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# RETROFITTING OF A BRIDGE FORM HISTORICAL STATION USING SEISMIC ISOLATION

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***Abstract***

Being the first railway station as bridge form above the train track, constructed in Istanbul in 1915, Göztepe Train Station is one of the most special structures conserved in terms of both structural and architectural features till today. In the scope of Marmaray CR3 project, this historical landmark has been renovated and actively used as a train station. The original structural system was composite masonry, including brick masonry walls, steel beams to support timber roof, stone masonry walls and a volta slab to elevate the station. Since the region is seismically active, requirement for seismic strengthening was mandatory in order to maintain the station. There were two main goals during this project: Modifying the main train station building with minimum intervention while achieving target seismic performance level and satisfying the increased demand requirements. Structural system of the historical structure underneath the main station required in order to increase the number of train tracks from two to three. Masonry walls on the sides of the rail tracks have been removed and replaced with reinforced concrete shear walls. While working underneath, the existing station building was suspended until the new structural system below the superstructure is constructed. A special methodology has been developed for this purpose. This method allowed keeping the entire station building intact and preventing any risk of damage to the adjacent structures. Since masonry structures are primarily vulnerable to lateral forces, the masonry structural system is converted to reinforced concrete without modifying the exterior shell of the station. This conversion is carried out by employing in-situ concrete members where special care has been taken to maintain the original facades. Additionally, a seismic isolation system composed of nine curved surface sliding devices has been installed in order to reduce the seismic actions transmitted to the upper structure. It should be noted that seismic isolation also facilitates reduction for modifications at the upper structure. Structural models have been developed based on the characteristics of the base isolation devices, and by considering the modifications on the substructure and the superstructure. As a consequence of the implemented retrofit methodology, the historical structure has been modified at the minimum level, earthquake performance is brought to the target seismic performance level, and the structure was made suitable for functioning of the increased number of tracks.

*Keywords: Göztepe Station, Masonry Structure, Historical Building, Retrofit, Seismic Isolation.*

## 1. Introduction

### 1.1 Brief History

When the Haydarpaşa-Pendik route was put into operation as a single-track line at the end of 1872, the old passenger building of Göztepe Station, which is currently used as a lodging building was also serving to the passengers. However, as time passes, the single-track line became inadequate and the railway was modified to be double-track line in 1912. During this revision it is estimated that the Haydarpaşa-Pendik alignment has also been modified. Additionally, the track line was lowered about 11 meters due to the fact that the trains were struggling because of steep gradient towards the Göztepe Station. As a result of this process, passenger building of Göztepe Station has lost its accessibility and the current passenger building which is the subject of this study has been constructed in the form of a bridge over the railway. (Figures 1 to 8).

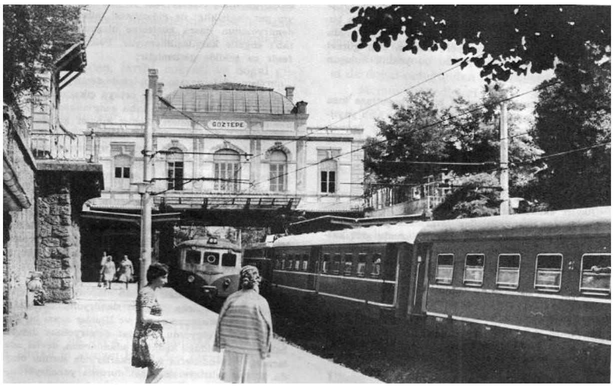
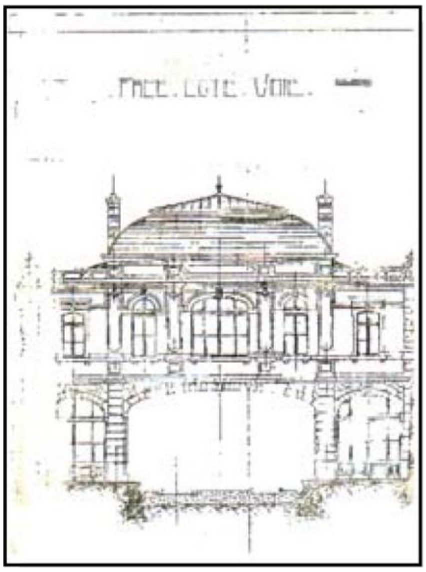


