

Seismic Retrofit of an Existing Multi-Block Hospital by Seismic Isolators

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SUMMARY:

Istanbul, a city with more than 13 million inhabitants, expects a devastating major earthquake. The majority of the building stock of the city has been built with the old seismic design practice. The need of emergency hospitals in service after such earthquakes is inevitable.

Marmara University Research and Training Hospital, built in 1991, has never been in service among these years. The structure was retrofitted in 2002; however the retrofitted structure still does not satisfy the requirements of the recent Turkish seismic code. Retrofitting with conventional methods heavily obstruct the architectural usage and cannot prevent damages to non structural elements and valuable equipments.

In this paper, probably the world's largest seismic retrofit project using base isolators is being discussed. The choice of isolation interface, seismic risk analysis, isolator characteristics, unique solutions created in merging of 16 blocks, positioning of the isolators and construction techniques have been discussed.

Keywords: seismic isolators, base isolation, retrofit, hospital, assessment

1. INTRODUCTION

Istanbul is a highly populated city with more than 13 million inhabitants. In the history of the city many devastating earthquakes occurred and statistical approaches reveal that the city is expecting another major earthquake in the near future. The building stock of the city, especially the ones constructed before the release of the 1997 seismic code, carries high risk potential for the inhabitants and economy of the country. The old seismic design practice, lack of ductile detailing, poor material quality and insufficient onsite control made thousands of this kind of structures vulnerable to a probable seismic activity. Thousands of deaths and casualties are inevitable. There is a great demand for hospitals in service immediately after a major seismic event. The new hospitals are being built with good seismic design expertise however there is a big demand for the rehabilitation of the existing ones.

Marmara University Research and Training Hospital is one of many assessed public buildings for its seismic performance as part of the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP). Started in early 2006, one of ISMEP's objectives is to improve the city of Istanbul's preparedness for a potential earthquake by strengthening critical public facilities. The project is financed by a loan to the Government of Turkey by European Investment Bank, and implemented by the Istanbul Project Coordination Unit which reports to the Istanbul Special Provincial Administration.

The hospital is located in the Asian part of the city on the Coast of Marmara Sea (Figure 1). It was built in 1991 and has never been in service among these years. The hospital consists of 16 mid and low rise adjacent blocks and a car park block. It has a total construction area of 112,440m² and 750 beds capacity (Figure 3).

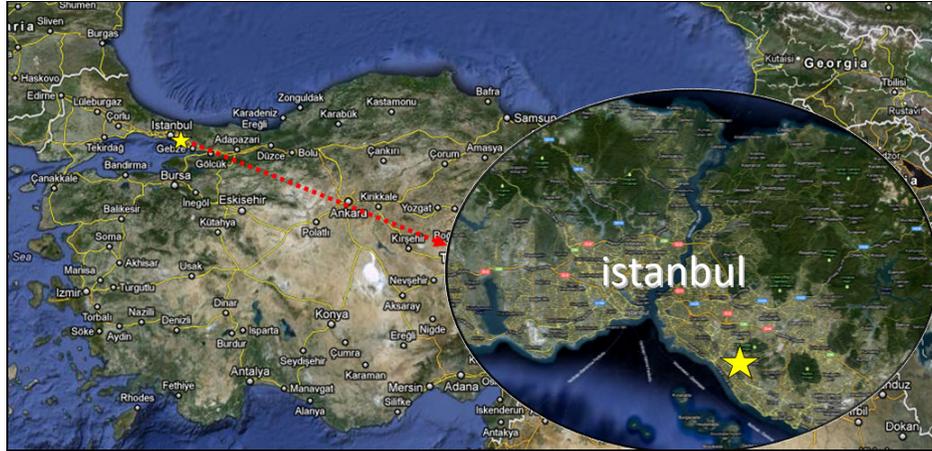


Figure 1. Location of the hospital

The hospital is located on an inclined topography. The altitude of the ground reduces from south to north between ± 0.00 m to -8.96 m levels and has been surrounded partially by reinforced concrete basement walls at lower levels.

