17th Greek Conference on Concrete Structures

Seismic Isolation Applications for the Retrofit of Existing and Design of New Hospitals

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- Seismic isolation of hospitals
- Codes and Standards
- Retrofit of Başıbüyük Hospital with seismic isolation
- Design and construction of Adana Health Complex with seismic isolation
- Future Perspectives and Conclusions

Seismic isolation is an effective strategy to protect the structures, non-structural components and contents of hospital buildings exposed to earthquakes.

In addition to life-safety hazard for the patients and to the disruption of service, the property loss are also important in the case of hospitals because of the high costs of the medical equipment.

Seismic isolation furthermore eliminates the need for thermal and seismic expansion joints

One of the largest base isolated hospital buildings in the world is the San Bernardino Hospital in California, which was built in 1993 and encompasses 400 HDRB type isolators. The new seismic isolated Stanford Hospital (90,000m2, 600 bed) under construction, employs 206 FPS type isolators

Applications of seismic isolation for hospital buildings are becoming very common in earthquake-prone regions in Europe, especially in Italy.

Construction of seismically isolated buildings should entail flexible linkages in the mechanical systems crossing the isolation interface to accommodate isolation displacements.

Performance Targets of Health Care Facilities

- The regulation of Ministry of Health with number of 2013/3 has an annex named as “Minimum Requirements for Design, Testing and Construction of Seismically Isolated Health Care Facilities”.
- In this document, the performance objectives have been defined as “operational -continuous functionality” at earthquake level of probability of exceedance 10% in 50 years (DBE) and “immediate occupancy” at the earthquake level of probability of exceedance in 2% in 50 years (MCE).

Operational | Immediate Occupancy | Life Safety | Collapse Prevention

CODES and STANDARDS

- TDY 2016   Turkish Seismic Isolation Code (not yet official)
- Eurocode 8 Design of Structures for Earthquake Resistance
- EN 15129 Anti Seismic Devices
- EN 1337 Structural Bearings
- ASCE 7-10 American Society of Civil Engineers, Minimum Design Loads for Buildings (ASCE 7-16, draft)
- AASHTO American Association of State Highway and Transportation Officials, Bridge Design Specifications
- AASHTO American Association of State Highway and Transportation Officials, Guide Specifications for Seismic Isolation Design
- ASCE 41-13 American Society of Civil Engineers, Seismic Evaluation and Rehabilitation of Existing Buildings

TURKISH SEISMIC ISOLATION CODE

In Turkey, due to the lack of the official seismic isolation design code engineers have used ASCE, EC8 and Japanese codes for the seismic isolation design for buildings and bridges. The different approaches and procedures in these codes, especially in the design ground motion definitions and testing have led to non-uniform applications.

A guideline for Seismic Isolation Design for Buildings was first published in 2008 (TASI, 2008). ISMEP (Istanbul Seismic Risk Mitigation and Emergency Preparedness Project) has adopted this guideline in some of the applications for hospitals.

A draft code, essentially based on the principles of ASCE 7-10 and EC8, is prepared and is expected to be adopted as a chapter of the new earthquake resistant design code by the end of 2016.

The new earthquake hazard map, that will be associated with the new code, is expected to accommodate long period spectral parameters to regulate the design of base isolated and other long period structures.

Some key points of the code are summarized as follows:

•Every stage of seismic isolation design conducted under of this Code shall be controlled and approved by the peer review board.

•For buildings, encompassed in this Code, the isolation system composed of isolation devices should be placed in an isolation interface located under the main mass of the building

•In the design process two levels of earthquake shall be taken into consideration: Design Basis Earthquake (DBE) Ground Motion Level: Site dependent ground motion with 10% probability of exceedance in 50 years. Maximum Credible Earthquake (MCE) Ground Motion Level: Site dependent ground motion with 2% probability of exceedance in 50 years.

• Seismically isolated buildings should remain functional (with no damage in structural and non-structural elements) at the design level earthquake.

• Seismically isolated buildings should receive no structural damage and the isolation system should be stable at the maximum credible earthquake level.

•The difference between the lateral force at maximum displacement and the lateral force at half of this displacement shall be greater than 1/40 of the total weight of the building.

•The design of the isolation units will be based on “European Standard EN 1337-3:2005: Structural Bearings - Elastomeric Bearings”.

•The isolation system must have the properties of: High vertical stiffness, Low lateral stiffness, Ability to carry vertical loads, Energy absorption, Ability to re-center after seismic motion, Adequate lateral stiffness against lateral forces (i.e. wind force) other than earthquake

•If the vertical vibration period of the isolated building is than 0.1s, the vertical degree of freedoms shall be considered in the sub and super structure models and both the vertical and horizontal component of the ground motion shall be taken in to account in the design process.

•Isolation system can be modelled as equivalent linear if:
(a) The ratio of the equivalent linear (secant) stiffness of the isolation system corresponding to the design displacement to the equivalent linear (secant) stiffness corresponding to 20% of the design displacement shall be at least ½,
(b) The properties of the isolation unit at design displacement shall differentiate at most 10% depending on the vertical loading and ,
(c) The equivalent damping ratio of the isolation system at design and maximum credible displacement levels shall not exceed 30%.

•The analysis methods listed below shall be used depending on the properties of the building and isolation system: (a) Equivalent Lateral Load Method, (b) Mode Superposition Method and, (c) Nonlinear Time History Analysis

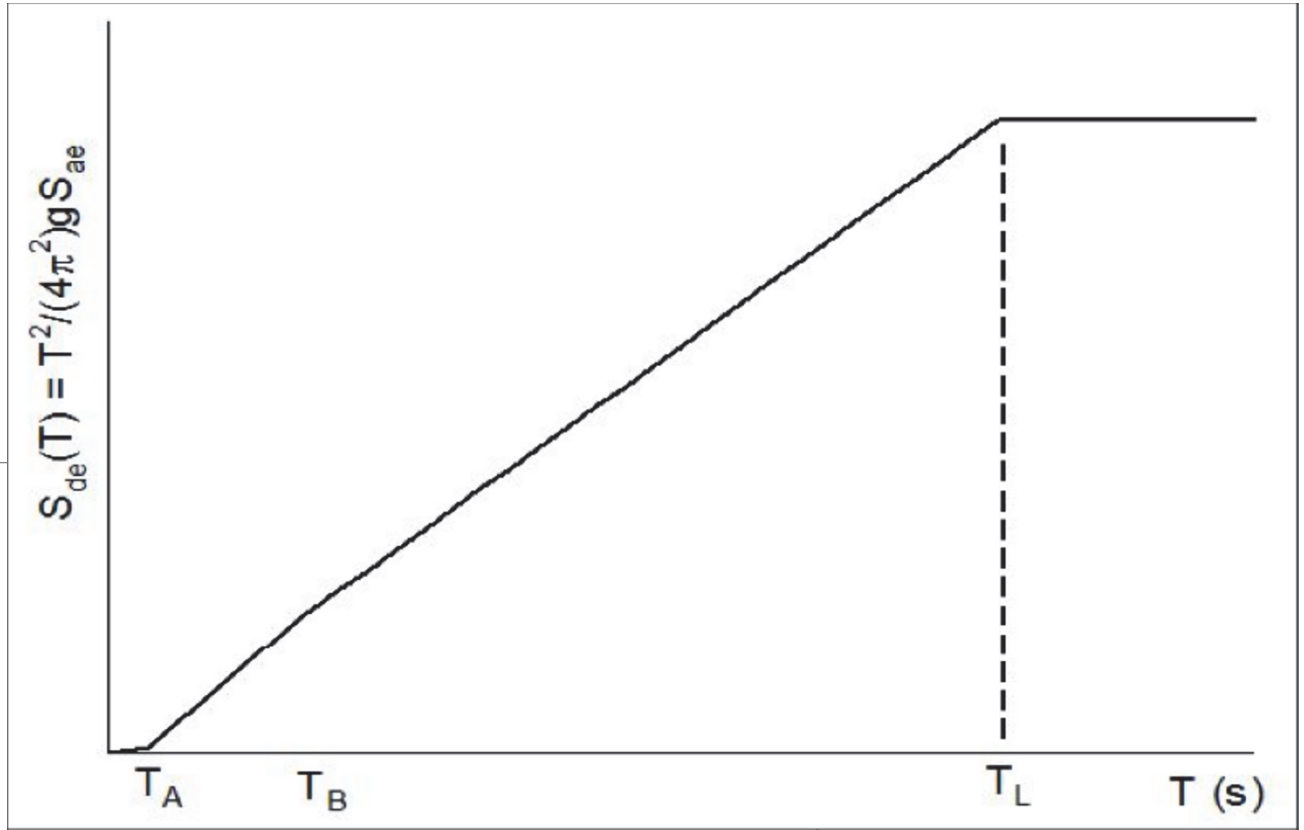
•The equivalent lateral load method is the basic analysis method and will be used for the initial design of the isolated building and, sizing of the isolator units and to provide reference design values.

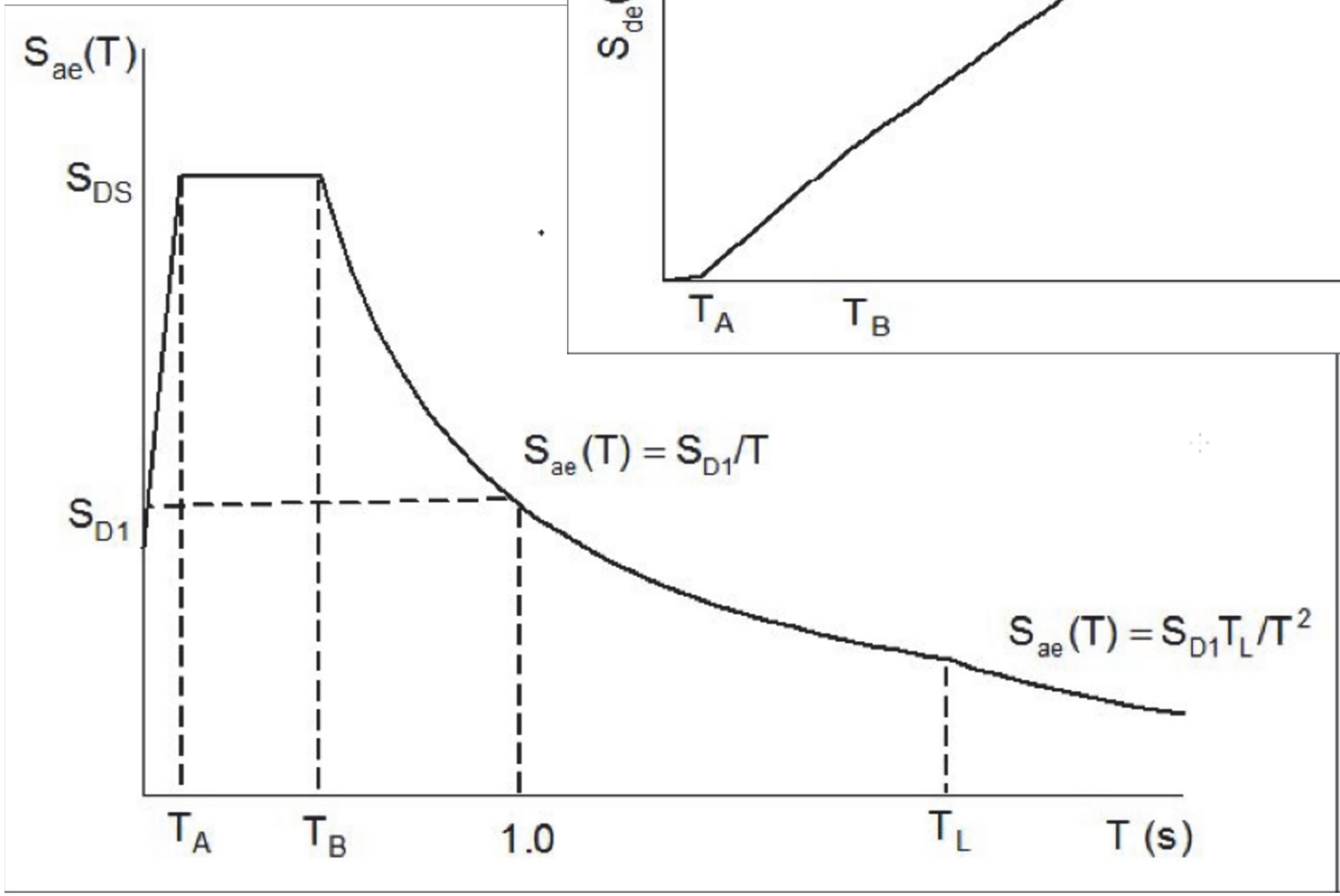
•The inter-story drift ratio of each story shall be less than 0.005 and 0.01 respectively for DBE and MCE ground motion levels.

•“Normal” ductility design for structural elements is adequate.

•The force–displacement characteristics, effective damping ratio, effective horizontal and vertical stiffness of the isolation units of the isolation system shall be determined by tests and verified with the values used in the design process.

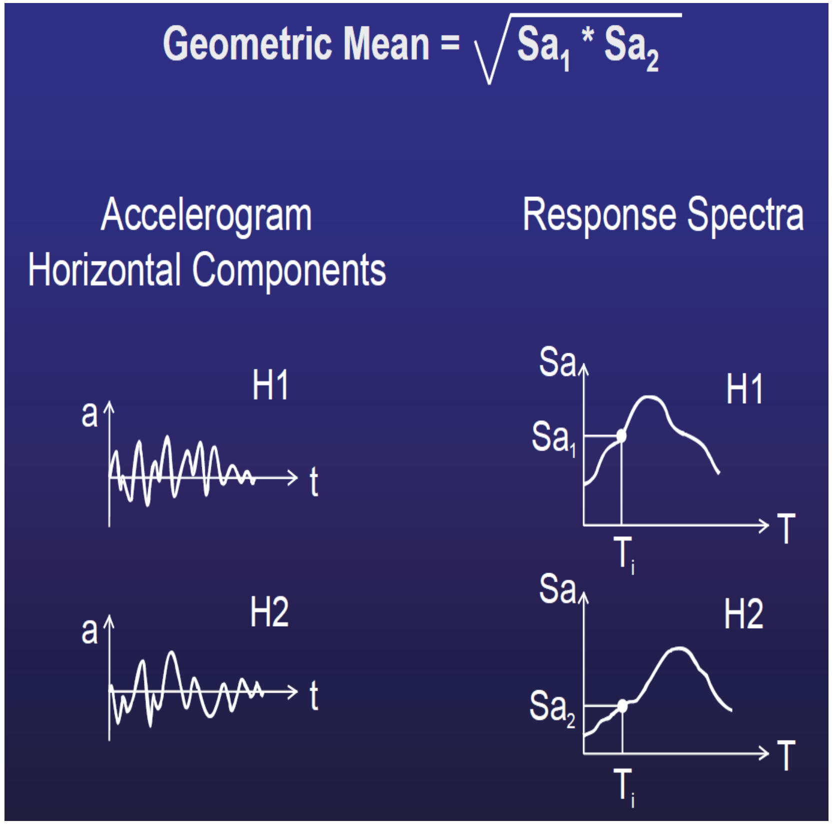
DESPLACEMENT
SPECTRUM

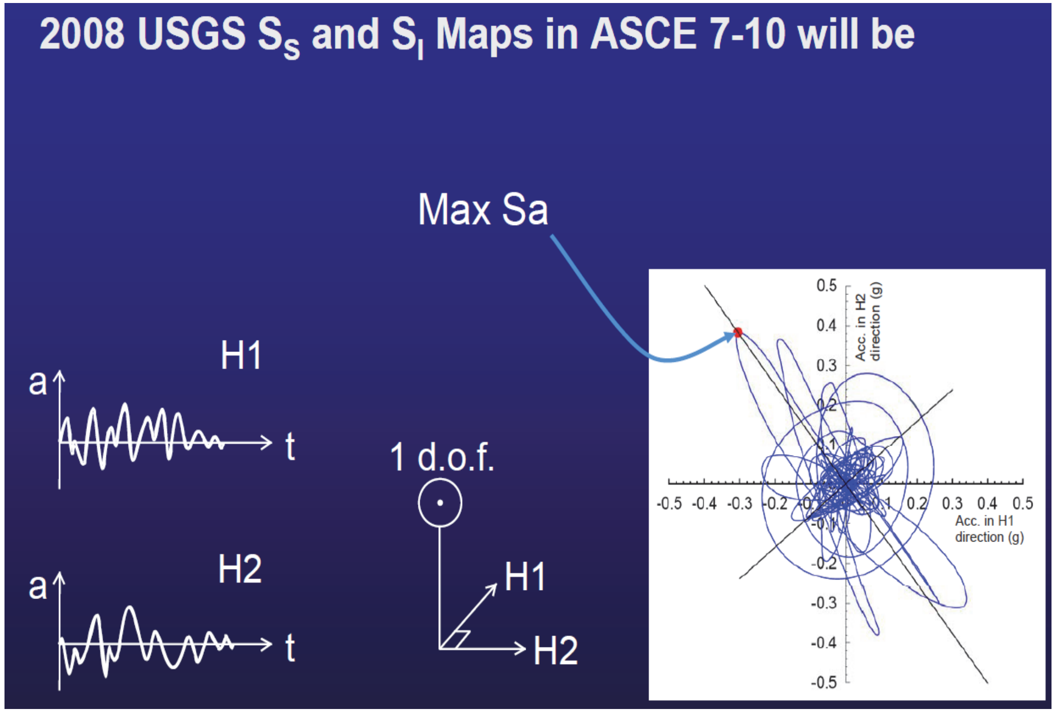


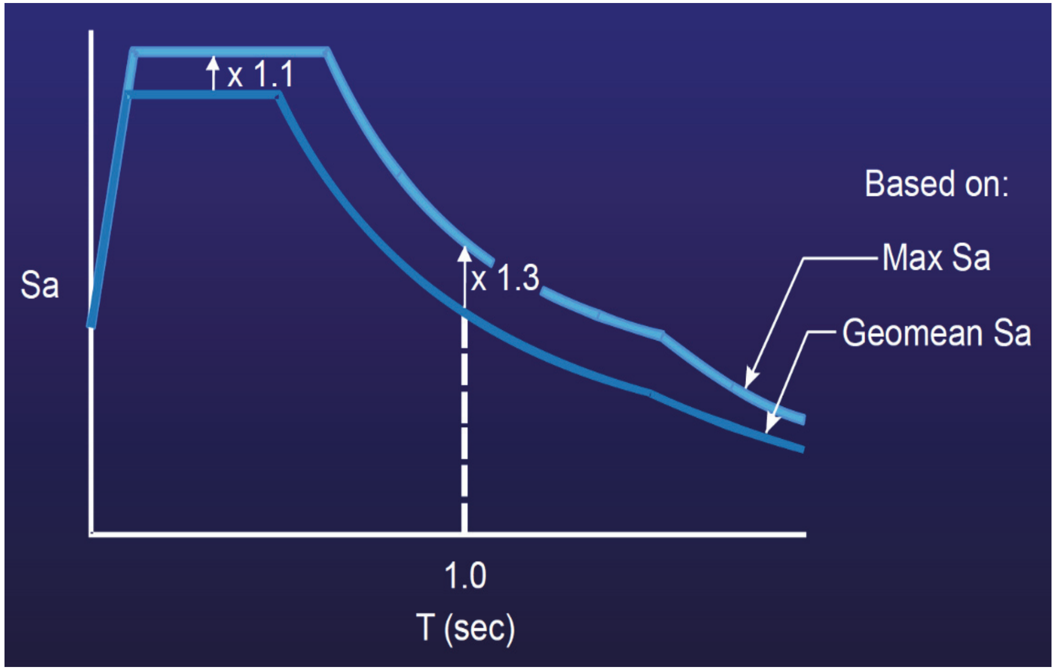


ACCELERATION
SPECTRUM

DIRECTIVITY
Maximum Direction Ground Motion versus GMRotI50 (GeoMean)

