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Seismic Retrofitting of the Marmara Başibüyük University Hospital in Istanbul

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Abstract

Strategic facilities like schools and hospitals have a primary role in the civil protection sphere in order to guarantee the continuity of the main services to citizenry, especially after a seismic event.

The continuous improvement of the knowledge in the field of civil protection, with particular reference to the seismic activity, necessarily brings to an update of the local seismic hazard map. Consequently, both from legislative and safety point of view, the continuous upgrade and compliance to the existing standards of those structures is of primary importance in order to supply such service to the citizenry.

Of course, also the seismic protection techniques have been improved during the last years, both for the type of material used and for their application. These techniques are more often used in structures even more irregular both in plan and in height, especially if they are built in very high seismic zones, or because very severe performances are request after seismic improvement.

In this context, The Başibüyük Marmara University Hospital, is one of the most important hospitals of Istanbul and it is well know that Turkey is a high seismicity country due to the presence of the Anatolian fault. Due to these main reasons, the seismic retrofitting of the hospital designed by Prota, one of the most important Turkish design company, based in Ankara, and under completion by the Turkish company Zek-San, required particular techniques, like the base isolation with consequent cut of the columns, like described in this paper.

Keywords: Retrofitting of Public Hospitals, Building Isolation, Lead Rubber Bearings, Dynamic Tests

1. DESCRIPTION OF THE STRUCTURE AND PERFORMANCE REQUESTS

The Başibüyük Marmara University Hospital is located in Maltepe district, in the Başibüyük quarter, in the Asiatic side of the town, on the Coast of Marmara Sea.

The building, composed by 16 independent blocks of rectangular shape raising to different heights and a block designated to car park, never started his duty, despite it has been built in 1991. The layout of the building with a total area of about 112000 m2 and a capacity of about 750 beds is shown in the Fig. 1 and Fig. 2 here below.

Fig. 1 – Building layout and representation of the different blocks (the color identify the different height)

The different blocks, even if they are regular both in plan and in height, show a different number of floors and in particular:

- blocks A1, A2 e A3 with 4 floors
- blocks A4, A7, B4 e B8 with 12 floors
- blocks A8 e B7 with 13 floors
- blocks A5 e A6 with 2 floors
- blocks B1, B2, B3, B5 e B6 with 3 floors
- block for car park with 2 floors

Globally the structure is made irregular in height due to the presence of not homogeneous blocks also because of the level of foundation is not constant but shared among three different levels: -14.5 m, -8.96m e ±0.00.

After the introduction of the seismic standard in 1998, the structure has been retrofitted in 2002 through the introduction of concrete shear walls and column jacketing.

Nevertheless, after the incoming of the current seismic standard in 2007, the retrofitting recently performed did not satisfy the request of the new standard. Only the car park block, after the seismic evaluation, was considered adequate for both the levels of safety and did not require any further operation of retrofit. On the other hand, all the rest of the structure needed proper operation of adaptation to the standard.

Fig. 2 – View of the different blocks of the building

The current seismic norms foresee that on existing buildings a performance-based evaluation on all the structural elements is performed on two different levels of safety. The first level, called Life Safety (LS) considers the application of a response spectrum obtained by an earthquake with 2% of probability of exceedance in 50 years (2475 years return period). The second level called Immediate Occupancy (IO) considers the application of a response spectrum with 10% of probability of exceedance in 50 years (475 years return period).

The seismicity of Istanbul is defined by a map giving the seismic zone for the building locations. The hospital is located in first category zone, according to Turkish code, with 0.4g of PGA, as shown in the Fig. 3.

With reference to the return period of the two limit states and to the peak ground acceleration, the two response spectra with which the structural element will be assessed are defined. The two response spectrum are shown in the Fig. 4 and Fig. 5.

On the basis of the two defined spectra, the assessment of the existing building considered different solution to meet the standard requirements.

The first one foresaw the structural strengthening with conventional methods. This solution has been considered not applicable since it would have been too strong from the architectural point of view and it would have generated damages to non-structural elements, hence without satisfying the requirements of the Immediate Occupancy limit state.

The optimal solution which was able to satisfy both the requirements of Life Safety and of Immediate Occupancy, granting at the same time a satisfactory a good architectonical equilibrium, was the base isolation of the whole structure linking all the 16 blocks in one rigid element except the car park block.

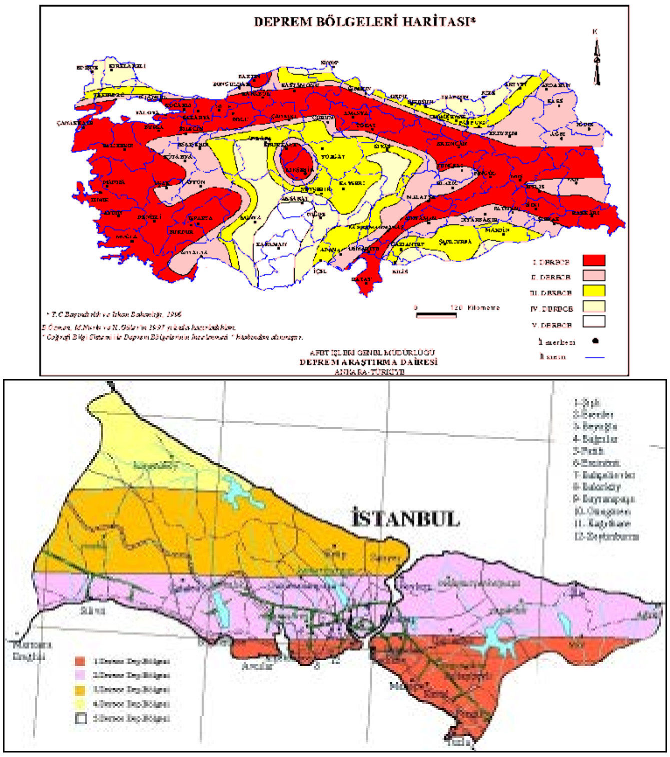

Fig. 3 – Seismic zones of Turkey and Istanbul.