The parking block is located on the west part of the campus. It is a 2 storey building with 2 basement floors. Blocks A1, A2 and A3 have 2 basement and 2 typical floors. Blocks A4, A7 and B8 have 2 basement floors and 10 typical floors. Blocks A5 and A6 do not have basement floors and consist of 2 typical floors. Block A8 has 2 basement and 11 floors. Blocks B1, B2, B3, B5 and B6 have 2 basement floors and 1 typical floor. Block B7 has 3 basement floors and 10 typical floors (Figure 2).

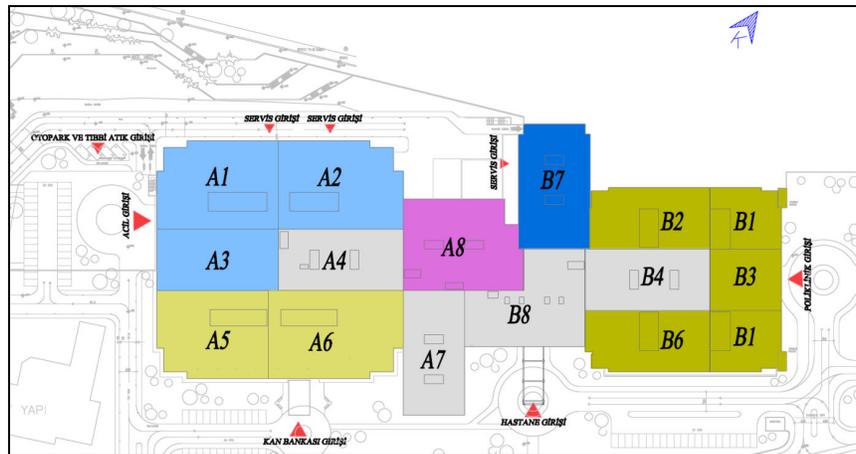


Figure 2. Plan layout of the blocks. (colours indicate different storey numbers)

Typical storey height is 448cm and the structure has 3 foundation levels. Below the Block B7, the foundation level is at -14.49 m while it is at -8.96 m in the majority parts of the complex with the exception of Blocks A5 and A6 which do not have basement floors where foundation level is at ± 0.00 m. The roof top levels for the parking block is at ± 0.00 , for Block A8 is at $+39.50$ m, for Blocks A4, A7, B4, B7 and B8 is at $+36.16$ m, for the rest of A Blocks is at $+8.96$ m and for the rest of B Blocks is at $+4.48$ m.

In 2002 all blocks of the hospital were retrofitted by adding reinforced concrete shear walls and jacketing the columns. The retrofit decision in 2002 had been taken according to the previous seismic code published in 1998.



Figure 3. Existing condition of the hospital

Seismic code of 1998 was assessing existing buildings as if they were new buildings. The buildings were being assigned a behaviour factor and an importance factor. Structural elements like beams, columns and shear walls were being checked by capacity/demand ratios. There was an element based pass/ fail system. Meanwhile the current code of 2007 includes a new chapter with a performance-based assessment and retrofit approach for the existing buildings.

Performance based seismic assessment has been conducted on all of the blocks of the hospital according to the current Turkish Seismic code. Assessment included the retrofitted members of the previous retrofit application as well. The buildings have been assessed for Life Safety (LS) performance level using the response spectrum of the earthquake with 2% probability of exceedence in 50 years (2475 years return period). The buildings that satisfy the LS performance level requirements have further been assessed for Immediate Occupancy (IO) performance level using the response spectrum of the earthquake with 10% probability of exceedence in 50 years (475 years return period).

The parking block is the only block that satisfies both LS and IO performance levels. The rest of the blocks needed further retrofitting according to the 2007 Turkish seismic code.

1.1. Retrofit options

Marmara University Research and Training Hospital has been planned to be used as an emergency hospital after a devastating earthquake that may take place in Istanbul and vicinity. The hospital is required to be in service immediately after the earthquake.

