SEISMIC PROTECTION FOR THE 1081-BED HOSPITAL IN ESKIŞEHIR CITY IN TURKEY

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Abstract

The Eskişehir City Hospital with a total mass of 530,000 t is located 250 km south east of Istanbul in a highly seismic zone with up to 0.6g PGA.

To prevent fatalities and enable continued functionality after the maximum considerable earthquake (MCE), it was not possible to simply strengthen the building structure, even this was not economical, too. Therefore it was decided to apply seismic isolation with 980 pcs. pendulum isolators to mitigate the seismic accelerations down to levels not creating any damages to the building content anymore.

The structural design requires to limit the base shear on isolator top level for the MCE event down to less than 13% of seismic structural weight. On the upper building floor levels max. 0.2g acceleration was specified to be acceptable. For these shear level requirements the isolator performance was adjusted with its inner specific stiffness and friction performance to 3.5 s effective period and 26 % damping.

With strict quality supervision, third party prototype testing at EUCENTRE in Pavia and with third party production testing at University Munich, the reliability and durability of the isolators to resist up to five or more MCE events without damages was proven.

The design approach for this project is unique in a way that absolute no damages to the structure, to the content and the seismic isolators have been acceptable for the MCE event. The hospital must be ready for service immediately after the earthquake to be granted with suitable seismic isolators.

The paper will show the design approach, selection of the isolator type, isolator design and isolator testing to achieve serviceability of the entire hospital even after severe seismic events.

Keywords: Seismic protection, isolators, acceleration reduction, continued function

1. Introduction

In Turkey several new hospitals have been built during the past years. One of these is the Eskişehir City Hospital (Fig. 1) with 1081 nos. beds in the Odunpazari District of Eskişehir 250 km south east of Istanbul. Due to the high seismicity of this region with up to 0.6 g PGA the published standard [1] by Ministry of Health (MOT) required to apply seismic isolation for this structure with 977 nos. devices to reduce the base shear on the upper floor levels even down to less than 0.2 g [2]. For seismic isolation it was required to apply friction pendulum devices, lead rubber bearings or high damping rubber bearings. Finally the friction pendulum type of isolator was identified to be the only one fulfilling the requirement of 70 years service life, technically the best, maintenance-free and even it has been the most economic solution considering the project requirements.

Fig. 1 – Eskişehir City Hospital issued by DOST Construction

For the isolator design it was acceptable to apply ASCE 7-10, EN15129 or IBC 2012 upon approval by the MOT.

The entire hospital consists of four single main blocks A, B, C and D (Fig. 2) with isolators on the second cellar level.

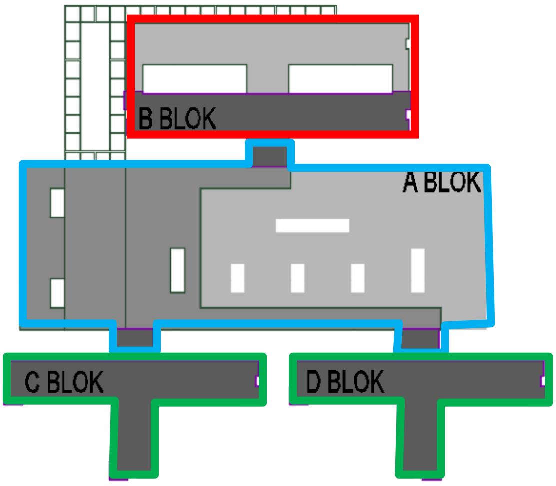


Fig. 2 – Single blocks of hospital complex [2]

Block A has 561 nos. isolators, block B has 216 nos., block C has 100 nos. and block D has 100 nos. [2].

2. Design of Isolation System

For the isolation system Sliding Isolation Pendulums with double sliding plate (SIP D), which represents a well developed and reliable type of isolation pendulum system, were applied. For their proper design various input data had to be considered.