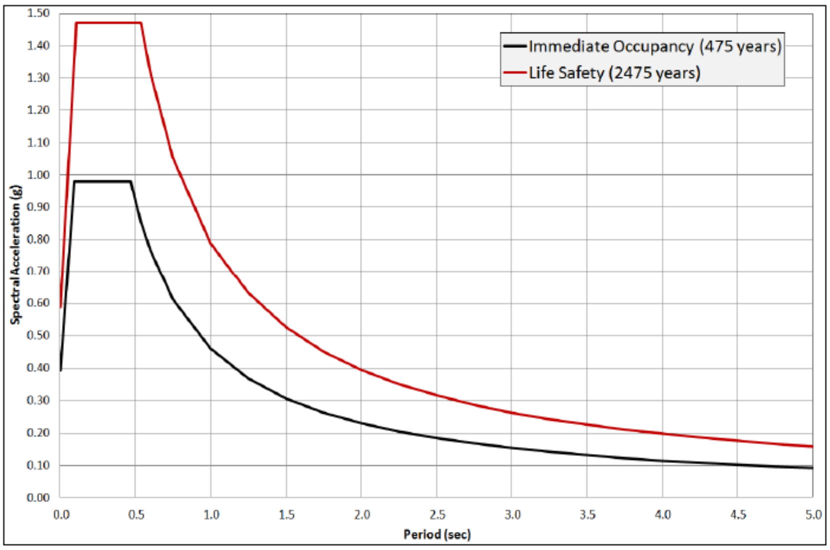

Fig. 4 – Design Acceleration Spectra (5% Damping)

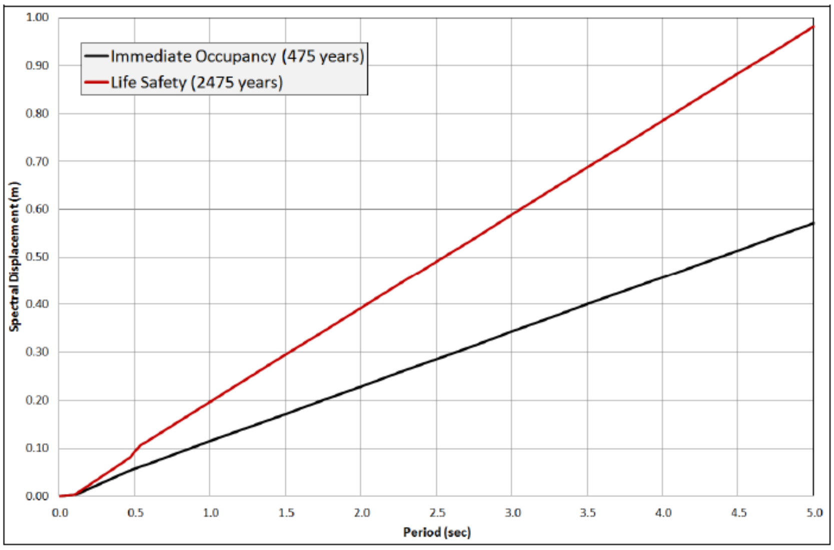

Fig. 5 – Design Displacement Spectra (5% Damping)

Normally, when a base isolation is applied, the isolators are installed on the foundation level. This was almost impossible for the Başibüyük Marmara University Hospital, due to the not homogenous level of foundation of the different blocks. The part of the blocks underground is different depending on the block and so it is not possible to define the first slab out of ground. The solution was to install the isolation system at the second floor, in order to be sure that the building could move freely outside the ground (Fig. 6).

Nevertheless, the stairs and the lift, if not properly let free to move during the seismic event, could create interference. The solution chosen foresaw to connect the walls containing the stairs and the lift to the isolated floor installing also few sliding bearings below the walls, in order to bear their weight. Of course a proper gap has been left to allow for the seismic movement.

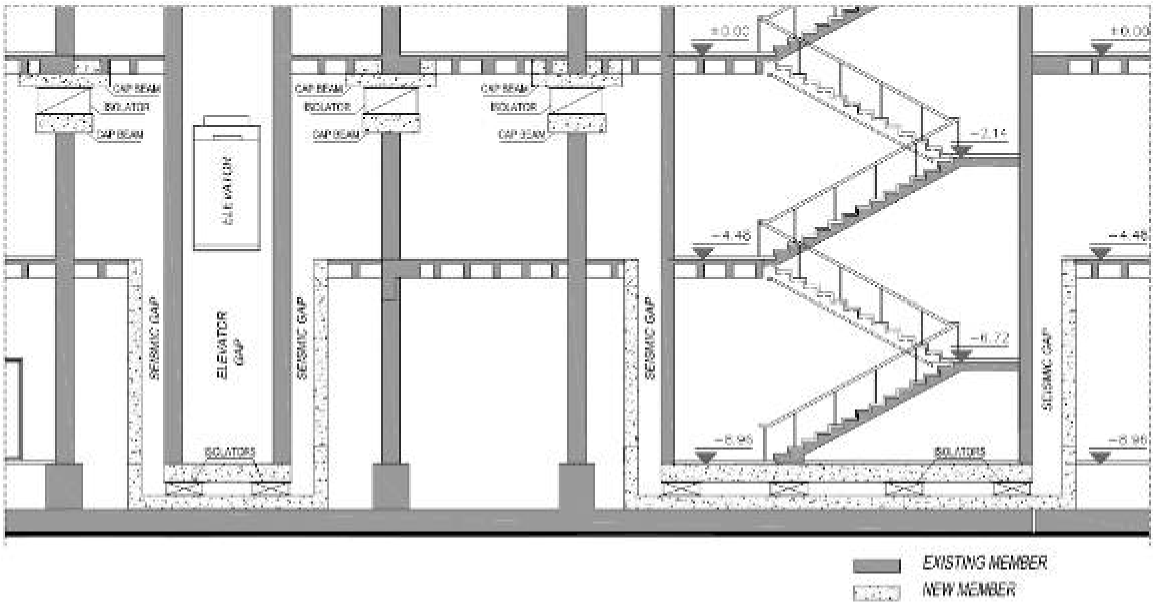

Fig. 6 – Isolation interface

The Başibüyük Marmara University Hospital is considered a strategic building and then it will provide the necessary essential services to the town of Istanbul and to the neighbor immediately after a seismic event.

