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Seismic isolation code developments and significant applications in Turkey

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ABSTRACT

There is a special need to preserve the functionality of critical structures, such as hospitals, under severe earthquakes. In this sense, seismic isolation technology serves as a vital design method for the protection of their functionality.

In Turkey, seismic isolation technology has been applied at an accelerated pace to new or retrofitted buildings and infrastructures for earthquake protection essentially after the 1999 Kocaeli Mw7.4 Earthquake. Several guidelines and a new official code are prepared to encourage and regulate the on-going applications.

To enable the post-earthquake functionality of hospitals, the Ministry of Health public private partnership program foresees to build health campuses with seismic isolation. As of 2017, 21 health projects are complete or under construction with total investment of more than USD 23 billion.

Following a general review of seismic isolation design, the essential features of the recent seismic isolation code are provided and compared with European, Japanese and US Codes.

After a brief survey of base isolated hospitals in the world, two examples of large scale hospitals with seismic isolation are provided.

The Basibüyük Training and Research Hospital in Istanbul, retrofitted with seismic isolation, encompasses 750 beds in 113.000 m^2 floor area and is the largest hospital in the world retrofitted with a seismic isolation system consisting of 688 lead rubber and 154 sliding bearings.

The newly built Adana Integrated Health Campus (City Hospital) has 430,000 m^2 floor area and houses 1500 beds. With an isolation system composed of 1552 triple curved surface friction sliders, the hospital is currently the largest base isolated hospital in the world.

1. Introduction

Earthquake is a threat to human lives and assets. Population growth and increasing urbanization in earthquake-prone areas suggest that earthquake impacts on human populations will continue in the coming decades.

Although, seismic design codes have been very successful in reducing collapse of structures, and have saved the lives of people, the same level of success is not seen in non-structural and business losses. In fact, in developed countries, over the past 20 years, most of the economic losses caused by earthquakes have resulted from non-structural damage and loss of facility use.

Modern buildings contain sensitive and costly equipment that are vital in business, commerce, education and health care. The contents of these buildings are generally more costly and valuable than the buildings themselves. Furthermore, hospitals, communication and emergency centers, and police and fire stations must be operational immediately after an earthquake, when the need is greatest. In connection with the “Performance Based Seismic Design” approach, the expected performance objective for such critical facilities should be "fully operational", under exposure to the design basis earthquake (DBE).

Conventional construction techniques may result in very high floor accelerations in stiff buildings and large inter-story drifts in flexible structures, causing difficulties in ensuring the safety of the non-structural components and contents. In order to achieve a "fully operational" performance, the most promising design approach is to use seismic isolation technique.

Seismic isolation allows for the installation of specially designed bearing (isolator) units at the foundation or any other convenient floor level to substantially decouple the superstructure from earthquake motions.

Increasing the fundamental period of vibration away from high spectral acceleration zone and the concentration of nonlinearity at the isolation interface serves to avoid the inelastic response of the superstructure and keeps the earthquake induced responses in the limited ductility level (Fig. 1). In addition, seismic isolators also reduce the floor accelerations and the inter-story displacements.

Although, contemporary seismic isolation technologies were first proposed as an innovative performance enhancement strategy from 1970s to 2000s, nowadays it is transformed to mature and arguably the best way of earthquake protection method. As of 2014, more than 23,000 structures, located in over 30 countries, have been so far

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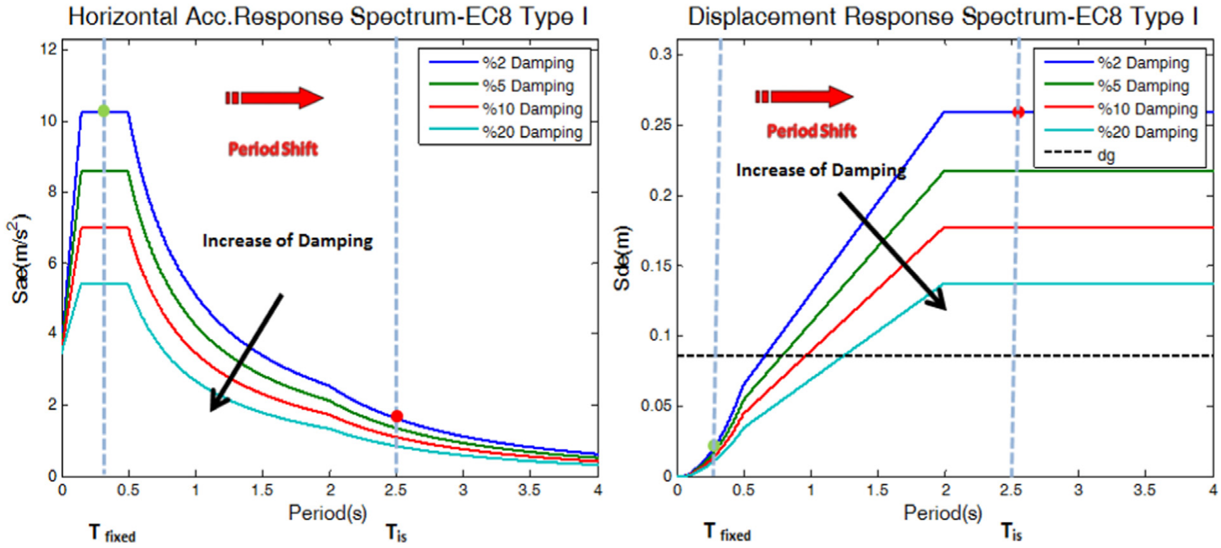

