

# State of the Art on Application, R&D and Design Rules for Seismic Isolation and Energy Dissipation for Buildings, Bridges and Viaducts, Cultural Heritage and Chemical Plants in Turkey



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**ABSTRACT:** This paper provides a brief survey of the structures in Turkey with passive structural control. The utilization of the technique of seismic isolation for new structures and retrofit of existing structures is developing at a high rate in the country. As of 2016 there exist about 100 structures with seismic isolation. The list includes buildings, airport terminals, LNG storage tanks, highway and railway viaducts, stadium, hospitals and schools. Most of the recent activity seems to have focused on viaducts and hospital buildings as the Ministry of Health made it mandatory to use seismic isolation for public hospitals in the high earthquake hazard zones of Turkey. Similarly, the currently active WB project (ISMEP) that foresees the earthquake retrofit of schools and hospitals in Istanbul, requires seismic isolation for the construction of new and retrofit of existing hospitals in Istanbul. The new seismic isolation design code for building is prepared along the lines of relevant ASCE and EC codes. A critical comparison of this new code with the relevant ASCE, CE and Japanese codes is provided.

## 1 INTRODUCTION

In Turkey, passive control technologies are being applied at an accelerated pace to new or retrofitted buildings and infrastructures for earthquake protection. A draft code on seismic isolation of buildings is finalized and ready for adoption as the national official code. To date, the numbers of structures constructed with seismic isolation devices is 103. Most applications of seismic isolation involve large medical facilities and important bridges/viaducts. The use of passive control technologies remains highly limited for residential buildings and industrial structures. In this paper, the draft seismic design code for seismic isolation of will be briefly introduced and sample applications of seismic isolation and other passive control technologies will be provided.

## 2 SEISMIC ISOLATION DESIGN CODE FOR BUILDINGS

Due to the lack of the official seismic isolation design code have led professional engineers to the use the US (ASCE 7-5, ASCE 7-10, AASHTO) and European (EC8) codes for the seismic isolation design for buildings and bridges. The different approaches and procedures in these codes, especially in the design ground motion, have led to non-uniform applications. The testing of the bearings also followed these codes (and even mixtures of them) caused incompatible test results with the design parameters used. The basic design criteria and the performance objectives of the code are 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, modified for directionality and directivity effects, shall be taken into consideration: Design Basis Earthquake (DBE) Ground Motion Level: Site dependent ground motion with 10% probability of exceedance in 50 years and;

Maximum Credible Earthquake (MCE) Ground Motion Level: Site dependent ground motion with 2% probability of exceedance in 50 years.

- Buildings seismically isolated and designed according to this Code should remain functional with no damage in structural and non-structural elements at the design level earthquake and; the structural system should receive no damage and the isolation system should be stable at the maximum credible earthquake level.
- The design of the isolation units will be based on “European Standard EN 1337-3:2005: Structural Bearings - Elastomeric Bearings” for the provisions that are not involved this Code.
- The isolation system must have the properties of high vertical stiffness, low lateral stiffness, ability to carry vertical loads, energy absorption, ability to re-centre after MCE seismic motion and, adequate lateral stiffness against lateral forces other than earthquake
- If the vertical vibration period of the isolated building is than 0.1 s (Section 6.1.1.), 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 the following requirements are satisfied; (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  $\frac{1}{2}$ , (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%.
- A minimum eleven sets of earthquake ground motions (acceleration records with two orthogonal horizontal and one vertical component) with the following properties shall be selected for the analysis to be performed in the time domain.
- The following analysis methods 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 shall be used for the initial design of the isolated building and, sizing of the isolator units and to provide reference design values.
- For the design, the appropriate combination of the upper and lower bound values of the isolation system properties shall be used.
- 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.
- For important and critical buildings the seismic load reduction is 1. For other buildings, the factor can have a maximum value of 1.5.
- “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.

### **3 APPLICATIONS OF PASSIVE STRUCTURAL CONTROL IN TURKEY**

As of 2017 103 projects (buildings and bridges/viaducts), with seismic isolation applications, are either finished or in the final construction phase. These structures include hospitals, terminal buildings, data centers, sports arenas and bridges/viaducts. Some of these applications involve big structures encompassing in the order of 1000 isolator units.

### 3.1 Seismic Isolation Applications for Airport Terminals

The new passenger terminal building at Ataturk International Airport was retrofitted by isolating the roof with 183 curved friction slider type isolation units. Seismic retrofit project of Antalya International Airport terminal building is completed with the incorporation of 500 lead rubber bearings together with pot bearings.

