Seismic Isolated Hospital Design Practice in Turkey: Erzurum Medical Campus

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SUMMARY:
Seismic base isolation is the most well known and proven way of keeping structures safe and immediately in service after major seismic activities. Although it is widely practiced in some countries like USA and Japan, it is fairly a new and unknown area of knowledge in Turkey.

Erzurum Medical Campus has been designed as one of the world's largest seismic isolated hospital. The campus consists of five to be built and one already built isolated blocks. In this paper, initially these five blocks are described then the choice of isolation interface for each block, site specific seismic risk analysis, the isolator characteristics used in the design have been discussed. The building performances in means of modal properties, story shears, and absolute/relative story displacements of isolated blocks have been compared with the case these blocks had been constructed conventionally with fixed bases.

Keywords: seismic isolation, base isolation, design, hospital

1. INTRODUCTION

The hospital is going to be built at the centre of Erzurum City in Turkey (Figure 1) next to the existing base isolated Erzurum Region Research and Training Hospital. The hospital consists of 5 isolated blocks (Blocks A, B, C, D and E) and 2 non-isolated blocks (G and F) (Figure 2). This paper includes information about only isolated blocks. The new medical campus has 1500 bed capacities and pronounced to be the world's largest seismic isolated hospital.

Generic isolator design independent of isolator type has been conducted for all blocks. At the time this paper being written, the isolator type and characteristic were not yet defined.

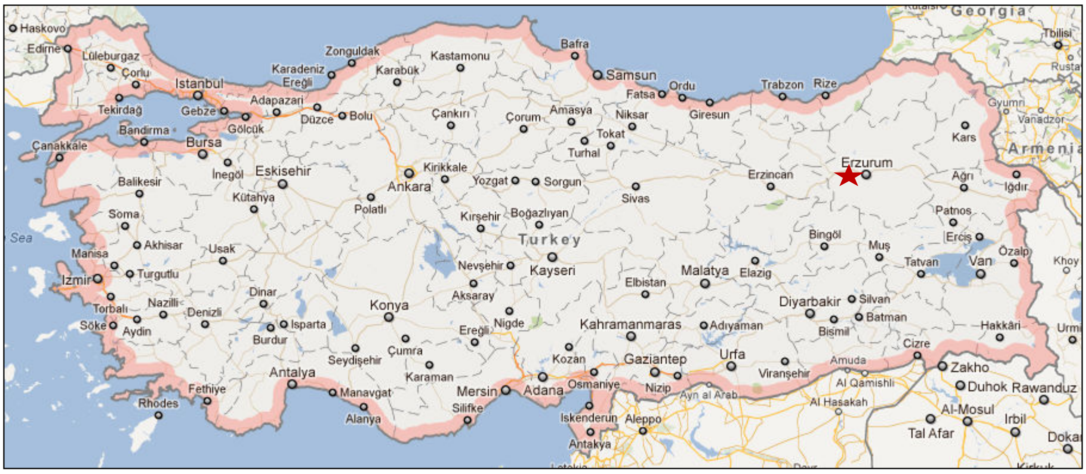

Figure 1. Location of the hospital (the red star represents the hospital)

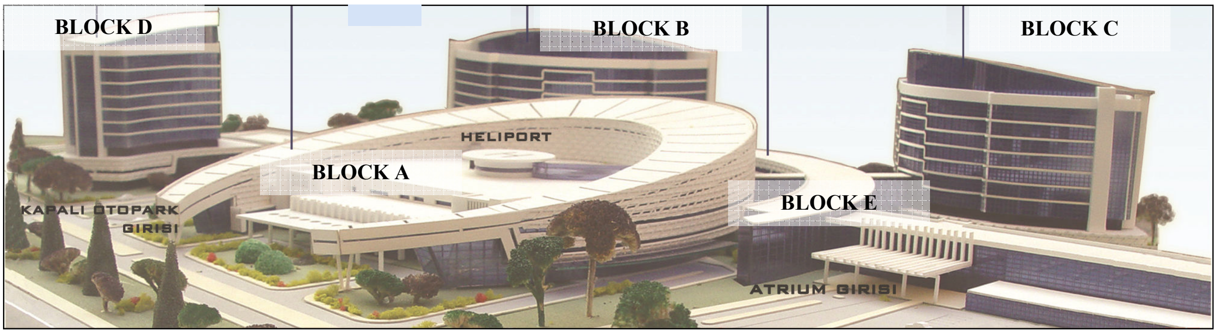

Figure 2. Visualization of the medical campus (in courtesy of Aymaz Architecure)

1.1. Block A

Block A consists of emergency service units, intensive care units and operating theatres. It is a 7 storey reinforced concrete building with two basement floors and 5 floors with different plan dimensions. It has a mixed type reinforced concrete and steel roof that partially covers the structure. Typical floor height is 4.80m, highest roof level is at +32.0m while lowest roof level is at +9.52m and foundation level is at -10.60m. Block A is surrounded by peripheral basement walls.