The isolation system, in order to satisfy the requirement foreseen by the two above described limit states, must be able to respect limits for both the levels of earthquake. In particular, for the response spectrum defined with 2% of probability of exceedance in 50 years (2475 years return period) the maximum displacement of the isolation system has been limited to 500 mm. For the same response spectrum the base shear transmitted by the upper structure has been limited to 15.27% of the seismic weight of the structure, identified in 1 359 973 kN. On the other hand, for the response spectrum with 10% of probability of exceedance in 50 years (475 years return period) the base shear has been limited to 9.58% of the above mentioned seismic weight.

2. THE BASE ISOLATION

The base isolation of the Başibüyük Marmara University Hospital, in order to respect all the design criteria, both in term of displacement for an earthquake with return period 2475 years and of shear force transmitted by the isolators for both the considered level of earthquake, requires necessarily the use of very flexible devices and, in the same time, a high level of damping.

In fact, in order to limit as much as possible the shear force transmitted to the columns, a limitation of the seismic acceleration is needed. This can be obtained reducing the response spectra thanks to the high level of damping generated by the isolators and in the same time by a shift of the natural period of the system thanks to the very flexible devices.

Fig. 7 shows how the two contributes above mentioned of period shift and damping contribute to lower the seismic acceleration and consequently the shear force acting on the columns.

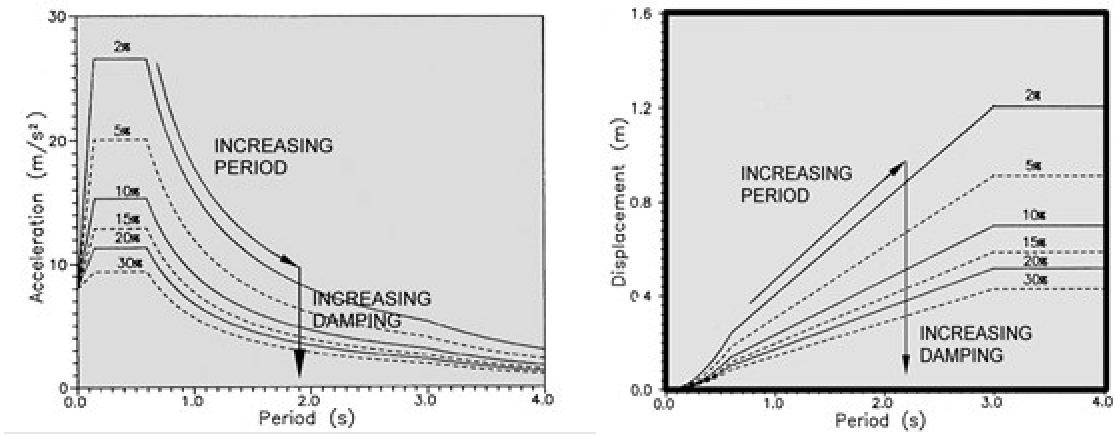

Fig. 7 – Reduction of the seismic action

A first simplified analysis has been performed using the two mentioned response spectra considering the whole structure as a system of a single degree of freedom (SDOF) of mass M corresponding to the total seismic weight connected to a spring of stiffness K and to a damper able to provide an equivalent viscous damping ξ.

This first simplified analysis was able to provide a first estimation of the seismic response of the system. The main parameters of the isolation system are indicated in Table 1, while the graphic representation on the response spectra is given in Fig. 8.

Table 1 – Main parameters of the Single Degree Of Freedom System

Number of Isolators	V_{seism} (G+0.3Q) (kN)	d_{max} (mm)	F_{max} (kN)	K_{eff} (kN/mm)	Energy dissipated at every cycle of displacement EDC (kNm)	Equivalent viscous damping ξ
687	1359973	380	197856	521	140926	30%

The stiffness and damping indicated in Fig. 8 represent the whole isolation system. On the basis of the characteristics indicated in Table 1 the maximum displacement generated by the response spectrum with return period of 2475 years was of 380 mm.

All the indicated characteristics have been successively validated by a non-linear dynamic analysis of the whole structure with accelerograms.