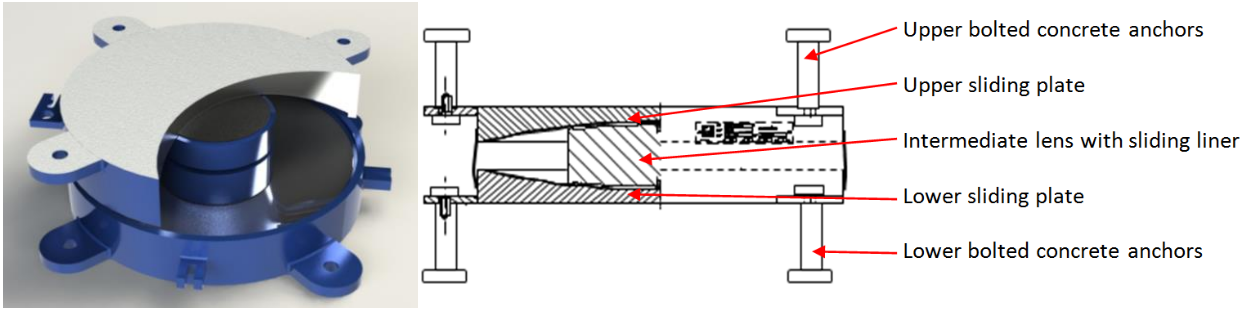


Fig. 3 – Principle design of SIP D device

The two inside the bearing applied sliding liner pads have got a thickness of 8mm. The material behaves per pad vertically with 0.5mm elastic and for the first loading effect with 0.5mm plastic deformation. This performance together with 8mm thickness grants perfect full surface alignment to the stainless steel sheet combined with constant friction behavior and no wearing effects of the material.

2.1 Seismic hazard analysis

The Odunpazari District of Eskişehir is in 2nd degree seismic zone (Fig. 4) according to the Turkish Earthquake Code 2007 [3].

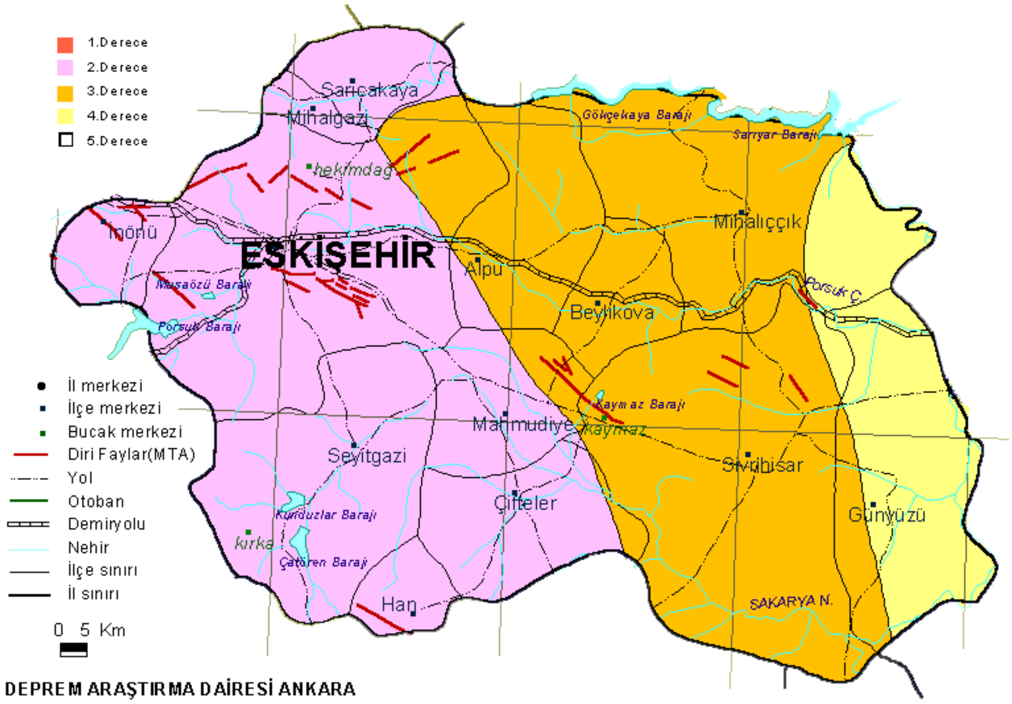


Fig. 4 – Eskişehir earthquake map according to Turkish Earthquake Code 2007

The seismic hazard analysis was carried out by SismoLab Engineering in Ankara. The required horizontal site spectra for the 475 and 2475 years return periods are shown in Fig. 5.

