have been detailed to have some additional allowance for the displacements computed at MCE level to avoid pounding of the blocks.

2 INVESTIGATED HOSPITALS

The reported five hospitals and seismic zones of Turkey per 1996 study have been shown in Figure 1. All of these hospitals are in the high seismic risk zones and some of them are close to major fault lines.

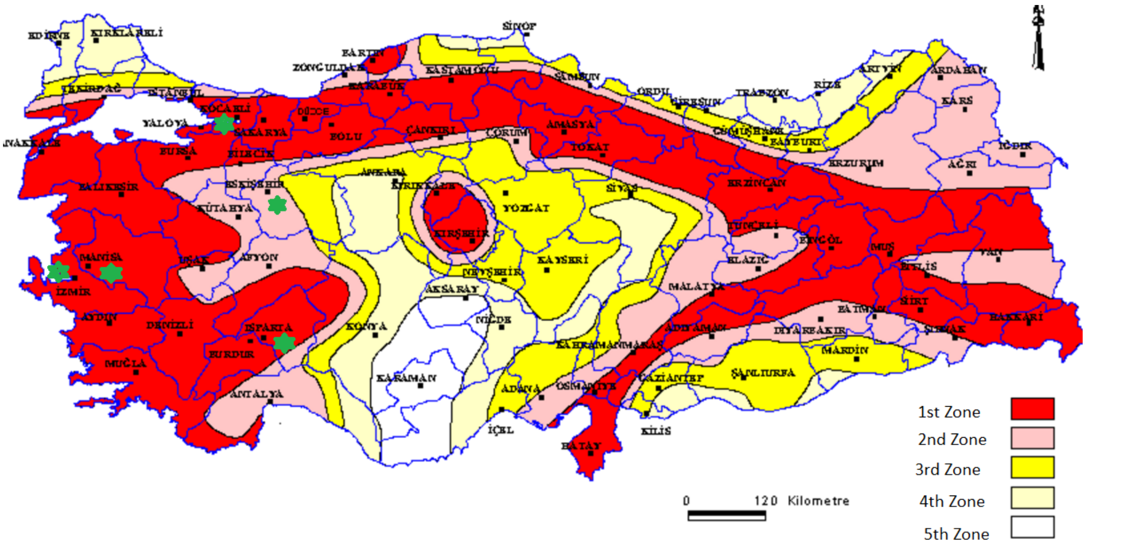

Figure 1. Seismic Zones of Turkey 1996 and Location of Hospitals

In Figure 2, seismicity of the sites of five hospitals is presented based on MCE response spectra derived from site-specific probabilistic seismic hazard analyses.

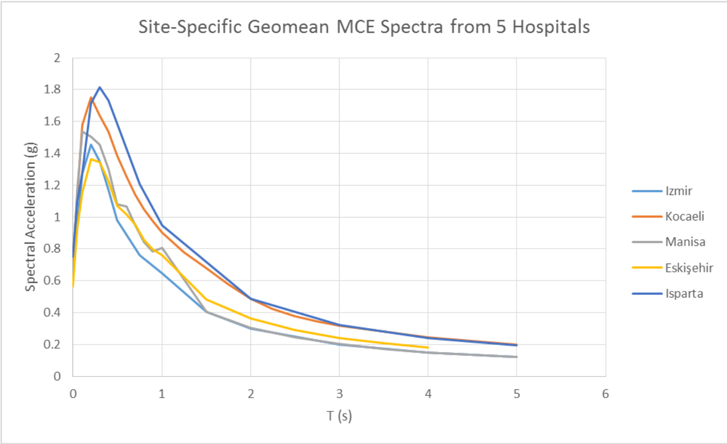

Figure 2. Site-Specific MCE Response Spectrum Curves from the Sites of Five Hospitals