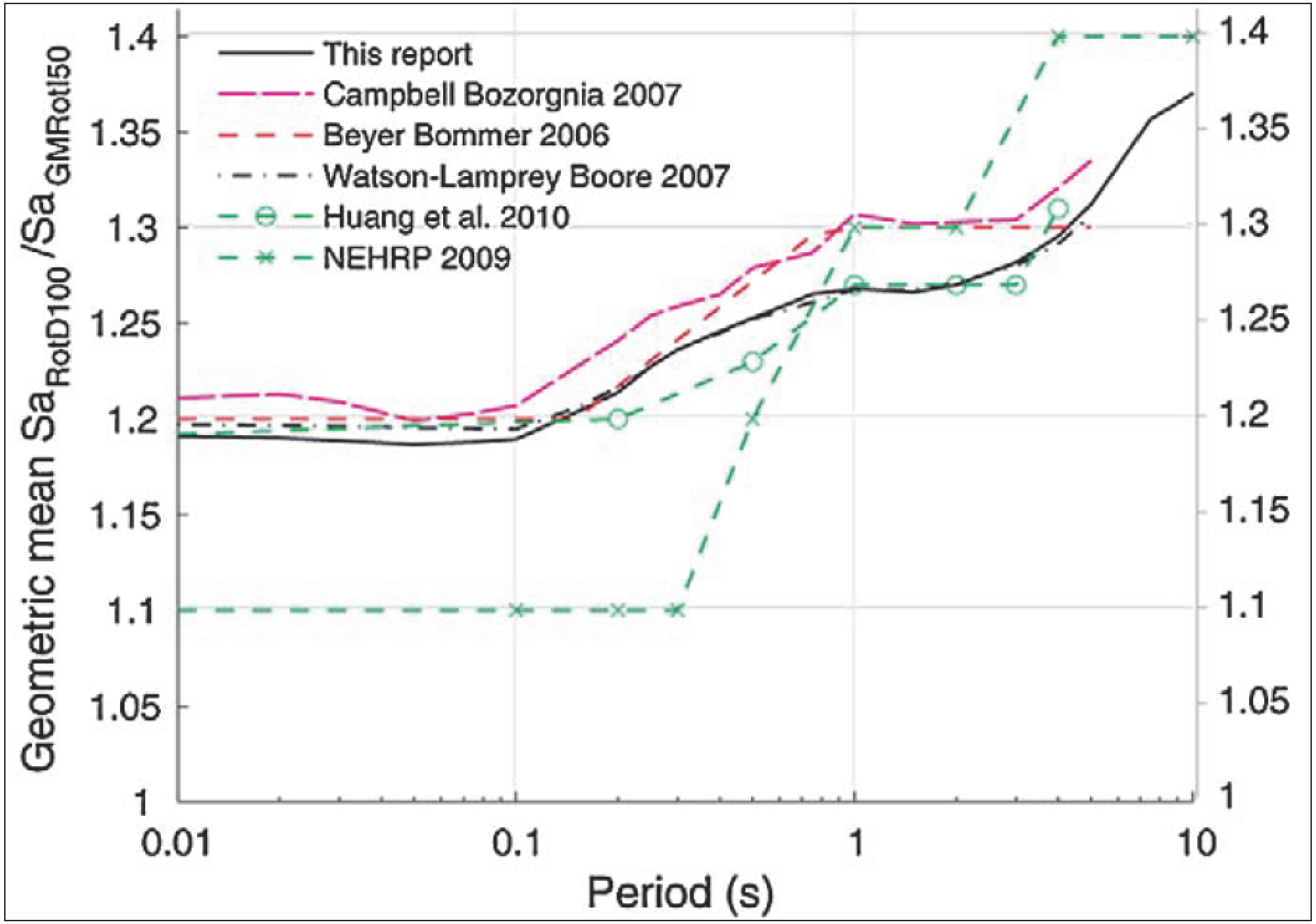






Directionality

Several researchers have studied polarization or directionality of ground motions. Recent GMPEs predicts the median Sa over all orientations ($Sa_{GMRotI50}$), which is essentially equal to the geometric mean of the two recorded horizontal (Sa)s. The maximum direction (100th percentile) value of Sa is computed over all orientations ($Sa_{RotD100}$).

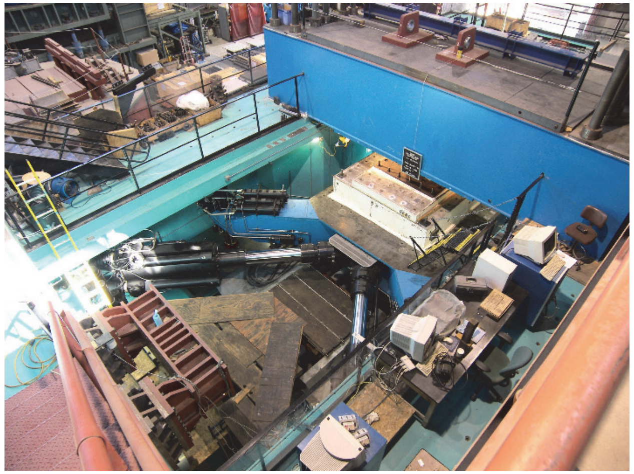


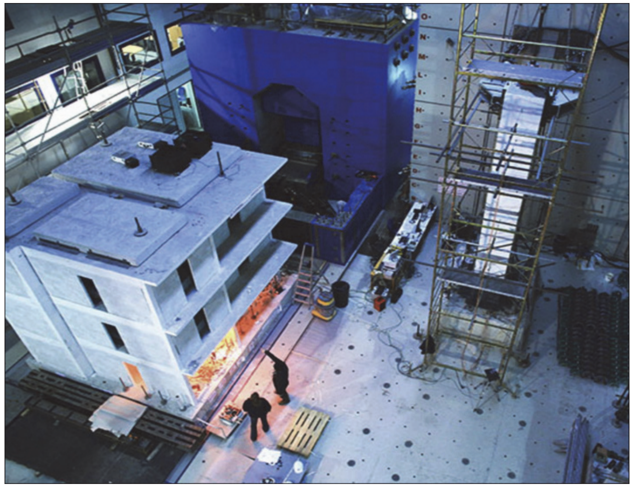
Comparison of various models for $Sa_{RotD100}/Sa_{GMRotI50}$ ratios

(Shahi and Baker, 2014).

ISOLATOR TESTING FACILITIES

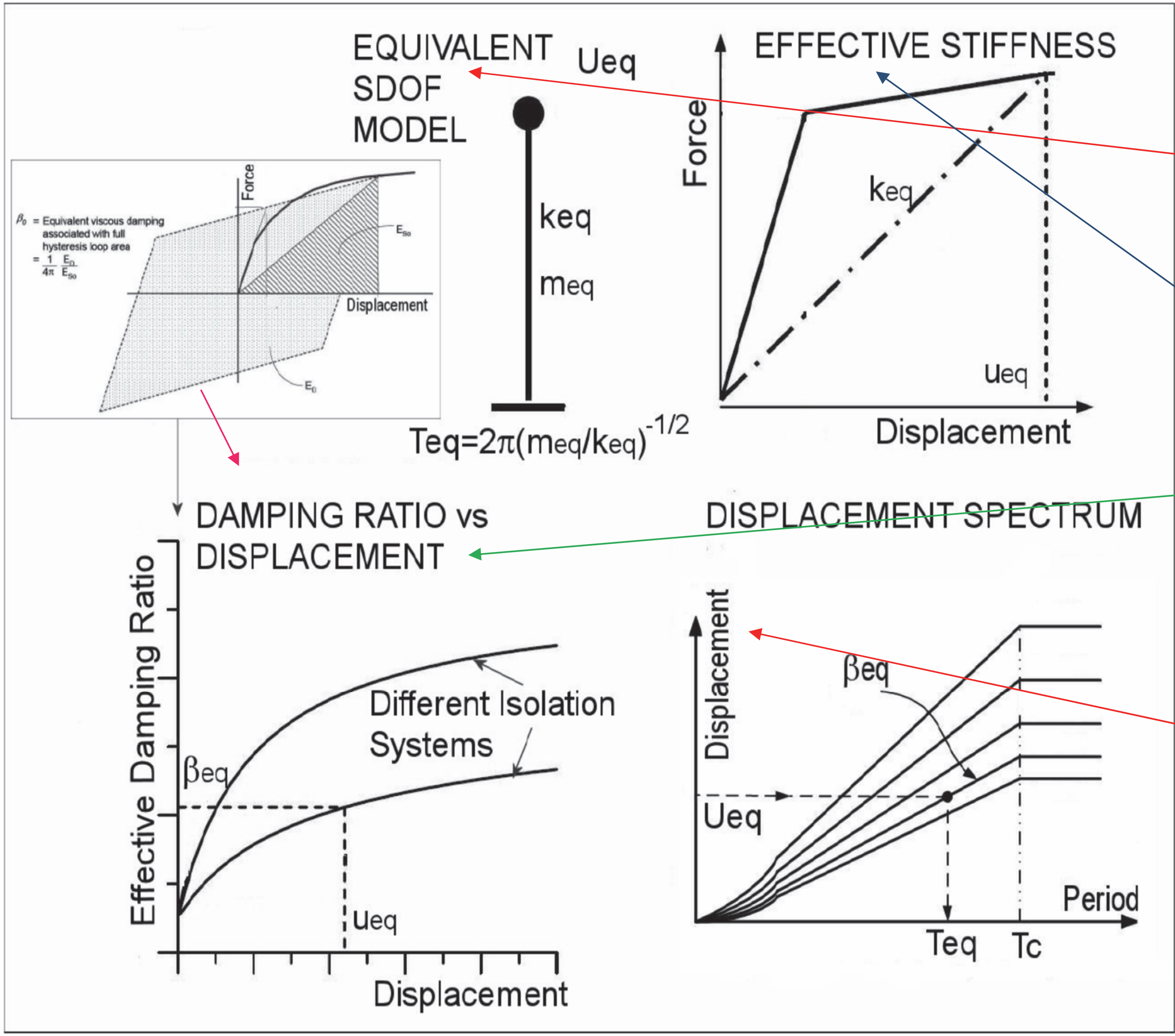
DYNAMIC TESTING CAPABILITIES OF LABORATORIES					
LABORATORY	SRMD (6D)	MATS (6D)	EUCENTRE (5D)	EPS (2D)	HIRUN
Vertical Force	Dyn54.4MN	60MN	50/Dyn10MN	Dyn70MN	75MN
Horizontal Force	8.9MN	-4.4/+3.54MN	6MN	20MN	6MN
Horizontal Disp.	1.22m	1.2/0.5m	0.54m	2m	1.2m
Horizontal Velocity	180cm/s	2.5/20 cm/s	220m/s	200cm/s	100cm/s





EQUIVALENT LATERAL LOAD

DDBD Procedure for Seismically Isolated Buildings.



Development of the equivalent SDOF model

Effective stiffnesses (hysteresis curve)

Relationship between effective damping ratio and the displacement

Displacement spectrum for different effective damping ratios.

Assume T_{eq} and β_{eq}, and determine u_{eq}

From u_{eq} find k_{eq}

Using k_{eq} and u_{eq} find T_{eq} and β_{eq}

Comparison Between Code Requirements

Design Basis Earthquake Ground Motion Return Period and Story Drifts

Level	Japan	ASCE 7-10	Italy (EC8)	TR Draft Code
Level 1 Return period	50 *(Estimate)*	---	50 *(Estimate)*	----
Level 2 Return period	500 *(Estimate)*	---	475	475
Max. Eq. Return period	–	2475 (MCE_R)	975 *(Estimate)*	2475
Level 1 Drift Ratio	1/200	---	1/200	1/200
Level 2 Drift Ratio	1/50 *(Estimate)*	1/50	----	1/100

Comparison Between Essential Code Requirements

	Japan	ASCE 7-10	EU (EC8-Italy)	TR (Draft) Code
Design methods	No Calc. /ELFM /NLTHA	ELFM / RSA / NLTHA	ELFM / RSA / NLTHA	ELFM / RSA / NLTHA
Return Period (year)	(50/500 Estimated)	MCE (2475 or ε=1)	475	475/2475
Design Spectra (IS/BLD)	DE/DE	MCE/DE=2/3MCE	DE/DE	10%-50 / 2%-50
Spectrum	Dominant component	Max.Rot.Comp	Dominant component	TBD
Importance factor	Yes	No	Yes (<=1.4)	No
Vertical load	Included	Included	Included	Included
Ageing/dispersion	1.2	From tests	From tests	From tests
Safety factor on Isolation capacity	Elastomeric = 0.8 – sliding/friction = 0.9	Implicit in the MCE design level	1.2 (Reliability Factor)	Implicit in the 2%-50 design level
Torsion in ELFM	1.1	Calculated	Calculated	Calculated
	Max ecc. 3% L	No limit	Max ecc. 2.5% L	Max ecc. 5% L
BLD requirements	Elastic	low ductile (max R=2)	low ductile (max R=1.5)	low ductile (max R=2)
	$V_{base} = 1.3\ V_{ELFM}$	$V_{base} = 1.0\ V_{ELFM,DE}$	$V_{base} = 1.0\ V_{ELFM}$	$V_{base} = 1.0\ V_{ELFM,DE}$
Modeling	Simple 2D, even for NLTHA	2D for ELFM, otherwise 3D	2D for ELFM, otherwise 3D	2D for ELFM, otherwise 3D
ELFM basic conditions	$T_2 > 2.5s$, $F_y > 0.03W$	More stringent	More stringent	More stringent
Drift Ratio	1:200 / 1:50	1:50	1:200	1:200

Comparison Between Code Requirements

ELFM Limits of Applicability

Code	Japan	ASCE 7-10	Italy (EC-8)	TR Draft Code
Limitation on site seismicity	—	$S_1 < 0.6g$	—	$S_{MR}(1) < 0.6g$
Limitation on soil class	1,2	A, B, C, D	---	TBD
Maximum plan dimension	—	—	50m	----
Maximum height of	60m	20m	20m	20m
Maximum number of stories	—	4	5	----
Location of devices	Base only	---	—	----
Maximum mass-stiffness centers eccentricity	3%	---	3%	5%
K_v/K_e	---	---	≥ 800	———
Tension in isolator	Not allowed	Allowed	Not Allowed	Not Allowed
Yield strength	$> 0.03W$	---	—	---
Period range of T_e	$T_2 > 2.5s$	$3T_f$ - 3.0s	$3T_f$ - 3.0s	$3T_f$ - 3.0s
Maximum value of T_v	—	—	$< 0.1s$	$< 0.1s$

W: total weight above the isolation interface
T_f: natural period of the fixed-base super-structure.
T_2: period of the isolation system considering only the stiffness of rubber bearings.
T_e: equivalent period of the isolation system (Design Earthquake Level).
T_V: period of the isolation system in vertical direction

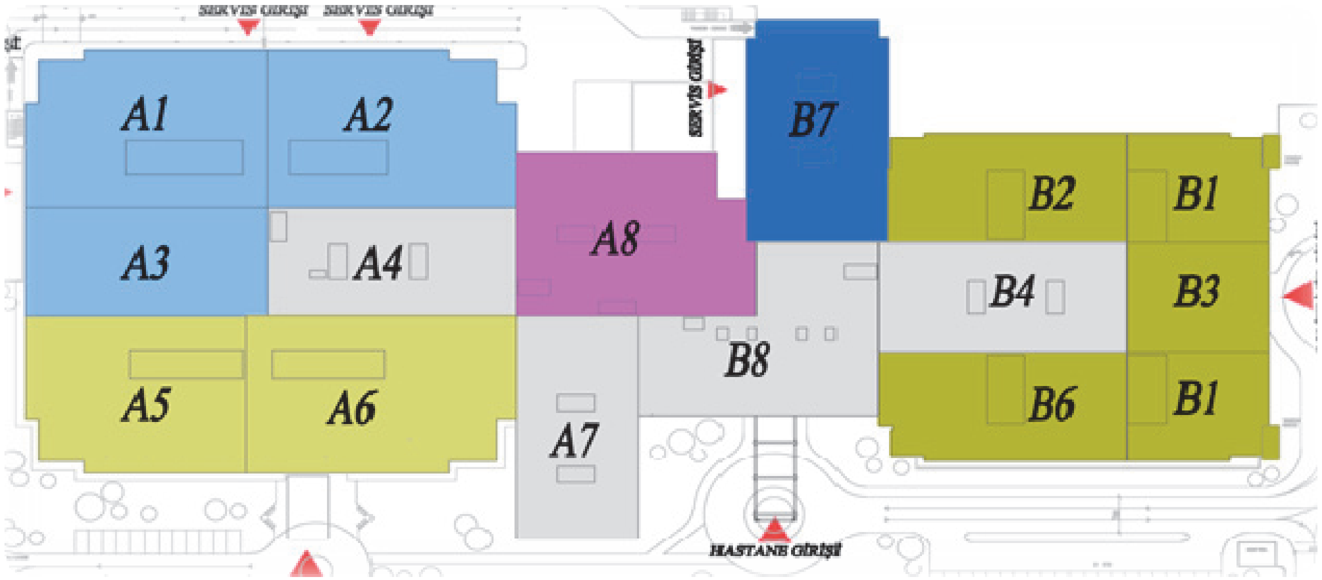
Seismic Isolation Application Case Studies

Brief information will be provided on the design, testing and application seismic isolation system of

•Başıbüyük Training and Research Hospital (750 bed), which is a retrofit project in Istanbul.

•Design and construction of a (1500 bed) Adana Health Care Center in Adana City, southern Turkey.

Marmara University Başıbüyük Training and Research Hospital



Maltepe Basibuyuk Training and Research Hospital Application

The hospital complex, built in 1991, is located in Anatolian side of Istanbul.

It is composed of 16 blocks with number of storeys 5 to 10, houses 750 beds and has a total floor area of 113.000 m^2.

Steps for Retrofit Design of the Hospital

1. **Condition Assessment :** The first step is collecting all available data regarding structural and architectural drawings, structural material properties, soil and foundation characteristics, damages from previous earthquakes, damages from external conditions (humidity, leakage, corrosion, etc.), electrical and mechanical building systems have been reviewed in terms of efficient use and operation after a possible earthquake event were completely finished.

2. **Seismic Assessment of the Existing Building :** The existing structure hospital building does not satisfy Immediate Occupancy Performance according to Turkish Earthquake Code, 2007. The building's performance on earthquake should be increased.

