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Seismically isolated buildings in Italy: State-of-the-art review and applications

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ABSTRACT

This paper presents a state-of-the-art on seismic isolation in Italy and the most important applications. After a brief introduction on the basic concepts of seismic isolation, applications to new strategic and public buildings are shown, as well as to new residential buildings, pointing out the very good behavior shown by the seismically isolated structures during real seismic events. Then, attention is focused on the retrofit of existing buildings, which represents the real challenge for the future. The most interesting applications on existing reinforced concrete, masonry and historic structures are shown, pointing out the specific challenges for each case. Finally, recordings obtained during the seismic sequence that struck Central Italy since August 24th, 2016, are presented and discussed. These are useful in analyzing the behavior of base isolation systems and their effectiveness under low energy earthquakes.

1. Introduction

It is well-known that seismic isolation increases the fundamental period of vibration of a building so that accelerations in the superstructure can be reduced significantly [1]. This reduction is offset in terms of displacements, which increase substantially with the vibration period (Fig. 1, dashed line). However, in the presence of isolation devices, these displacements can be concentrated at the base of the building, while the superstructure behaves almost like a rigid body.

Seismic actions on structures can be described by the acceleration elastic response spectrum at the site, which assumes the shape shown in Fig. 1 (continuous line), according to both Italian and European codes. In the range [T_B, T_C] the acceleration is constant, and is equal to its maximum value:

$$S_{e,\,\max} = a_g F S \eta$$

where a_g is the peak ground acceleration on rigid ground, F is the structural amplification factor, S is the soil amplification factor and $\eta = \sqrt{10/(5+\xi)}$ is a damping coefficient that corrects the elastic spectrum for values of the damping ratios ξ different from 5% (η = 1 for ξ = 5%, which represents the reference value for conventional structures). In the range [T_C, T_D], characterized by a constant velocity, the elastic spectrum is:

$$S_e(T) = S_{e,\,\max}\frac{T_C}{T}$$

For $T > T_D$, it is characterized by constant displacement:

$$S_e(T) = S_{e,\,\max}\frac{T_C T_D}{T^2}$$

The usual values of the fundamental periods of vibration of conventional structures are often in the range of maximum seismic amplification.

The actual reduction of the seismic action due to the use of seismic isolation is given by the spectral ratio

$$\frac{S_{e,is}}{S_{e,fb}}\cdot\frac{\eta_{fb}}{\eta_{is}}$$

where $S_{e,is}$ is the elastic spectral amplitude at the fundamental period of vibration of the isolated building T_{is}, and $S_{e,fb}$ is the elastic spectral amplitude at the fundamental period of vibration T_{fb} of the same building considered as fixed at its base. This ratio also accounts for the higher damping introduced by the isolation devices with respect to the conventional building. Usually $\eta_{fb} = 1$ and $\eta_{is}/\eta_{fb} < 1$. In Fig. 2, this spectral ratio is plotted versus T_{is}/T_{fb}. The two cases of $T_{is} \in]T_C, T_D]$ and $T_{is} \in]T_D, 4.0]$ must be distinguished. In the first one, the curve (upper line) is unique if $T_{bf} = T_C$ is assumed when $T_{bf} \le T_C$. In the second case, different curves for different values of T_{bf}/T_D ($T_D = 2.5$ s was assumed) are plotted. These start from the upper curve at the abscissa at which $T_{is} = T_D$. As one can see, acceleration reduction reaches substantial values, especially for $T_{is}/T_{fb} \ge 3$, which is also a suitable value to guarantee the

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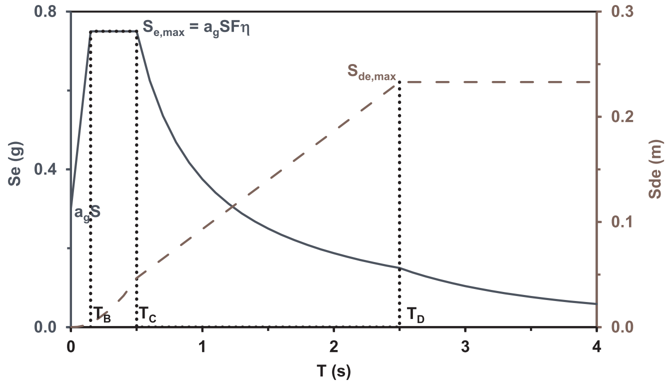

Fig. 1. Elastic response spectrum.