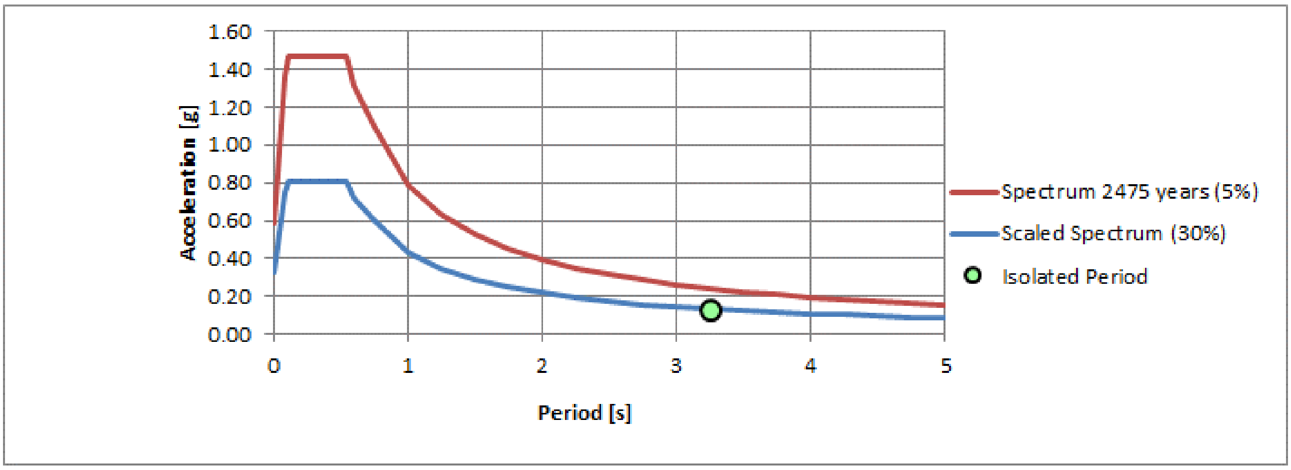

Fig. 8 – Seismic response of the Single Degree of Freedom (2475 years return period)

The required global characteristics of stiffness and damping could be easily provided by Lead Rubber Bearings (LRB). These devices, designed by Alga and supplied by Freyssinet Group, are composed by a series of layers of dissipative elastomer and steel plates. The lead core installed in the center of the device allows to dissipate energy thanks to the hysteretic cycles developed during the movement.

These devices, in addition to the characteristics of stiffness and damping needed for the seismic isolation, have also the very important function of carrying the vertical loads acting on the columns of the building, both in static and seismic condition. Fig. 9 show a typical Lead Rubber Bearing with corresponding hysteretic cycle obtained by experimental tests.

In parallel to the lead rubber bearings, sliding elastomeric bearings provided by sliding plate (NTm) were installed. These bearings, shown in Fig. 11, are composed by a series of elastomeric layers without dissipative properties and steel plates and a steel sliding plate. The sliding surface is composed by PTFE mating with stainless steel sheet.

The installation of these elastomeric bearings provided of sliding plate in parallel with lead rubber bearings has the big advantage to grant the vertical load capacity in some columns but to provide no stiffness to the isolation stiffness. In fact, for this type of sliding bearings, the movement does not involve the elastomer deformation but on a low-friction sliding surface which does not generate appreciable reaction forces.