Seismic isolators to be used in this block are going to be placed at two isolation interfaces. The main isolation interface is at ± 0.00m level below the ground floor slab. Isolators are going to be placed on top of the basement floor columns. Total number of isolators at this level is 236. Secondary isolation interface is above -10.60m foundation level. The elevator and staircase walls are suspended to the ground floor slab and isolated at the secondary isolation interface. There will be sufficient seismic gap between the elevator/stair walls and the -4.80m basement floor slab to accommodate the isolator movement. Total number of isolators at the secondary isolation interface is 94.

All of the isolators at secondary isolation interface and 12 of the isolators that are going to be placed under the columns supporting the roof will be of slider type. Horizontal stiffness and friction of the slider type isolators will be as low as possible.

1.2. Twin Blocks B&C

Blocks B and C have the same structural configuration and will serve as maternity and cardiovascular hospitals. They are 13 storey reinforced concrete buildings with total height of 56.90m. Typical floor heights are 4.80m and 4.00m. They both have single isolation interface below -9.60m level floor slab, 198 isolators for each block will be placed over the foundation level.

1.3. Block D

Block D has been designed as oncology hospital. It is a 13 storey reinforced concrete building with total height of 50m. Typical floor heights are 4.80m and 4.00m. It has two isolation interfaces. 114 isolators will be placed below the -4.80m slab over the foundation system and 4 of the isolators will be placed below ±0.00m floor slab.

1.4. Block E

Block E has been designed as connecting atrium block and radiotherapy center. It is a reinforced concrete building consisting of 5 sub blocks. It has a single isolation interface at -9.60m level. All sub blocks have been isolated together below a common floor diaphragm and common foundation. Adequate seismic gap has been given between these sub blocks over the isolation interface. The total block height is variable. 404 isolators will be used at this block over the foundation at -9.60m level.

2. SEISMIC RISK ANALYSIS

Erzurum Medical Campus is located in the second seismic zone (A0=0.3g) according to the Turkish Seismic Code (TSC2007) (Figure 3).

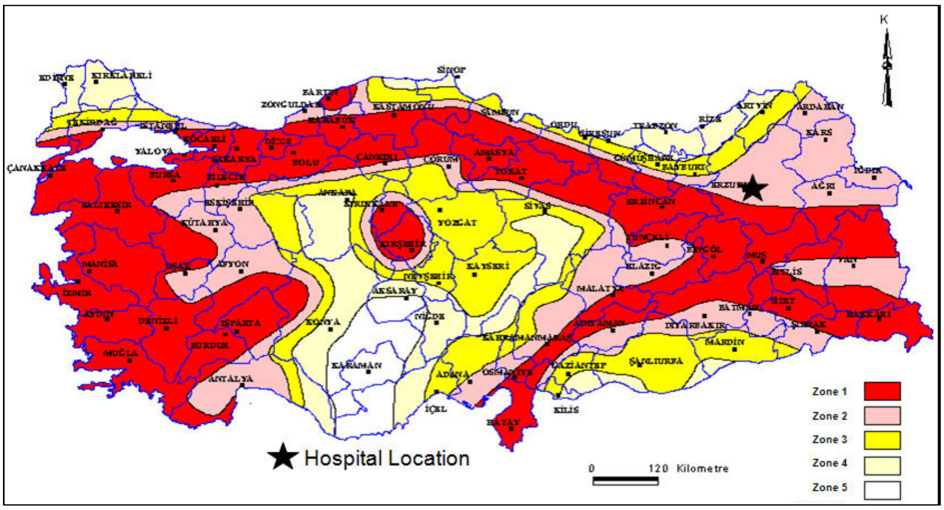

Figure 3. Seismic zonation map of Turkey

Probabilistic seismic risk analyses have been performed for the campus site. This study reviewed the historical earthquake data and considered active faults in the region. As result of seismic risk analyses, two site specific design response spectra having 2% and 10% probability of occurrence in 50 years with 2475 and 475 years return periods respectively have been obtained. Erzurum fault which is at 3km distance to the hospital site (Figure 4) has also been considered in the analyses even though this fault has some seismotechnical uncertainties.