Figure 1 - 2. Views of the Göztepe Station from 1920's



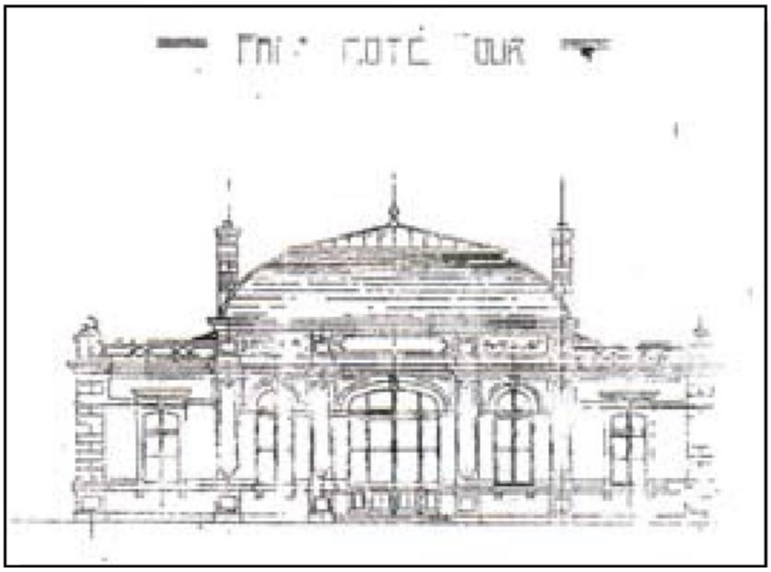
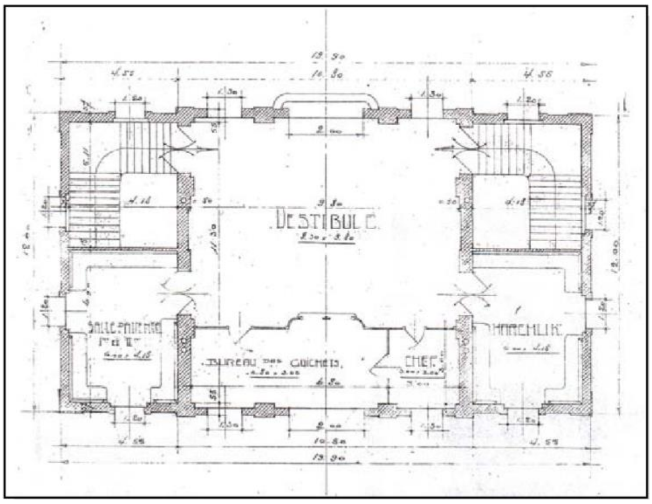