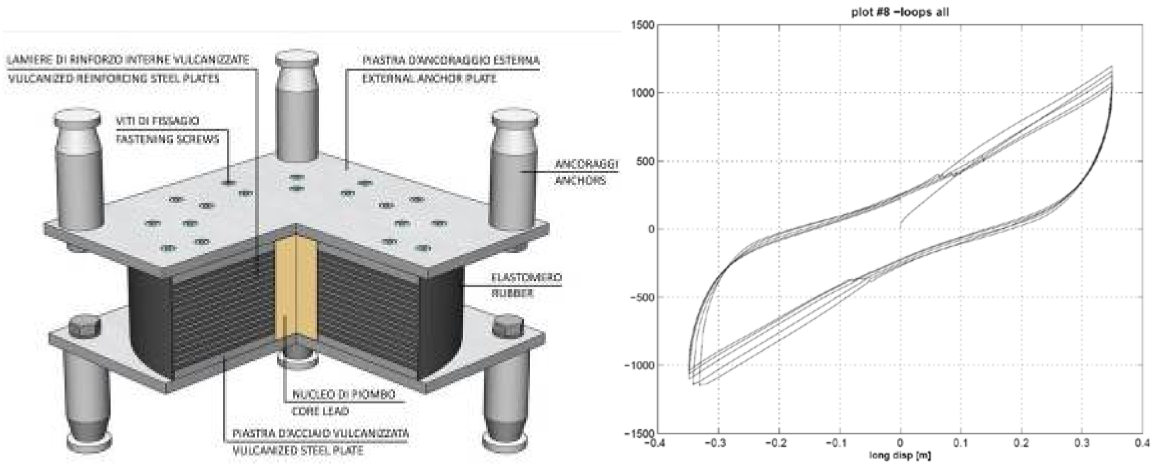

Fig. 9 – Lead Rubber Bearing and typical Force-Displacement loop

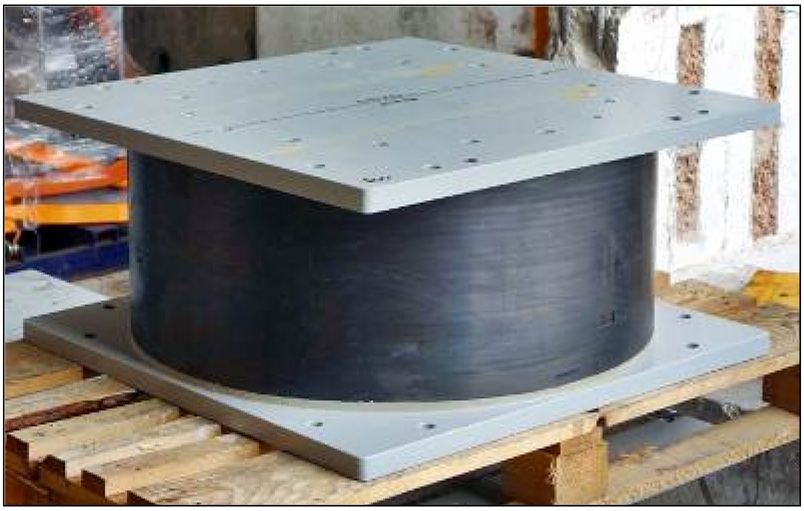

Fig. 10 – Lead Rubber Bearing

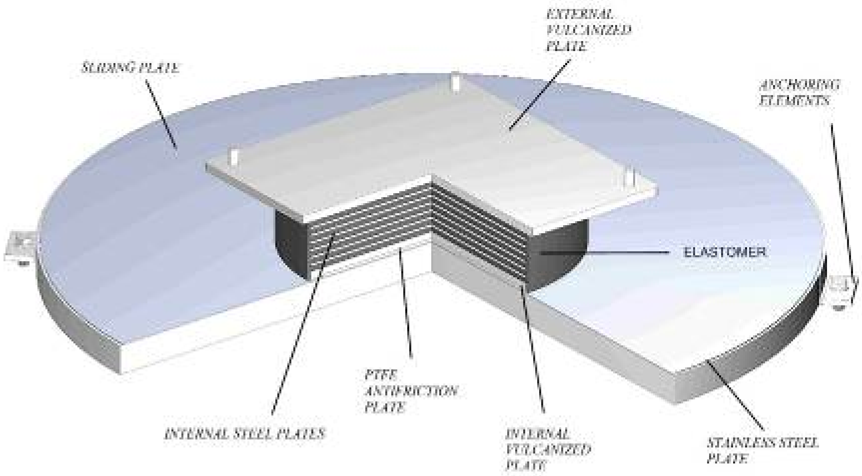

Fig. 11 – Sliding bearing NTm.

Fig. 12 – NTm Sliding elastomeric bearings provided by red clamp plates.

The use of sliding bearings in the isolation of Başibüyük Marmara University Hospital has been considered essential due to the very low required global stiffness together with the high global damping.

If only lead rubber bearings would be used, the single devices would have necessarily been designed to have a very low stiffness and in the same time a high level of damping. These two characteristics are countertrend.

In fact, in order to have an LRB isolator with low stiffness, the rubber height must be increased as much as possible, limiting at the same time the lead core dimension. On the other hand, in order to have a high level of damping the lead core should have a big dimension and a limited height.

Moreover, it is very important in an isolation system composed by different type of devices, like the one under study, to take under control the vertical stiffness. Elastomeric devices, both LRB and sliding devices, normally have vertical stiffness able to develop small settlement when they are loaded. LRB isolators during the movement generated by the earthquake, since they are vertically loaded by the weight of the structure, withstand an additional vertical displacement due to rubber deformation. Sliding elastomeric bearing, on the other hand, does not withstand such increased displacement due to horizontal movement.

The settlement due to static vertical loads can be easily controlled during the installation phases through an appropriate loading of the devices, while differential vertical displacement due to seismic movement could cause an unexpected variation of the vertical load in the columns if they are not considered during the design stage.

As described previously, the building is composed by various blocks with different number of floors. Consequently, the vertical loads acting on the single columns in the seismic combination including the vertical components due to seismic analysis with accelerograms, have values almost spread starting from 100 kN up to about 14000 kN. A reasonable distribution of the isolators along the plan of the building allowed to keep the centre of stiffness, obtained by the centroid of the stiffness of the single isolators, very close to the centre of mass of the structure with only an eccentricity of 1.5 m. In this way the torsional effects are limited as much as possible. This distribution was reached thanks to an optimization of the isolation system subdividing the total number of isolators into five classes based on vertical load made up of isolators designed in order to obtain a horizontal stiffness proportional to the seismic vertical load. The characteristics of the devices for the seismic isolation of the Başibüyük Marmara University Hospital are indicated in Table 2.

Table 2 – Main characteristics of the devices

Type	qty	d_{max} (mm)	Static N_{max} (kN)	Seismic N_{max} (kN)	F_{max} (kN)	K_{eff} (kN/mm)	Energy dissipated per cycle (kNm)	Damping (%)
LRS 650 / 283	127	380	2017	1000	435	1.146	319	30.7%
NTm 300 / 44	145	380	2017	1000	-	-	-	-
LRS 750 / 363	92	380	3925	2000	433	1.140	332	32.1%
NTM 400 / 65	68	380	3925	2000	-	-	-	-
LRS 800 / 297	97	380	7470	4000	630	1.658	473	31.5%
NTm 500 / 102	81	380	7470	4000	-	-	-	-
LRS 850 / 301	36	380	11220	6000	819	2.156	645	33.0%
NTm 600 / 124	25	380	11220	6000	-	-	-	-
LRS 1000 / 314	10	380	15564	13068	1185	3.118	986	34.9%
NTm 700 / 127	6	380	15564	13068	-	-	-	-
Total	**687**	**380**	**-**	**-**	**197592**	**520**	**150017**	**31.8%**

All the devices above shown, as described previously, are installed just below the second floor.

Below the walls for the stirs and lift, sliding bearings are installed in order to carry the weight and in the same time to allow for the movements due to the earthquake. These sliding elements are composed by bearings with a confined elastomeric disc with sliding plate and mating surface in PTFE and stainless steel (pot sliding bearings). Fig. 13 show this sliding bearing.

Fig. 13 – Pot bearings installed below walls for stairs and lift

The idea to install NTm sliding elastomeric bearings instead of the classical Pot bearings below the second floor was born by the fact that with this devices is possible to calibrate the vertical stiffness to values close to the values of lead rubber isolators, in order to limit as much as possible the differential vertical settlement between adjacent isolators.

Pot bearing, on the other hand, are installed at the basis of walls of stairs and lift where differential settlements are not a matter, being the walls composed by 40 cm concrete walls with very high stiffness.

All the LRB installed have been designed and tested according to European standard EN 15129 and they are provided of CE mark.

Initial type tests (ITT) of the LRB devices have been performed at the laboratory of Eucentre (European centre for training and research in earthquake engineering) in Pavia, Italy while the Factory Production Control (FPC) tests were performed at Isolab, which is the laboratory of Freyssinet Group for dynamic tests, at Montebello della Battaglia (PV), Italy. Also NTM and Pot bearings, even provided by CE mark and hence not necessary and not required by the reference standard EN 1337, were tested at Isolab both for checking the vertical load capacity and for checking the friction coefficient of the sliding surface through a dynamic test.