### 3.2 Seismic Isolation Applications for Hospitals

It is vital to preserve the functionality of hospitals and protection of costly medical equipment immediately after major earthquakes. The Ministry of Health enforces seismic isolation of all new hospitals with more than 100 beds exposed to DBE level PGA exceeding 0.3g.

Kocaeli University hospital is the first seismically isolated hospital building in Turkey. Construction completed in 2001 with 256 curved friction sliders used in the isolation system. Erzurum Regional Research and Training Hospital is an 180,000-meter square complex with 400-bed capacity encompassing 386 lead rubber bearings in its isolation system (Erdik, 2015).

Erzurum Medical Campus consists of 5 isolated hospital blocks with 190,000m<sup>2</sup> area housing 700 beds. The isolation system consists of 1048 curved surface friction slider units (Figure 1).



Figure 1. Erzurum Medical Campus

Van Gynaecology, Obstetrics and CVC Hospital complex with 500 bed capacity was constructed in 2013. It has a covered area of 125,000 square meter and 512 curved surface friction slider type isolators are used in seismic the isolation system (Figure 2).



Figure 2. Van Gynaecology, Obstetrics and CVC Hospital

Istanbul Okmeydanı Hospital is 250,000m<sup>2</sup> in size accommodating 1150 beds and is isolated with 879 triple friction pendulum type bearings (Figure 3).



Figure 3. Istanbul Okmeydanı Hospital

Istanbul Göztepe Hospital is 250000m<sup>2</sup> in size accommodating 1150 beds and is isolated with 921 triple friction pendulum type bearing (Figure 4).



Figure 4. Göztepe Hospital

Kartal Lütü Kırda Hospital, 280,000m<sup>2</sup> in size with 920 bed capacity, is isolated with 855 triple friction pendulum type bearings (*Figure 5*).



Figure 5. Kartal Lütü Kırda Hospital

Maltepe Başıbüyük Training and Research Hospital in İstanbul is retrofitted with seismic isolation. The hospital has a total area of 113.000m<sup>2</sup>. The isolation system consists of 687 rubber bearings and 154 sliding bearing (*Figure 6*).



Figure 6. Maltepe Başıbüyük Training and Research Hospital

Adana Heath Complex has 1500 bed capacity and approximately 437,000m<sup>2</sup> square meter total area. The isolation system is composed of 1552 triple friction pendulum type isolators (*Figure 7*).



Figure 7. Adana Heath Complex

Elazığ hospital, with a total area of 350,000m<sup>2</sup> encompassing 1040 beds, has a seismic isolation system with 878 triple friction pendulum isolator units (*Figure 8*).



Figure 8. Adana Heath Complex



Çorum hospital, encompassing 650 beds with a total area of 143,000m<sup>2</sup>, is seismically isolated with 741 lead rubber bearings (*Figure 9*).



Figure 9. Adana Heath Complex

*Figure 10* provides pictures of Manisa (150,000m<sup>2</sup>, 560 beds, 734 LRB units) and Isparta City Hospital (178,000m<sup>2</sup>, 755 beds and 903 curved surface friction slider units).



Figure 10. Manisa and Isparta City Hospitals

Bursa City Hospital, encompassing 1355 beds with a total area of 366,000m<sup>2</sup>, is seismically isolated with 859 lead rubber bearings (*Figure 11*).



Figure 11. Bursa City Hospital

Eskişehir City Hospital, encompassing 1081 beds with a total area of 291,000m<sup>2</sup>, is seismically isolated with 973 curved surface friction slider units (*Figure 12*).



Figure 12. Eskişehir City Hospital

Antalya Muratpaşa (52,000m<sup>2</sup>, 300 beds, 443 LRB units), Kahramanmaraş Elbistan (49,000m<sup>2</sup>, 300 beds and 455 curved surface friction slider units) and Manisa Merkez Efendi (68,000m<sup>2</sup>, 458 beds and 501 curved surface friction slider units) hospitals are shown in *Figure 13*.



Figure 13. Antalya Muratpaşa, Kahramanmaraş Elbistan and Manisa Merkez Efendi Hospitals

Balıkesir Burhaniye (30,000m<sup>2</sup>, 100 beds, 158 LRB units), Bursa Gemlik (35,000m<sup>2</sup>, 150 beds and 236 LRB + 24 slider units), Edirne Keşan (26,000m<sup>2</sup>, 150 beds, 180 LRB + 12 slider units), Bursa Şevket Yılmaz (40,000m<sup>2</sup>, 150 beds and 188 curved surface friction slider units), Bursa Kestel (27,000m<sup>2</sup>, 125 beds and 192 curved surface friction slider units), Çanakkale Biga (23,000m<sup>2</sup>, 150 beds, 280 LRB units), İstanbul Çekmeköy (49,000m<sup>2</sup>, 150 beds and 173 curved surface friction slider units) and İstanbul Yedikule (29,000m<sup>2</sup>, 200 beds, 102 LRB units) are the smaller hospitals with base isolation systems.