The first option considered was strengthening the structure with conventional methods. However retrofitting with conventional methods heavily obstructs the architectural usage and cannot prevent damages to non-structural elements and valuable equipment, hence cannot satisfy the IO performance requirements.

The second option was seismic base isolation. Seismic base isolation has been proven-out to be the safest construction and retrofit technique. By placing seismic isolators, the hospital would satisfy both IO and LS performance levels with minimum obstruction to the architectural usage.

2. SEISMIC ISOLATION DESIGN

2.1. Isolation solutions

The first step in seismic isolation design is the decision of the location of the isolation interface. The isolation interface can be at the foundation level as well as at an appropriate floor level. Even though the best location for the isolation interface is the foundation level, sometimes especially for the retrofitting of existing buildings, it may well be impossible or infeasible to mount the isolators at the foundation level.

Marmara University Research and Training Hospital is vertically irregular. Car park block has 2 basement floors but no typical floors, while Blocks A5 and A6 do not have basement floors. Block B7 has 3 basement floors while the rest of the blocks have 2 basement floors. 6 blocks in the centre of hospital complex are high rise with 10-11 typical floors while the rest of the A and B Blocks have 1-2 typical floors. There is an underground radiology unit with massive walls between -8.96m and -2.81m levels.

If the isolation interface had been chosen at the base (-8.96m) then massive radiology unit had to be demolished or relocated at the surface with heavy excavations. Since Blocks A5 and A6 do not have basements they had to be whether demolished or isolation interface would be undesirably in different levels. Moreover in order to have adequate seismic peripheral gap, southern side of the hospital had to be totally excavated and retaining walls with nearly 10m height had to be constructed. These and other similar problems made isolation at the base of the structure infeasible.

After studying several other options, it was decided that the most suitable isolation interface level would be the top of the basement floors (below the ground floor slab, $\pm 0.00\text{m}$). However in this case elevators and staircases would create problem. During the movement of the isolators, the service of the elevators would be interrupted. During an earthquake if the elevators were at the level of the isolation interface there could be fatal injuries for the people in the elevators or elevators might block the movement of the isolators. Similar scenario exists for the people at the stairs at the level of isolation interface during the seismic event.

Two solutions were proposed to the University administration. The unaccepted first option was to unlink the elevators at basement floors where elevators would move independently at the floors over and under the isolation interface. The accepted final decision was to suspend the isolator walls and staircase walls to the isolated ground floor and place the isolators underneath these walls at the foundation level. However in this case, sufficient gap should be provided between the elevator/staircase walls and the basement floor slabs in order to allow collision-free isolator movement (Figure 4).

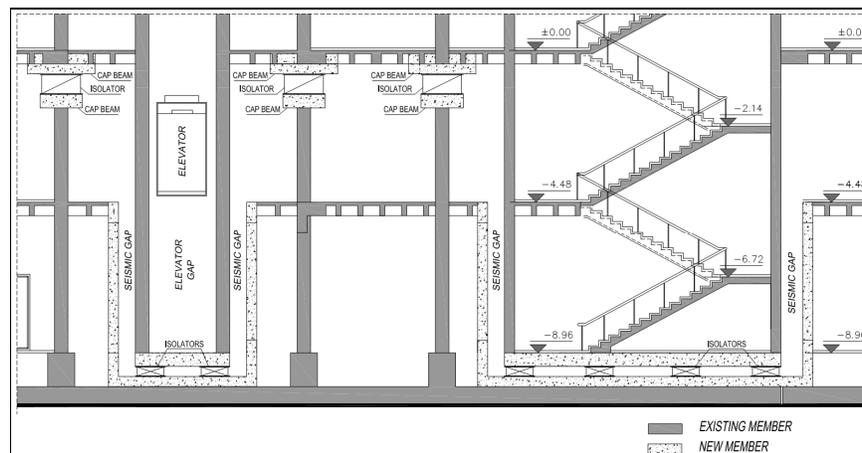


Figure 4. Isolation interface

The substructure below the isolation interface must be sufficiently rigid to support the floating structure above. The existing building partially surrounded by reinforced concrete basement walls due to the inclination of the surface and does not have completely rigid basement floors. For this reason, peripheral shear walls have been added and the basement floors have been transformed into rigid basement floors. All blocks under the isolation interface have been merged into a single block by jacketing the neighbouring columns and connecting to the adjacent shear walls.