Fig. 14 shows some phases of the tests at Eucentre performed on LRB, while Fig. 15 and Fig. 16 show some phases of tests performed at Isolab on NTm and Pot bearings.

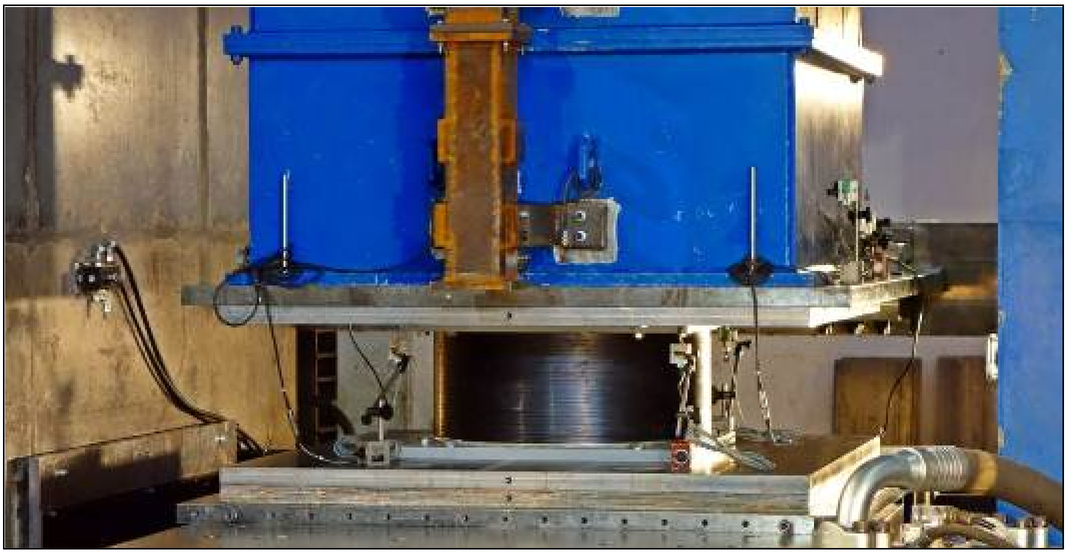

Fig. 14 – Test on LRB at Eucentre

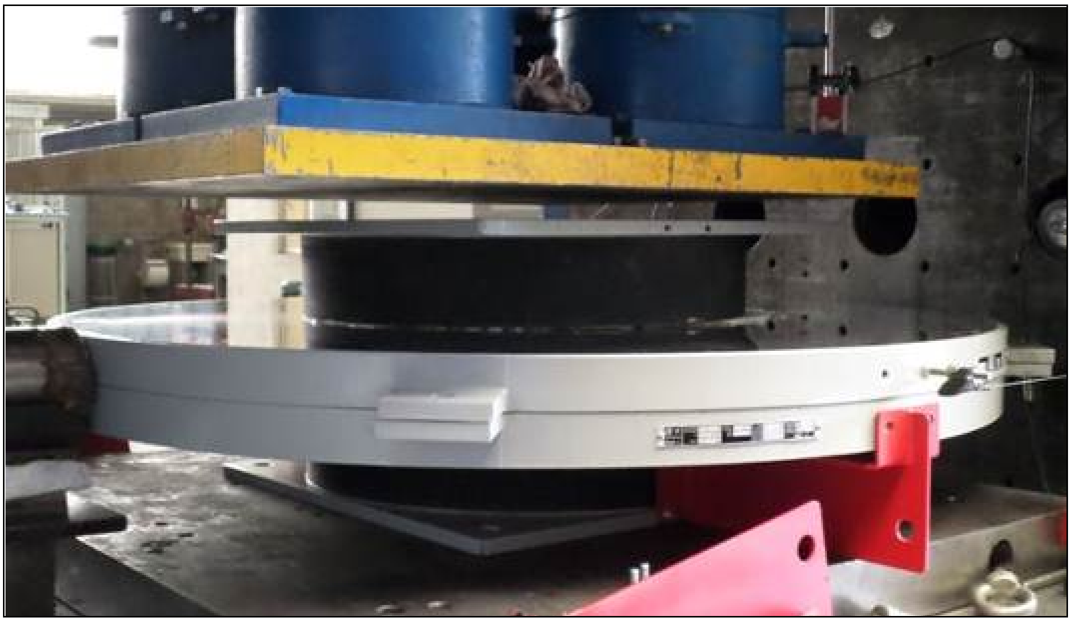

Fig. 15 – Test on NTm elastomeric bearing at Isolab

Fig. 16 – Test on Pot bearing at Isolab

3. INSTALLATION PROCEDURE

3.1. Preliminary structural strengthening

Normally, in a seismic retrofitting project, the level of installation of the isolators is at the top of the columns or at the base of the existing column. In order to limit the effect of seismic differential displacements, it is normally foresee to create an additional slab or beam grid so that the horizontal loads are transferred uniformly. For this project, using the installation procedure described in the following, these horizontal rigid frames have not been designed but the columns have been strengthen for the first two levels, which compose practically the substructure.

The retrofitting of the columns and walls was needed for two main reasons. The first is geometric, since a bearing surface was needed, just to install the isolators and bearings, especially the NTm with their sliding plates of diameter from 106 up to 146 cm. the second reason is linked to the design of an adequate reinforcement to resist to the horizontal loads acting during the seismic phase.

With reference to the last point, it is important to remind to the difference in terms of load eccentricity between LRB devices and sliding bearings NTm. During a seismic movement (d), LRBs share the eccentricity on both the substructure and the superstructure (e=d/2), while the NTms gives the total eccentricity equal to the total seismic displacement (e=d) only on one side, depending on how the bearing is orientated.