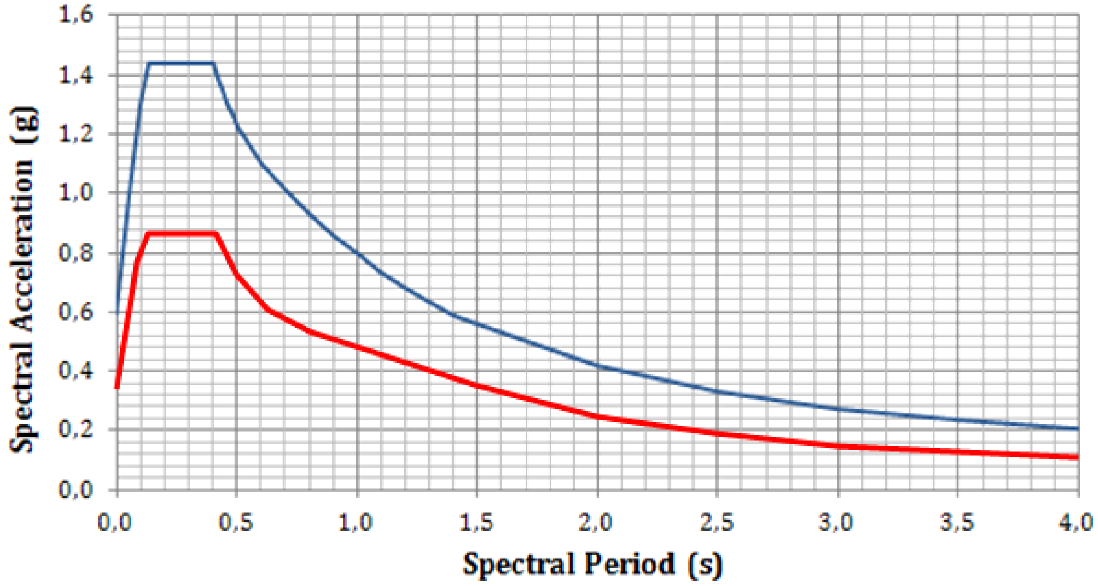


Fig. 5 – Horizontal specific spectra for 475 years (red) and 2475 years (blue) return period (5 % damping)

2.2 Structural performance demand

To grant that after the MCE earthquake absolutely no damages within the structure occur, certain demands [2] must be considered.

1. Relative displacement between stories must be less than 0.5 % of height level.
2. Maximum horizontal story acceleration on any floor must be less than 0.2 g.
3. Maximum vertically acting force onto the isolator will be obtained from the load case 1.2 Dead Load + Live Load + Earthquake Load. The minimum axial force comes from 0.9 Dead Load - Earthquake Load.
4. Maximum displacement including reliabilities shall be less than 500 mm.
5. Stability and integrity of isolators must be granted

2.3 Seismic analysis of structure

To determine suitable isolator characteristics fulfilling the structural demands an equivalent linear analysis and a nonlinear time-history analysis was performed.

The property modification factors for the SIP D isolators representing the lower and upper bound performance levels were taken according to previous testing and design experience on similar devices for Isparta City Hospital and Erzurum Medical Campus as follows:

$$\lambda_{min} = 0.9 \text{ and } \lambda_{max} = 1.54 \quad (1)$$

Taking into account the response spectra in Fig. 5 & 6 and the property modification factors, the equivalent damping ratio of the isolation system for the design and for the design based earthquake level exceeded 30 %. Thus it was required according to the code to go for the nonlinear time-history analysis.

The project specification [2] required to apply the seismic records of the earthquakes of Imperial Valley (1979), Morgan Hill (1984), Chalfant Valley-02 (1986), Superstition Hill-02, Landers (1992), Kocaeli (1999) and Joshua Tree (1992) (Fig. 6 & 7). These had to be scaled to the required levels in Fig. 5.