The slab over the isolation interface (ground floor slab) has been joined by special connectors. Since

high-rise blocks have the risk of hammering during a shake they have been merged together to guarantee synchronized motion. Low-rise buildings which have typically 1-2 floors have been left unmerged above the isolation interface since hammering effect determined to have much less risk.

The existing parking block satisfies both of the IO and LS performance level criteria and does not need further retrofit. Hence it has been decided not to be isolated and completely detached from the isolated blocks by providing sufficient gap for the displacement of the isolators. In order to construct this gap, existing edge columns are removed and new columns at a distance are added.

2.2. Installation of the isolators

In order to install the isolators the columns are going to be cut below the ground floor slab as much as the height of the isolators going to be placed. The column where isolator is going to be installed will be unloaded by hydraulic jacks. The props will be continuous to the foundation and at the superior storey. Suggested propping system is given in Figure 5.

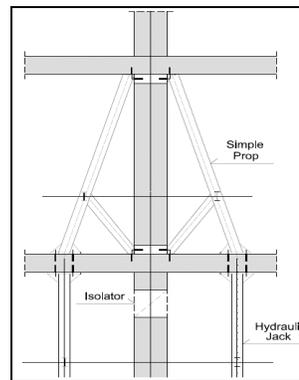


Figure 5. Suggested propping system

The upper mounting interface will be created by filling up the hollow ribbed slab with concrete, creating a concrete block. Similarly the lower isolator mounting interface will be created whether by column jacketing or cap beams. Anchorages with couplings are placed in the concrete of upper and lower mounting interfaces. The isolators are going to be mounted to these pre-installed anchorage couplings.

2.2. Seismic scenario

The hospital is located in the 1st seismic zone according to the Turkish seismic code (Figure 6). Peak ground acceleration is 0.4g for the 1st seismic zone and decreases by 0.1g for each consequent zone.

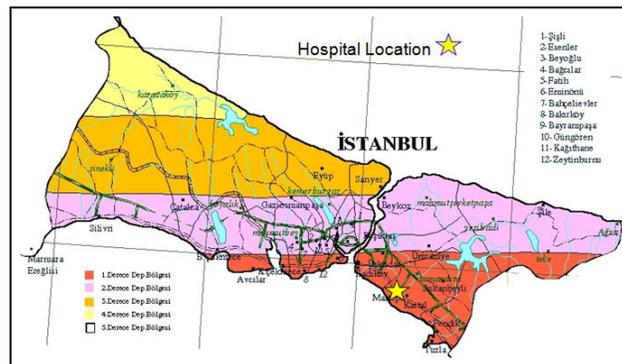


Figure 6. Code seismic zonation in Istanbul

The seismic performance of the base isolated hospital has been assessed at two different levels of seismic input. Life Safety (LS) performance level criteria of Turkish seismic code has been checked for ground shaking with a return period of 2475 years (2% probability of exceedence in 50 years) and Immediate Occupancy (IO) performance level criteria has been checked for ground shaking with a return period of 475 years (10% probability of exceedence in 50 years).

Site specific risk analysis has been conducted for the hospital site and two spectra have been created for LS and IO performance levels. These spectra have been compared with that of the Turkish seismic code and have been found less conservative. Eventually the code spectra have been selected for being used in the seismic analysis. Since the spectra provided by the current Turkish code are not suitable for displacement based analysis, that of a more recent seismic code with similar acceleration magnitude levels published by Ministry of Transportation for the construction of railways, airports and harbour structures have been utilized (Figure 7 and 8). These spectra are created for the exact location of the structure by providing its global coordinates.