For this project, the most convenient solution was to install NTms with sliding plate on the lower side, as shown in Fig. 12, so that the eccentricity is transmitted to the substructure.

3.2. Description of the installation phases

The installation of the isolators, performed by Freysaş, company of the Freyssinet Group based in Turkey, has followed a procedure developed by Alga which foresee the cut of the columns with temporary support of the vertical load through proper metallic structures.

This type of technology consists in the application to each column of two special steel clamps, installed at a proper distance between them of about 40-50 cm, which, after being positioned, they are clamped to the column through high strength steel prestressing bars. After that, hydraulic jacks are loaded and this allows for downloading the column from the building weight.

Finally, using a diamond wire, the part of the column is removed and the isolator can be installed just after having casted the corresponding masonry plates.

Each clamp is composed by two transverse beams laid in parallel to the wider side of the column and by two secondary beams parallel to the smaller side. The main beams which provide the 80% of the clamping force have also the function of house the four hydraulic jacks with the aim to transfer the vertical load from the column. The secondary beams, on the other hand, which apply the remaining 20% of the clamping force, are lighter and easily manageable and they are installed first, allowing so a more easy installation of the main beams.

The big advantage of an intervention of this type is the ease and speed of execution. They are in fact operations that require a very precise and delicate application, even if they are very easy from the theoretical point of view in order to assure the perfect functionality of the full system. Alga, thanks to the experience developed in similar works already performed in the past, is able to offer a perfect efficiency in the installation.

Moreover, from the point of view of safety, this intervention does not present any criticality. The fact of operating in the same time on only a couple of columns and the possibility to minimize the deformation induced to the structure, since the downloading of the columns require a relative displacement of the order of about 2 mm, guarantees the structural stability for all the time of intervention.

The experience developed allows also a good speed in the operations. It is possible to consider between two or three days as average for each column. The contemporary operations of installation of the devices on no more than two or three columns allows to guarantee the structural integrity of the system at every level.

This procedure is characterized by low space required. Its application is limited to only the floor where the isolators are placed and consequently also the retrofitting operations like the local jacketing of the columns and installation of the isolator concern only that specific floor. All the level above the isolation level does not require any intervention and the original architectonic characteristics can be maintained. Unlike all the other techniques, at the end of the working phases no architectonical obstruction are remaining. The cut work of the columns and installation of the isolators can be performed without interfere with the activity performed at the levels above.

The technique described is adaptable to different cases, like for example when the isolation level is at the base of the column, or at the top of them. In all these very frequent cases, the installation is more simplified. When concrete walls are present, the application of the clamps is not even needed, since recesses can be opened for the installation of the isolator before the complete cut of the wall.

3.3. Operative sequence

In the following the sequence adopted for the installation of the isolators on the columns is described.

1. Strengthening of the exixting section of the columns/walls through 15-20 cm of jacketing depending on the considered column
2. Application of the upper and lower secondary clamps (Fig. 17)
3. Installation of the upper and lower primary (Fig. 18)
4. Tensioning of the prestressing bar in order to guarantee the friction between concrete and steel needed to carry the vertical load
5. Installation of the 4 hydraulic jacks and of the corresponding spacers
6. Connection of all the hydraulic circuit (pump, high pressure pipes, etc)
7. Downloading of the column in the part between the two clamps with loading of the hydraulic jacks and lock of them with safety rings
8. Installation of the cutting machine with diamond (Fig. 19)
9. upper and lower cutting execution and removal of the portion of cut column (Fig. 20)