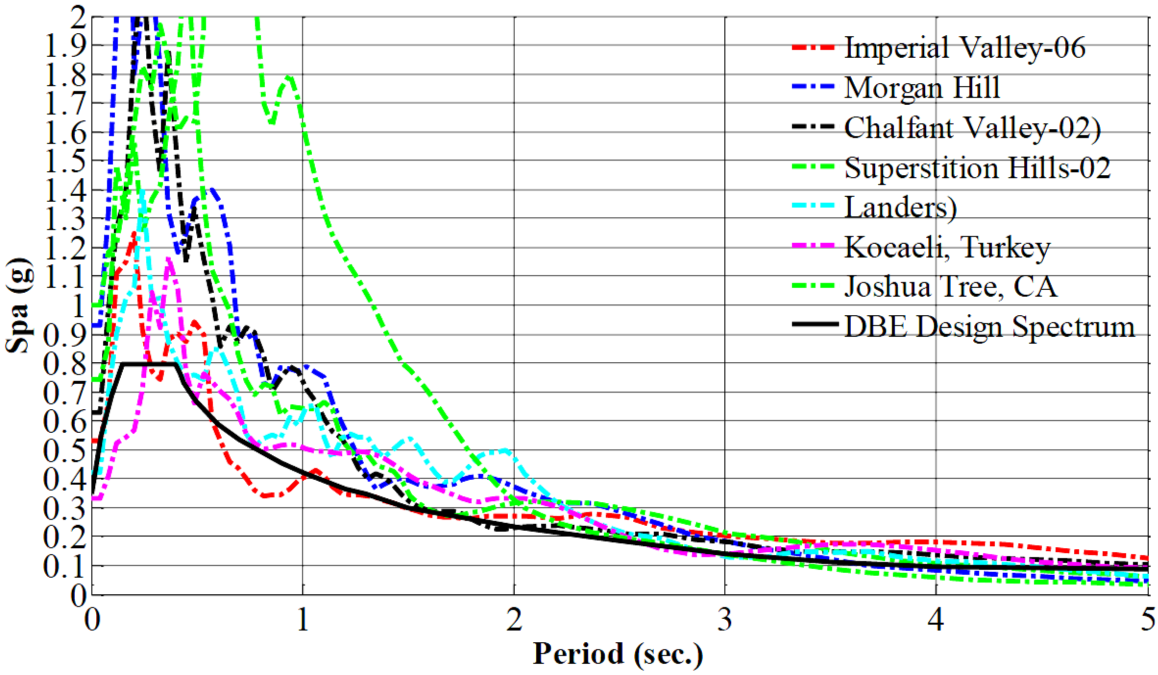


Fig. 6 – Horizontal pseudo acceleration spectrum (5 % damping) for DBE-level ground motion

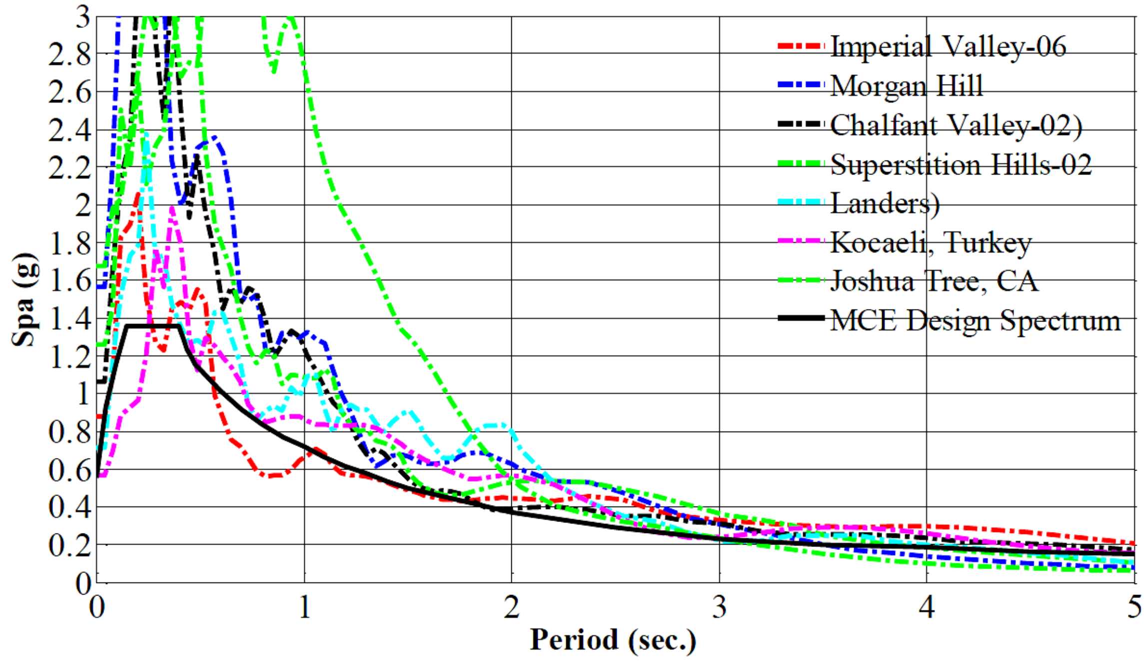


Fig. 7 – Horizontal pseudo acceleration spectrum (5 % damping) for MCE-level ground motion

Together with the provided 3D FE model and the soil data a nonlinear time-history analysis was carried out, while achieving 377 mm maximum displacement for MCE and 177 mm for DBE load case with $\lambda min = 0.9$.

$$W/R\ d_{max} + W\ \lambda min\ \mu = 12.4\ \%\ W \tag{1}$$

With W = 537,600 t

R = 5 m

d_{max} = 0.377 m

μ = 0.05

λmin = 0.9

The max. MCE-base shear at the isolator for λmax = 1.54 is 12.9 % of the structural seismic weight, which was defined to be seismic weight with Dead Load + 0.3 Live Load [1]. The DBE-base shear will then be limited to 9.6 % for λmax = 1.54.