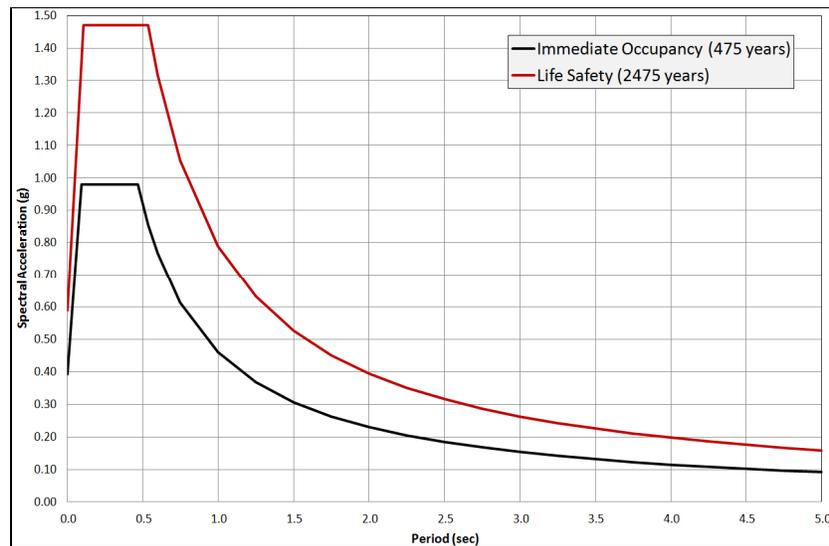


Figure 7. Design acceleration spectra (5% damping)



Figure 8. Design displacement spectra (5% damping)

Spectrum reduction factor for additional damping provided by isolators shall be taken from ASCE-07 (Table 2.1).

Table 2.1. Spectrum reduction factors for additional damping provided by the isolators

Effective Damping	Spectral Reduction Factor
≤ 2	0.8
5	1.0
10	1.2
20	1.5
30	1.7
40	1.9
≥ 50	2.0

2.3. Isolator performance demand

688 isolators were determined to be mounted at the primary isolation interface. Moreover, 154 isolators are going to be mounted additionally under the elevator/staircase walls at the foundation level. The total seismic weight of the structure is 1,359,973 kN.

For ground shaking with 2% probability of exceedence in 50 years, the maximum isolator displacement has been limited to 500 mm and the base shear transmitted to the superstructure has been limited to 13.35% of the total seismic weight. For ground shaking with 10% probability of exceedence in 50 years, the maximum isolator displacement has not been limited but the base shear transmitted to the superstructure has been limited to 8.46%.. The manufacturer has been provided flexibility to select the effective damping and period of the isolated system considering these requirements.

All the isolator designs are going to be confirmed by laboratory tests and detailed seismic analysis. Laboratory tests shall be done according to Eurocode EN 15129:2009 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. STRUCTURAL ANALYSIS

A generic design process has been followed in retrofit design of the hospital. 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 shall have minimum possible horizontal stiffness (eg. sliders).

3.1. Structural modelling and isolator properties

The structural model has been created and structural analysis has 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.

Since they are merged into one single block by special connectors, high rise blocks have been idealized as one single structure above the isolation interface. On the other hand, low rise blocks have been modelled separately since they are disconnected from each other by expansion joints. The whole structural analysis model (Figure 9) has been used for vertical load analysis.



Figure 9. Structural analysis model

During the retrofit design stage the basic properties and types of the isolators were not yet been defined. All analyses have been conducted by assumed isolator properties given in Table 3.1 where T is period, ξ is effective damping ratio, B is spectrum reduction factor, K_{\min} is minimum isolator system stiffness, k_{\min} is minimum single isolator stiffness and Δ is the isolator displacement. The isolator manufacturer is not bounded by these assumed isolator properties.

Table 3.1. Assumed isolator characteristics for the analysis

Immediate Occupancy				Life Safety			
T (sec)	3.2	K_{\min} (kN/m)	534,467	T (sec)	3.7	K_{\min} (kN/m)	399,777
ξ	30%	k_{\min} (kN/m)	635	ξ	25%	k_{\min} (kN/m)	475
B	1.7	Δ (m)	0.215	B	1.6	Δ (m)	0.454

3.2. Performance level criteria

Retrofitted buildings should satisfy both the Life Safety and Immediate Occupancy performance level criteria according to Turkish Seismic Code.

