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SEISMIC RETROFIT OF LARGE SCALE BRIDGES IN ISTANBUL

N. M. Apaydin [1]

ABSTRACT

This study describes the seismic retrofit and structural strengthening campaign for large scale bridges in Istanbul. Istanbul is the largest city in Turkey, with a history and cultural heritage that extends over twenty-six centuries. The two main motorways namely O-1 and O-2 motorways connect Europe and Asia continents each other and these motorways are the main transportation arteries of the city. There are two suspension bridges and several large scale steel and concrete bridges on the motorways. Istanbul is located on high seismic zone and investigations show that a major earthquake may occur with a high probability in the near future. These bridges are the critical nodes of this highway network and any broken link due to the bridges failure during a destructive earthquake may totally paralyze the whole transportation system in the city. Therefore to avoid negative condition and provide transportation continuity, serious studies have been started after 1999 Marmara earthquake. In this study, the methodology to determine the seismic performance and retrofitting requirements were elaborated and retrofit analysis and retrofit design criteria of the bridges were presented.

[1] Associate Professor and Deputy Director, General Directorate of State Highways, Istanbul, Turkey.

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Seismic Retrofit of Large Scale Bridges in Istanbul

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This study describes the seismic retrofit and structural strengthening campaign for large scale bridges in Istanbul. Istanbul is the largest city in Turkey, with a history and cultural heritage that extends over twenty-six centuries. The two main motorways namely O-1 and O-2 motorways connect Europe and Asia continents each other and these motorways are the main transportation arteries of the city. There are two suspension bridges and several large scale steel and concrete bridges on the motorways. Istanbul is located on high seismic zone and investigations show that a major earthquake may occur with a high probability in the near future. These bridges are the critical nodes of this highway network and any broken link due to the bridges failure during a destructive earthquake may totally paralyze the whole transportation system in the city. Therefore to avoid negative condition and provide transportation continuity, serious studies have been started after 1999 Marmara earthquake. In this study, the methodology to determine the seismic performance and retrofitting requirements were elaborated and retrofit analysis and retrofit design criteria of the bridges were presented.

Introduction

The Earthquake of magnitude 7.4 occurred in the Marmara Region in 1999 caused major physical, social and economic losses in Turkey. In neighboring provinces, some bridges had various damages however; damage on the bridges in Istanbul was not detected after the 1999 earthquake. The epicenter of the 1999 earthquake was located approximately 80 km. south east of Istanbul, in general, the highway system performed well. However, investigations and research show that a major Earthquake may occur with a high probability in Istanbul in the near future. Under these circumstances the performance assessment and, if needed, the retrofitting of bridges in Istanbul emerged as an urgent problem [1].

Istanbul city, located on the Bosporus junction of the continents of Asia and Europe, has 15 million populations and is considered as Turkey's commercial center. Istanbul is the center of Marmara Region as economically and culturally. Marmara Region encompasses seven provinces in western part of Turkey. Two main motorways at east-west axis connect the two continents by this way two parts of the city. These motorways serve domestic trade as well as international trade between Europe and Middle East countries and they serve to the city traffic at the same time. In the event of a possible earthquake, the earthquake losses may increase due to failure of the transportation network. Critical nodes of this network are the bridges. Any broken link due to the bridge failures during a destructive earthquake may totally paralyze the whole transportation system in the city. For this reason, earthquake protection of the suspension bridges and other bridges has great importance for the transportation network of Istanbul [2].

1st Division Directorate of State Highways of Turkey is responsible for roads and bridges on motorways and intercity road network located in the Marmara Region. In the region, there are

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totally 730 bridges located within the same transportation network. 120 of them are considered as large scale bridges. A general layout of motorways in the city center is given in Fig. 1 [3, 4]. The motorways O-1 and O-2 in the metropolitan area of Istanbul contain 165 bridges in the city center. Two of them are suspension bridges and 16 of them are large scale steel and concrete bridges. About 3 billion vehicles passed through O-1 motorway since 1973. Besides O-1 motorway, O-2 motorway carried especially heavy vehicles over 1.5 billion since 1998 the opening of the service. These statistics show the importance of the bridges clearly [5].

Figure 1. General layout of motorways in the city center.