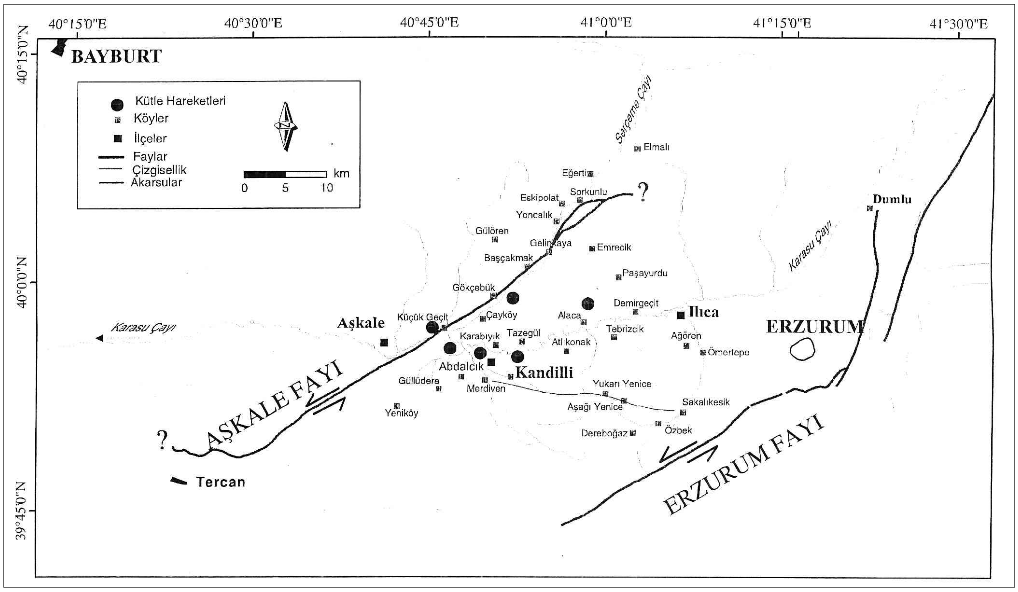

Figure 4. The location of Erzurum fault (Doğan et.al., 2004)

Site specific acceleration spectra have been compared with acceleration spectra given in Turkish Seismic code (Figure 5) and found to have higher demand at short periods. However they seem to have lower demand at longer periods since Turkish Seismic Code spectra are not displacement compatible. The seismic analyses have been performed considering site specific spectra.

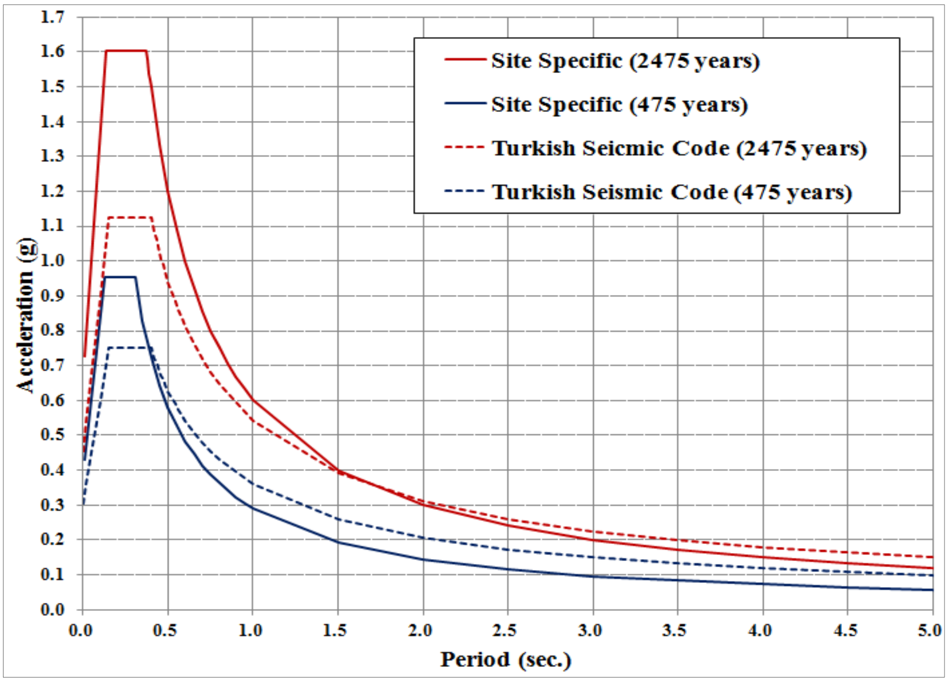

Figure 5. Comparison of site specific and code acceleration spectra for the site (5% damping)

The spectra given in Figure 5 are for the systems with 5% damping ratio. 5 different empirical definitions have been observed for the conversion of 5% damped spectra to higher levels of damping supplied additionally by the isolators (Figure 6). It has been decided that Eqn 2.1 which formularises the damping for the pulse type near fault events (Priestley et.al, 2003) is the one best suit to the seismic scenario of the case.