Within the structural 3D-FE model of the single blocks it could be shown that the 0.2 g max. lateral acceleration was not exceeded on the top floor levels. Therefore it might be expected with this rather soft isolation system that no structural damages and no damages to the medical equipment will occur.

2.4 Design of isolators

For the given loads between 2,500 kN and 25,100 kN, the average dynamic friction of 5 % and the applied pendulum radius of 5 m, the average MCE-damping was 25 % considering displacement of +/- 377 mm and average DBE-damping was 37 % considering displacement of +/- 177 mm.

Any isolation system with lead rubber or even high damping rubber bearings turned out to be approx.. 25 % more expensive compared to pendulum isolators. The rubber bearings suffered of stability problems when combining max. load with max. displacements. Therefore the friction pendulum type with two sliding plates was chosen (Fig. 3 & 8). The effective period was ultimately between 3.16 s for DBE and 3.55 s for MCE. These values were requiring 5000 mm effective pendulum radius within the isolator and a nominal dynamic friction of 5 % considering Dead Load + 0.3 Live Load [1].

The applied sliding liner material is called MSM®, which is a patented, high-performance, absolutely non-ageing sliding material for structural bearings resisting 240MPa or even greater seismic stress levels. Compared to virgin white PTFE this is double stress level. The MSM an ultra high molecular weight polyethylene modified with various additives, featuring enhanced rather durable sliding characteristics for accumulated sliding path of 10,000 m to 50,000 m or more depending on the application. The applied sliding material is able to guarantee the integrity and vertical stability of the isolators at max. load combined with max. displacement. The wear resistance and extreme ability to withstand high sliding velocities of more than 1m/s without showing wearing effects results in seismic isolators working as long as building service life time.

Based on the above, the structural designer and investor can be sure that even after several MCE events none of these SIP D bearings need maintenance or must be exchanged during the life time of the Eskişehir City Hospital [4] [5]. The SIP D design and all applied materials together with the quality management system is conform to an European Technical Assessment (ETA) for spherical structural bearings of MAURER SE [6]. This ETA certifies to the investor in addition to the relevant standards that the durability and long term function will be achieved by all means.

The displacement capability of 377 mm for the lower bound properties of the isolators was increased on demand of the designer by 15 % to 430 mm displacement. These 15 % reliability will cover structural uncertainties like not perfect re-centering.

For dust protection a high efficient dust wiper system between the upper and the lower concave plate was applied. The lateral forces induced by the isolators´ inner friction and stiffness were anchored with 4-6 nos. massive bolted concrete anchor dowels (up to 65 mm diameter and 390 mm length) into the concrete (Fig. 8).