2.1 Isparta City Hospital

Isparta is located in the first high risk seismic zone. Isparta City Hospital having a patient bed capacity of 755 was designed and constructed as one of the seismically isolated PPP (Public Private Partnership) projects in Turkey per on the requirements of technical memorandum of the Ministry of Health. Isparta City Hospital in terms of its patient capacity will become one of the first three city hospitals in its category. Total indoor area of the Isparta City Hospital is 178,143 m^2. Figure 3 illustrates the architectural render of the hospital. In this hospital, a total number of 903 isolators of which are double friction pendulum were used. To avoid loss of rentable area and a secondary foundation for base isolation, the isolation level is formed in the ceiling of first basement floor of which is above the foundation level. The first basement floor is utilized as a carpark area. For each of three separate blocks constituting the superstructure, the isolation level is formed individually. In Figure 3, three separate blocks are presented as two of them are T-like shaped in the north and south directions of the page and one of them is in rectangular form in the center.

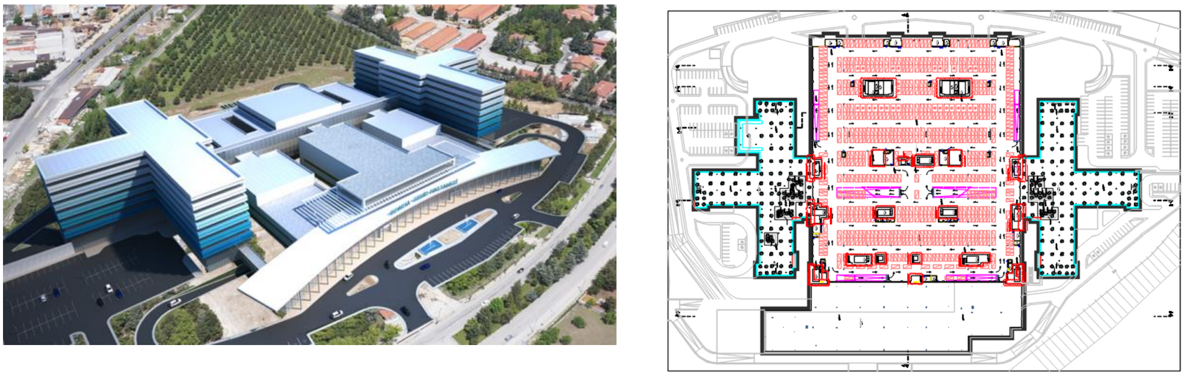

Figure 3. Isparta City Hospital, Architectural Render and Seismic Isolation Layout

Seismic isolation units are designed as 6 types of double friction pendulum having different axial load capacities. The nominal isolation displacement at MCE level is calculated as 250 mm. Maximum dimension of the largest isolation unit is 750 mm.

2.2 Manisa Training and Research Hospital

Manisa is an Aegean city located in the first high seismic zone where normal-fault focal mechanism is dominant and low to moderate earthquakes occur frequently. Manisa Training and Research Hospital is one of the seismically isolated PPP projects that had planned for Manisa with a complete rough construction by January of the year 2017. The health complex has a total patient bed capacity of 558 with a total indoor area of around 179,000 m^2. In Figure 4, general architectural view of the hospital has been shown.

Figure 4. Manisa Training and Research Hospital, Architectural Render

Manisa Training and Research Hospital is one of the projects with elastomeric isolators. In this hospital, 734 elastomeric lead rubber bearings are assembled in the ceiling of first basement floor for the same reason as of Isparta City Hospital. Unlike in the case of Isparta City Hospital, the isolation level is formed as a monolithic slab having a thickness of 600 mm. Superstructure above the isolation level is formed from five different blocks having different number of floors. These blocks are separated from each other by a distance of 150 mm to prevent pounding of the adjacent blocks and adverse effects of creep and shrinkage due to temperature loading. In Figure 5, seismically isolated blocks T1, T2, C1, C2 and MH lying on the monolithic slab above the isolation level is simply demonstrated.