$$B_D = \left(\frac{0.07}{0.02+\xi}\right)^{0.25} \tag{2.1}$$

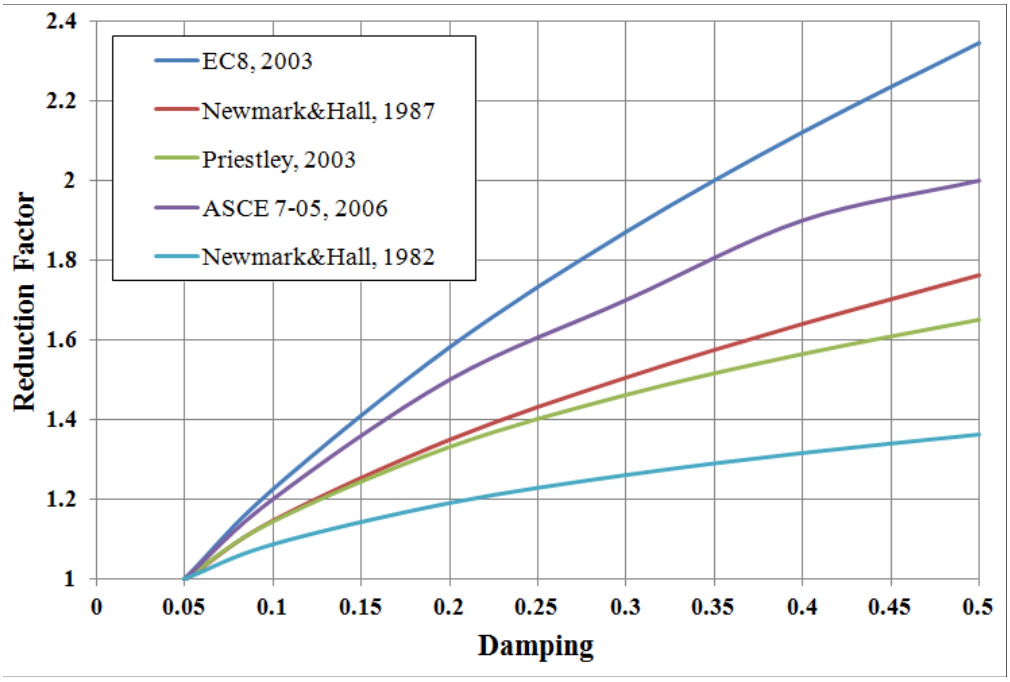

Figure 6. Comparison of damping reduction factors at different sources

3. STRUCTURAL ANALYSES AND ISOLATOR DESIGN

A generic design process has been followed in design of the blocks of the medical campus. Following the performance requirements in technical specifications created for isolator design, any isolator type (eg. lead rubber bearings, friction pendulum isolators etc.) can be used. The isolators to be used below the elevator and staircase walls at Block A shall be of slider type having minimum possible horizontal stiffness.

Structural analyses results have been summarized for Blocks A and B due to limitations. Structural models have been created and structural analyses have been conducted using Prota's in-house development Probina Orion software (v16). All column, beam and shear wall elements are modelled as elastic frame elements while isolators are idealized by elastic link elements (Figures 7 and 8).

During the design stage the basic properties and types of the isolators were not yet been defined. Analyses have been conducted by assumed isolator properties. All structural design has been performed by elastic mode superposition method however structural design shall be verified by non-linear time history analyses when the isolator type and characteristics are defined.

3.1. Isolator performance demand

ASCE SEI 7-05 has been followed together with Turkish Seismic Code at the design of the blocks of the medical campus. ASCE SEI 7-05 requires that structure shall be designed using the spectrum having 10% probability of occurrence in 50 years while maximum isolator displacement shall be checked using the spectrum having 2% probability of occurrence in 50 years. The maximum base shear shall be calculated using a structural behaviour factor of 1.5 (R=1.5).

The performance requirements have been summarized at Table 3.1 below for all blocks of the hospital where Iso.# denotes the number of isolators to be used, V_{b-D} denotes the maximum base shear transmitted to the isolated superstructure for design earthquake and D_{TM} denotes the maximum displacement of isolation system including the torsion effects. The manufacturer has been provided flexibility to select the effective damping and period of the isolated system considering these requirements. Isolation system shall be designed to minimize the torsion effects.

Table 3.1. Performance requirements for the isolation system

	Iso. #	V_{b-D}	D_{TM} (cm)
Block A	330	0.081W	50
Block B	198	0.072W	50
Block C	198	0.072W	50
Block D	118	0.065W	50
Block E	404	0.096W	50

All the isolator designs are going to be confirmed by laboratory tests and detailed seismic analysis. Laboratory tests shall be done according to ASCE SEI 7-05 or an equivalent code agreed with the designer and the administration. Seismic analysis shall be performed upon completion of design of the isolators using the exact properties of each isolator. The base shear transferred to the superstructure and maximum displacement limit shall be checked by nonlinear time history analysis using 7 spectrum compatible accelerograms.