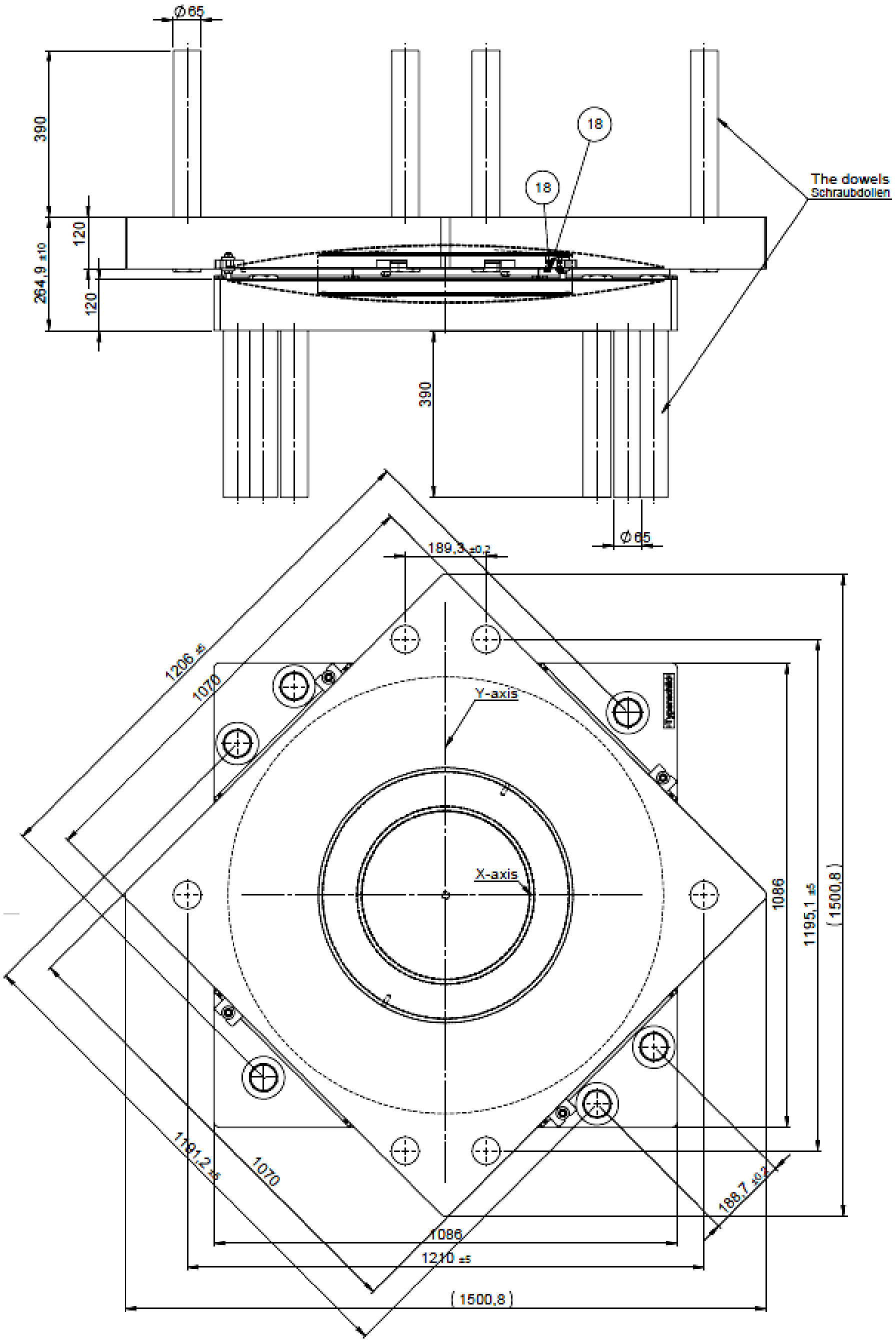


Fig. 8 – Design of the largest SIP D isolator

2.5 Testing of isolators

For testing ASCE 7-10 or EN15129 or IBC 2012 was accepted. The chosen SIP D isolator design is based on the European Technical Assessment [6] for spherical bearings and therefore it was most reasonable to perform the testing according to the European standard EN15129.

The participating three Universities from Bochum, Munich and Pavia with their high commitment made it possible to test 12 nos. prototypes and 293 nos. production bearings within three months only.

2.5.1 Prototype testing

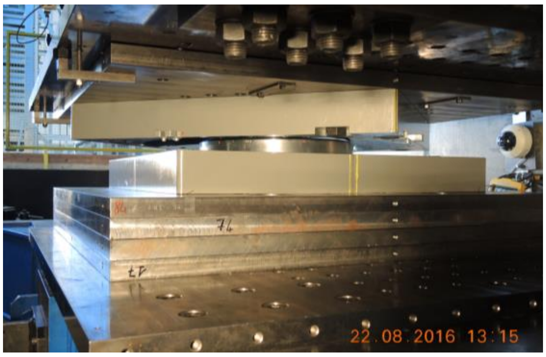
Two samples of each of the six isolator types – in total 12 nos. - had to be tested. The test matrix of Tab. 1 was applied. The EUCENTRE Foundation in Pavia, Italy was chosen for these type tests (Fig. 9-left) to fulfil the testing requirements of max. 500 mm/s velocity combined with max. 430 mm displacement amplitude.

After testing the isolators were opened to determine any degradation or damages to the liner or device itself (Fig. 9-right). No damages were found. There were no signs of wearing, extrusion or scratches in the liner and not on the stainless steel.

The simulation of more than three MCE events on the same SIP D device showed no signs of wearing and the performance characteristics did also not change at all even when tested at max. loads combined with maximum displacements (Fig. 9 on right).