Figure 3 - 4. Historical Elevations from Southwest and Northeast



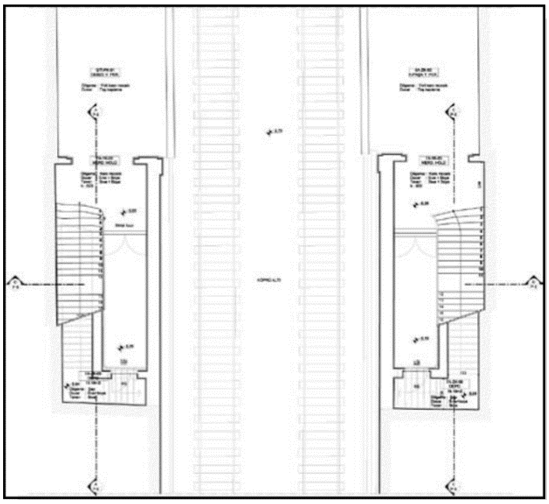


Figure 5 - 6. *Architectural Plans of the Station Building*

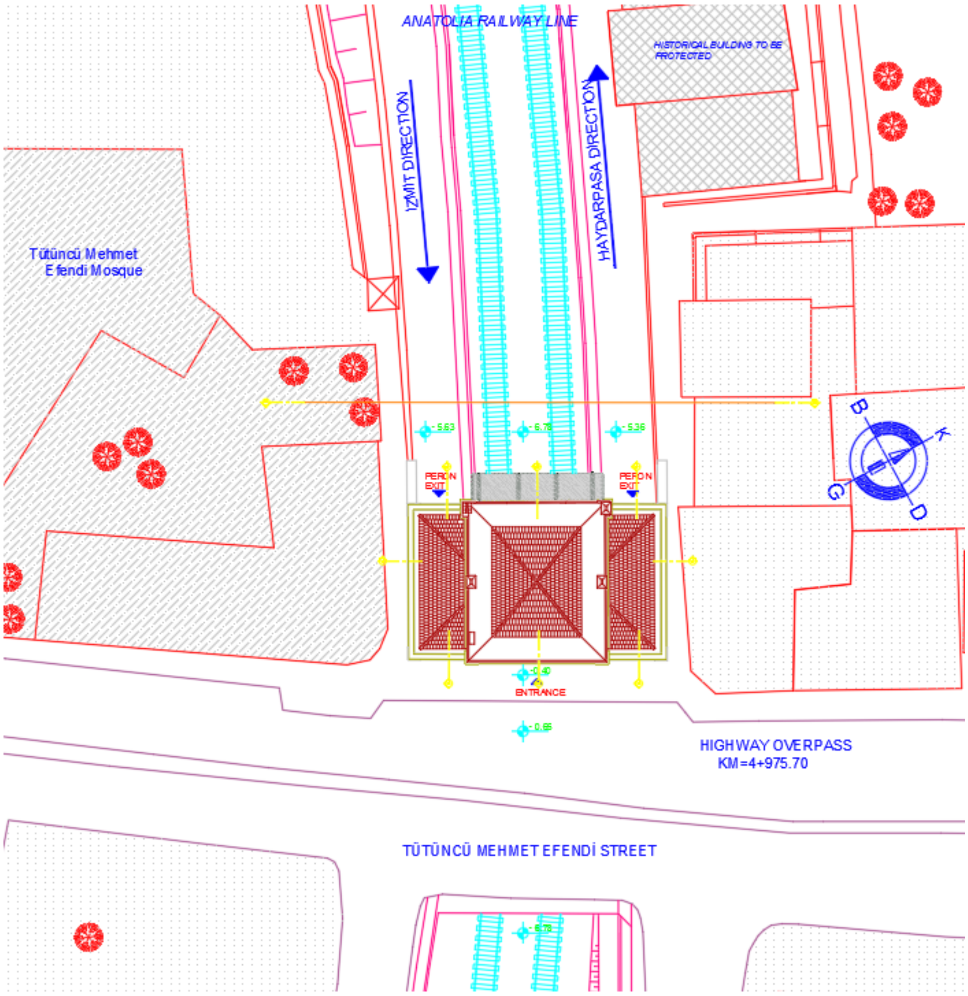



Figure 7. *Layout Plan of the Region*

## 1.2 Structural System and Materials of the Existing Structure

Göztepe railway station has been constructed as a 20 x 12 m rectangular block shaped bridge. Height of the building is approximately 15 m. The station consists of a platform level and a ground floor which is used as a ticket office and launch. The structural system of station is composite stone and brick masonry.

The primary load-bearing piers of the structure are the stone masonry stairs blocks leading to the platform at both sides of the building. Slab system of the building was constructed using one-way I-shape steel ribs with approximately 800 mm centres. Spaces between the steel ribs were filled using hollow bricks to create a slab system called Volta.

The ground level walls are brick masonry spanning from floor to the roof. All of the walls have been plastered. Walls thickness is around 700 mm at platform level and 400 mm at ground floor. All interior walls are also brick masonry with 300 mm thickness. These masonry walls carry the grey vault having a raised section at the middle of the structure. At both sides of the vault, gable roofs are constructed. During the assessment works conducted to determine the as built state of the building, no reinforced concrete elements were observed.

Observations revealed that some sections of the flooring system have experienced some revisions in time, since different timber cover sizes were measured in office areas. Original floor covers having thicknesses around 75 to 150 mm were used in these areas, whereas 200 x 200 mm square mosaic tiles were employed in the ground floor. It was also determined that the building did not experience any significant structural or architectural revision since it was constructed, with the exception of the canopies at the platform level that were added at a later date.

Figure 8. *Recent Photographs of the Station Before Strengthening*

### 1.3 Material Test Results of the Building

Several material tests were conducted by the Construction Materials Lab of Civil Engineering Department of Yildiz Technical University. The results using the samples taken at locations shown in Figure 9 are summarized below:

It has been determined that shear strength (**τ**) values between brick and mortar is around 0.26 to 0.44 MPa with the exception of KT1, which was significantly lower (**τ**KT1 = 0.03 MPa).

Similarly, displacements measured under maximum loading were around 1.93-8.12 mm again with the exception of except KT1 location, which was 0.004 mm.

Based on the results of the uniaxial compressing test of bricks, it was determined that standardized compressive strength value varies between 3.7 – 4.4 MPa. Average compressive strength is accepted as 4.10 MPa. This value is slightly below the old 'National Classification for Bricks' code requirement which was 5 MPa.

According to the point loading test results which have been carried out to determine the mechanical properties of mortar samples, compressive strength was found to be as low as 0.2 to 0.4 MPa with conversion factor is taken as 11.

Physical properties of bricks, mortar and plaster samples reveal that they exhibit porous texture (p ~ 40%), having unit weight around 1.65 g/cm3 and specific gravity of 2.7 g/cm3. When open pores that indicate water absorption ratio by volume are examined, it is determined that approximately 75% are open pores.

Acid loss analysis of mortar material also indicate that this value, being 15%, is much lower compared to air-slaked lime mortars. When the low compressive strength of mortar (fc,h < 0,5 MPa) is considered, it is estimated that hydraulic lime have been used as binding material.

As a result of the sieve analysis, it has been determined that maximum aggregate size in mortars and plasters were 5.6 and 4 mm, respectively.