Fig. 1. Benefits of seismic isolation through the elongation of fundamental vibration period and limitation of excessive deformations with increase in damping (after [15]).

protected by passive anti-seismic systems, mainly by the seismic isolation [36]. Japan is the leading country for the overall number of applications, followed by China, Russia, Italy and USA.

Turkey is located in an earthquake prone region and suffered high amount of casualties and loss of property due to earthquakes over many centuries. Potential impacts of large earthquakes on urban societies need to be mitigated through multi-disciplinary approaches. In Turkey, seismic isolation technology has been applied at an accelerated pace to new or retrofitted buildings and infrastructures for earthquake protection essentially after the 1999 Kocaeli Mw7.4 Earthquake. As of 2017, there exist a multitude of structures with seismic isolation, including hospitals, schools, airport terminals, LNG storage tanks, highway and railway viaducts and stadia. Most of the recent activity have focused on viaducts and hospital buildings. To date, the numbers of structures constructed with seismic isolation devices is 72.

These fast developments on seismic isolation also necessitated the preparation of a national official design code for the seismic isolation applications on building.

Turkey, especially for large hospitals, is firmly committed to base-isolation methodology, since the health care facilities are expected to be functional and serve after a major seismic event. Notably, Turkey has embarked on a program to build numerous large hospitals complexes with seismic isolation [23,27,29].

Engineering News Record (ENR) has recently selected the largest 10 base isolated buildings in the world (https://www.enr.com/articles/42366-the-10-largest-base-isolated-buildings-in-the-world). The ranking was based on the total closed floor area. Three of these largest base isolated buildings are located in Turkey.

In summary, today, seismic isolation method is a justified, mature and reliable performance enhancement strategy for a wide range of structural systems. As a result of the targeted response modification, high performance expectations and earthquake resilience can be achieved during the service life of structures that are in compliance with the design code requirements.

2. Seismic isolation design

In general, conventional (i.e. fixed base) buildings designed in conformity with earthquake resistant design codes should: (1) Resist a minor level earthquake ground motion without damage; (2) Resist a moderate level earthquake ground motion without structural damage, but possibly with nonstructural damage and; (3) Resist a major level earthquake without collapse.

Performance objectives in building design codes differ for traditional fixed-base and seismically isolated structures. Design provisions for isolated buildings, aim to avoid the structural damages and limit the non-structural damages to ensure "immediate occupancy" performance level under exposure to a design earthquake ground motion.

In this regard, the EC-8 [21] allows a maximum behavior (or response modification) factor of 1.5, ASCE/SEI 7-16 (2016) allows the response modification factor to be 0.375 times that used for the corresponding fixed-base structure (however, capped at 2) and, the Japanese building code (BSL-2015) allows for only limited inelastic response.

The design earthquake ground motion in EC-8 [21] corresponds to a seismic action with probability of exceedance 10% in 50 years (i.e. 475 year average return period). However, an importance factor of 1.4 is assigned for vital or strategic buildings (e.g. hospitals) which implicitly increases the return period to about 2000 years and, furthermore, tests of isolation devices is made by multiplying the actions by a factor of 1.2. In ASCE/SEI 7–10 the design earthquake is taken as the 2/3 of the MCE_R (Risk-Targeted Maximum Considered Earthquake, approximately equal to 2475 year return period earthquake with deterministic caps), whereas in ASCE/SEI 7–16, the design earthquake is taken directly as the MCE_R ground motion. In Japanese building code the design basis ground motion is prescriptively defined and can be estimated to correspond to a 500 year average return period for life-safety limit design (Otani [42]).

Inter-story drifts and floor accelerations are two key parameters in the seismic design of structures to avoid excessive damages both in structural and drift-sensitive non-structural elements. The maximum drift ratio of the superstructure varies between different codes. In ASCE/SEI 7–16 (2016) it is limited to 1.5% of the story height, for response spectrum analysis, whereas, 2% is allowed in response history analysis. In EC8 [21] the maximum drift ratio is 0.5% to protect brittle non-structural elements (0.75% otherwise) in the damage limitation level design. In Japanese code (BSL-2015) the drift limits are set as 0.5% and 2% respectively for damage limitation and life safety level designs.

2.1. Direct displacement based design for seismic isolation

Almost all codes on seismic isolation design use a mixture of force- (or strength-) based design and displacement based procedures. It is widely recognized that the traditional force-based design cannot directly implement the concepts of performance-based earthquake