Table 1 – Test matrix for prototype testing for one certain bearing type 1

test #	test name	label	main dof	Ampl. [m]	max vel [m/s]	freq [Hz]	load shape	vert load [kN]	cycles [#]
0	Pre-test 0	P0	long	±0,430	0,500	0,185	sine	2493	3
1	Pre-test 1	PT1	vert	-	-	-	constant	2493	-
2	Frictional Resistance	FR	long	±0,006	0,0001	0,0042	triangular	2493	1
3	Service	S	long	±0,010	0,005	0,080	sine	2493	20
4	Benchmark	P1	long	±0,185	0,050	0,043	sine	2493	3
5	Dynamic 1	D1	long	±0,108	0,500	0,740	sine	2493	3
6	Dynamic 2	D2	long	±0,215	0,500	0,370	sine	2493	3
7	Dynamic 3	D3	long	±0,430	0,500	0,185	sine	2493	3
8	Seismic (N_Ed, max)	E1	long	±0,430	0,500	0,185	sine	7039	3
9	Seismic (N_Ed, min)	E2	long	±0,430	0,500	0,185	sine	1500	3
10	Property verification	P2	long	±0,430	0,500	0,185	sine	2493	3
11	Bi-Directional	B	long	±0,430	0,500	0,185	sine	2493	3
12	Load Bearing Capacity	BC	vert	-	-	-	constant	7039	-
13	Post-test	PT2	vert	-	-	-	constant	2493	-



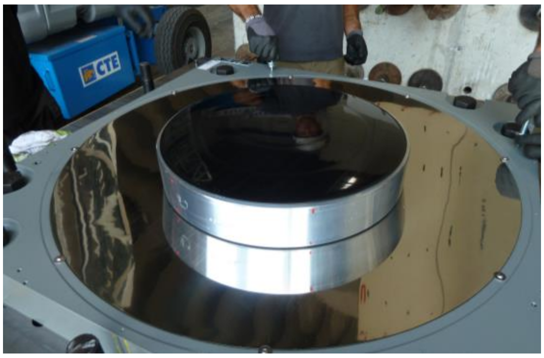


Fig. 9 – Prototype testing at EUCENTRE in Pavia (left); Integrity check of isolator after testing (right)

The test results have proven the reliability of the isolators´ damping capability based on 5 % dynamic friction and min./max. seismic weight condition during several simulated MCE events.

The isolators created constant hysteretic loops (Fig. 10), while showing very low static friction values of 6.00 % to 6.25 %, i.e. this is not creating any horizontal system locking effects for any frequently returning earthquakes with undesired accelerations inside the building.

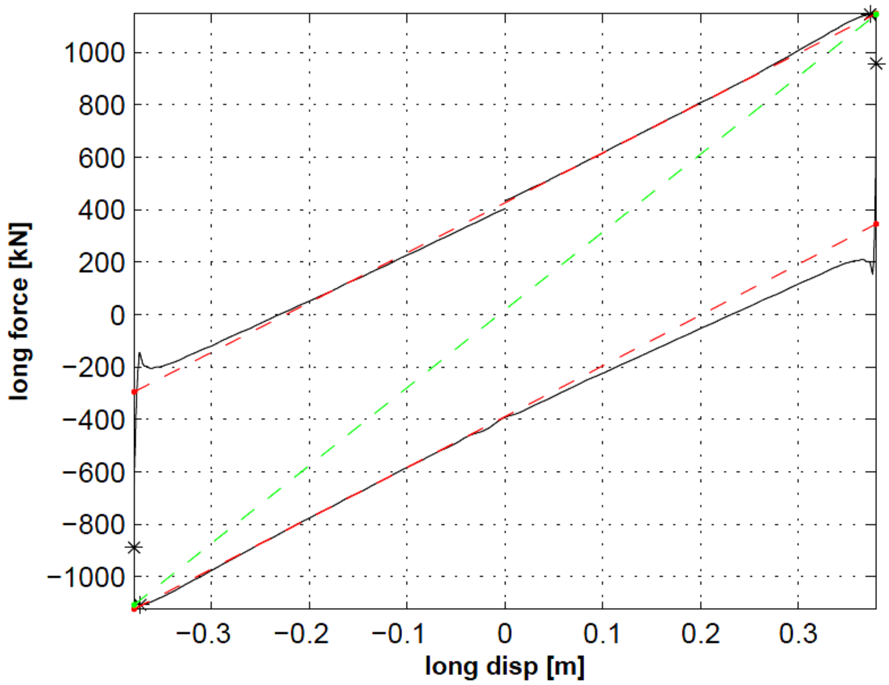


Fig. 10 – Hysteretic loop of isolator under load of 9,712 kN, 430 mm displacement and 500 mm/s velocity

Therefore it can be concluded that the isolators will work properly during the entire life time of the structure, which for this building typology is 80-120 years. The testing criteria had been fulfilled.

2.5.2 Production testing

In total 293 nos. – corresponding to approx. 30 % out of all 977 nos. devices – had to be tested within the production test framework. These tests were performed at Universitaet der Bundeswehr in Munich/Germany and Ruhruniversitaet Bochum/Germany to get 292 nos. devices tested just in time. Per day 2 to 5 nos. devices, which were randomly chosen by the construction company, were tested.