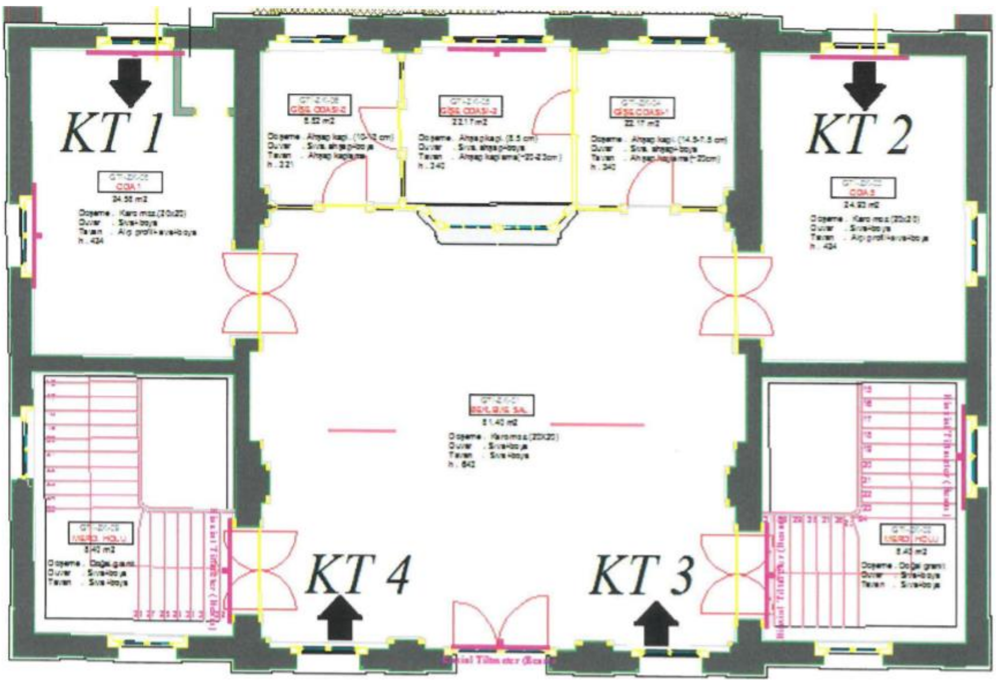



Figure 9. *Test Sample Locations [1]*

### 1.4 Assessment of the Existing Structural System

Based on the results obtained from the assessment analyses of the existing structural system, it has been determined that the building does not satisfy the "Life Safety" performance target under the design earthquake with 10% exceedance probability in 50 years (475 years return period earthquake). Moreover, the capacities of specific elements were determined to be significantly less than the seismic demands. Therefore, the decision was taken to replace the existing masonry bearing system with the composite system developed in this context.

Table 1 – Shear Demand and Capacity Checks of Masonry Walls

| **Shear Force Checks of Masonry Walls** | | | |
|---|---|---|---|
| **1st Floor** | | | |
| Direction | Total Masonry Wall Area (m²) | Total Member Capacity (kN) | Total Seismic Demand (kN) |
| X | 2.81 | **982** | **36697** |
| Y | 33.86 | **11852** | **36697** |
| **2nd Floor** | | | |
| Direction | Total Masonry Wall Area (m²) | Total Member Capacity (kN) | Total Seismic Demand (kN) |
| X | 13.12 | **4593** | **16109** |
| Y | 13.37 | **4678** | **16109** |

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## 2. Assessment of Strengthening Needs and Methods

### 2.1 Determination of Retrofit Requirement

Historical Göztepe Station has been designed to meet the requirements of its era to serve with two tracks. Since the new Marmaray Project is designed with 3 tracks based on todays requirements, the station has to be revised to be a bridge structure allowing 3 tracks, as well as being strengthened to meet the seismic requirements of the current design codes.

The existing structural system of Historical Göztepe Station is masonry. In general, lateral design of low masonry structures are governed by shear stresses. Istanbul city is one of the highest seismic regions of the country (1st Earthquake Design Class according to the current seismic code). This fact increases the importance of shear capacity of the building, due to the fact that low strength and ductility materials used in the building that may yield to a brittle failure during even a moderate seismic activity. Consequently, retrofit decision became inevitable.

### 2.2 Determination of Construction Methodology

Factors taken into consideration in determination of strengthening approach:

- Expanding the historical bridge in order to allow the new design with 3-tracks,
- Increasing the seismic performance of the structure in order to satisfy the seismic performance target,
- Creating a solution that meets the principles of restoration with minimal interference to the original structure and unconditionally preserving its exterior appearance,
- Employing a construction methodology in order to preserve the historical texture of the building without creating any risk for neighbouring buildings during strengthening,
- Employing a method that is applicable and faster implementation.

### 2.3 Main Principles of Applied Methodology

The main principles of the applied strengthening approach are summarized below;

- Conventional cast-in-place reinforced concrete technique has been employed as strengthening method. It is found to be the most appropriate approach to be used to modify a brick/stone masonry structure. For this reason, contribution of the existing structural system (masonry structure and steel volta slab) was ignored and new system is established.
- It is noted that, it was not possible to provide sufficient lateral strength without excessive modification of the system. Therefore, seismic base isolation was utilized to reduce the effects transferred to the upper structure.
- All new structural elements employed for strengthening purposes are located at the interior of the structure in order to preserve the exterior facade.
- Existing load-bearing system has utilized in stages during until the completion of the construction. At each phase of construction, as the new system structural elements are created, the existing system gradually lost its functionality. For example; volta slab was actively supporting the floor until the new reinforced concrete slabs are constructed.

Figure 10 illustrates the final target of the strengthening process.