Buildings satisfying the two conditions below are regarded as meeting the Life Safety performance level, provided that any member subjected to brittle failure should be retrofitted.

- The ratio of the total shear force carried by the columns and shear walls in the “Severe Damage Zone” to the total shear force at any storey for any direction of loading shall be less than or equal to 0.4 for the top storey, and 0.2 elsewhere.
- Less than or equal to 30% of the primary beams shall be in the “Severe Damage Zone” for any direction of earthquake loading.

Buildings satisfying the two conditions below are regarded as meeting the Immediate Occupancy performance level, provided that any member subjected to brittle failure should be retrofitted.

- All the columns and shear walls should be in “minimal damage zone”
- Less than or equal to 10% of the primary beams shall be in the “Moderate Damage Zone” for any direction of earthquake loading.

3.3. Analysis results

Life Safety and Immediate Occupancy performance level criteria given in Section 3.2 have been satisfied at each independent block (over the isolation interface). Isolation system stiffness of each block has been adjusted to fit the target periods given in Table 3.1. The base shears calculated for each individual isolated block are given in Table 3.2. Absolute storey displacements (Figure 10), relative storey displacements (Figure 11) and storey shears (Figure 12) are here given for the monoblock of higher blocks (A4, A7, A8, B4, B7, B8) as an example.

Table 3.2. The base shears calculated for each individual isolated block

Block	IO	LS	Block	IO	LS	Block	IO	LS
A1	3,218	5,078	A6	3,505	5,480	B5	794	1,249
A2	3,332	5,169	B1	747	1,181	B6	1,473	2,321
A3	2,503	3,957	B2	1,445	2,284	Higher Bl.	94,718	150,305
A5	2,921	4,576	B3	934	1,471	Total	115,590	183,071