3.2. Structural analyses results for Block A

The structure is composed of isolated superstructure and non-isolated basement floors. Two mathematical models have been used for the analyses. The first model (Figure 7) includes both basement floors and the superstructure for the estimation of the vertical load on the isolators and for the design of the basement floors. The design of the basement floors has been conducted using 5% damped spectra and behaviour factor of unity since they are not isolated. The second model includes only the isolated superstructure where additional damping of the isolators has been considered and behaviour factor has been chosen as 1.5.

The design of the isolated superstructure has been conducted with assumed isolator damping of 25% using the spectrum with 10% probability of occurrence in 50 years. The damping reduction factor has been calculated using Eqn. 3.1 for this level of damping. The target period has been chosen as 2.5 seconds and the stiffness of the isolators have been modified to reach this period.

The isolator displacements have been checked for the spectrum of the earthquake with 2% probability of occurrence in 50 years. Assumed target displacement for this level of earthquake is 3.0 seconds with 20% damping.

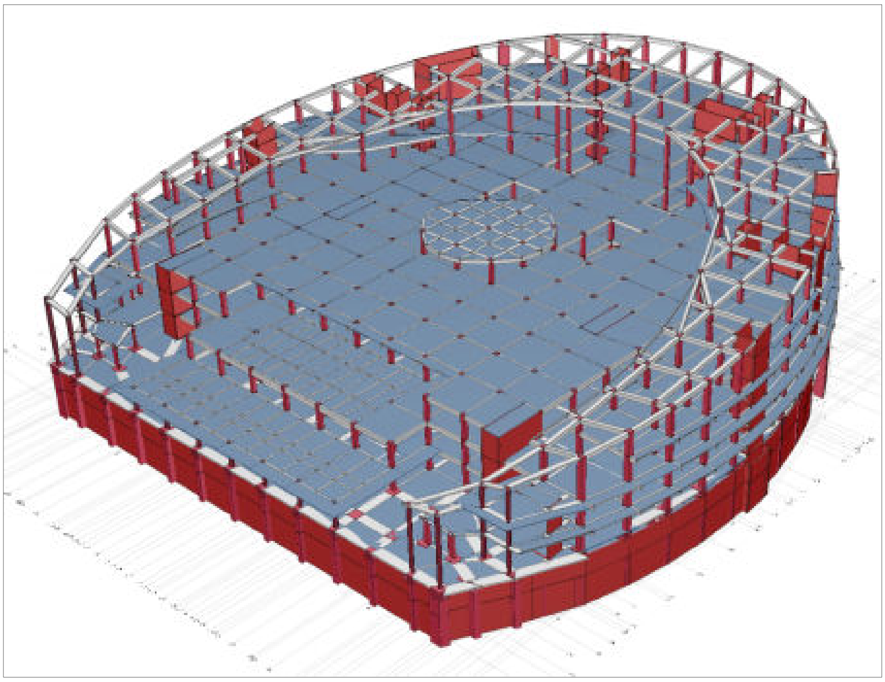

Figure 7. Structural analysis model of Block A

The structural performance of the block has been summarized and compared with the fixed base case in means of modal properties (Table 3.2), relative storey displacements (Figure 8), absolute storey displacements (Figure 9) and storey shears (Figure 10).

Table 3.2. Modal properties for (a) the isolated structure for the earthquake with 475 year return period (b) the isolated structure with 2475 year return period and (c) for the fixed base structure

	T	%Mx	%My	%Mz
Mode 1	2.49	59.42	0.17	36.44
Mode 2	2.45	0.11	98.59	0.05
Mode 3	1.89	39.16	0.00	56.67
Mode 4	0.34	0.10	0.00	2.09
Mode 5	0.31	0.00	0.03	0.02
Sum (5 Modes)		98.79	98.79	95.28
Analysis Sum		100.00	100.00	100.00

(a)

	T	%Mx	%My	%Mz
Mode 1	3.03	59.50	0.29	36.55
Mode 2	2.98	0.18	99.70	0.09
Mode 3	2.30	40.27	0.00	55.15
Mode 4	0.35	0.05	0.00	2.42
Mode 5	0.31	0.00	0.01	0.02
Sum (5 Modes)		100.00	100.00	94.24
Analysis Sum		100.00	100.00	100.00

(b)

	T	%Mx	%My	%Mz
Mode 1	0.49	58.25	0.02	5.31
Mode 2	0.42	0.08	53.50	3.02
Mode 3	0.39	2.71	3.49	41.77
Mode 4	0.18	11.00	0.00	0.18
Mode 5	0.15	0.01	16.29	0.06
Sum (5 Modes)		72.05	73.31	50.34
Analysis Sum		100.00	100.00	100.00

(c)