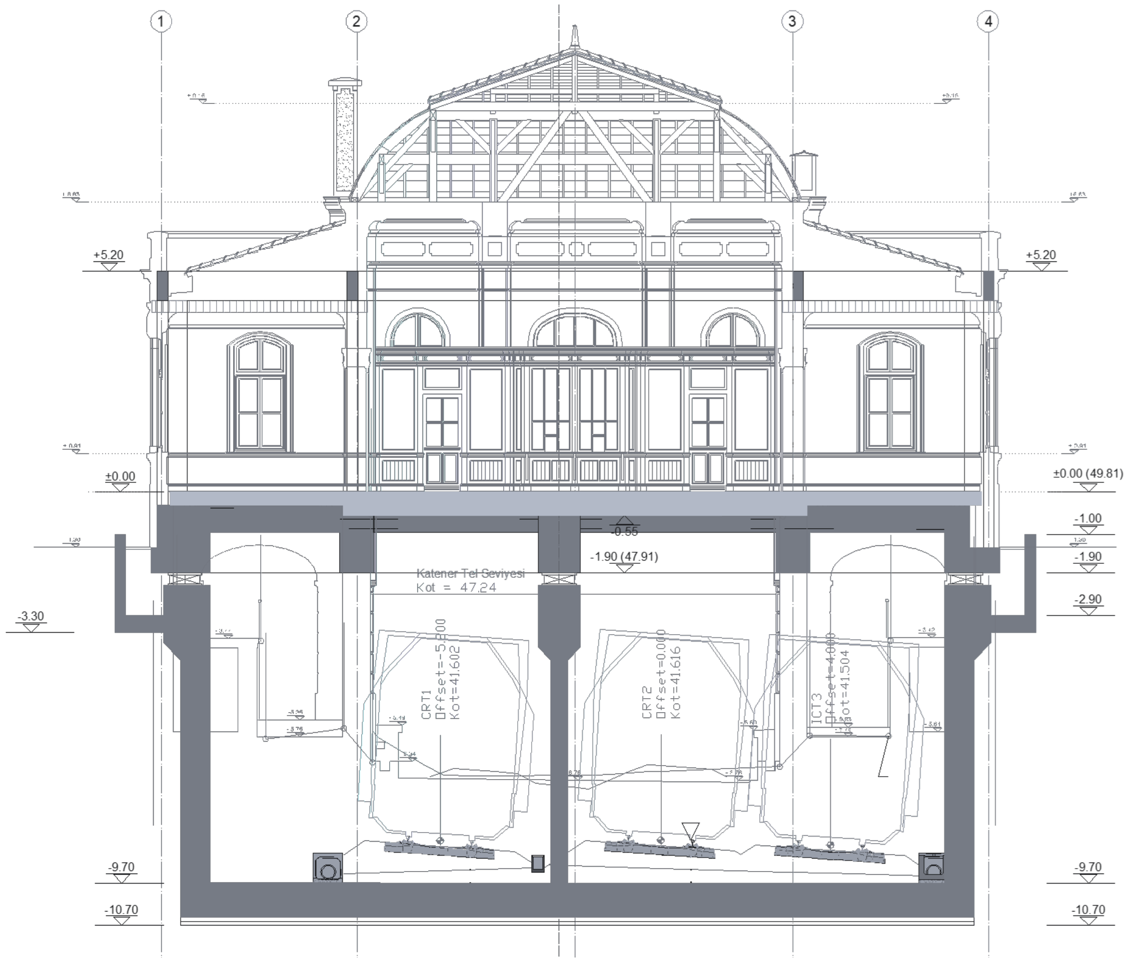


Figure 10. *The targeted state of the structure after strengthening (Elevation from Gebze direction).*

## 2. Assessment of Strengthening Needs and Methods

### 3.1 General Design Approach

The station is located in Kadıköy district of Istanbul, which is one of the highest seismicity regions of the city. As stated above, in order to reduce the seismic effects transferred to the building an isolation layer is considered just above the bridge piers.

Due to the fact that the function of the structure changed after strengthening, maximum architectural flexibility has been provided. Therefore, a system that consists of concrete beam, slab and column structure located at modular intervals has been designed. This system ensures the preservation of the historical essence of the structure by keeping the interference level at minimum. The architectural facade is preserved as is using design criteria that have been considered in conjunction with state-of-the-art construction techniques.

### 3.2 Earthquake Loading and Analyses

Structural design is based on the design earthquake that has 10% probability of exceedance in 50 years [2] (475 years return period Design Basis Earthquake). All structural members are designed considering this seismicity level in order to ensure "Life Safety" performance level[3]. In order to ensure that the displacement limits of the base isolator units under Maximum Credible Earthquake is not exceeded, isolators are designed to satisfy the displacements calculated using of 2% probability of exceedance in 50 years earthquake (2475 years return period) (Figure 11).