The testing was performed with the specified seismic weight load combination of “Dead Load + 0.3 Live Load” with 50 mm/s and +/-185 mm displacement. All isolators passed the testing criteria and requirements according to EN15129.

2.6 Installation of isolators

All devices were supplied as one unit (Fig. 11-left). Finally the concrete anchors had to be assembled on site to the isolator upper and lower sliding plate.

Fig. 11 – SIP D isolators ready for dispatch (left); positioning of isolator on plinth in the cellar level (right)

The units with a mass of 410 kg to 2,020 kg could be rather easily installed with a lifting crane and two workers (Fig. 11-right). When the isolator is adjusted horizontally in the final position a high strength grout joint of 30-50mm thickness provides under the device the full surface contact to the plinth (Fig. 12).

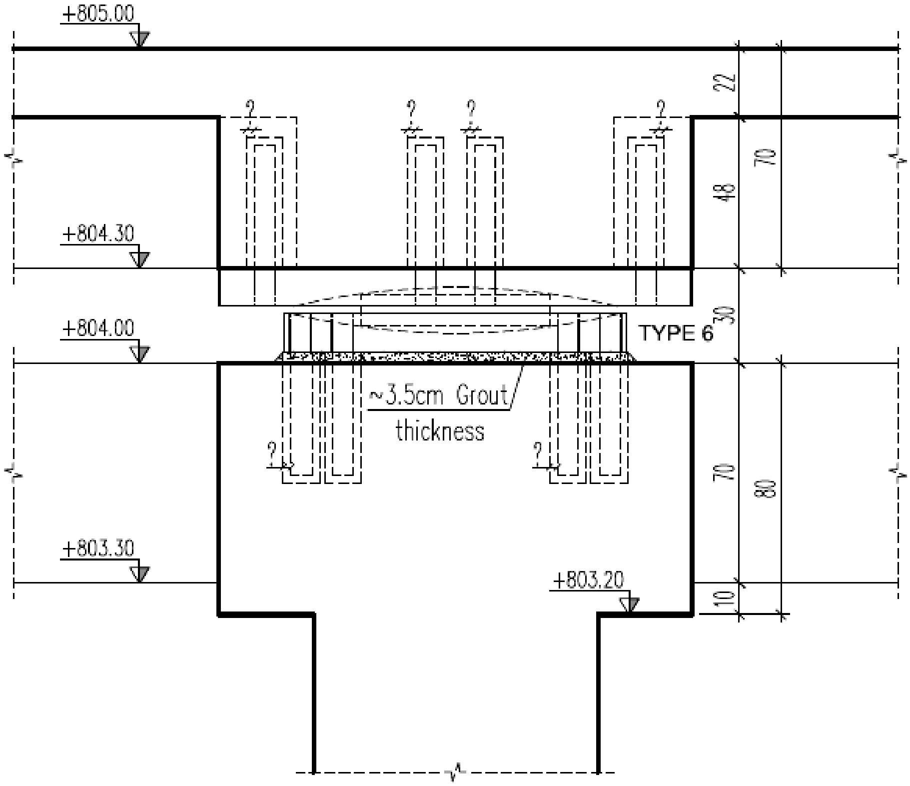


Fig. 12 – SIP D isolator on plinth with upper structural slab and grout joint

3. Conclusions

For the Eskişehir City Hospital a seismic isolation system consisting of Sliding Isolation Pendulums (SIP D) was chosen, as it deemed to be best in terms of technical performance, durability and economical demands.

Within a structural time-history analysis the SIP D performance parameters – like damping, displacement and period - were evaluated to be most suitable to fulfil the challenging demand of max. 0.2 g acceleration limit on the upper floor building levels.

The isolator design according to the European Technical Assessment [6] is ensuring the highest possible quality level. The devices were consequently adapted to the rather great loads of up to 25.1 MN and the demand for absolute integrity combined with extreme durability even after several MCE events.

The third party testing under severe testing conditions at Universities in Bochum, Munich and Pavia confirmed the performance stability together with excellent reliability.

Based on the proven isolator performance it could be ensured that maintenance will not be needed as ageing and wearing will not occur. Concluding from this, the service life time of the isolation system will be identical to the building or even longer.

The selected SIP D device type is fulfilling together with its adjusted special performance the no-damage-criteria even for the MCE earthquake and the Eskişehir City Hospital can go for continued functionality after any seismic event.

4. Acknowledgements

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