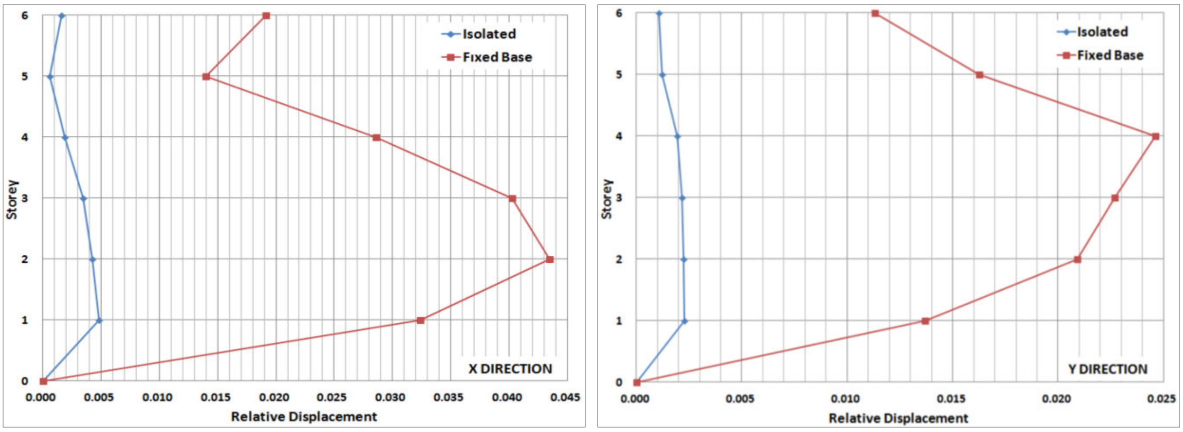

Figure 8. Relative storey displacements of Block A for the earthquake with 475 year return period

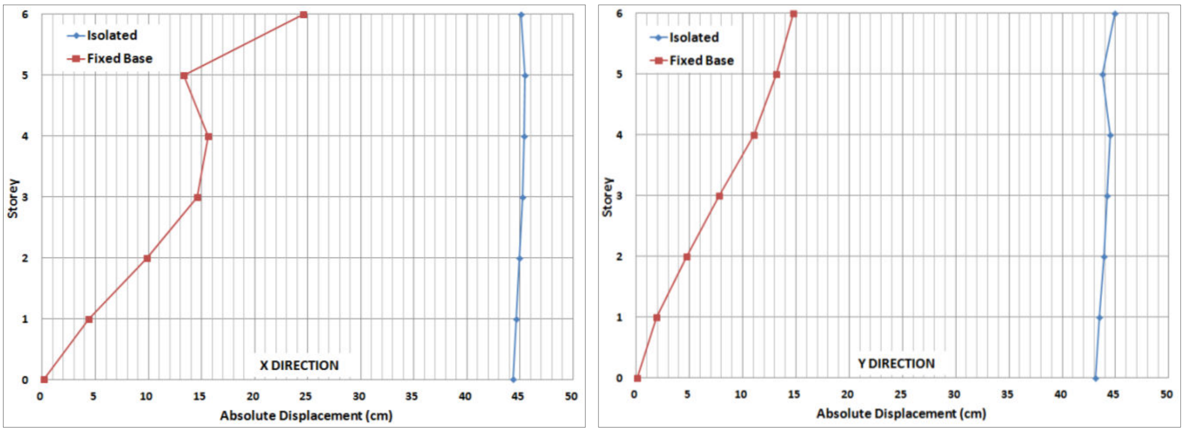

Figure 9. Absolute storey displacements of Block A for the earthquake with 2475 year return period

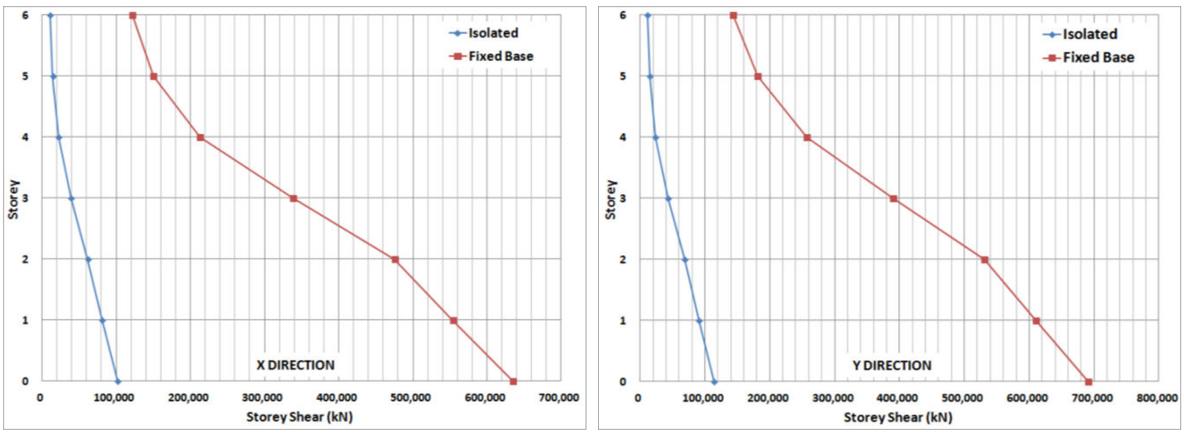

Figure 10. Storey shears of Block A for the earthquake with 475 year return period (R=1)