3. **Selection of Structural Retrofitting Method :**

   A) Conventional Retrofitting

   B) Seismic Base Isolation

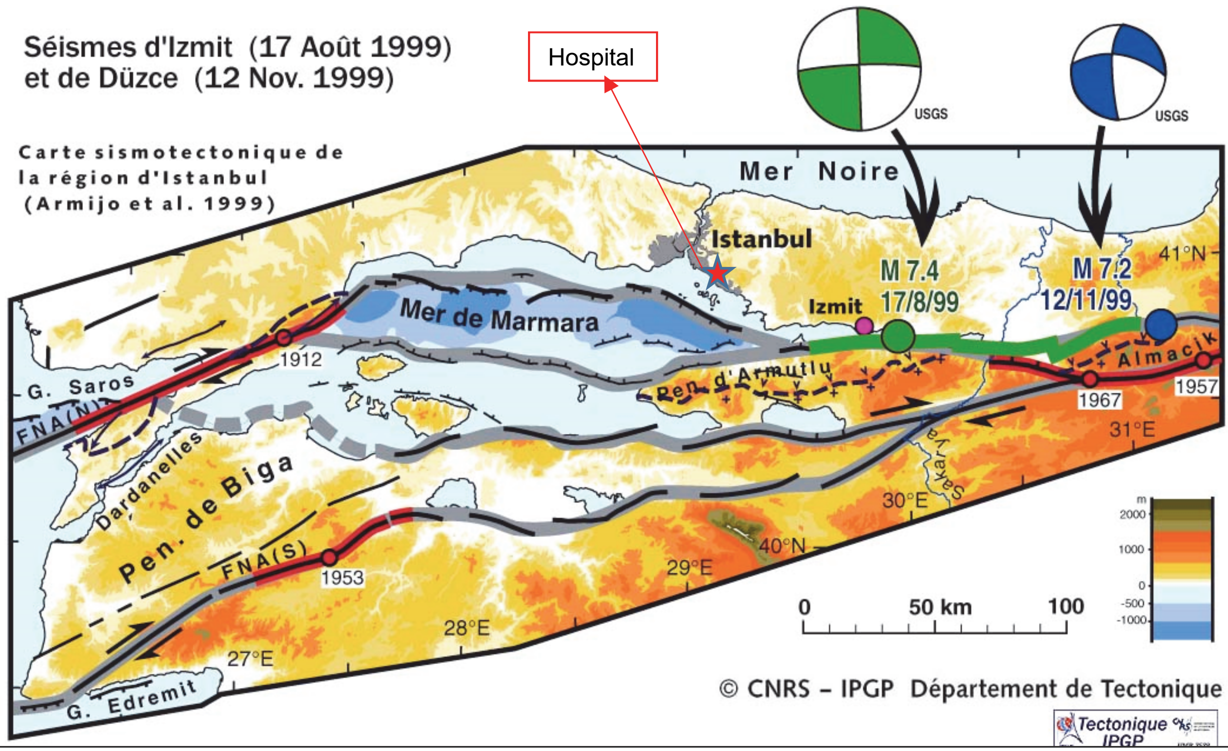
A) Conventional Retrofitting

The practical performance-based procedure suggests increasing the strength by adding new concrete shear walls from inside or outside meanwhile correcting the deficiencies of the critical elements controlling the deformation capacity and stability of the existing system.

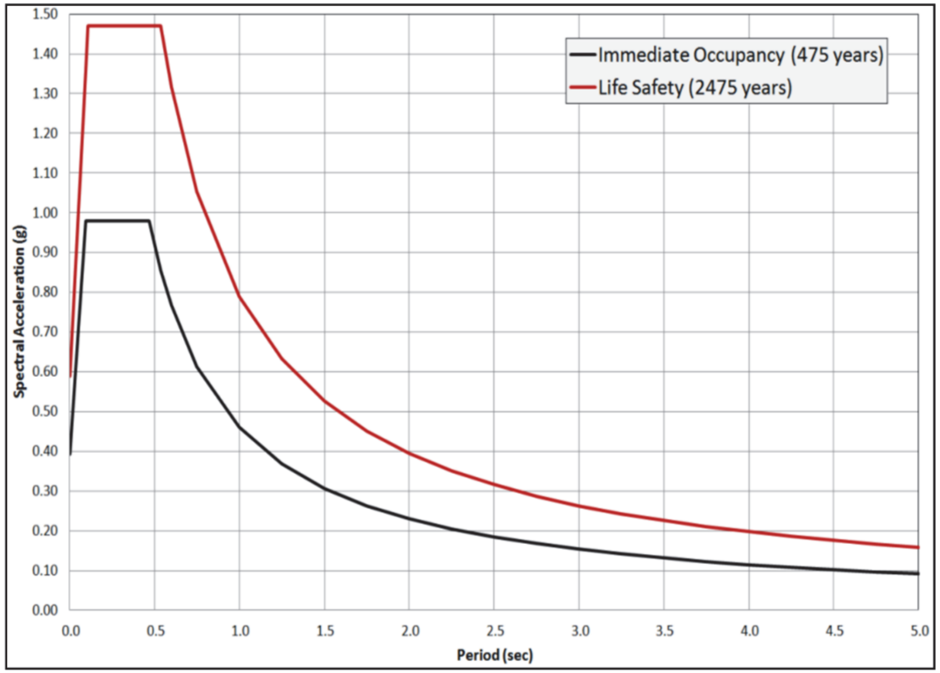
- Construction work at every floor
- Added shear walls obstruct architectural usage
- High cost with unsatisfactory performance
- Possible damage to medical equipments and architectural elements
- High acceleration felt during the earthquake rising panic and disturbance
- Medical service will be interrupted after the earthquake

B) Seismic Base Isolation

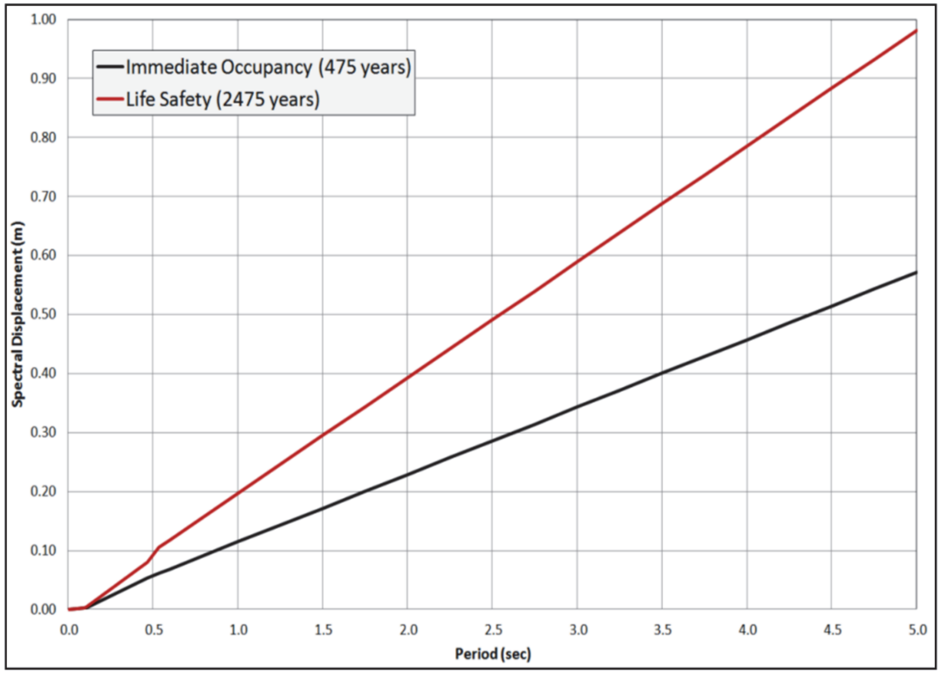
- No damage to neither structural and architectural elements nor medical equipments
- Minimum obstructions of architectural usage
- No interruption of medical service after the earthquake
- No interventions at upper floors except unifying the high rise blocks



Séismes d'Izmit (17 Août 1999)
et de Düzce (12 Nov. 1999)
Hospital
Carte sismotectonique de
la région d'Istanbul
(Armijo et al. 1999)
Mer Noire
Istanbul
Mer de Marmara
Izmit
M 7.4
17/8/99
M 7.2
12/11/99
USGS
41°N
1912
G. Saros
FNA(N)
Pen. d'Armutlu
Almacik
1967
1957
31°E
Dardanelles
Pen. de Biga
FNA(S)
1953
30°E
Sakarya
40°N
29°E
28°E
27°E
G. Edremit
0
50 km
100
© CNRS – IPGP Département de Tectonique



Immediate Occupancy (475 years)
Life Safety (2475 years)
Spectral Acceleration (g)
Period (sec)



Immediate Occupancy (475 years)
Life Safety (2475 years)
Spectral Displacement (m)
Period (sec)

Retrofit Application of the Başıbüyük Training and Research Hospital

•The hospital complex has been originally designed according to 1975 Turkish seismic code and as the result of the seismic assessment calculations seismic performance of the structure has been determined as under code limits.

•The retrofit strategy has a performance objective of “continuous functionality” as such in order to upgrade the seismic performance of the structure seismic isolation methodology is selected.

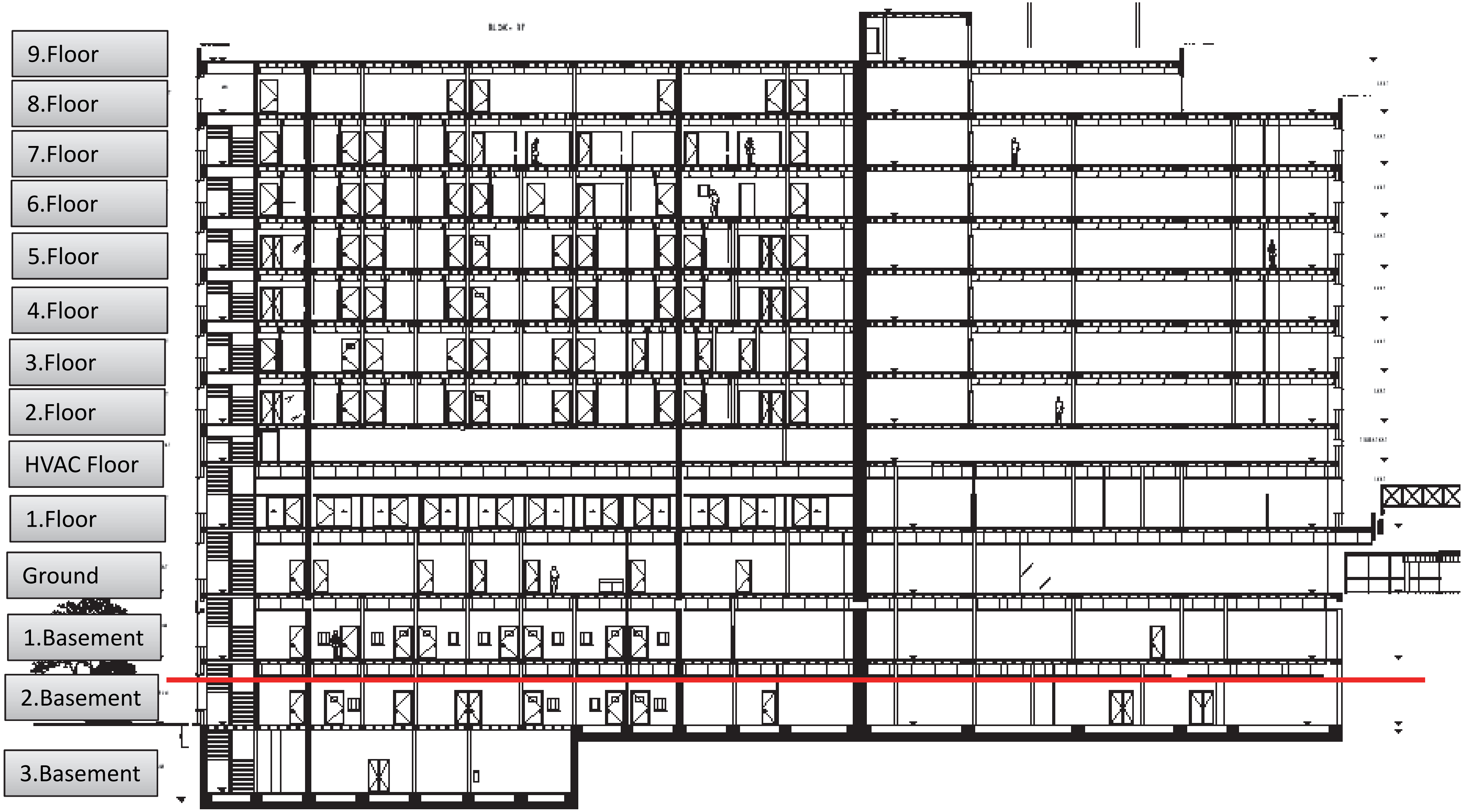
•Prota Engineering Inc. has conducted the retrofit and renovation design with base isolation system within the scope of the ISMEP-IPCU “Consultancy Services Retrofitting Design of Selected Public Buildings in Istanbul (EIB-CB1.3A)” project. Funded by European Investment Bank

- As the isolation design approach instead of determining the isolation system type in advance, a generic solution has been proposed by the designer in terms of displacement and damping and the manufacturers are asked to meet these requirements.

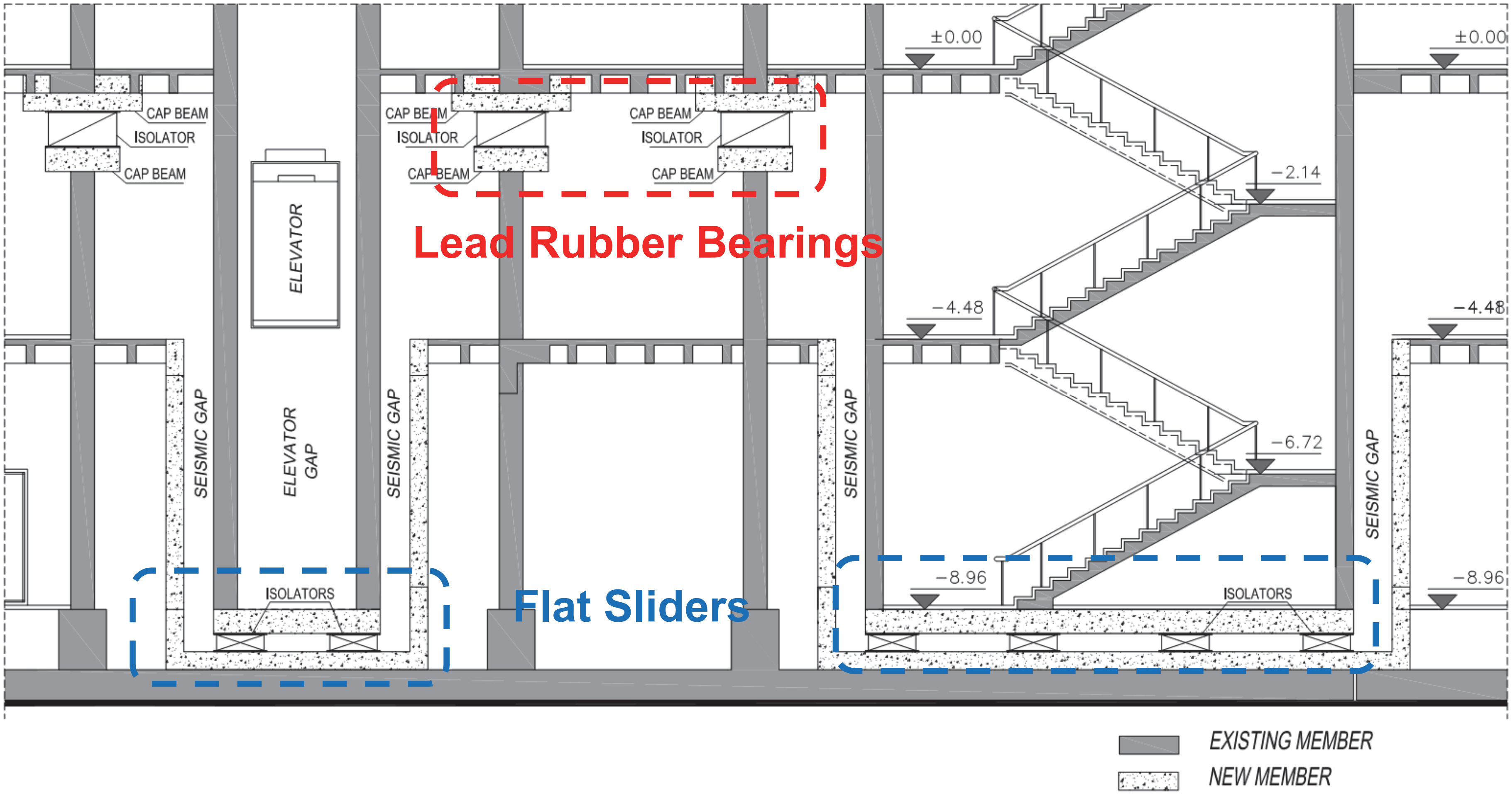
- This approach has an advantage as having a flexibility to compare different type of isolator types but has a disadvantage as having a long period of time in design process.

- The seismic isolation system design criteria is to limit the base shear to 12.5% of the superstructure weight at DBE earthquake level and to limit the drift values to 0.5% and 1.0% respectively for the DBE and MCE earthquake levels.