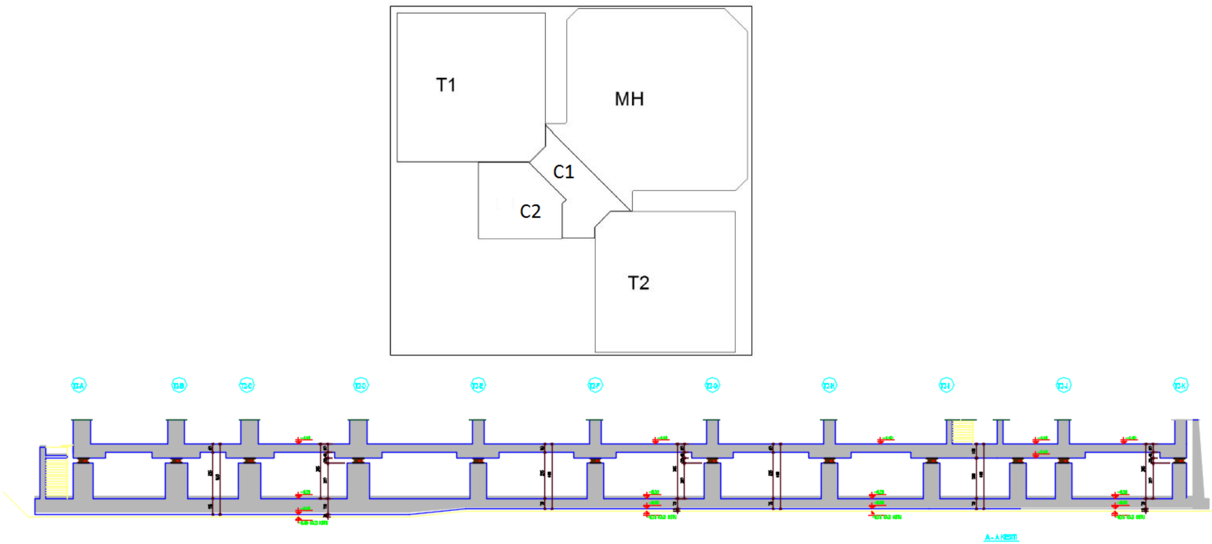

Figure 5. Manisa Training and Research Hospital, Seismically Isolated Blocks & A Typical System Section

In this hospital, nominal MCE displacement is determined by the procedure specified in design philosophy section of this paper, as 300 mm. Based on the vertical load ranges through the whole system, three types of isolators are used. Compared to friction pendulum systems, lead rubber bearing systems have larger uncertainty, which leads to the different vertical load levels to be represented in larger ranges with less number of types. The isolator type having the largest plan dimensions is generally located under the shear walls. The maximum plan dimension for this type is 970 mm. Note that design of a lead rubber bearing unit ends up with a smaller dimension compared to a friction pendulum isolation unit.

2.3 **Eskisehir City Hospital**

Eskisehir City Hospital to be constructed per the technical memorandum of the Ministry of Health is in the second highest seismic zone. The hospital is still under construction as of February 2017. The patient bed capacity of Eskisehir City Hospital is 1081 and the gross area of the hospital is about 330,000 m^2. In Figure 6, prospective 3-D view of the hospital is provided. Seismic isolation layout principle of Eskisehir City Hospital is similar to Isparta City Hospital, such that, each block having different number of floors has its own isolation floor and seismic gaps are formed between the blocks. Unlike Manisa Training and Research Hospital, the isolation level, which is a car parking area too, is designed as frame

system with beams formed in both above and below the isolators. Seismically isolated blocks of Eskisehir City Hospital are illustrated in Figure 7.