3.3. Structural analyses results for Block B

Single structural model (Figure 11) has been used in the design since this block has no basement floors. The design of the structure has been conducted with assumed isolator damping of 20% using the spectrum with 10% probability of occurrence in 50 years. The damping reduction factor has been calculated using Eqn. 3.1 for this level of damping. The target period has been chosen as 3.0 seconds and the stiffness of the isolators have been modified to reach this period.

The isolator displacements have been checked for the spectrum of the earthquake with 2% probability of occurrence in 50 years. Assumed target displacement for this level of earthquake is 3.5 seconds with 15% damping.

The structural performance of the block has been summarized and compared with the fixed base case in means of modal properties (Table 3.3), relative storey displacements (Figure 12), absolute storey displacements (Figure 13) and storey shears (Figure 14).

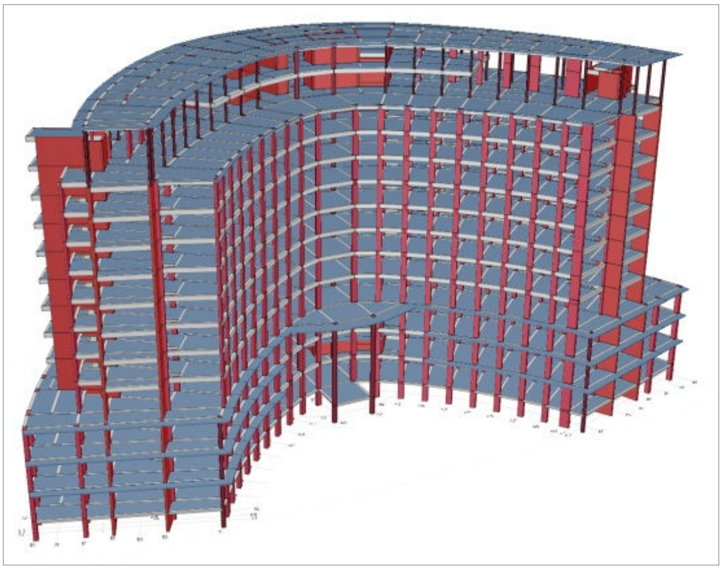

Figure 11. Structural analysis model of Block B

Table 3.3. Modal properties for (a) the isolated structure for the earthquake with 475 year return period (b) the isolated structure with 2475 year return period and (c) for the fixed base structure

	T	%Mx	%My	%Mz
Mode 1	2.99	1.72	96.67	0.07
Mode 2	2.97	85.92	1.76	10.94
Mode 3	2.75	11.01	0.04	87.87
Sum (3 Modes)		98.66	98.47	98.88
Analysis Sum		100.00	100.00	100.00

(a)

	T	%Mx	%My	%Mz
Mode 1	3.49	7.01	91.22	0.61
Mode 2	3.48	82.62	7.61	8.71
Mode 3	3.22	9.30	0.01	90.04
Sum (3 Modes)		98.93	98.83	99.36
Analysis Sum		100.00	100.00	100.00

(b)

	T	%Mx	%My	%Mz
Mode 1	1.08	0.83	68.85	0.04
Mode 2	1.05	8.83	0.02	55.85
Mode 3	0.95	60.18	0.87	9.01
Sum (3 Modes)		69.83	69.75	64.90
Analysis Sum		100.00	100.00	100.00

(c)