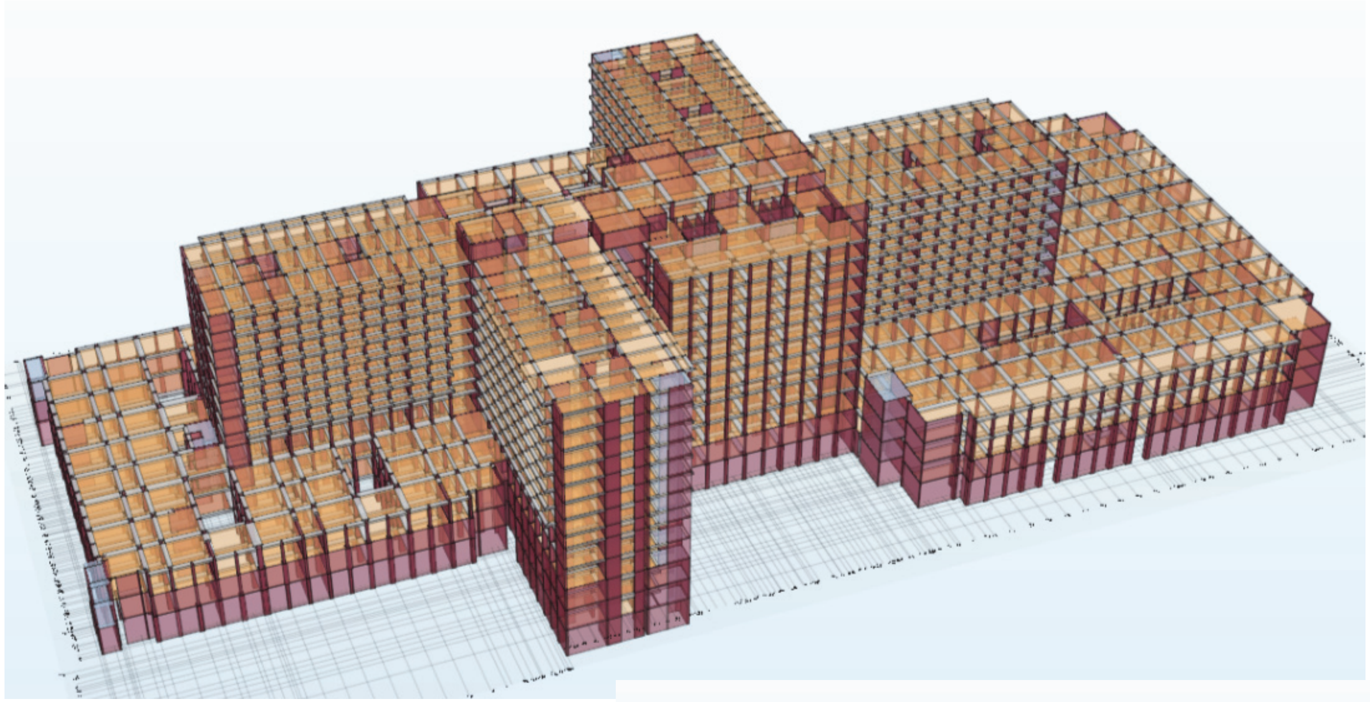
General Section



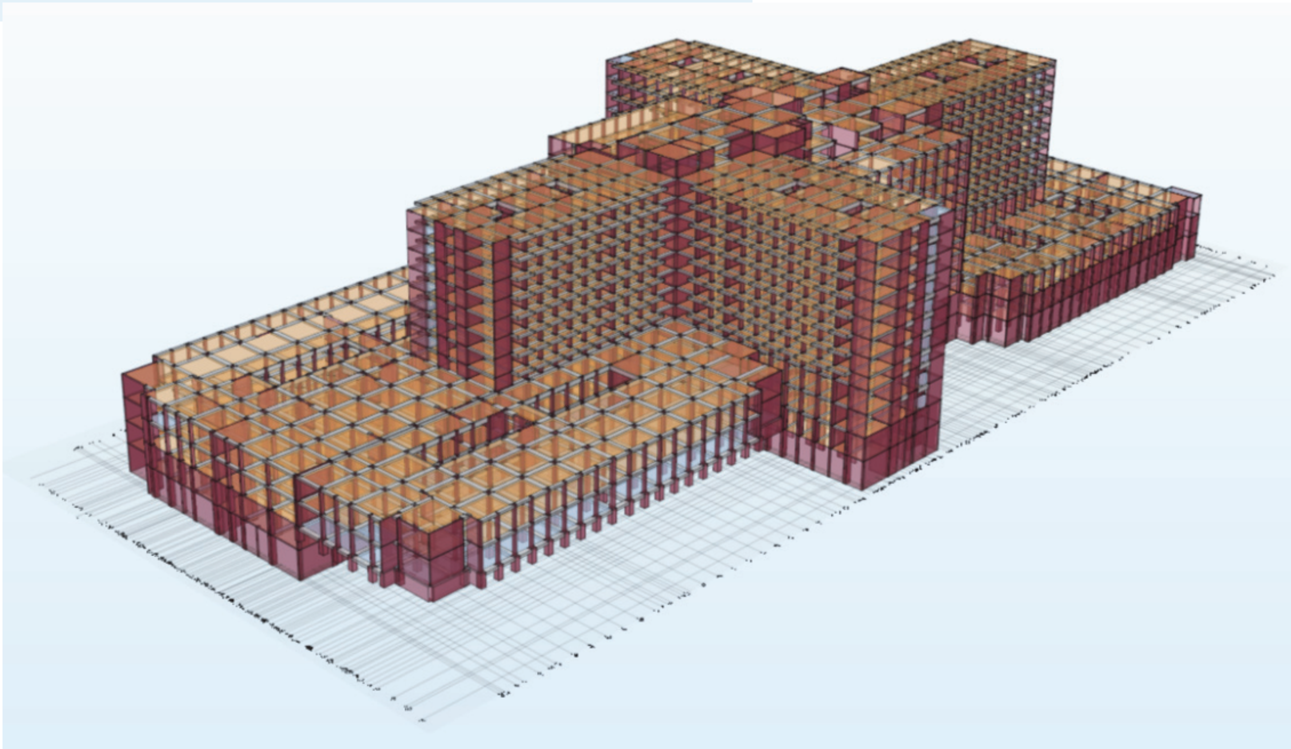
Considering the architectural limitations and construction practice the isolation layer has been selected as the top of the second basement floor. The columns below isolation layer were retrofitted through RC jacketing.



688 LRB Isolators at Ground Floor Level
154 Slider Type Isolators at Foundation Level
In Total 843 Isolators



Structural Analysis Model



16 Blocks modeled together

20,798 Frame Elements
1,144 Link Elements
11,367 Joints
68,202 DOF's

Seismic Isolators

The isolators were designed in order to fulfill different requirement for the DME and MCE level spectra.

- Maximum allowable shear force for the 2475 years return period (MCE):
  $V_{b\text{-}CG}$= 207668 kN
- Maximum allowable shear force for the 475 years return period (DBE) :
  $V_{b\text{-}HK}$= 130285 kN
- Maximum allowable displacement for the 2475 years return period (MCE):
  D_{TM}= 500 mm

As the first step, the type and the property of the devices has been set by considered the vertical load acting on each unit.

- Five groups of bearings were considered at the ±0.00m elevation level.
- One type of flat slider bearing was considered at the -8.96m level.

Seismic Isolators

The following types of seismic isolators were considered:

1) Friction Pendulum Sliders (FPS)
2) Lead Rubber Bearings (LRB)

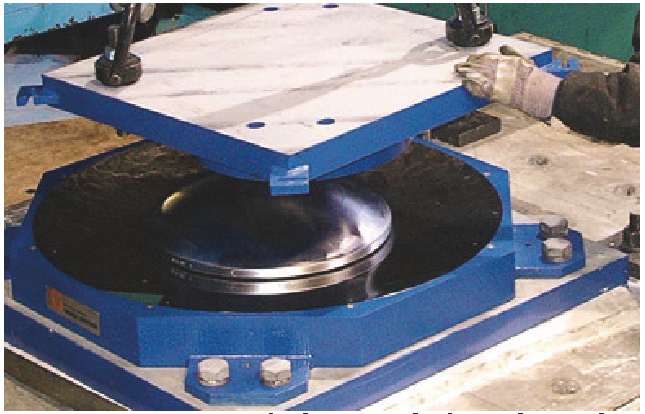
All pros and cons of the two types of isolators have been studied and LRB type of isolators were decided to be used in this Project.

• LRB type of isolators have smoother movement than FPS type (important for buildings with vulnerable devices like hospitals)

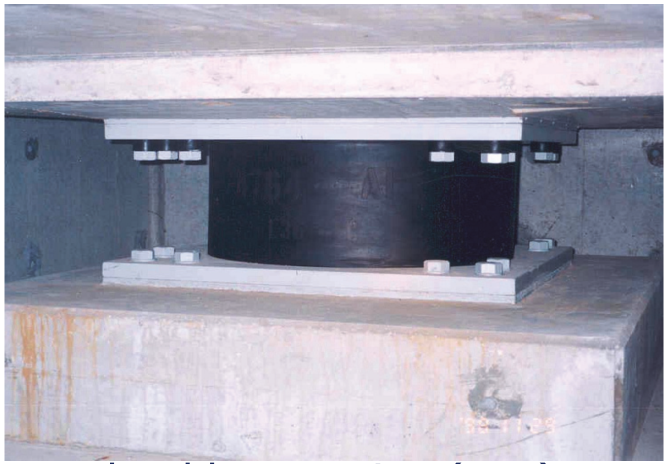
•LRB isolators can accomodate higher geometric tolerances that FPS bearings.

•LRB isolators can work together with flat sliding bearings

The final selection of the isolator types were a combination of LRBs and Flat Sliding Bearings.



Friction Pendulum Slider (FPS)



Lead Rubber Bearing (LRB)

USE OF LRBs TOGETHER WITH FLAT SLIDING BEARINGS

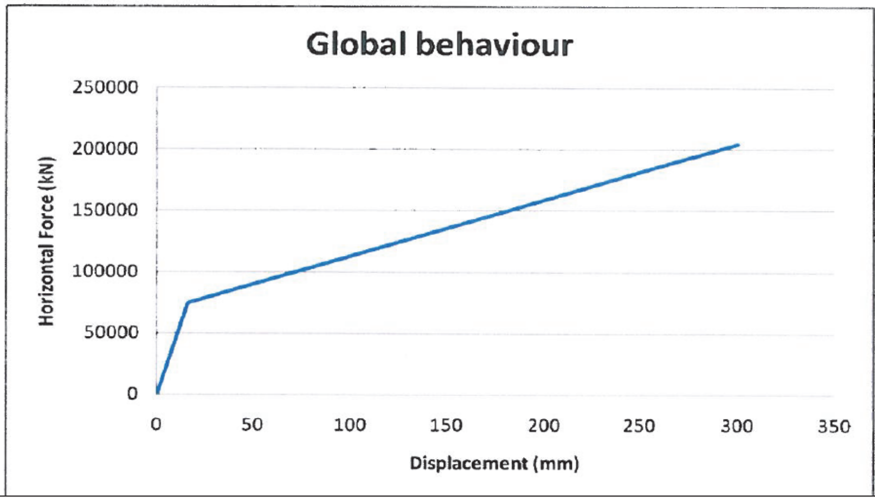
Design of isolators (LRB) and flat sliding bearings were done according to «EN15129 Anti Seismic Devices» and «EN1337-5 Structural Bearings-Part 5:Pot Bearings»

Lead Rubber Bearings displace also downwards during lateral movement. However, flat sliding bearings (under the elevator/stair shear walls) have much greater vertical stiffness and do not deform vertically

In the Primary Design the vertical deflection (Total Deflection – Static Deflection) of the LRB isolators at 300mm lateral displacement was between 1.17 to 1.77 mm. Since the flat sliding bearings cannot accomodate this deflection, the failure of the beams connected to elevator/stair shear walls shorter than 2m length was a possibility.

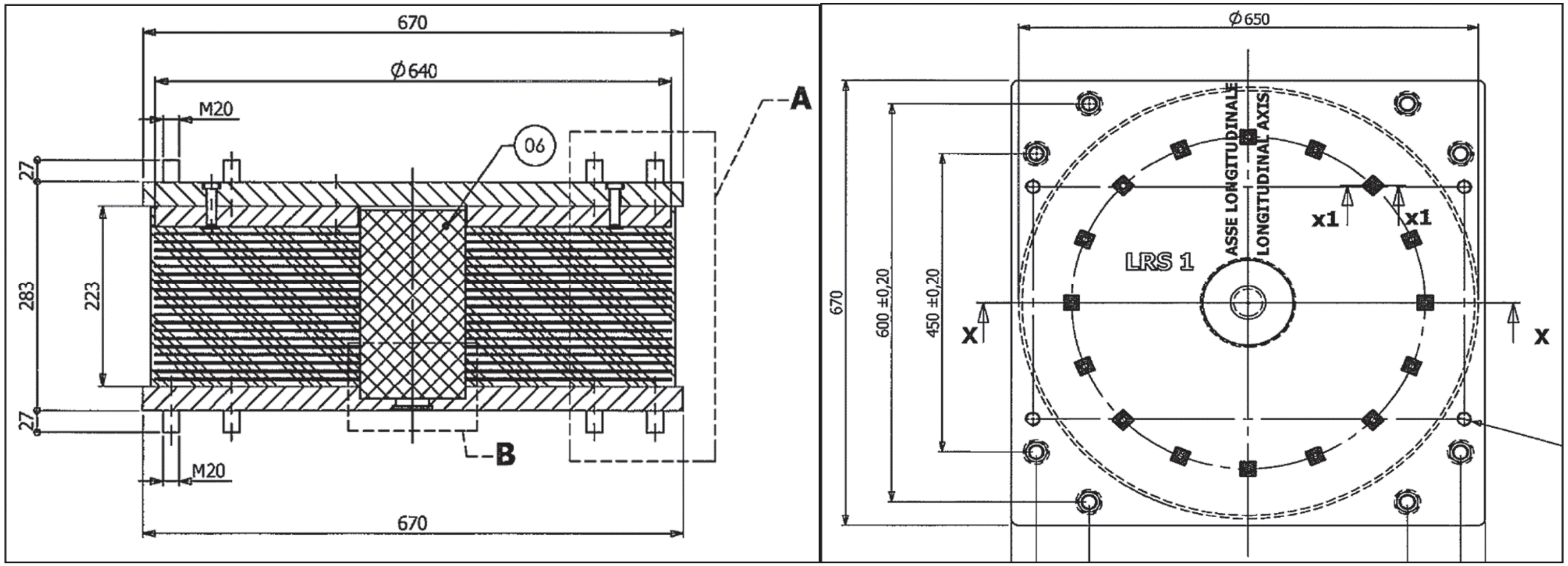
Lead Rubber Bearing design was revised to achieve higher vertical stiffness hence lower vertical deflection, such that in the Final Design the vertical deflection of the LRB isolators was less than 1mm.

The global damping at d_{max}(300mm) results in 32%.
Shear force for the 2475 years return period :V_{b-CG}= 203313 < 207668 kN
Shear force for the 475 years return period :V_{b-HK}= 129234 < 130285 kN
Max. displacement for the 2475 years return period :D_{TM}= 300 < 500 mm



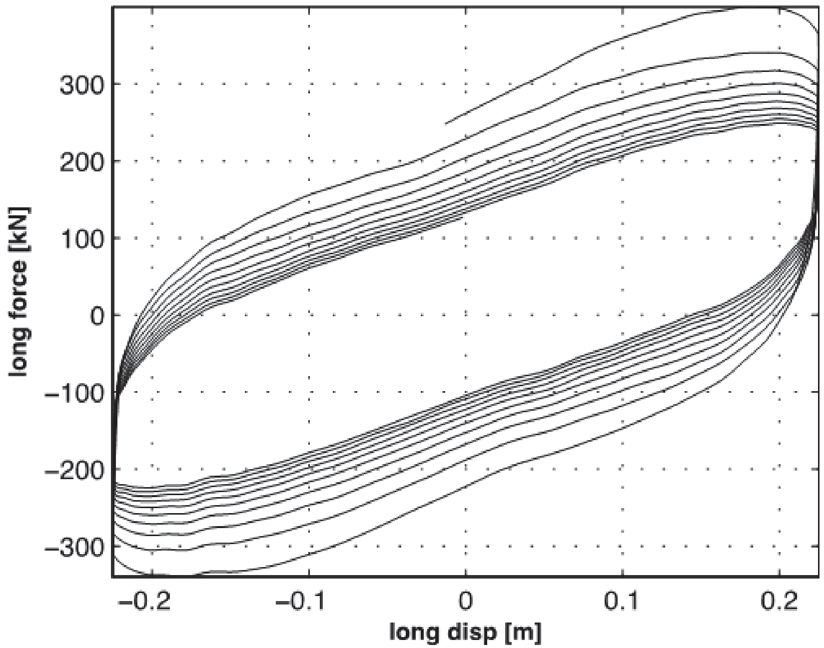
TYPE	d_y mm	F_y kN	d_{max} mm	F_{max} kN	ξ_{eff}
Type 0	18.9	96	300	239	33.8%
Type 1	18.5	96	300	243	33.5%
Type 2	18.8	106	300	264	33.5%
Type 3	14.1	126	300	380	33.7%
Type 4	9.2	136	300	569	25.3%

The Pot Bearings were designed with a displacement capacity of +/-300 mm under seismic and ULS loads.

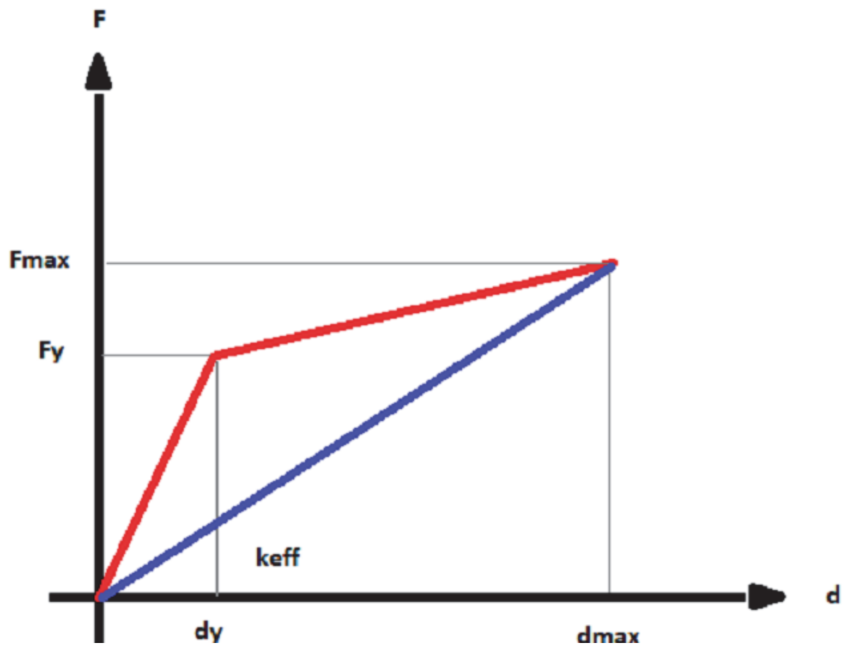


LRB 650 type isolator section and plan view (Supplied by Freyssinet Inc.)

Based on the analysis results and architectural limitations of the building, isolation system was determined as a combination of LRB (lead rubber bearing, 688 units) and NTM (sliding bearing, 154 units). Both the LRB and NTM type bearings are manufactured by Freyssinet Inc. The distribution of totally 688 unit of LRB type isolators with the displacement capacity of 500mm is determined to minimize the torsional response of the isolation system.