Figure 6. Eskişehir City Hospital, Architectural Render

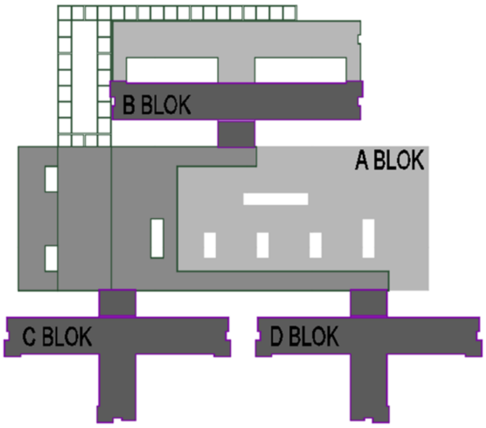

Figure 7. Eskişehir City Hospital, Seismically Isolated Blocks

In Eskisehir City Hospital, a total number of 973 double friction pendulum isolation units with 6 types are used. Displacement capacity of the isolators at MCE level is 430 mm and the maximum size of isolators is 1210 mm in two planar dimensions.

2.4 **Izmir Bayrakli Integrated Health Campus**

Izmir is a maritime city, which is very closely located to Manisa and susceptible to near fault effects by the active faults surrounding it. Izmir Bayrakli Integrated Health Campus is one of the projects to be designed and constructed as seismically isolated in Turkey. The architectural and structural design of this hospital is completed and the earthwork is proceeding. Seismic isolation is in preliminary design stage.

In Figure 8, conceptual architectural design of Izmir Bayrakli Integrated Health Campus is shown. With an impatient bed capacity of 1680 and a construction area of about 337,000 m^2, Izmir Bayrakli Integrated Health campus will be one of the largest complexes among its equivalents. Based on preliminary calculations for this hospital, the nominal MCE displacement of the isolators is around 350 mm. The isolation level is designed as a monolithic framing system with beams above the isolation level and to be utilized as a car parking area. In Figure 9, seismically isolated hospital blocks above the monolithic framed slab are displayed.

Figure 8. Izmir Bayrakli Integrated Health Campus, Architectural Render

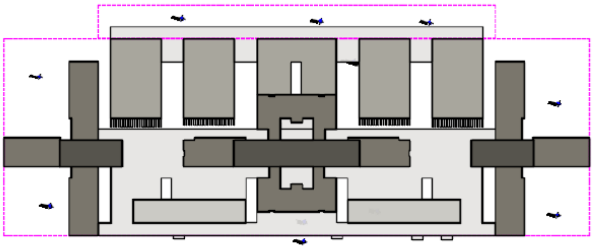

Figure 9. Izmir Bayrakli Integrated Health Campus, Seismically Isolated Blocks

In Izmir Bayrakli Integrated Health Campus, a number of 1246 friction pendulum isolation units are predicted to be used.

2.5 Kocaeli Integrated Health Campus

Kocaeli is located in one of the most vulnerable regions of Turkey and crossed by the dangerously famous North Anatolian Fault (NAF). The site of the Kocaeli Integrated Health Campus is 5 km away from the NAF. In the site specific probabilistic seismic hazard assessment of Kocaeli Integrated Health Campus, near fault effects are included since they are highly effective in long periods, which is the case of a seismically isolated system.

Design and construction process of Kocaeli Integrated Health Campus is the same as Izmir Bayrakli Integrated Health Campus. The health complex has patient bed capacity of 995 on a total construction area of around 201,500 m^2. Figure 10 demonstrates the most probable layout of the hospital. A relatively high nominal MCE isolator displacement from preliminary calculations of 590 mm stemmed from the relatively high seismicity of Kocaeli. Similar to Izmir Bayrakli Integrated Health Campus, the isolation level is designed as a monolithic framing system with beams above the isolators, as well as the isolators are placed in the ceiling of a basement floor utilized as a car parking area. Figure 11 demonstrates the configuration of the hospital blocks above the isolation level.

Figure 10. Kocaeli Integrated Health Campus, Architectural Render

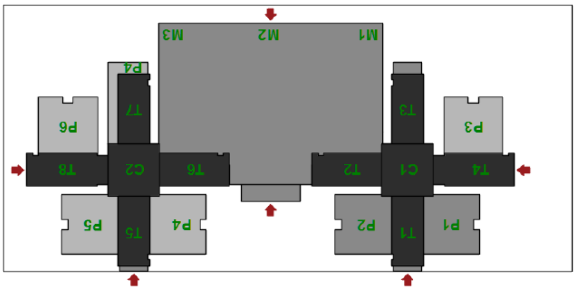

Figure 11. Kocaeli Integrated Health Campus, Seismically Isolated Blocks

In Kocaeli Integrated Health Campus, the prediction for the number of isolation units is 1065 as friction pendulum system.