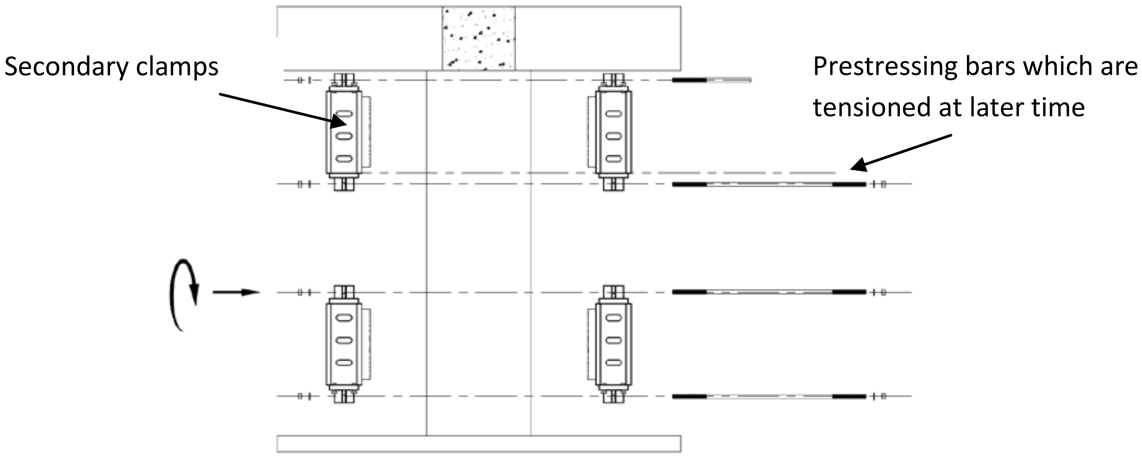

Fig. 17 – Application of the secondary clamps

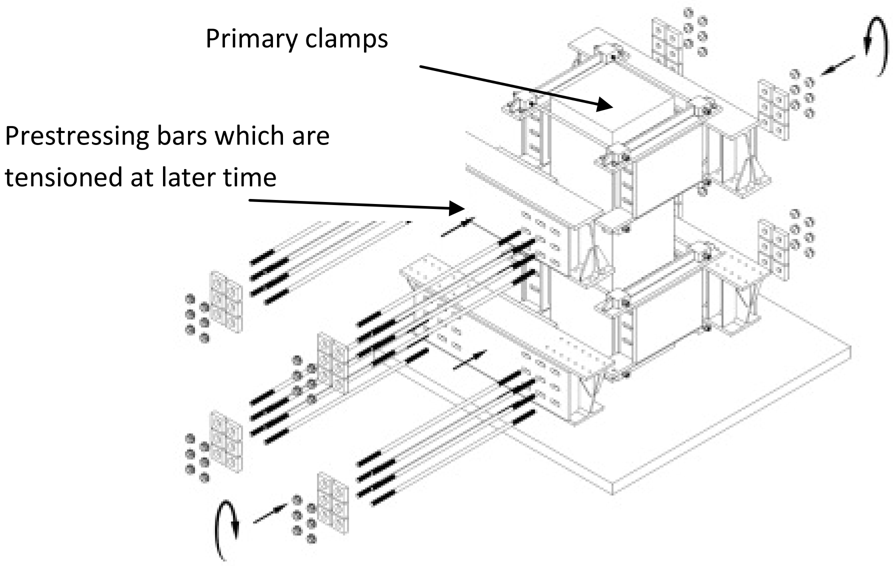

Fig. 18 – Application of the primary clamps and prestressing bars

Fig. 19 – Cutting machine with diamond wire

Fig. 20 – Removal of the portion of column

10. installation of the steel upper and lower masonry plates connecting the bearing with the structure (Fig. 21)

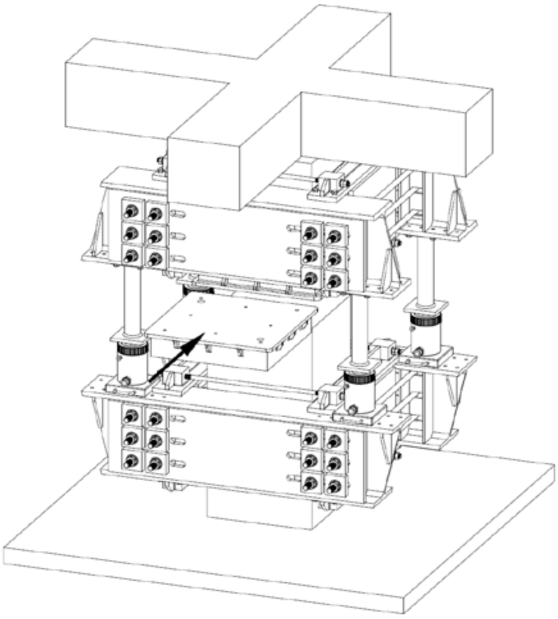

Fig. 21 – Installation of the lower masonry plate

11. installation of the isolator and fixing to the masonry plates with bolts (Fig. 22)

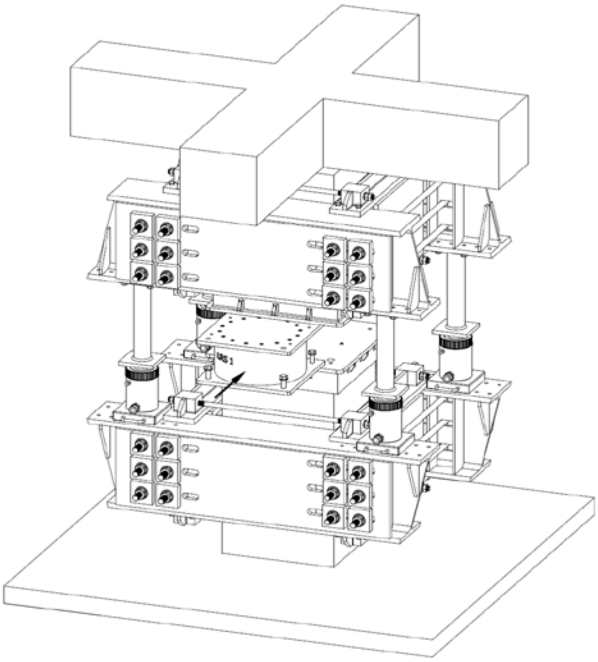

Fig. 22 – Installation of the isolator

12. casting of the levelling mortar (thickness about 3 cm) into the masonry plates
13. after curing of the mortar, downloading of the 4 jacks with consequent transfer of the load to the column with the isolator installed

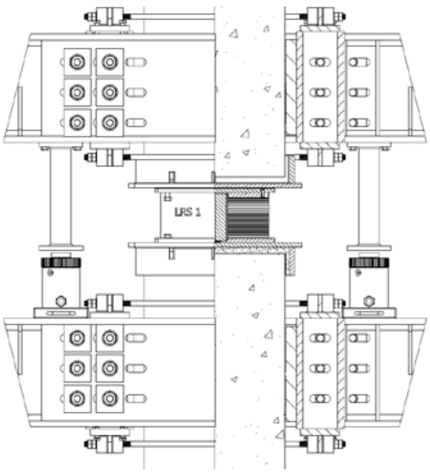

Fig. 23 – ½ view – ½ section of the isolator installed

14. removal of the clamps and cleaning of the area

4. CONCLUSIONS

The technique of the seismic isolation used for the seismic protection within the new Turkish standard of the Başibüyük Marmara University Hospital of Istanbul is here presented and described.

The seismic isolation allowed to solve in an easy way the severe restrains in terms of base shear force and displacement required by the respect of the existing standards.

The types of devices adopted have been presented together with their technical characteristics and the dynamic tests performed in order to demonstrate their adequacy to the structural problem.

Finally the installation phases has been presented and the description of the operating sequence needed to solve in a stellar way the problems linked to the cut of the column with a solution characterized by ease of execution, flexibility and the low space required both from a structural and architectonic point of view.

The manufacturing and test of all the devices is completed, while the operation of retrofitting of the building, is still ongoing.

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