Objectives and Strategy of Earthquake Retrofitting Campaign

The objective of the bridge retrofit campaign undertaken by General Directorate of Turkish State Highways was to mitigate the seismic risk. The aim is to keep the bridges open to traffic at strategic locations without causing any interruption of emergency services (fire, health, search-rescue, communications, etc.). After the 1999 Marmara Earthquake the methodologies for the performance assessment of the bridges were investigated in the recovery phase of the main shock. The most critical issues in assessing the retrofitting needs of existing bridges were the identification of the strategic importance of the bridge (prioritization) and the assessment of the structural deficiency. The first issue was treated by means of determining real needs of the people and the city. When we look at the city plan, we can see that the settlements areas are separated from each other with waterways. Considering the unusual geographical location of Istanbul, a lot of bridges have very important strategic position. For prioritization the whole Marmara Region was taken into consideration and a wide range studies was performed according to importance-based optimization of the resources.For evaluation of bridges in terms of seismic retrofit and structural strengthening needs, initial structural capacity assessments were made by using only earthquake resistant design parameters. For this purpose, the bridges were grouped with respect to their highways and on the basis of the outcome of the preliminary evaluation.

For the importance-based prioritization and optimization of the resources to be allocated the criteria listed below were taken to account.

- The proximity of the source of potential earthquake
- Their strategic location e.g. alternative bridges
- Alternative route and traffic volumes

- The proximity to the important centers such as airport-hospital etc.
- Structural systems, material types, method of construction, difficulty in repair
- Service life, environmental condition, timeworn, structural problems

Before determining the bridge retrofitting groups, inspections in the field were made and damage levels were taken into account. Furthermore, bridges exposure to outside influences, such as raining, traffic, icing, etc. in the service life it has been taken to consideration. As a result of selected criteria and related analysis, three main bridge network groups were determined;

1. 1. Bosporus and 2. Bosporus Suspension Bridges and Golden Horn Bridges (The highest strategic importance, there are no alternatives).
2. Other large-scale steel and concrete bridges on the O-1 and O-2 motorways (Bridges are under the heavy traffic at the center of the city and serve to the international airports and health centers).
3. Bridges in earthquake-prone areas.

After this prioritization phase, the seismic retrofitting campaign was performed following steps:

- Preliminary Evaluation and Ranking for each group
- Determination of Seismic Performance Criteria,
- Determination of Retrofit Design procedures and Details for Retrofitting

For all kind of retrofitting design requirements, criteria, strengthening details, all specifications used around the world were studied. On this issue; internationally accepted specifications, criteria and details which are appropriate for local conditions and construction methods were followed. ASSHTO Specifications and Japan Road Association (JRA) Specifications were used for the seismic design criteria depending on the structural features of the bridges. In addition, the relevant ATC guidelines were used for determining seismic performance criteria and the related FHWA, CALTRANS and JRA standards were used for retrofit design [6-30].

Seismic Vulnerability and Retrofitting Requirements of Bridges

For seismic retrofit design, requirements of seismic performance target levels were determined according to needs of transportation. The earthquake damage levels should be limited to minor damages and it should have performance levels to allow for prompt functional recovery. Target performance objectives for each group of bridges were assessed according to following three main issues:

- Safety against earthquake,
- Functionality after earthquake and
- Repair to be needed after earthquake.

Especially for very important bridges, seismic performance target was set to limited damages that would enable quick repair immediately after earthquake. The performance levels for the safety, serviceability and restoration are as follows;

1. Safety on the seismic reinforcement design: The safety in falling down of superstructure is secured,
2. Serviceability on the seismic reinforcement design: The function for a bridge should be promptly recoverable after an earthquake,

3. Restoration nature on the seismic reinforcement design-short-term restoration nature: The functional recovery can be perform by emergency restoration
4. Restoration nature on the seismic reinforcement design - long-term restoration nature: It should be easily possible to perform the permanent restoration [31].

Under exposure to the Functional Evaluation Earthquake (FEE) Ground Motion, damage level will be minimal (essentially elastic performance) and functionality of bridges will continue without interruption. This ground motion refers to high probability earthquakes that can affect the structure one or twice during its lifetime. This earthquake is generally associated with a 50% probability of exceedance in 50 years. Due to specific seismo-tectonic, FEE earthquake will be taken as site-specific ground motion that would result from Mw=7.5 scenario earthquake on the Main Marmara Fault. Under exposure to Safety Evaluation Earthquake (SEE) Ground Motion, only repairable damage will be allowed, such that, the damage can be repaired with a minimum risk of losing functionality without endangering and lives. In consideration of regional earthquake occurrences this level of ground motion is associated with a site-specific probabilistic ground motion associated with a 2% probability of occurrence in 50 years.