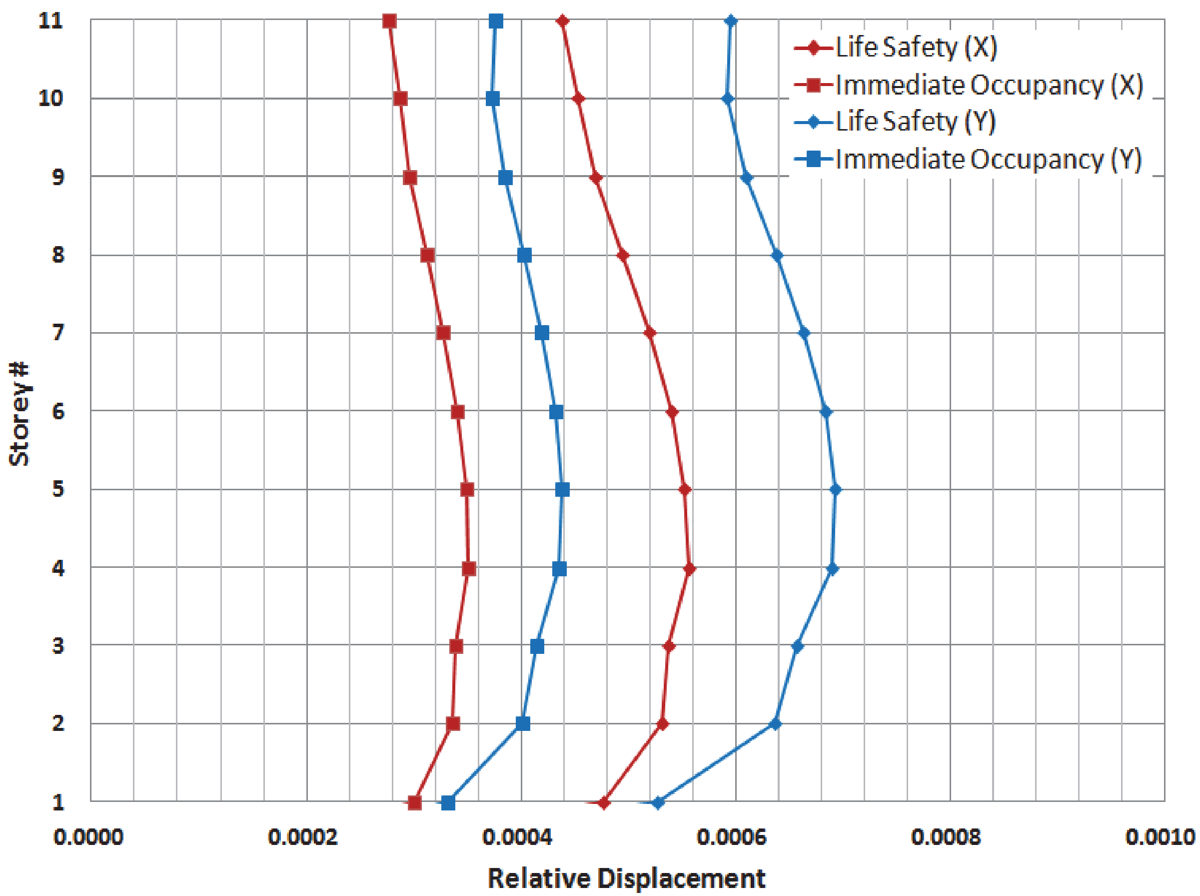
Time History Analysis



	Yield		Maximun		2475 years		475 years	
					keff	ξ	keff	ξ
Type	D [mm]	H [kN]	D [mm]	H [kN]	[kN/mm]	[%]	[kN/mm]	[%]
0	24.6	96	380	235	0.6192	31.9	0.9	40.8
1	24.2	96	380	238	0.6251	31.7	0.9	40.7
2	25	106	380	256	0.6725	32.1	0.9814	40.9
3	19.2	126	380	362	0.9529	28.9	1.32	38.5
4	11.8	136	380	562	1.4783	23.85	1.8772	32.8

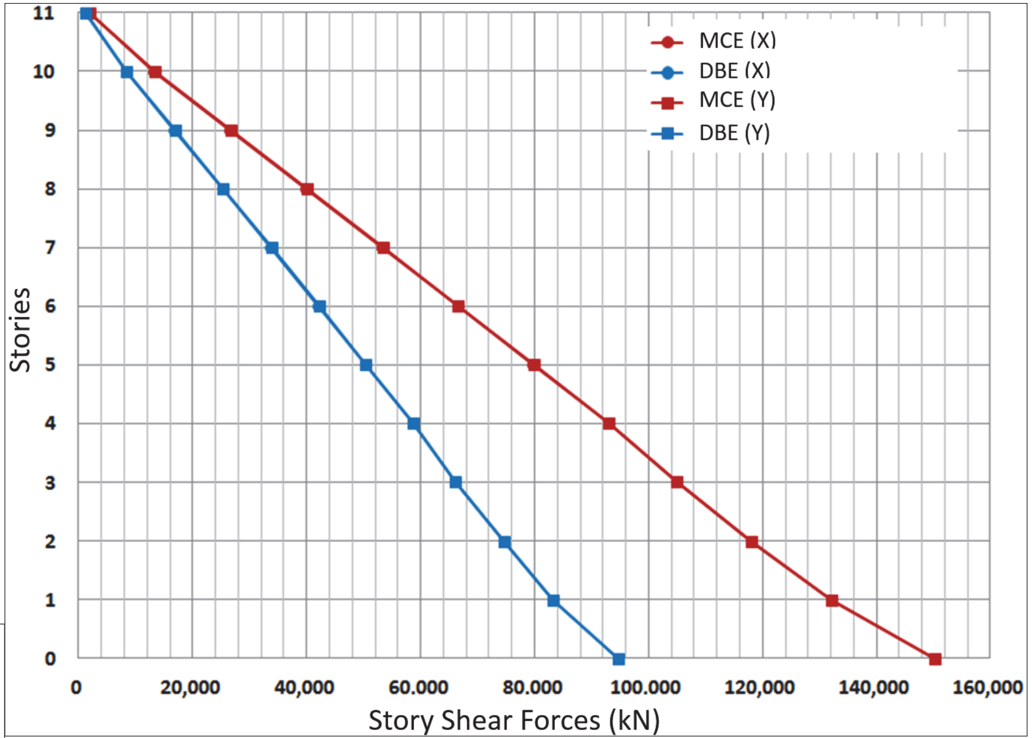
DRIFT PROFILES

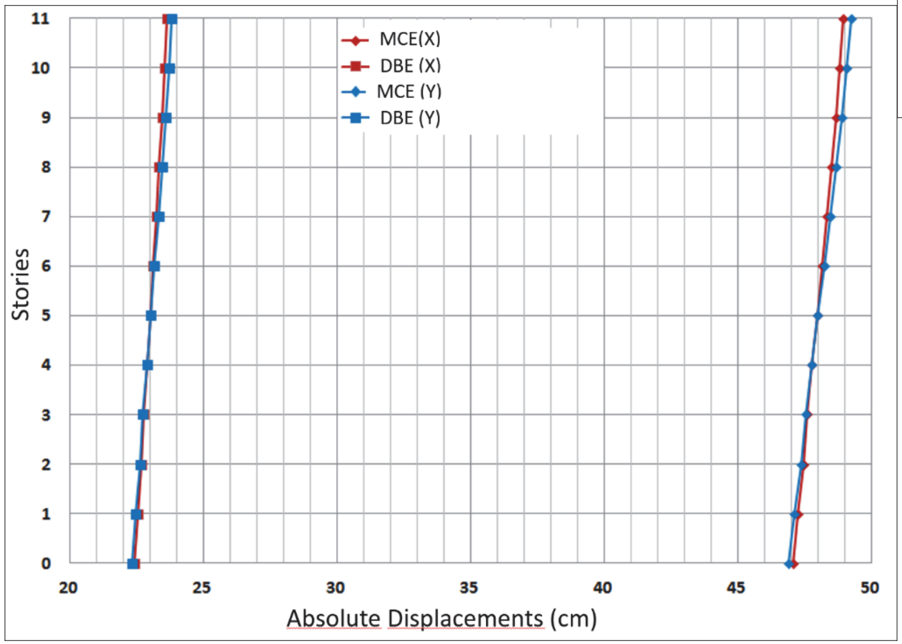
	DBE Level			MCE Level		
T (s)	3.2	K_{min} (kN/m)	534,467	3.7	K_{min} (kN/m)	399,777
ξ	30%	k_{min} (kN/m)	635	25%	k_{min} (kN/m)	475
B	1.7	Δ (m)	0.215	1.6	Δ (m)	0.454

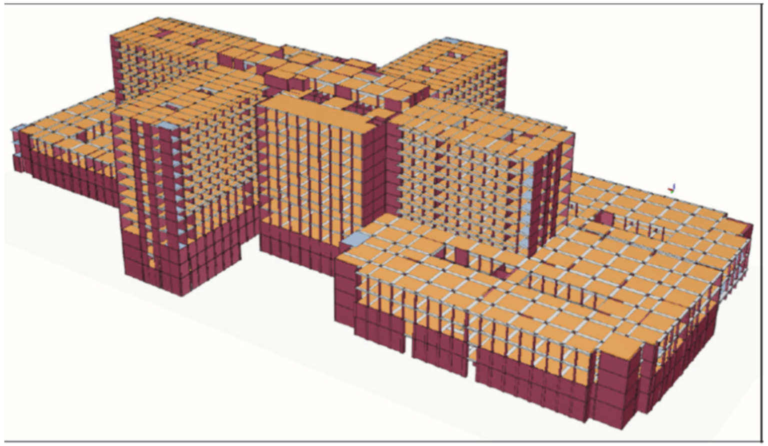


Drift profile for DBE (red) and MCE (blue) level

STORY SHEAR FORCES and ABSOLUTE DISPLACEMENTS





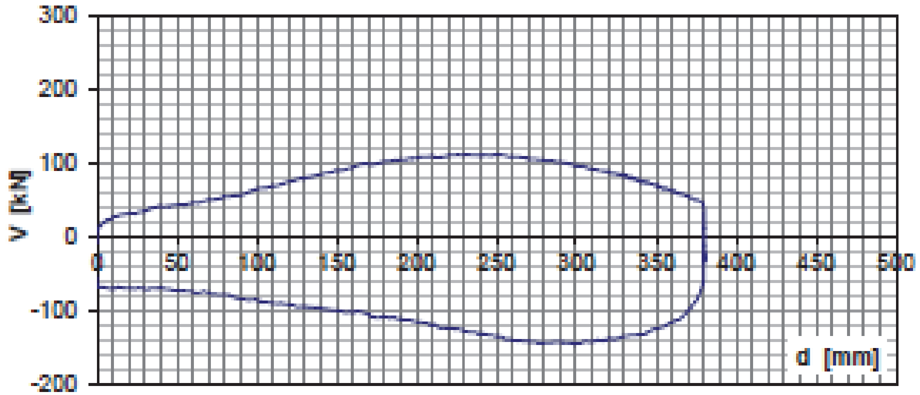


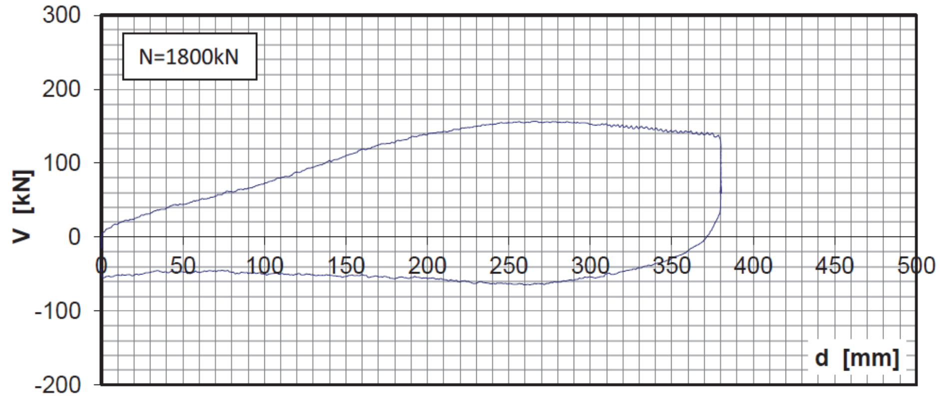
Prototype Tests at University Basilicata School of Engineering Lab.

Test Results

- The buckling stability problem has occured during the lateral capacity test of LRBs. The buckling stability didn’t match with the requirements of EN15129 and the project requirements.

TEST 12





8.2.3.4.4 Buckling stability under seismic actions

This sub-clause shall not apply to lead rubber bearings provided that the diameter of the lead plug exceeds 15 % of the minimum plan dimension. In case of multiple lead cores, the diameter of the equivalent single lead core is taken into account.

$$N_{Ed,max} < P_{cr}/2 \quad (21)$$

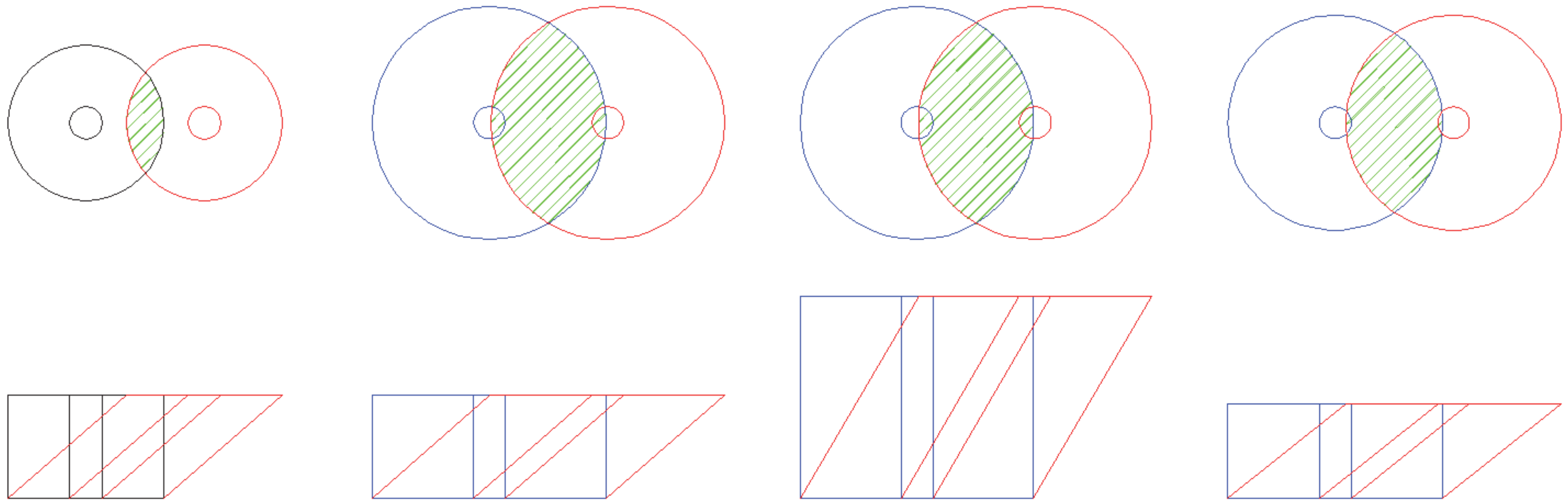
For $\frac{P_{cr}}{2} > N_{Ed,max} \geq \frac{P_{cr}}{4}$, the following condition shall be satisfied:

$$1 - \frac{2N_{Ed,max}}{P_{cr}} \geq 0{,}7\delta \quad (22)$$

and for $N_{Ed,max} < \frac{P_{cr}}{4}$ the following condition shall be satisfied:

$$\delta \leq 0{,}7 \quad (23)$$

RE-DESIGN CONSIDERATIONS



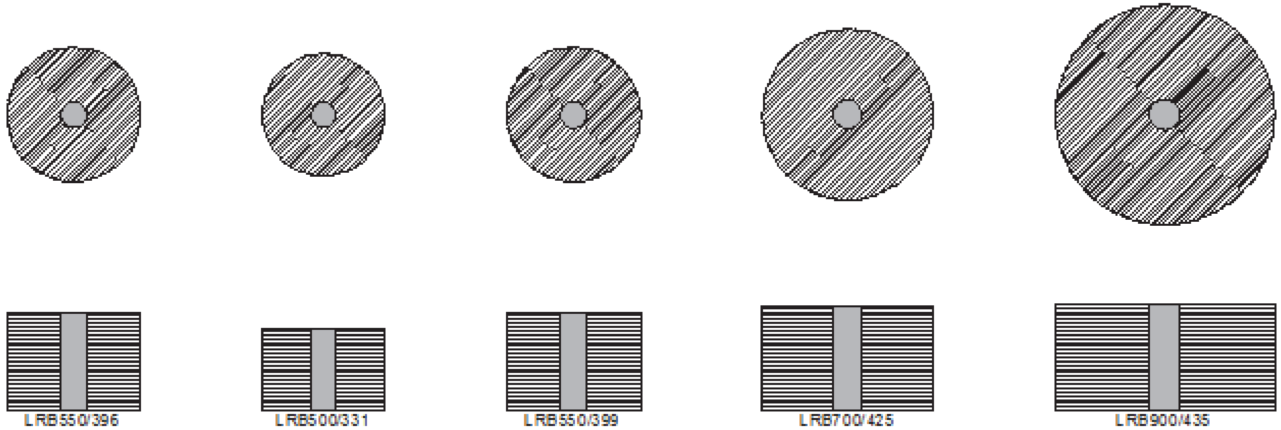
LRB section
tested in July
Low buckling
stability capacity

Diameter has been increased to respect to new buckling stability criteria
Height has been increased to respect to the horizontal shear force limit given by Project Specification

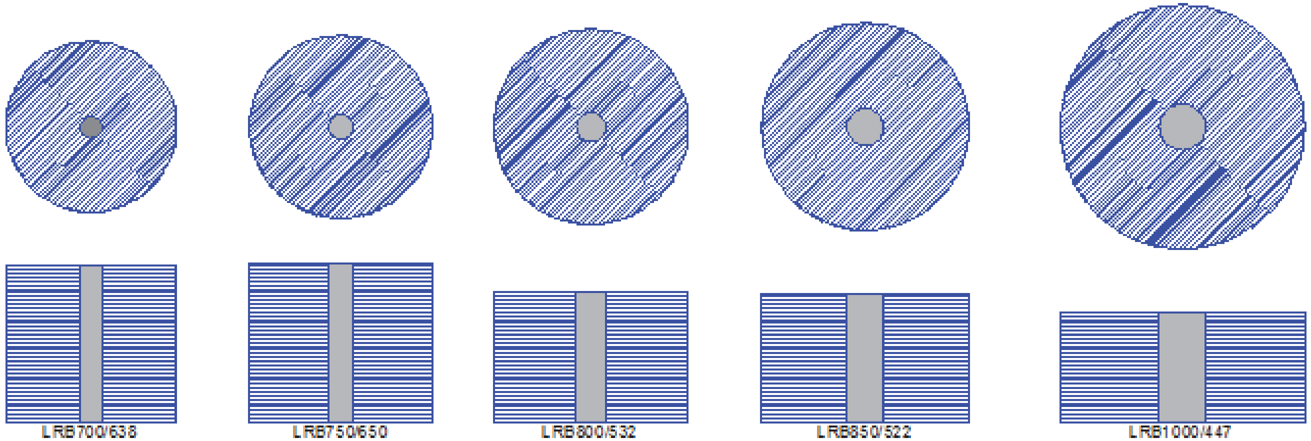
Good buckling stability performance
Consequence:
Low damping due to the slenderness of LRB core
Solution:
Use the same LRB designs + Additional FV dampers to be used to compensate the low damping

Second Solution:
The height can be decreased and as result of this, the horizontal stiffness will be increased.
No need additional FV damper
Verification of pillars retrofitting capacity

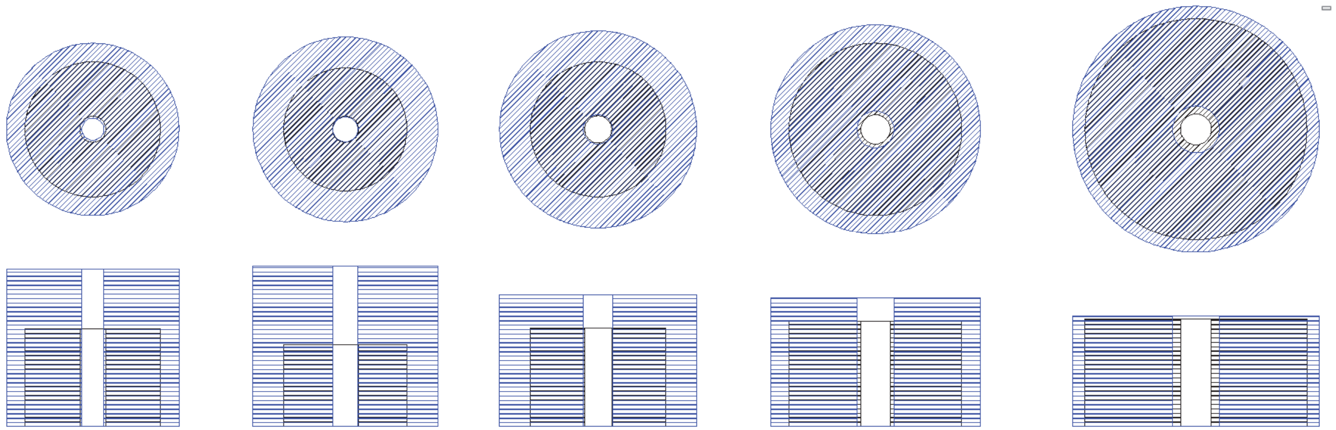
Redesign of the isolators is conducted with appropriate geometries and materials to provide the same (previous) stiffness and damping characteristics.