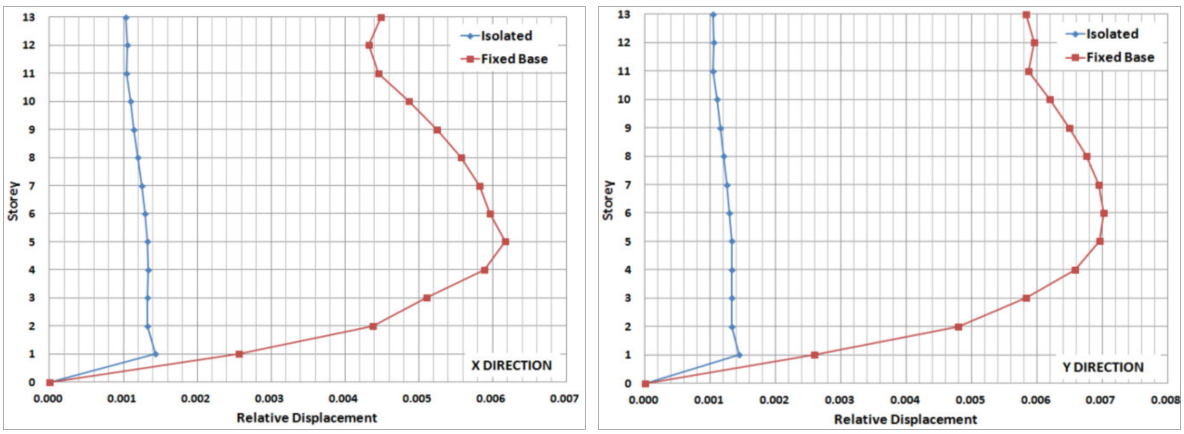

Figure 12. Relative storey displacements of Block B for the earthquake with 475 year return period

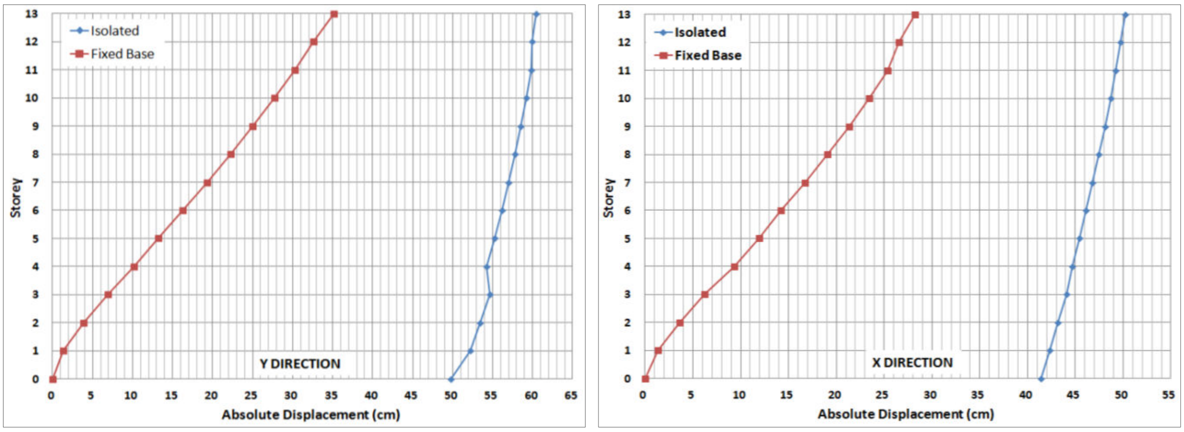

Figure 13. Absolute storey displacements of Block B for the earthquake with 2475 year return period

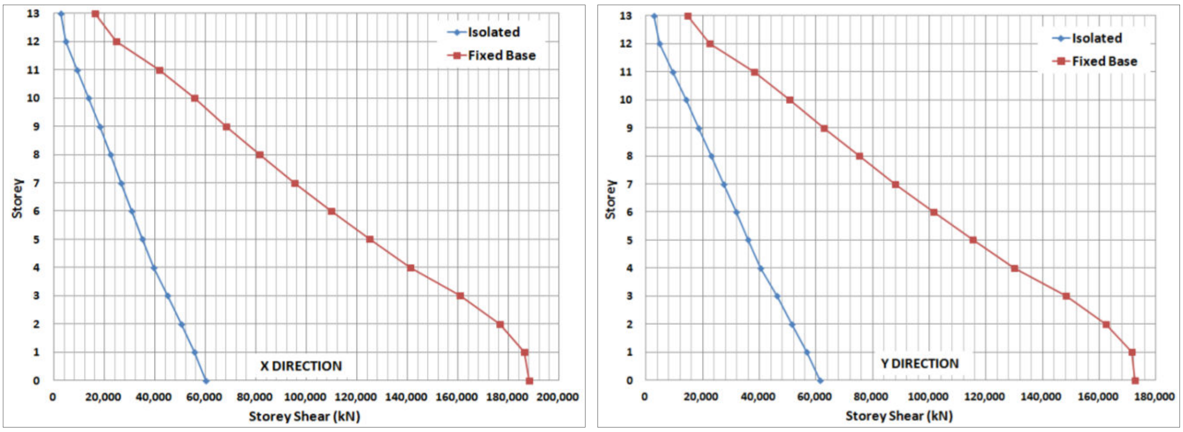

Figure 14. Storey shears of Block B for the earthquake with 475 year return period (R=1)

4. CONCLUSION

During the design stage the basic properties and types of the isolators were not yet been defined. Analyses have been conducted by assumed isolator properties. It has been shown in this paper that base isolation design greatly increases the structural performance by reducing the relative storey displacements and storey shears. The hospitals need to be immediately in service after major seismic events to treat casualties. The best proven way of protecting both the structure and the medical equipments is seismic isolation technology.

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