The performance criteria for both suspension bridges and viaducts under SEE (Safety Evaluation Earthquake) and FEE (Functional Evaluation Earthquake) were determined and requirements were listed. Targeted performances of several structural elements are given in Table 1-8 [32].

In consideration of the seismo-tectonics of the Marmara Region, the earthquake hazard assessment and generation of the retrofit design basis ground motion sets shown in Fig. 2 were prepared by Earthquake Engineering Department-Kandilli Observatory and Earth-quake Research Institute of Boğaziçi University [33].

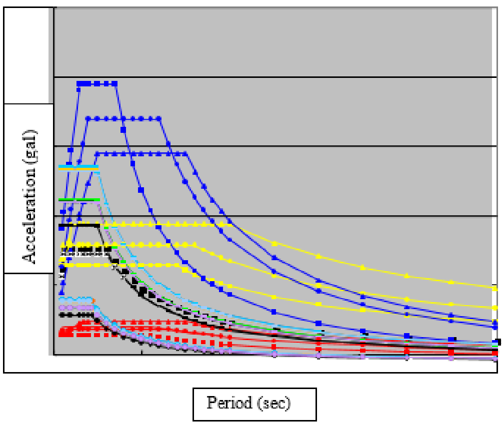

Figure 2. Response spectrum for important bridges **[33].**

Table 1. Targeted performance of structural elements of suspension bridges-cable, hanger plate and main girder.

	FEE Functional Evaluation Earthquake	**SEE Safety Evaluation Earthquake**
Cable Hanger Plate Main Girder	State : No Damage	State : No Damage
	Evaluation: In the range of elasticity	Evaluation: In the range of elasticity

Seismic Retrofit and Structural Strengthening Studies

Several researches pointed out that earthquake with magnitude ≥ 7 near Istanbul in the period 2004-2034 is approximately 40%. [34]. State Highways Authority made a quick and good organization to take precautions for possible earthquake. For this aim domestic and overseas financial resources were organized and earthquake strengthening efforts were performed simultaneously in several locations.

Table 2. Targeted performance of suspension bridges-tower.

	FEE Functional Evaluation Earthquake	**SEE Safety Evaluation Earthquake**
Tower	State : No Damage	State : Small Damage (No local buckling)
	Evaluation: In the range of elasticity	Evaluation: Strain of compression side< Allowable strain

Table 3. Targeted performance of structural elements-spread footing.

	FEE Functional Evaluation Earthquake	**SEE Safety Evaluation Earthquake**
Spread Footing	State : No Damage	State: Stable condition
	Evaluation: Shall not exceed shear failure of the ground	Evaluation: Shall not exceed allowable plasticity factor.

Table 4. Targeted performance of structural elements-steel bearings.

	FEE Functional Evaluation Earthquake	**SEE Safety Evaluation Earthquake**
Steel Bearings	State : No Damage	State: No Damage
	Evaluation: In the range of elasticity. Shall not exceed allowable stress	Evaluation: In the range of elasticity. Shall not exceed yield stress.

Table 5. Targeted performance of structural elements of viaducts-girder.

	FEE Functional Evaluation Earthquake	**SEE Safety Evaluation Earthquake**
Steel Bridge Main Girder	State : No Damage	State: Repairable Damage
	Evaluation: In the range of elasticity.	Evaluation: May exceed yield strength slightly on some part of girder.

Table 6. Targeted performance of structural elements-anchorage.

	FEE Functional Evaluation Earthquake	**SEE Safety Evaluation Earthquake**
Anch orage	State : No Damage	State : Stable Condition
	Evaluation: In the range of elasticity	Evaluation: Shall not exceed shear failure strength of the ground

Table 7. Targeted performance of structural elements of viaducts-concrete piers.

	FEE Functional Evaluation Earthquake	**SEE Safety Evaluation Earthquake**
Concrete Piers	State : No Damage	State: Small Damage (Repairable residual crack)
	Evaluation: In the range of elasticity.	Evaluation: Shall not exceed allowable plasticity factor.