### 3.3 Seismic Isolation Applications for Data Centers

Servers, storage and network switches in data centers located in major earthquake hazard employ seismic isolation techniques to provide safety for the protection of equipment and data, by minimizing failure in the event of an earthquake. In this connection: Turkcell Gebze (300 LRB + 12 slider and 12 viscous damper units), İş Bank (293 triple friction pendulum) and Star of Bosphorus (*Figure 14*, 138 triple friction pendulum) Data Centers are currently under construction.



Figure 14. Star of Bosphorus Data Center

### 3.4 Seismic Isolation Applications for other Buildings, Schools and Sports Stadia

İhsan Doğramacı Foundation-Erzurum Bilkent High School is the only school that uses seismic isolation, encompassing 203 seismic isolator units. AFAD (Department of Emergency Situations) building in Ankara has a base isolation system consisting of 52 LRB units. So far the only on example of base isolated residential building is Aykent Loft in Silivri-İstanbul, a four story building built on 12 lead rubber bearings. Türk Telekom, İzmir Halkapınar and Bursa Timsah Sports Arenas have roofs isolated with, respectively, 8 curved surface friction sliders, 20 NRP + and 40 viscous dampers and 24 curved surface friction slider units (Erdik, 2015).

### 3.5 Seismic Isolation Applications for Industrial Buildings

Utilization of seismic isolation for the industrial facilities has been rather limited. Two LNG tanks of the EgeGaz Aliğa Terminal, each with 82m-diameter and 140.000 m<sup>3</sup> capacity, was base isolated each with 706 LRB, representing the first industrial seismic isolation in Turkey in 2002. In recent years, two ammonia tanks (Gübretaş in Yarımca and Eti Maden in Samsun) were retrofitted with, respectively, 94 and 121 curved surface friction slider units (Erdik, 2015).

### 3.6 Seismic Isolation Applications of Bridges and Viaducts

Bridges and viaducts constitute one of the major components of transportation systems which serve as the lifelines. It is essential to maintain the functionality of critical bridges after major earthquakes. Starting with the retrofit of the Bolu Viaduct, a 2.3km long viaduct located on the Trans-European Motorway, in 2002, seismic isolation technique was extensively used for the retrofit of Mecidiyeköy Viaduct in Istanbul, Sakarya-II Viaduct on the Bozüyük-Mekece Highway, the Gülburnu Bridge on the Black Sea Coastal Highway and the Nissibi Bridge at Adıyaman, crossing the Atatürk Dam reservoir (Erdik, 2015).

The Turkish State Railways started building high speed rail lines in 2003. Most of the viaducts (18 of them) located between Eskişehir and Sapanca stations, on the 533km long Ankara-Istanbul high-speed railway were constructed with seismic isolation systems encompassing 464 curved surface friction isolators (Erdik, 2015).



The Gebze-Izmir Highway project comprises 377 km of motorway and 30 viaducts of 18.2km in total length. 11 of these viaducts in high earthquake hazard regions were constructed with seismic isolation that encompasses a total of 4874 lead rubber bearings. Gebze-Izmir highway encompasses the following important structures:

Osmangazi Suspension Bridge is a suspension bridge with 1550m long main span and two 566 m long side spans, and is the fourth longest suspension bridges in the world (Figure 14). The bridge is located in an area of high seismic activity, and crosses the North Anatolian Fault. The earthquake performance of the bridge was enhanced by building its pylons on a concrete foundation that rests on a large gravel bed to use the benefit of foundation-soil interaction (sliding). To further control its earthquake response: sliding spherical bearings (with uplift protection), to carry the vertical loads, and lateral elastomeric bearings to provide the transversal restraint were used. Four viscous dampers with lock-up devices control the thermal motion of the suspended deck (Figure 15).