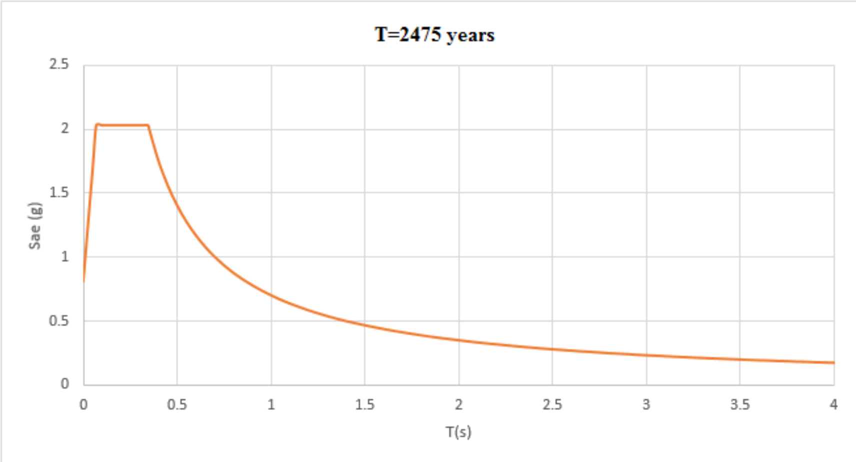


Figure 11. *Acceleration Design Spectrum of 2475 Years Earthquake Level*

### 3.3 Earthquake Performance of the Structure

Non-linear time history analyses were carried out using selected 11 earthquake acceleration records. These records are scaled using the 2475 year return period earthquake spectrum. Effective damping ratio is limited to 28% [4] in all analyses. The maximum horizontal displacement was calculated as 268 mm and with the application of 10% accidental torsion 294 mm is used for the determination of the seismic isolator unit dimensions. A similar analysis is also carried out for the design of the structural elements using the 475 year return period earthquake. The maximum base shear ratio has been determined as 8% (0.080W) [5]from this analysis. Consequently, 9 identical friction pendulum type isolators were used to support the building as illustrated in Figure 12 below.

Figure 13 illustrates the displacement history results [6] obtained for a selected column for all time history analyses. The surrounding circle illustrates the displacement limit of the base isolation units. Similarly, floor acceleration results are also plotted in Figures 14 and 15 for X and Y direction loading separately. In order to show the base shear time history, only one of the earthquake record (Duzce Earthquake) [7] is plotted for illustration purposes in Figure 16 below.