Table 8. Targeted performance of structural elements-expansion joints.

	FEE Functional Evaluation Earthquake	**SEE Safety Evaluation Earthquake**
Expansion Joint	State : No Damage	State: May Break
	Evaluation: Shall not exceed allowable displacement	Evaluation: Consider not to disturb the ease restoration

Studies were maintained by multi-project groups, consultants and contractors. Attempt was made to take necessary measures immediately before possible earthquake. The summary of seismic retrofitting and structural strengthening studies for bridges since 2001 in Istanbul is given in the Table 9. During this time, required and necessary measures were taken for all critical bridges as can be interpreted from the table. All these studies were made by fulfilling economic and technical requirements determined by the Specifications.

Table 9. Bridge inventory- seismic retrofit and structural strengthening studies.

Condition	Suspension Bridge	Bridge	Large Scale Bridge	Total
Completed jobs	2	88	39	123
Ongoing jobs	-	133	25	166
Preparing jobs	-	39	5	44

Seismic retrofitting and structural strengthening requirements at 1. Bosporus and 2. Bosporus Suspension Bridges and Golden Horn Bridges

Job items according to deficiencies at bridges are listed below and shown in Fig. 3, 4, 5 and 6 respectively;

- First Bosporus Bridge: Reinforcement of towers for collision between girder and tower, reinforcement of rocker bearings
- First Bosporus Approach Viaducts: Falling down prevention device at anchorage, expanding seat width at A1 abutment, replacement of expansion joint at anchorage, falling down prevention device at tower, replacement of bearing at towers, reinforcement of girder with new diaphragm at piers, installing dampers, retrofitting of cap beams
- Second Bosporus Bridge: Reinforcement of towers for collision between girder and tower
- Golden Horn Bridges: Replacement of elastomeric bearings, seismic retrofitting of piers/columns with steel jacketing, expanding of seat widths, replacement of expansion joint, installing falling down prevention cable, installing dampers.

Figure 3. Retrofitting of cap beams at Bosporus Bridge approach viaducts.

Figure 4. First Bosporus Bridge damper installation.

Figure 5. Damper and falling down prevention jacketing at Golden Horne Bridge.

Figure 6. Retrofitting of piers with steel jacketing at Golden Horne Bridge.

Seismic retrofitting and structural strengthening requirements at large-scale steel & concrete bridges on the O-1 and O-2 motorways and the other bridges in earthquake-prone areas

Besides Bosporus Suspension Bridges and Golden Horne bridges, job items at large scale bridges are given below; and shown in Fig. 8, 9, 10, 11 and 12, respectively.

- Seismic retrofitting of piers/columns with steel jacketing, seismic retrofitting of piers/columns with concrete jacketing,

Figure 8. Retrofitting of piers with concrete jacketing at Ortaköy V408 viaduct.

Figure 9. Damper installation at Old Golden Horn approach viaduct abutment.

Figure 10. Retrofitting of footing at Mahmutbey viaduct.

Figure 11. Installation of LRB bearings and retrofitting of piers with steel jacketing at Mecidiyeköy Viaduct.

- Seismic retrofitting of footings, base isolation using LRB, installing dampers, expanding of seat widths, construction of shear keys, replacement of expansion joints, reinforcement and/or construction of column bents, construction of additional piles, repair of cracks, replacement of elastomeric bearings, installing falling down prevention cable, expanding footings, installation of lock up device, retrofitting of cap-beam, construction of new cap beams.

Figure 12. Retrofitting of piers with concrete jacketing at Sagmalcilar viaduct.

Conclusion

For reducing earthquake losses, taking the precautions on time is very important issue. So both fast and reliable studies affect the number of losses. Seismic retrofitting of bridges in such a huge city like Istanbul is a challenging study. Success is depends on sufficient funds, using time efficiently, applying effective retrofitting methodologies and well organization in heavy traffic. The city is located on high seismic zone and bridges are critical nodes of highway network and any broken link due to bridges failure during a destructive earthquake may totally paralyze the whole transportation system. The aim of State Highways is retrofitting all risky bridges before possible earthquake and decreasing the earthquake losses in Istanbul. All critical bridges in the city center of Istanbul have been strengthened against earthquakes and this challenging work has been accomplished. For this aim, the studies on remaining bridges are being continuing close to the city center.

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