Design tested in July on Potenza



New Design fulfilled the new buckling stability criteria



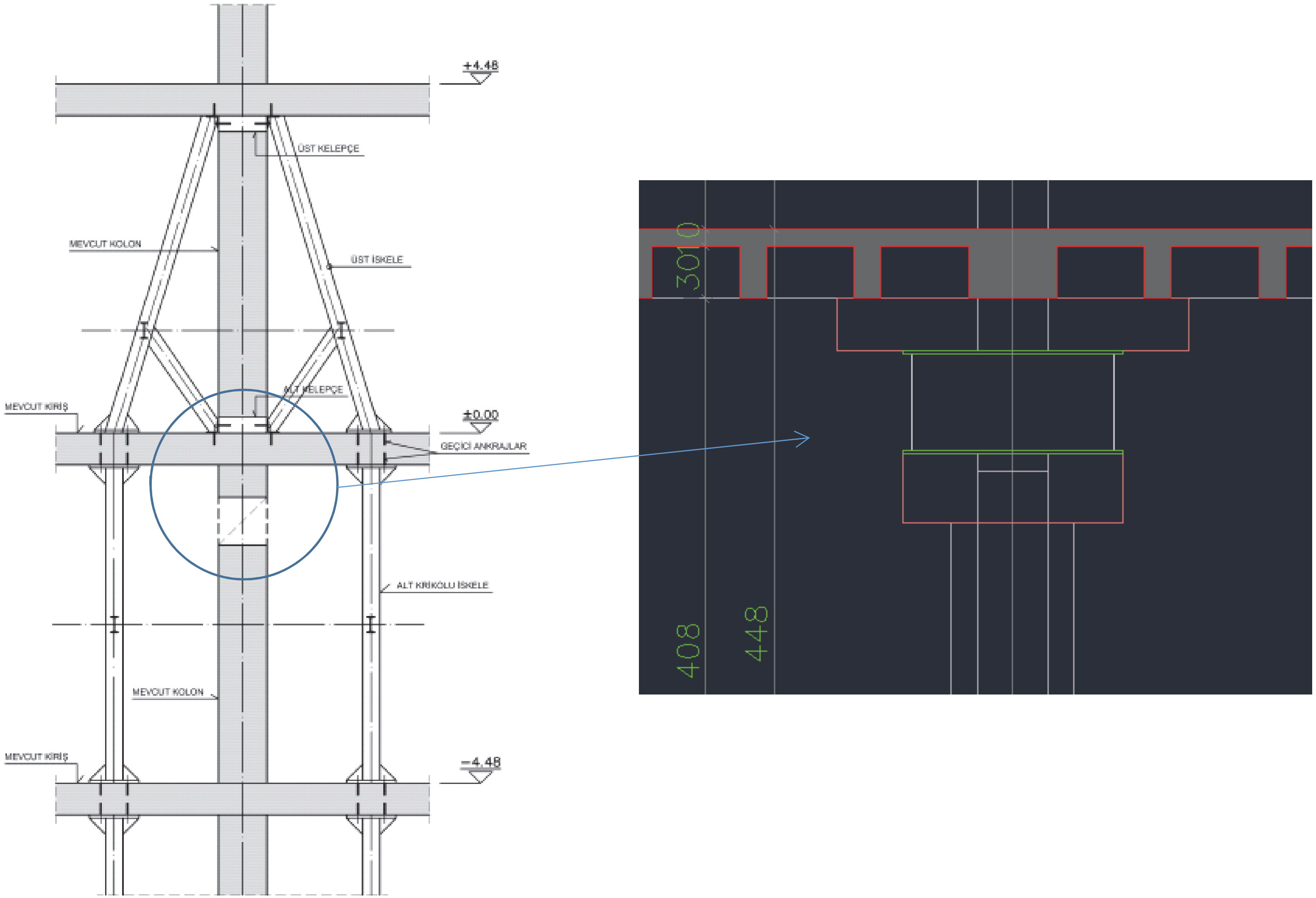
Comparison of the both design sections

Unification of Blocks at Seismic Joints

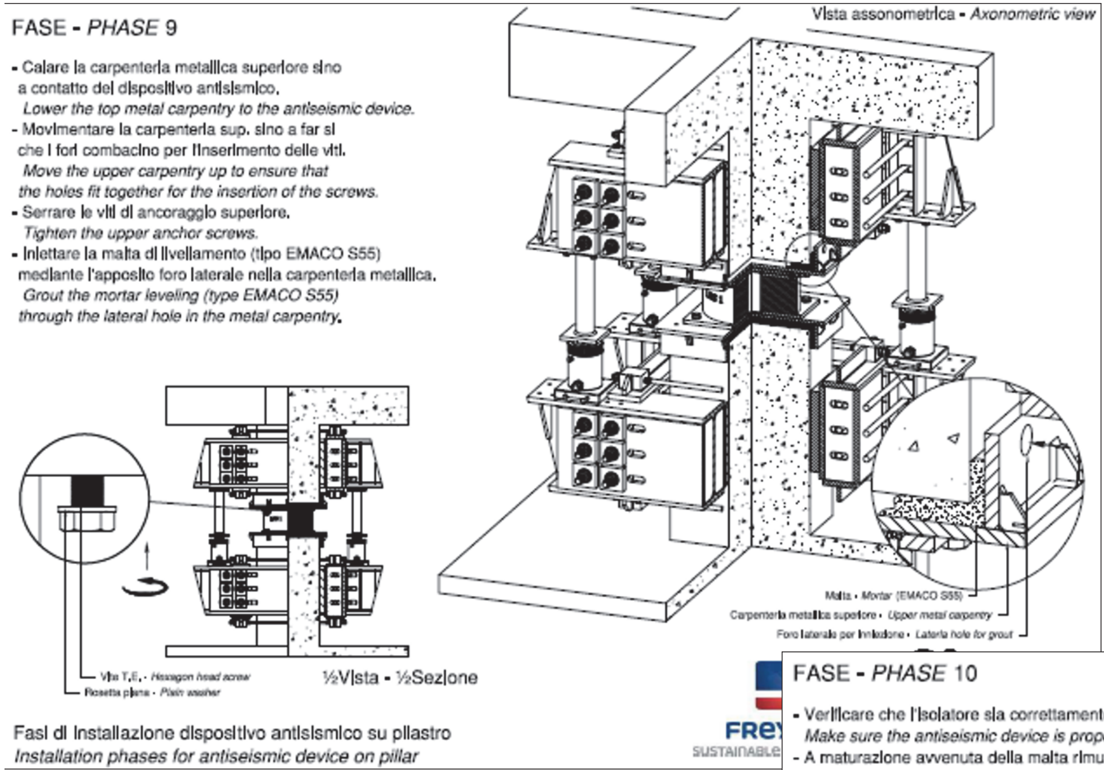
Seperation of Elavator and Staircase Shear Walls from the Floors

Jacketing of Columns

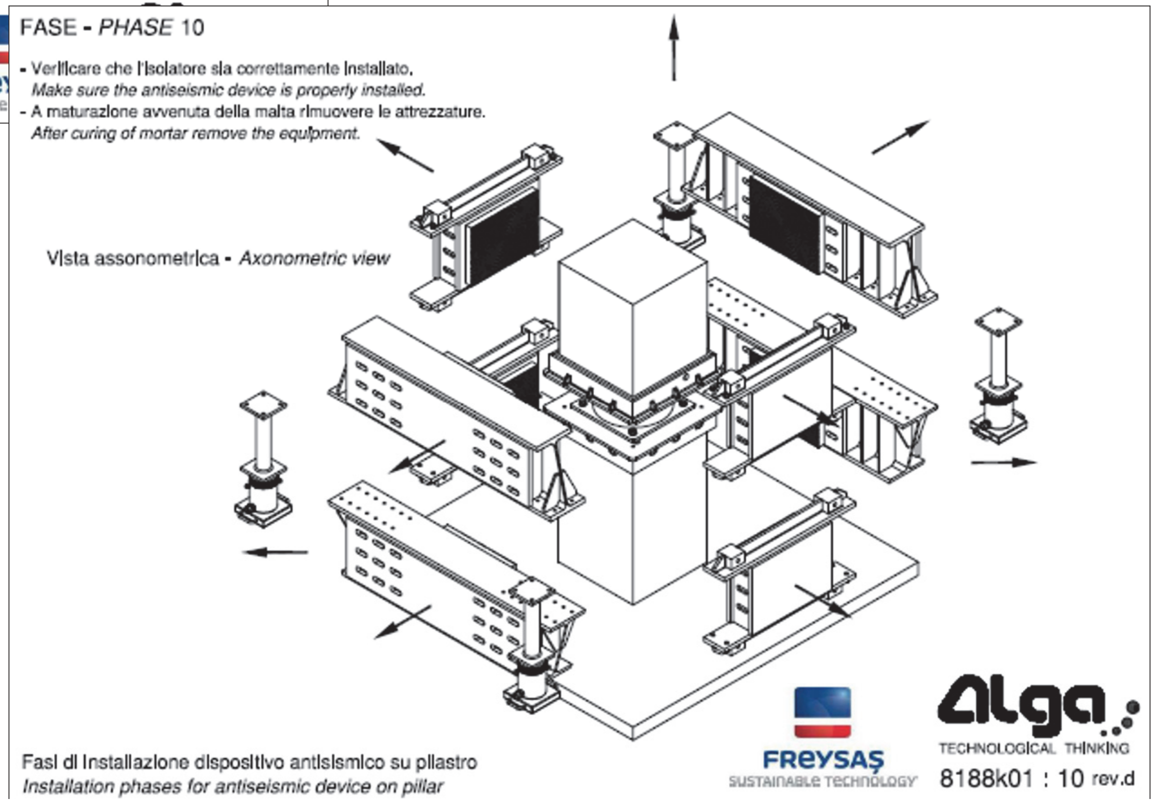
Considerations for the installation of bearings
Alternative 1



ÖRNEK ÇELİK ASKIYA ALMA DETAYI
(Sadece fikir vermesi için çizilmiştir. Uygulamada kullanılamaz.)



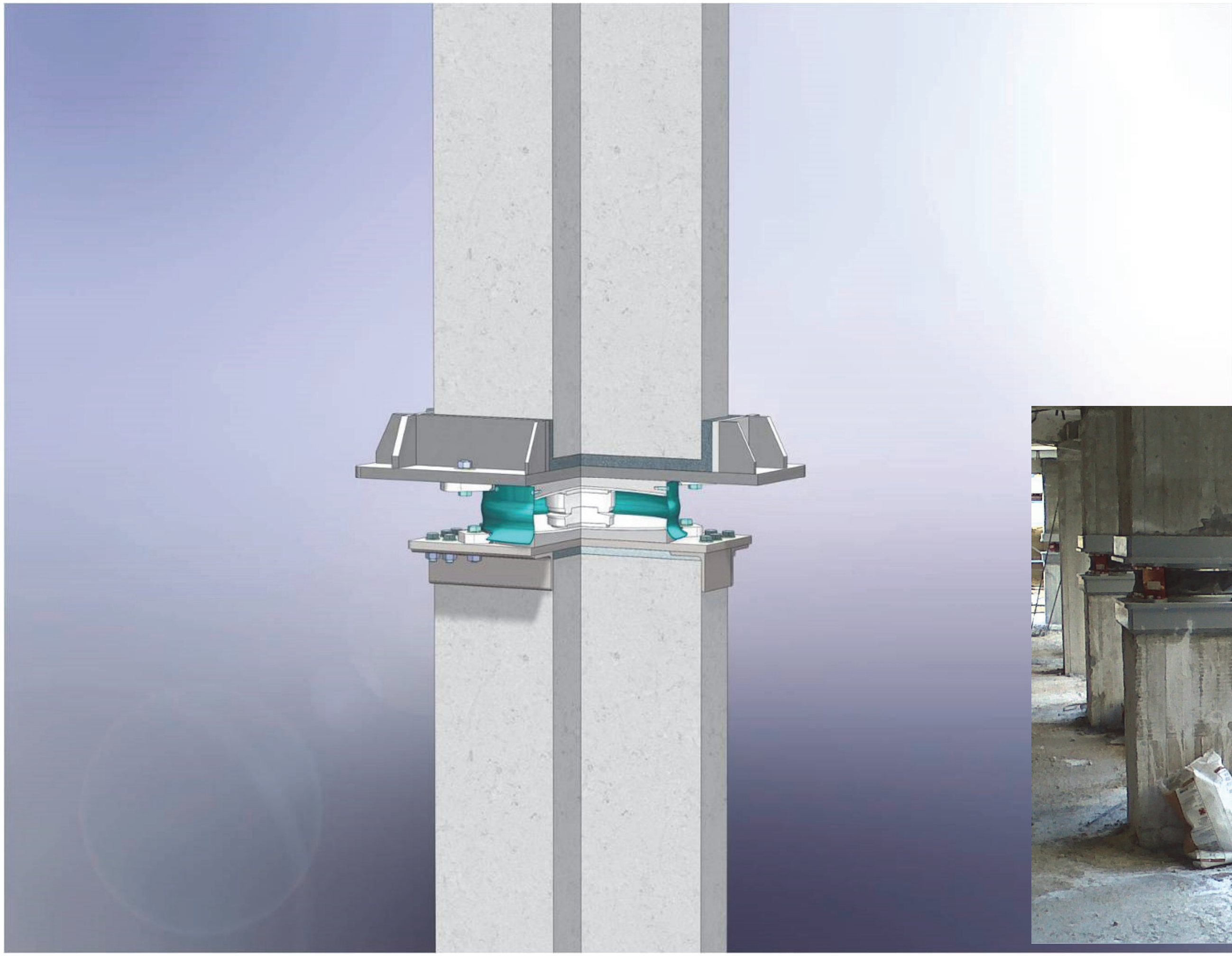
Considerations for the installation of bearings Alternative 2



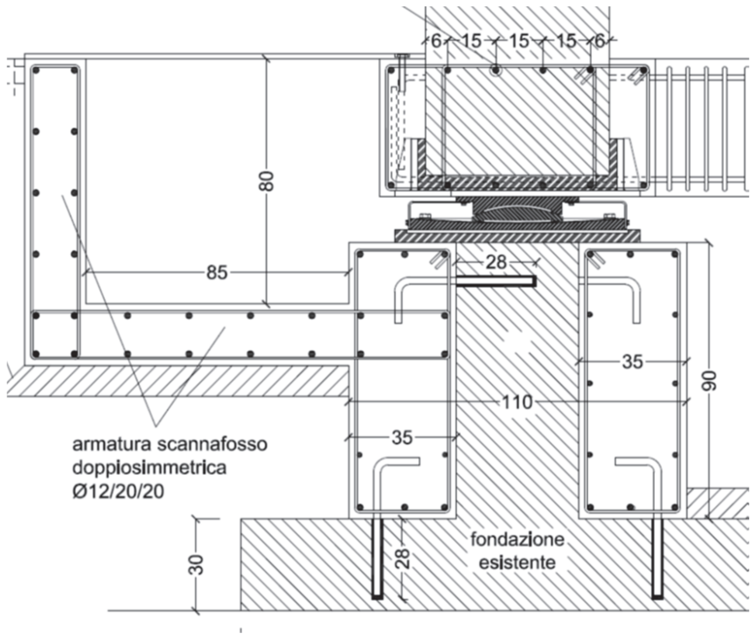
Selected

In the selected installation process, a mechanism with a post tensioning mechanism is located above and below the isolation layer. Once the adequate vertical load is satisfied, the column is cut and LRB unit is installed

Installation of the isolation unit at the top of first basement columns (Freysaş Inc.)