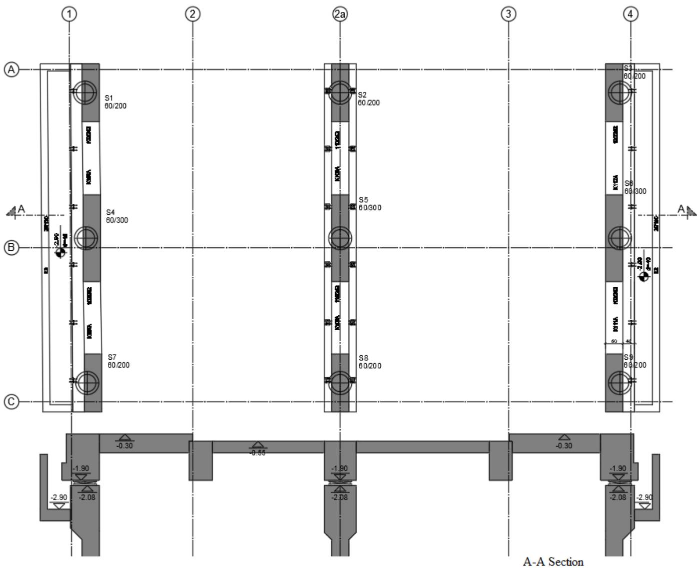


Figure 12. *Plan and section of isolator floor [8]*

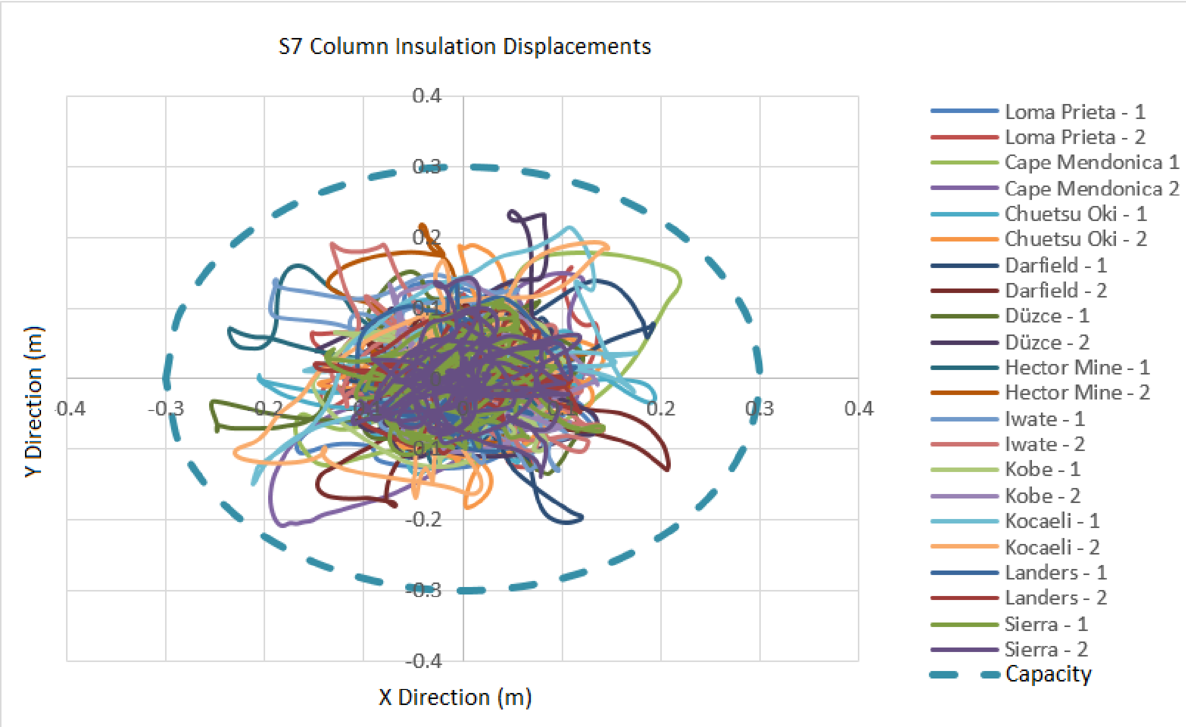


Figure 13. *Displacement History Result of Column S7*

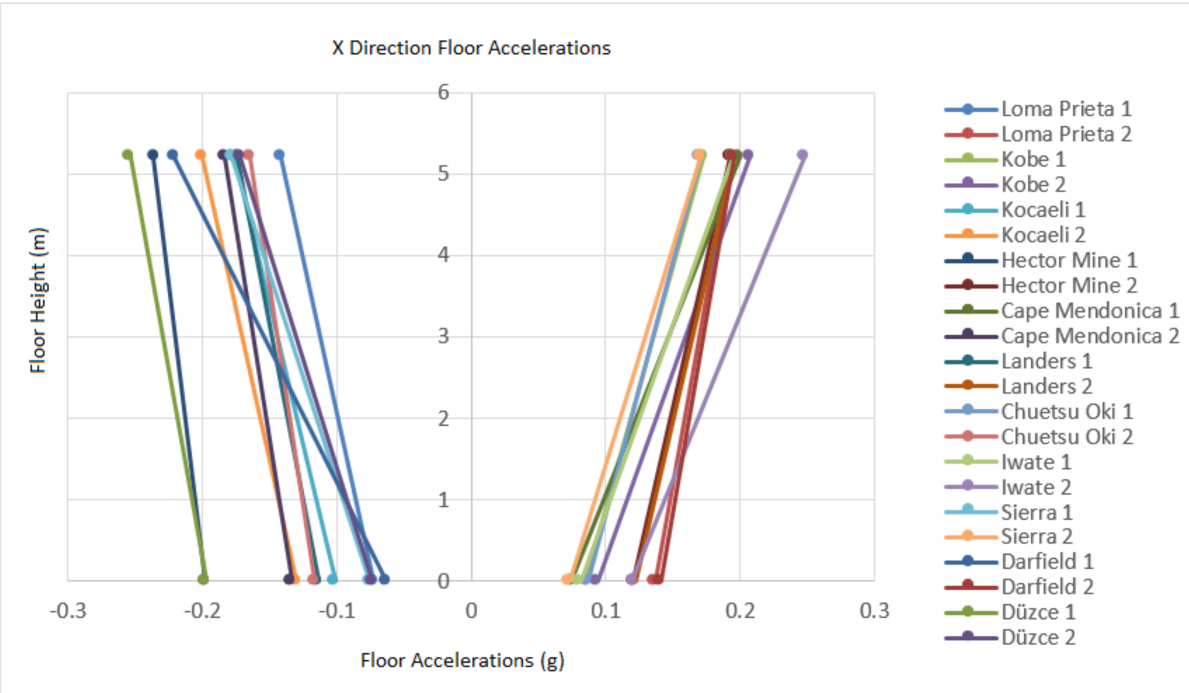


Figure 14. *X direction Floor Accelerations*

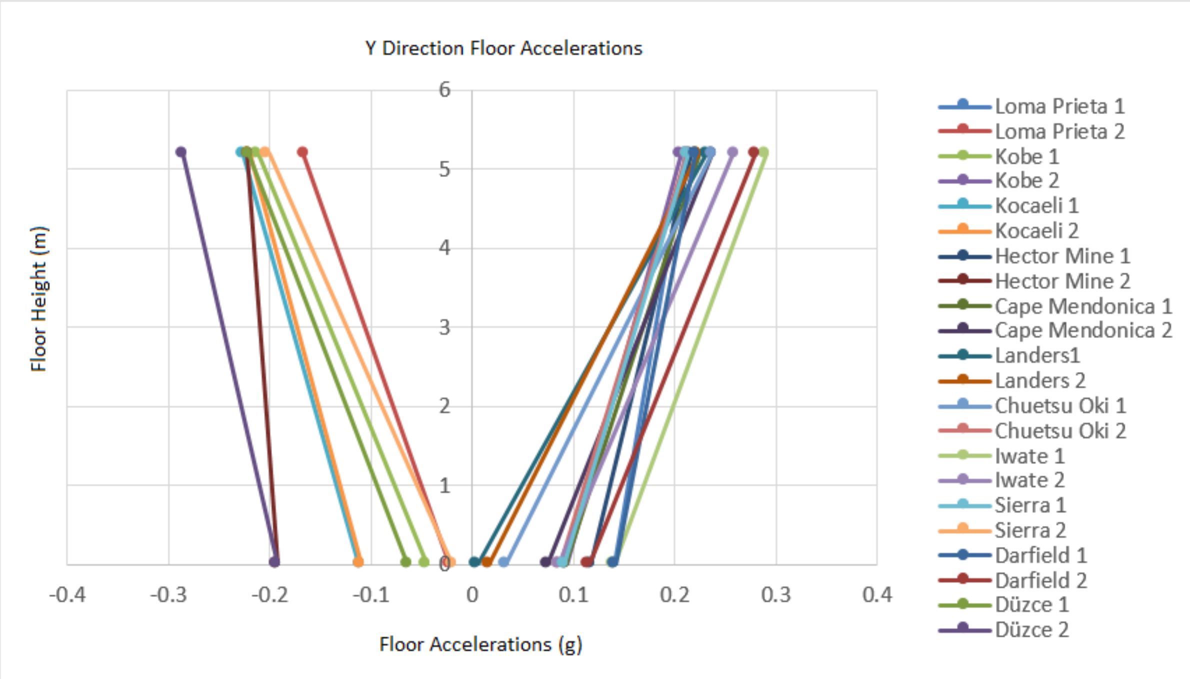


Figure 15. *Y direction Floor Accelerations*

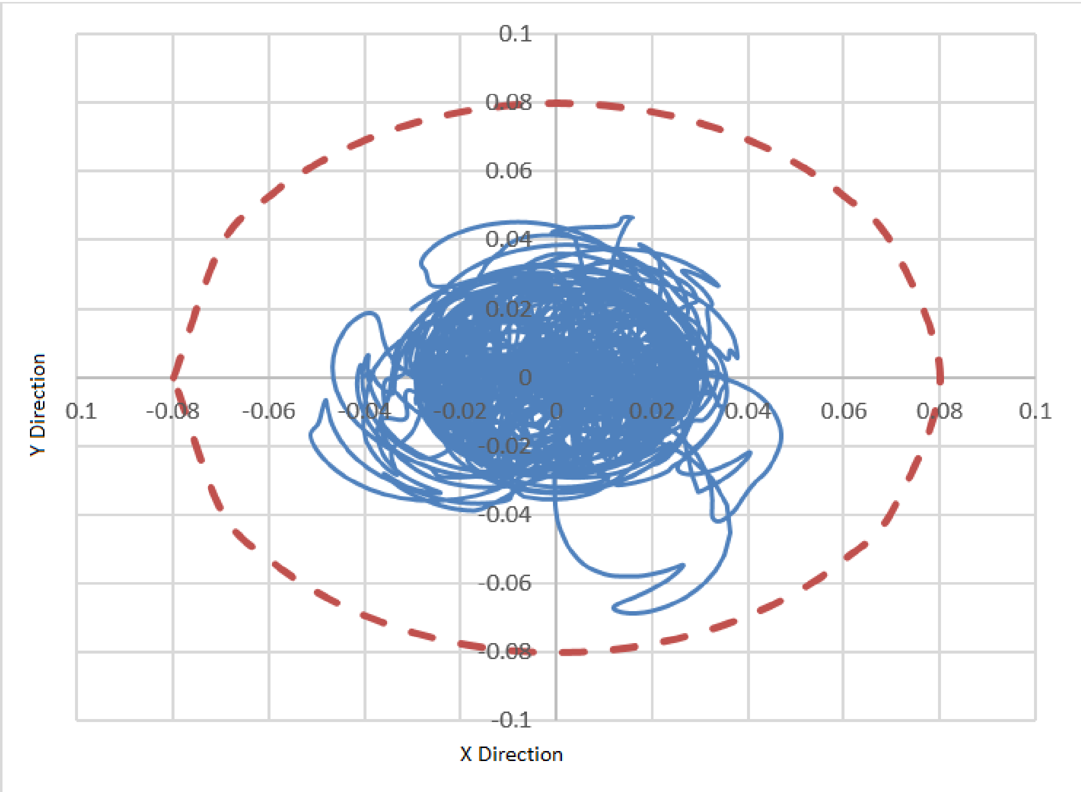


Figure 16. *Duzce Earthquake Base Shear Ratio*

## 4. Conclusions

The historical Göztepe Station, which was a composite masonry building was not satisfying the requirements of the current Turkish Earthquake Code 2007 and assessment analyses revealed that it should be retrofitted. Furthermore, as a bridge structure, it was not fulfilling the requirements of the 3-track rail system of the new Marmaray Project. As the consequence of this project developed for the protection of this important building:

Due to the historical importance of the building, the retrofit methodology was selected to have minimum interference to the existing facade and functionality. Most of the repair works and added elements were applied to the interior of the structure.

Most of the construction was carried out using conventional techniques.

Seismic performance of the structure was increased to satisfy the requirements of the current earthquake code. By the employment of the seismic isolators, most of the excitation was absorbed by the isolation layer.

The bridge was modified to fulfil the requirements of the new 3-track rail project.

## 5. Acknowledgement

We would like to express our special thanks to Prota Design Center for their contribution.

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