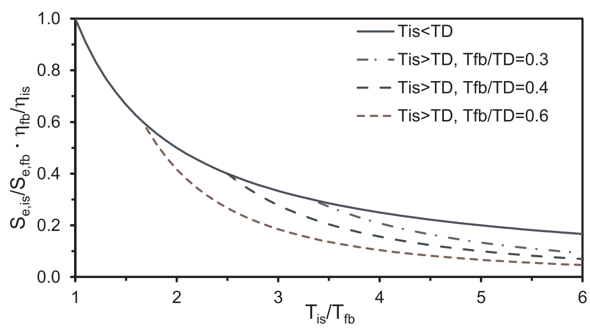

Fig. 2. Elastic spectra ratios $S_{e,is}/S_{e,bf}$.

decoupling of motions between the structure and the soil.

Seismic isolation is not a recent idea [1,2]. Ancient Greek temples, Chinese monasteries, temples, bridges and walls erected by the Incas, and even some ordinary buildings in Anatolia were protected by rudimentary seismic isolation systems. These consisted in layers of materials, in most cases clay mixed with charcoal and ashes, which separated the foundation from the ground, allowing relative displacements between them to occur during earthquakes. In Southern Italy, the foundations of three Doric temples at Paestum, including the Temple of Athena (6th century B.C.), are placed on a sand layer, which separates them from the soil. The first modern isolator probably appeared in 1868, when Stevenson invented the so called “aseismatic joint” to protect the lighting system in Japan. It was made of spherical rollers in niches. Similar systems were patented by other inventors; among these, the Italian engineers Mario Viscardini and Domenico Lodà in 1909 [3,4].

The first modern application of seismic isolation in Italy dates 1976 and concerns the Somplago Viaduct of the Udine-Tarvisio freeway

Fig. 3. The seismically isolated Sompago viaduct of the Udine-Tarvisio freeway, after its completion (courtesy of FIP Industriale).

Fig. 4. The first seismically isolated fire-command building in Naples (courtesy F.M. Mazzolani).

(Fig. 3). Thanks to its seismic isolation system (comprising sliding devices on the piers and rubber bumpers between the deck and the abutments), the Somplago viaduct survived the two shocks of the September 11th (magnitude M = 5.3 and 5.6, respectively) and the two shocks of the September 15th (M = 5.9 and 6.0, respectively), 1976 Friuli earthquake, with epicentres only a few kilometres from the viaduct. This was without any damage, contrary to most other structures located in the epicentral area.

The excellent behavior of the Somplago Viaduct, dating from the years of construction of the Italian highway system, caused an immediate rapid extension of the application of anti-seismic systems to new Italian bridges and viaducts. The devices used were mainly dampers and Shock Transmitter Units (STUs). The bridges and viaducts protected by such systems numbered already 150 at the beginning of the 1990's: this ensured, at that time, worldwide leadership to Italy for the number and importance of anti-seismic systems applied to bridges and viaducts.

The first Italian application of seismic isolation in buildings dates 1981 and concerned a fire-command building in Naples (Fig. 4). It is a steel structure suspended from a top reticular beam, which is supported by reinforced concrete towers. The building had been designed before the November 23rd, 1980, Campano-Lucano earthquake (M = 6.9), without accounting for seismic actions, the area not being considered seismic at the time. As a result, the original design was retrofitted by just inserting Neoprene Bearings (NBs) at the top of the reinforced concrete towers as supports for the reticular steel beam, and floor dampers and Shock Transmitter Units inside the building (structural design by F.M. Mazzolani). Similar devices were used also for a second fire-command building nearby, which was opened for use in 1985.

The progress of applications of new anti-seismic technologies (including energy dissipation systems) in buildings was slower in the following years; however, the trend accelerated in the beginning of the 1990s, following the construction of the Telecom Italia Centre of the Marche Region at Ancona. In total, 297 High Damping Rubber Bearings (HDRBs) were used and impressive on-site release tests were performed on one of the five buildings (Fig. 5, structural design by G. Giuliani, acceptance certificate by A. Martelli).

Nowadays Italy is the fifth country in the world and the first country in Western Europe for the overall number of applications of passive anti-seismic devices [3]. As far as seismic isolation is concerned, it is the fourth country in the world for the number of isolated buildings, with over 400 applications already in place by 2013 [5–7]. In several applications, the isolators used are HDRBs and plane surface Sliding Devices (SDs), often used in parallel to optimize the dynamic behavior of the structure. More specifically, the stiffness centre of the isolation system should be almost coincident with the projection of the centre of gravity, to minimize torsion effects. Lead Rubber Bearings (LRBs), which enable a higher damping (up to an equivalent damping ratio of