INSTALLATION IN SHEAR WALLS AND EXTERNAL WALLS







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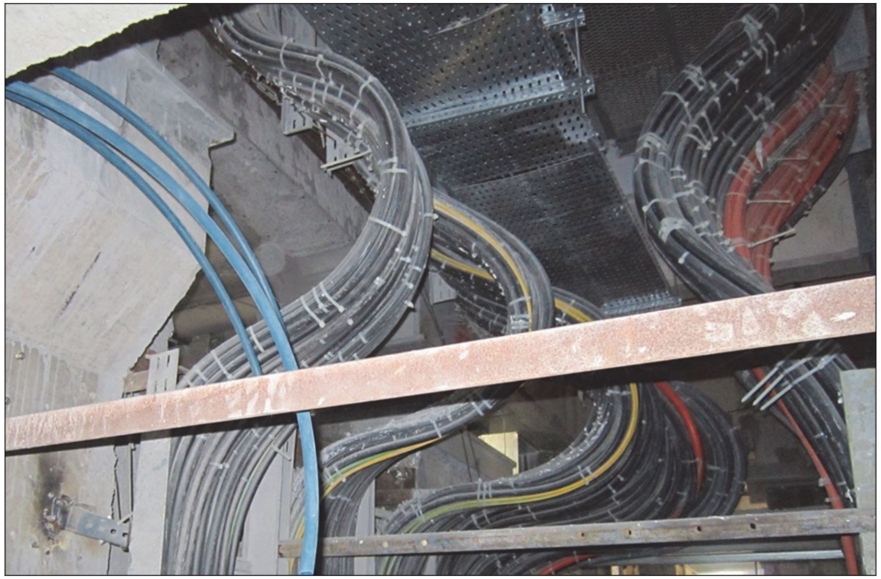


Retrofited Başıbüyük Hospital Ready to Provide Service

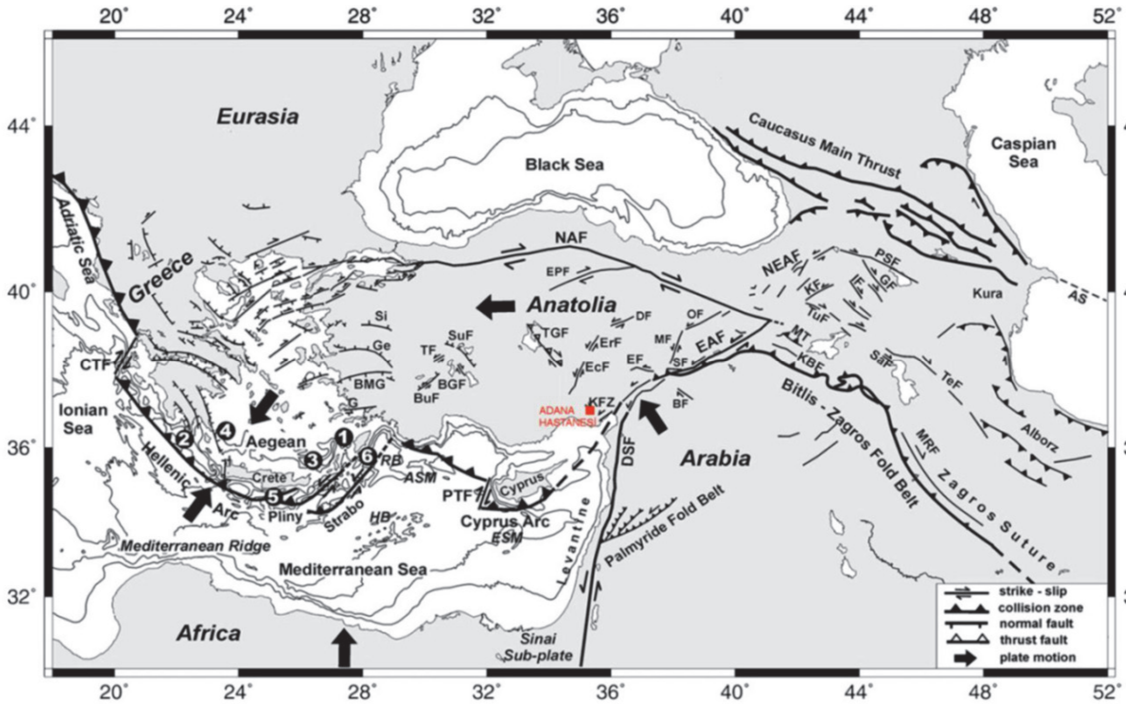
SEISMIC ISOLATION APPLICATION AT ADANA HEALTH COMPLEX

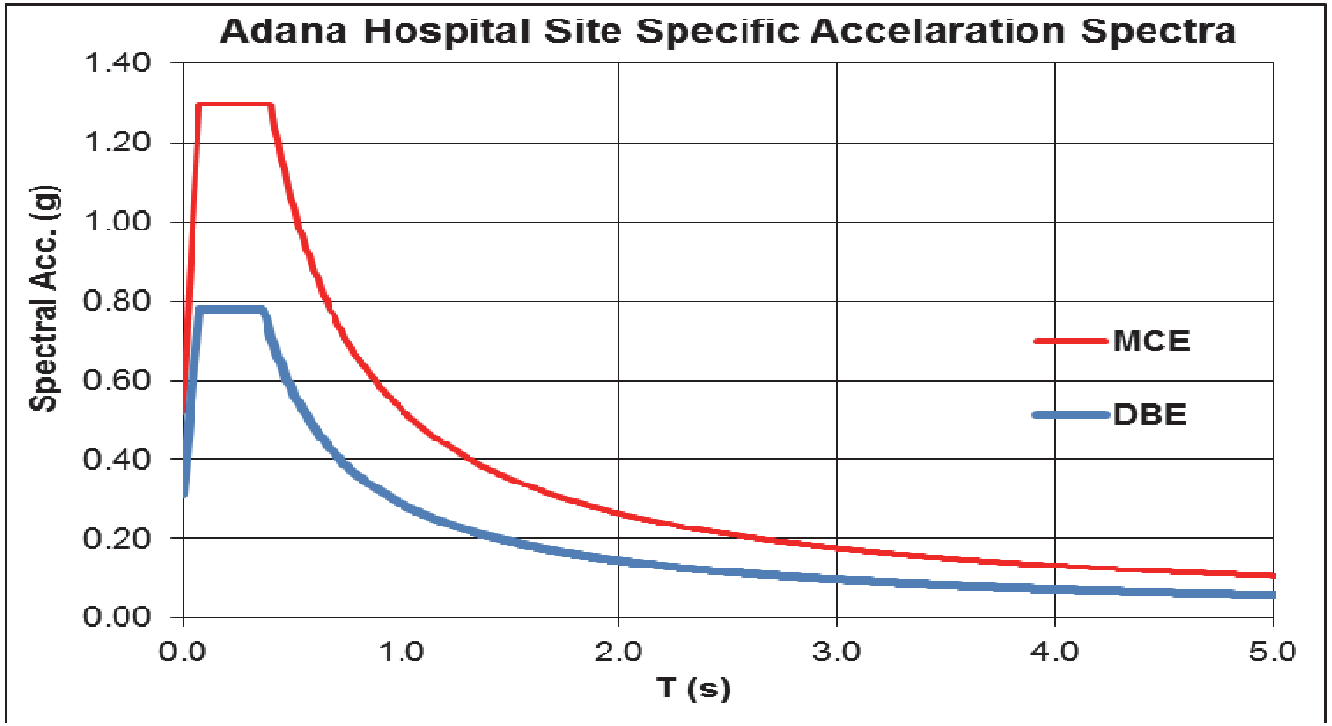
- The hospital complex is located in Adana southern part of Turkey with 1500 bed capacity and approximately 450000m2 total area.
- The isolation layer is located at the base of the structure and the isolation system is composed of 1552 triple pendulum isolators.
- The complex is located on a octagonal base and 4 towers with 11 storey stand at each corner in a symmetric fashion.

3D view of Adana health complex

Adana Health Complex Application

- The performance objectives of the building are as follows:
  - ✓ Minimum Damage / Operational Structural Status for DBE level
  - ✓ Operational Non Structural Status for DBE level
    Maximum 0.2g floor acceleration
    Maximum 0.005 inter-story drift ratio
  - ✓ Minimum Damage Structural Status for MCE level
  - ✓ Operational Structural Status for the isolation and below isolation level for MCE level
- A base shear of 0.10W at the isolation level is targeted for DBE level using upper bound isolator properties to ensure the operational status.
- A maximum displacement of 50 cm is targeted for MCE event using lower bound isolator properties.
- Finally a maximum inter-story drift ratio of 0.01 is targeted for MCE level.





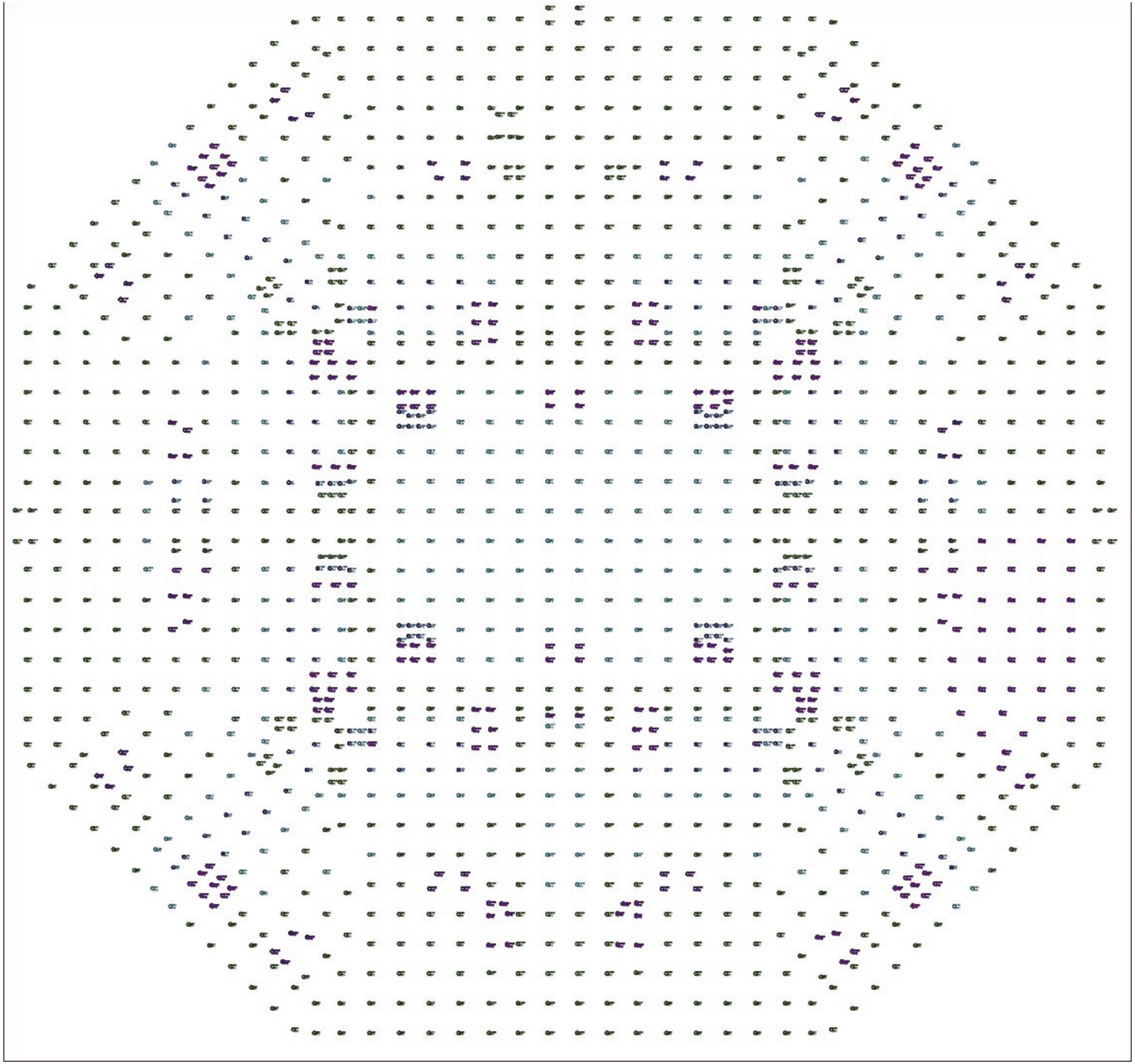
The site specific acceleration response spectra for Adana Health Complex at DBE and MCE levels

Analysis Results

Based on the analysis results based of nonlinear time history analysis, the response quantities in terms of effective stiffness, effective damping and effective period is determined for lower bound, upper bound and nominal values of the isolator units.

Isolation system properties at UB, LB and nominal values

	Upper Bound (DBE)	Lower Bound (MCE)	Nominal
k_{eff} (kN/mm/kN)	0.000453	0.000322	0.000380
β_{eff}	28.6%	16.4%	22.8%
T_{eff} (s)	2.98	3.53	3.25



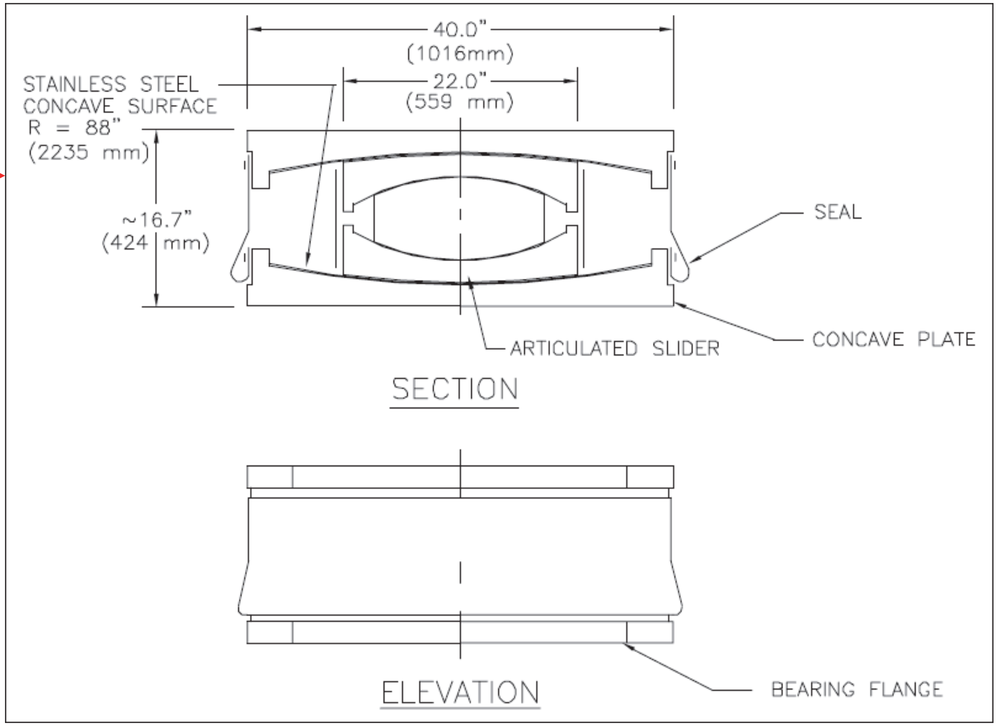
Isolator
(1552)
Locations

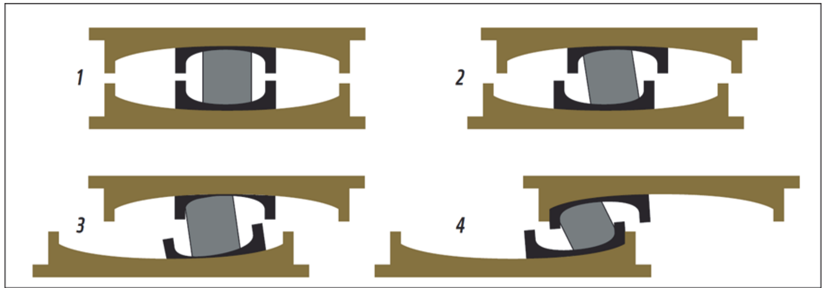
Quantities and types of Triple Pendulum bearings :

70 – FPT8836/22-20/16-8

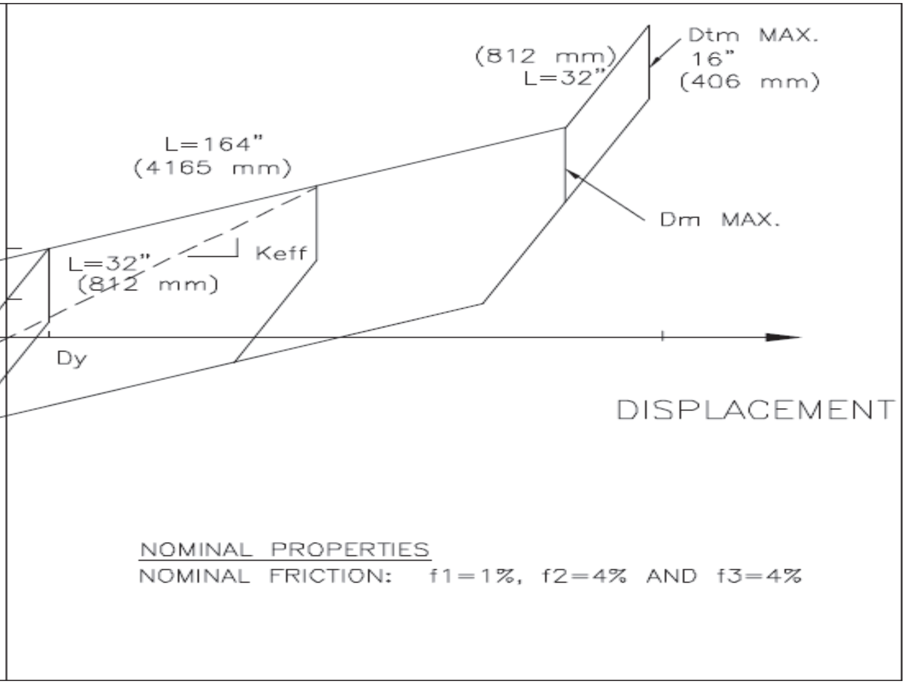
277 – FPT8831/18-16/12-7

1121 – FPT8827/14-12/10-6

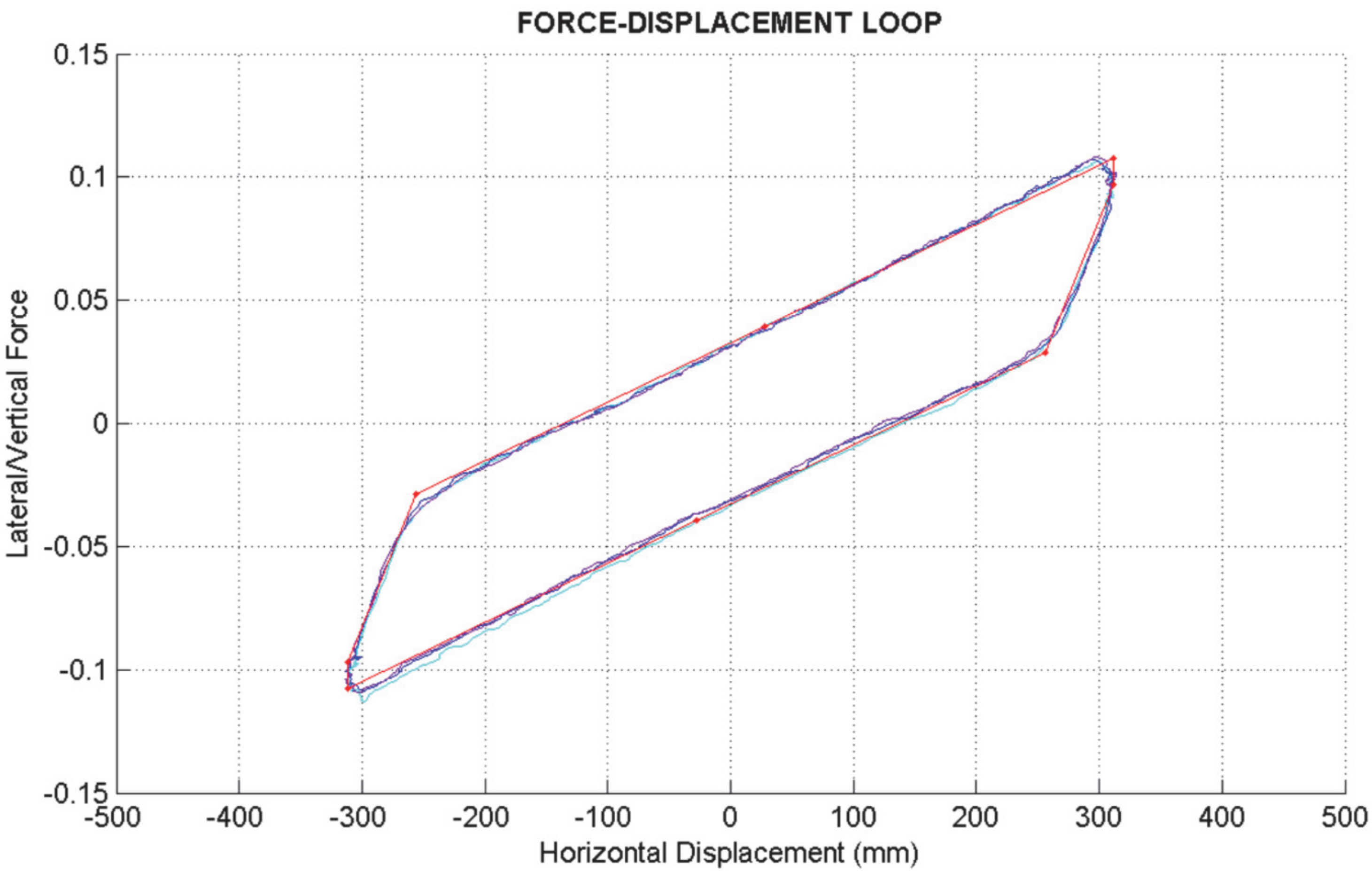




Lateral Displacement Capacities:
Dtmc=406mm; Dmc=368mm
Vertical Load Capacities:
Elastic=35886kN; Ultimate=53829kN



The isolator units have been tested in EPS Inc. facilities, based on the procedure defined in Chapter 17 of ASCE 7-10 document. The tests have been performed with the actual velocity, in other words dynamically.