2.6 Summary of Findings

The summary of the case studies indicate that the seismic isolation has been applied to the hospital buildings having 9 stories to 11 stories above the isolation level. Use of shear walls are tried to be minimized for these types of structures. Placing seismic isolation becomes a very complex problem under shear walls especially at elevator shafts. In some instances, sliders have been used instead of seismic isolation systems. Table 1 summarizes the very general seismic isolation properties of the systems studied. In Table 2, some of the structural and seismic parameters are also provided. In Table 1, FPS corresponds to “Friction Pendulum System” and LRB to “Lead Rubber Bearing.” Note that V_{s30} in Table 2 stands for the average shear wave velocity between 0 and 30 meter depth.

Table 1. Summary of isolation properties and structural characteristics.

Hospital	Structural System	Type	# of types	# of isolators	Effective Stiffness Range (kN/m) (min-max)	Effective Damping at MCE
Isparta	Moment Frame	FPS	6	903	409-2207	20 %
Manisa	Moment Frame	LRB	3	734	1550-7645	22 %
Eskisehir	Moment Frame	FPS	6	973	499-1942	25 %
Izmir	Moment Frame	FPS	6	1246	2951-7378	14 %
Kocaeli	Moment Frame	FPS	5	1065	1084-4338	18 %

Table 2. Summary of case studies.

Hospital	PGA of MCE (g)	V_{s30} (m/s)	Max. # of stories	Effective period at MCE (sec)	Max. displacement (mm)
Isparta	0.75	350	11	3.00	250
Manisa	0.63	620	9	3.00	300
Eskisehir	0.55	360	9	4.49	430
Izmir	0.62	750	11	3.38	350
Kocaeli	0.72	840	10	3.81	590

3 CONCLUSION

The following conclusions can be gathered from this study.

- The use of seismic isolation has been performed up to eleven stories above the isolation level in Turkey. The structural analyses have been usually conducted at two different levels of earthquake being DBE and MCE. At DBE level structure has been designed and at MCE level seismic isolation has been designed.
- The floor excitations have been tried to be controlled by supplemental braces if in exceedance of 0.2g at DBE level.
- In Turkey, seismic isolation knowledge is in growing up stage and project stakeholders have been gaining experience in implementing seismic isolation technology.
- In similar scale projects, different applications regarding seismic isolation design considerations are encountered.
- With the growing experience and knowledge in seismic isolation in Turkey, project-specific and site-specific applications may improve in Turkey, which is an earthquake-prone country.

4 REFERENCES

ASCE. (2010). *Minimum Design Loads for Buildings and Other Structures*.

Burks, L. S., Zimmerman, R. S. & Baker J. W. (2015). *Evaluation of Hybrid Broadband Ground Motion Simulations for Response History Analysis and Design,* Earthquake Spectra, 13, (3), 1691-1710.

Cardone, D., Flora, A. & Gesualdi, G. (2013). *Inelastic Response of RC Frame Buildings with Seismic Isolation,* Earthquake Engng Struct. Dyn. 2013; 42:871–889

Khoshnoudian, F. & Mehrparvar, B. (2008). *Evaluation of IBC Equivalent Static Procedure for Base Shear Distribution of Seismic Isolated Structures,* Journal of Earthquake Engineering, 12:681–703

Ozdemir, S. (2016). Investigation of Seismic Isolation Efficiency for Building Structures, *A Thesis Submitted to the Graduate School of Natural and Applied Sciences of Middle East Technical University, in Partial Fulfilment of the Requirements for the Degree of Master of Science in Earthquake Studies.*