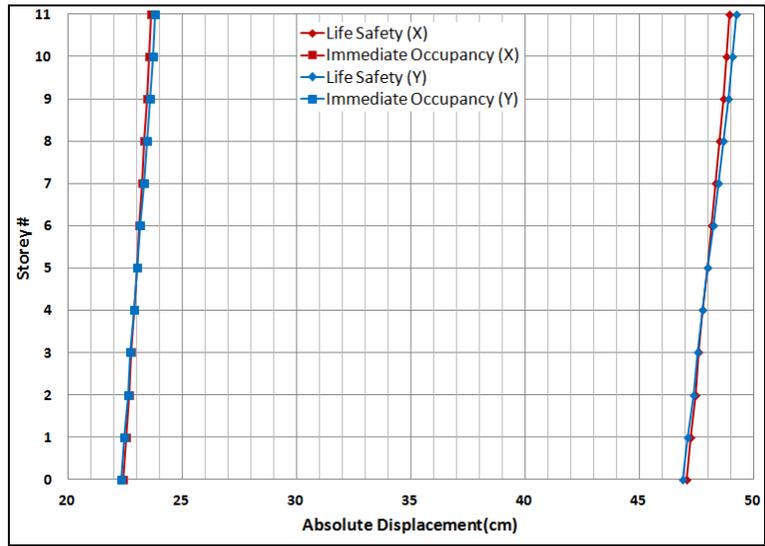


Figure 10. Higher blocks, superstructure storey absolute displacements

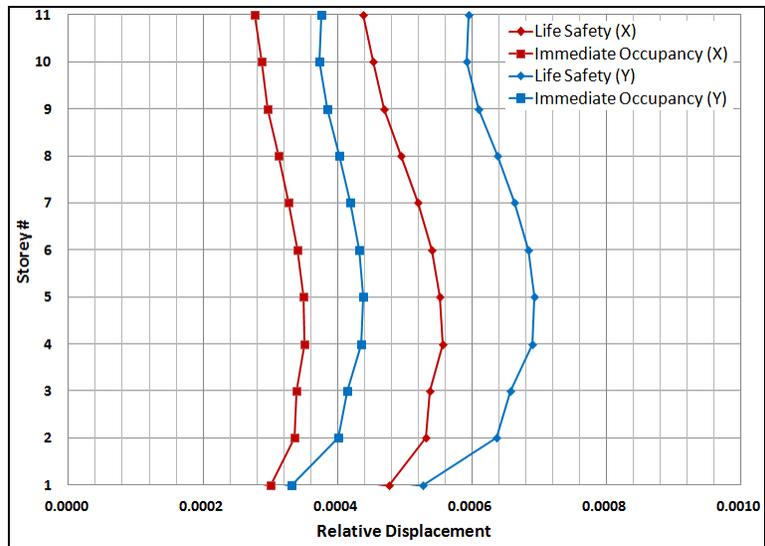


Figure 11. Higher blocks, superstructure storey relative displacements

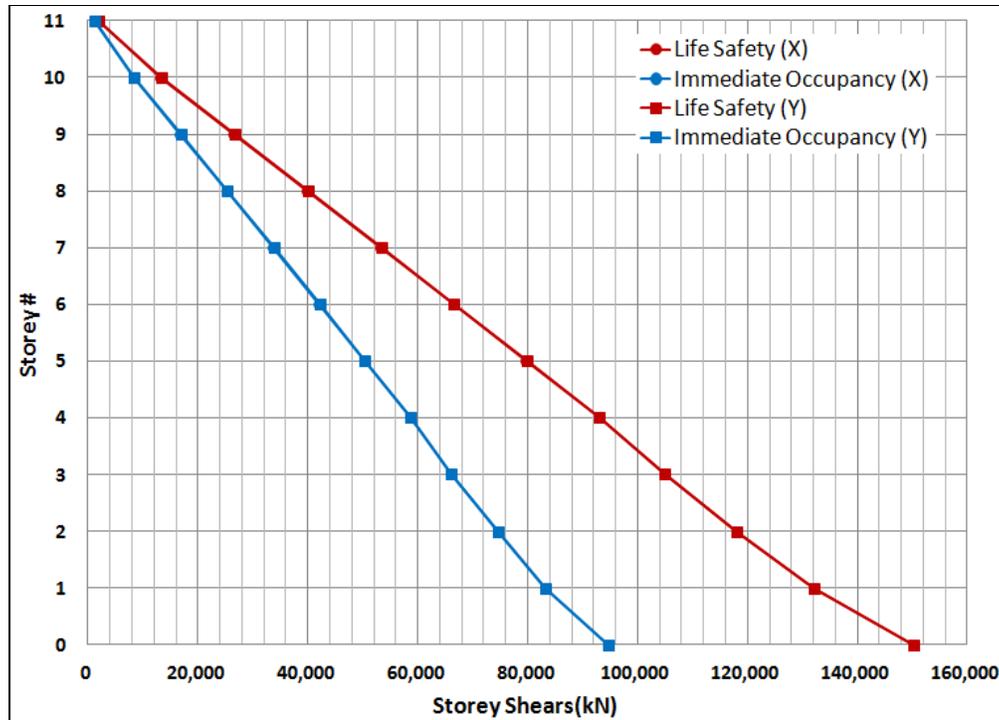


Figure 12. Higher blocks, superstructure storey shears

4. CONCLUSION

There is a big demand for emergency hospitals in high seismic risk cities like Istanbul. Marmara University Research and Training Hospital has never been in service since its construction in 1991. After the completion of the construction of this seismic retrofit, the hospital will be ready for such scenario not only structurally but also architecturally. Retrofitting by base isolation provides more architectural freedom compared to conventional retrofitting by added shear walls. Moreover all mechanical and electrical systems of the hospital are going to be re-designed to comply the base isolation design. Upon completion of the retrofit and renovation process Istanbul will have a new, contemporary and earthquake-resistant emergency hospital.

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