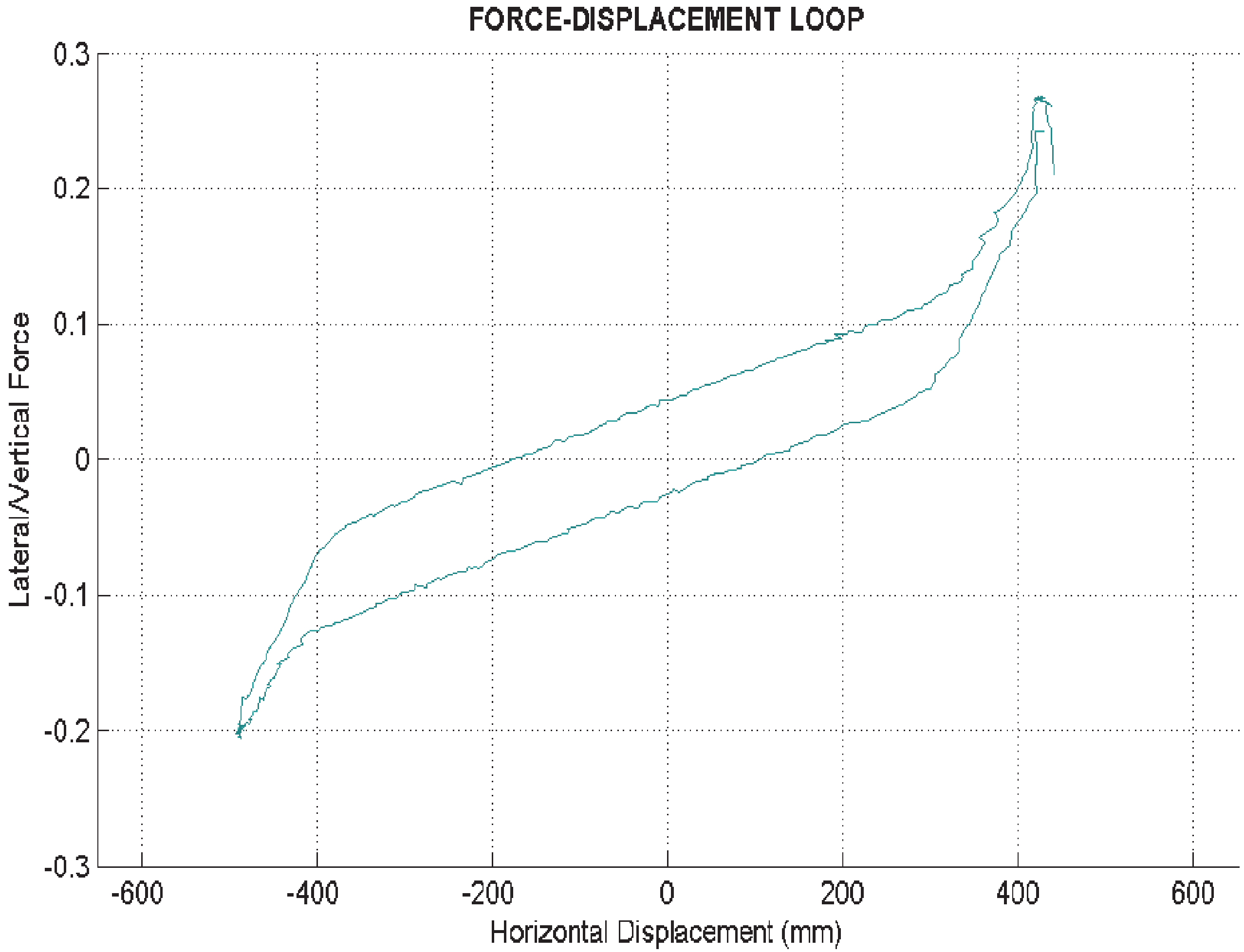
Sample prototype test result (EPS Inc.)

03-Mar-2015 EPS Bearing Test Report for FPT8836/22-20/16-8, PT1 SLC2400

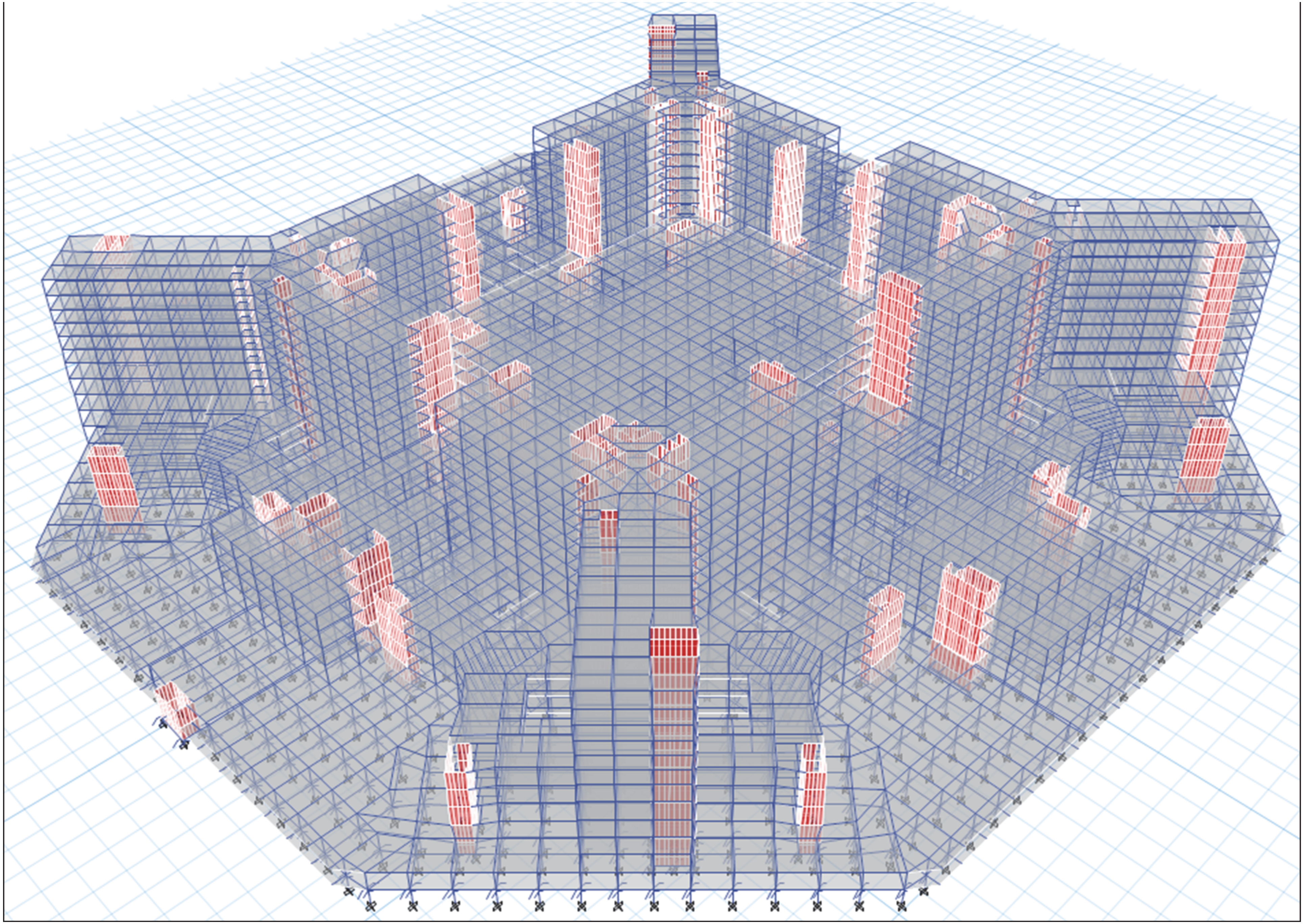
Test Date: 2-24-2015; Test Time: 12:21:01.5; Test Data File: ADA.8836.22.PT1.SLC2400

Bearing Dim.: Rc = 88 Rsc = 20, IDc = 36, ODsc = 22, IDsc = 20, ODsi = 16, tsc = 2, hsi = 8 in; Targ. Frictions: μ1 = 0.01, μ2 = 0.04, μ3 = 0.04

Target Test: 1 Cycle; Vertical Load: 2400 kips; Target Cyclic Displacement: 17.4 in



Vert Load: 10802.9 kN avg, 11626.7 kN max, 10025.9 kN min; Velocity: 120.2 mm/sec max, 32.4 mm/sec avg; Shear Load: 3090.9 kN max, -2176.3 kN min



Adana health complex structural model

Structural Model

- A 3 tier analysis – design methodology has been used for the Adana Hospital Main Building.

- *Preliminary Design*

✓ Detailed linear model of the structure has been developed for the superstructure. The member dimensions have been determined based on the 0.10W isolation level shear force as the seismic force.

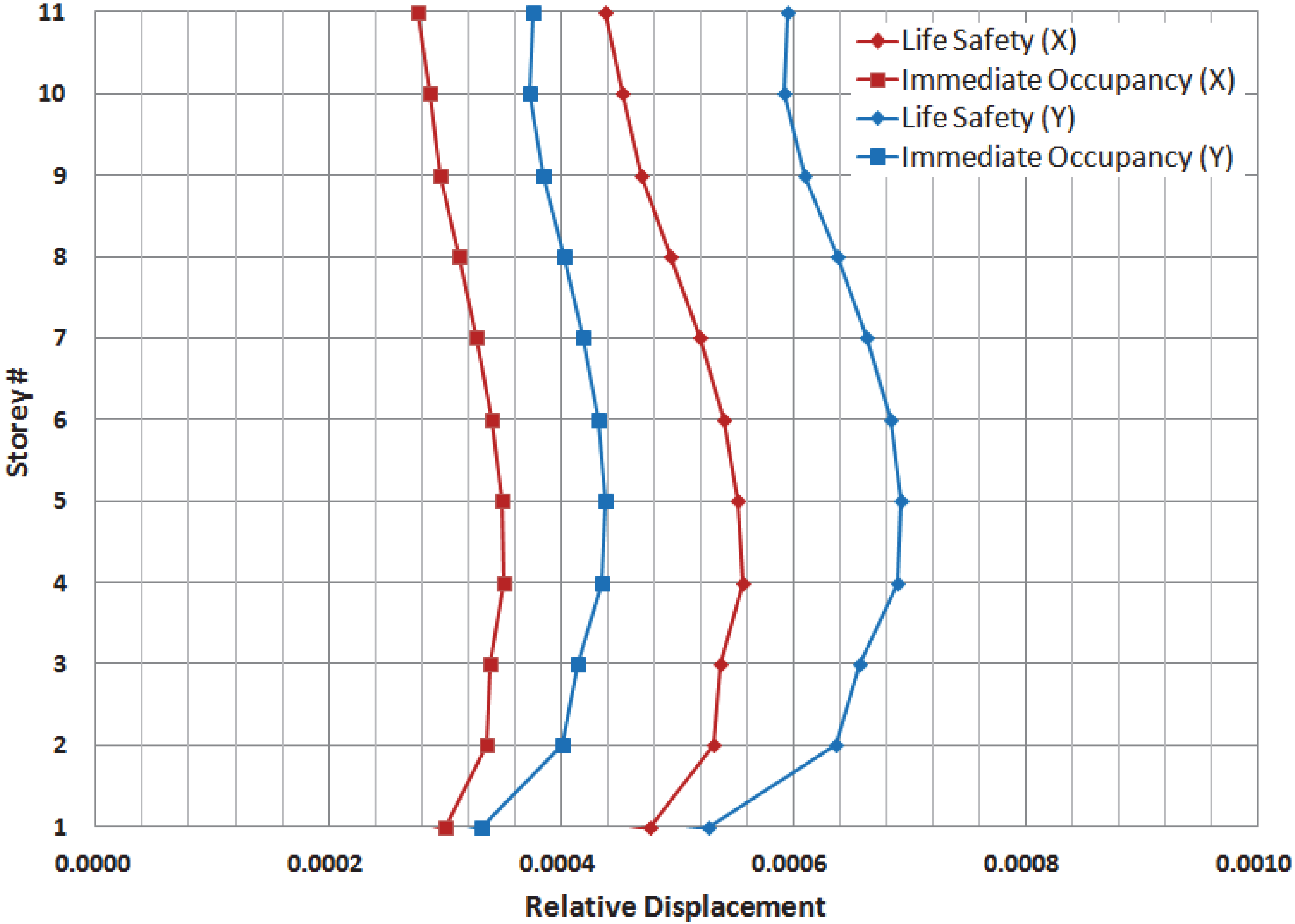
- *Verification Analysis*

✓ The model has been further developed to include the isolator nonlinearity and the sub structure. Based on the data obtained from the manufacturer related to the isolator properties, 7 nonlinear direct integration time histories has been performed in two orthogonal directions for two different hazard levels.

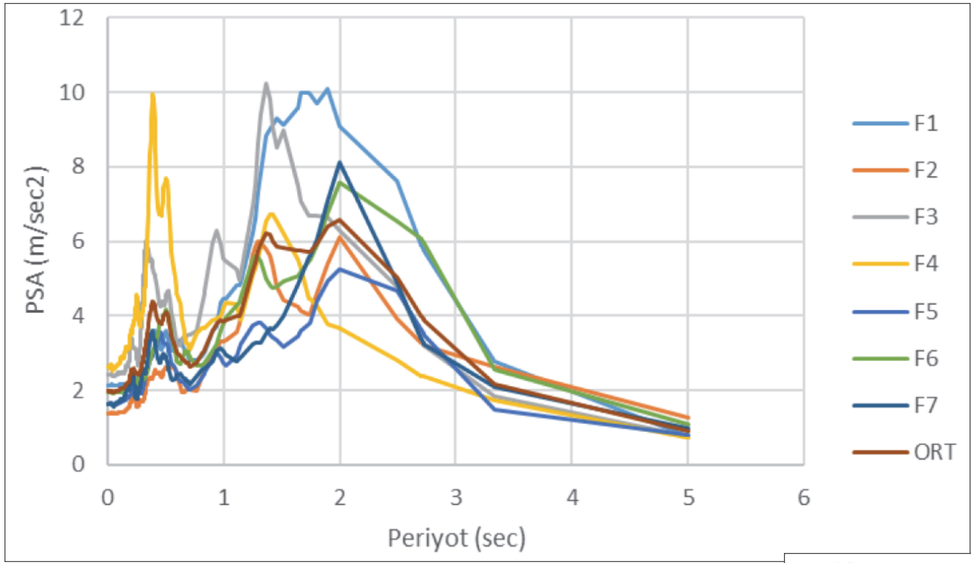
✓ Capacity of the isolators and the adequacy of the structure have been verified, approval for the prototype testing of the isolators and the testing criteria has been determined at this stage.

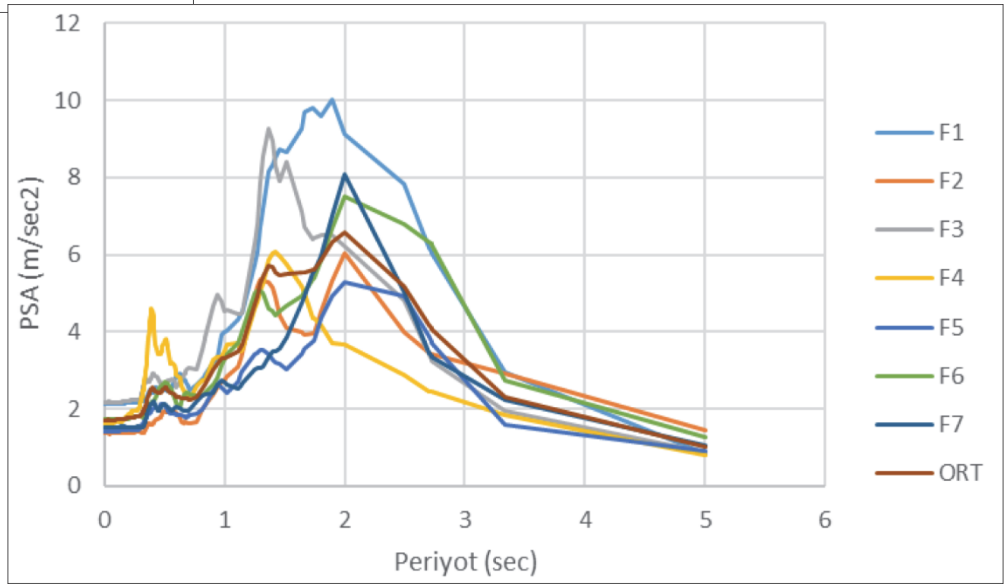
- *Detailed Design*

✓ Based on the results of the verification analysis, detailed design of the structure shall be realized. ACI 209 has been used to determine in plane behaviour of the podium diaphragm above the isolation level. P-Δ effects have been considered for the design of the sub structure



Drift profile for DBE (red) and MCE (blue) level





DBE Level floor spectra for two different earthquake records


OYAK BETON

CONCLUSIONS

- Passive control technologies, especially seismic isolation, are being implemented in Turkey at an accelerated rate after the 1999 Kocaeli earthquake. Currently 70+ buildings employ seismic isolation

- The enforcement of Ministry of Health for the use of seismic isolation for hospitals in medium-to-high seismic hazard regions is an important and rational decision.

- The code prepared for the seismic isolation design for buildings as the official code will certainly regulate as well as encourage the new applications.

- Training of engineers for the proper and correct utilization of seismic isolation techniques, as well as licensing, needs to be considered.

- The peer review process needs to be structured and become an integral part of the design and implementation of the passive structural control.

ACKNOWLEDGEMENTS

I have freely used the contents of the studies that were made by the following entities and firms and I am grateful for this contribution:
ISMEP-Istanbul Project Coordination Unit, Ministry of Health-General Directorate of Health Investments, Renaissance Inc., Prota Ltd., DO-KA Ltd., EPS Inc., FREYSAŞ, Stipe&Tima Inc., Zeksan Inc.

The collaboration with my students/colleagues Cüneyt Tüzün, Ömer Ülker, Bahadır Şadan and Cem Yenidoğan and the assistance they have provided is gratefully acknowledged.

THANKS
ΕΥΧΑΡΙΣΤΏ