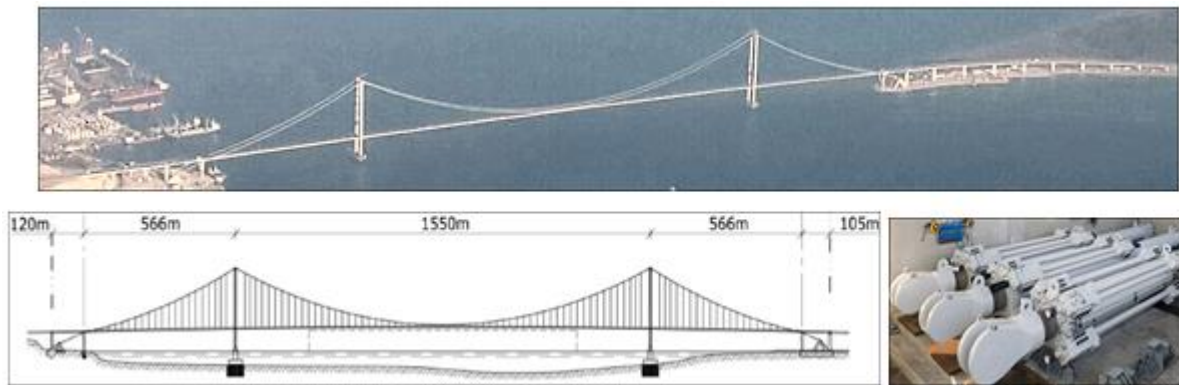


Figure 15. General layout of Osmangazi Suspension Bridge and the viscous dampers used

The seismic isolation system used for the South Approach Viaduct of the Osmangazi Suspension Bridge consists of 22 isolation units, each comprising two LRB isolators placed side by side, together with 108 viscous dampers placed both in the longitudinal and transverse directions (Figure 16).



Figure 16. General view of South Approach Viaduct and the LRB units used

The seismic isolation system used for the North Approach Viaduct of the Osmangazi Suspension Bridge consists of 40 LRB units (Figure 17).



Figure 17. General view of North Approach Viaduct and the LRB units used

The seismic isolation system used for the Gemlik Viaduct of the Gebze-Izmir Highway consists of 418 LRB units (Figure 18).



Figure 18. General view of Gemlik Viaduct of the Gebze-İzmir Highway

### 3.7 Use of Dampers, Buckling Restrained Braces and Tuned Mass Dampers

Renaissance Tower in Istanbul, Istanbul Technical University-Technopark Building in İstanbul and Folkart Twin Towers in İzmir has employed unbounded braces in their earthquake resistant design. The earthquake retrofit of the Turkcell Maltepe Plaza building in Istanbul encompasses 36 viscous dampers as diagonal bracing elements. Earthquake retrofit of the Bosphorus Suspension Bridge included the use of four viscous dampers as buffers between the deck and the towers. Hysteretic dampers were used in connection with the earthquake retrofits of the Old and New Golden Horn Bridges and the Ortaköy approach viaduct of the Bosphorus Suspension Bridge. The use of tuned mass dampers in Turkey has been so far limited to tall industrial stacks (Erdik, 2015). The Yavuz Sultan Selim Bridge, is the third bridge to be built in Istanbul across the Bosphorus Straits with eight traffic lanes and two railway tracks. The hybrid cable-stayed / suspension bridge, has main span of 1408m, 322m-tall towers and 58m-wide deck – three world records for this bridge type. The entire system is supported by two A-shaped concrete towers. To control the vibration of the back span and stay high angle stay cables external viscous dampers were used (*Figure 19*). The low angle long stay cables in the main span were cross linked to each other to introduce damping (*Figure 20*).

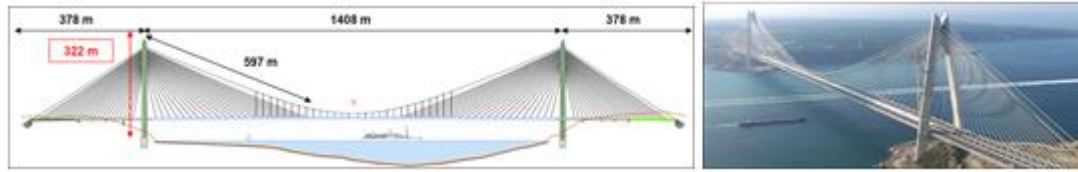


Figure 19. General outline and view of the Yavuz Sultan Selim Bridge



Figure 20. Viscous dampers and the cross-links used on the Yavuz Sultan Selim Bridge stay cables

## 4 CONCLUSIONS

The enforcement of the code for the seismic isolation design for buildings will certainly encourage and regulate applications. Training and licencing of engineers for the proper and correct utilization of seismic isolation techniques, as well as peer review is needed for the healthy development of applications. The use of passive control for residential buildings and industrial facilities has been very limited and a concerted action of the professional engineers and academia is needed to promote such applications. The Turkish Association for Seismic Isolation should facilitate the adoption of seismic isolation.

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#### 4.2 REFERENCES

Erdik, M. (2015). State of the Art on Application, R&D and Design Rules for Seismic Isolation and Energy Dissipation for Buildings, Bridges and Viaducts, Cultural Heritage and Chemical Plants in Turkey Evaluation of Seismic Isolation Applications of Health Care Facilities in Turkey, Proc. 14WCSI