



Seismic Isolated Structures: Concept, Review, Design & Worldwide Application

An Online Continuing Education Course for Engineers

**Course Number: S-2029
Credit: 2 Hour/ 2 PDH/ 2CPD**

Seismic Isolated Structures: Concept, Review, Design & Worldwide Application

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Introduction:

This course presents a state-of-the-art study of seismic isolation and its most important applications. After a brief introduction to 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.

Next, attention is focused on the retrofit of existing buildings, which represents a 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.

1. Understanding Seismic Isolation Technique

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. 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 [TB, TC] 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 the 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% ($\eta = 1$ for $\xi = 5\%$, which represents the reference value for conventional structures). In the range [TC, TD], characterized by a constant velocity, the elastic spectrum is:

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

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

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

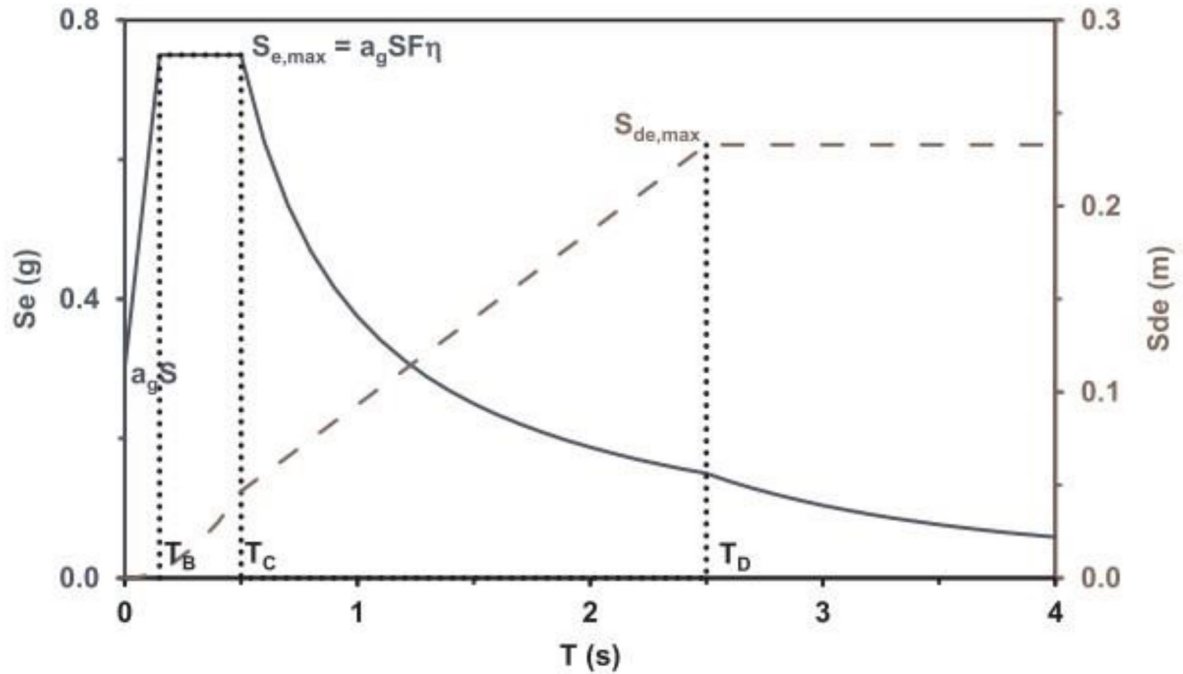


Fig. 1- Elastic response spectrum

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 $T_{bf} \leq T_C$. 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 $T_{is}/T_{fb} \geq 3$, which is also a suitable value to guarantee the decoupling of motions between the structure and the soil.

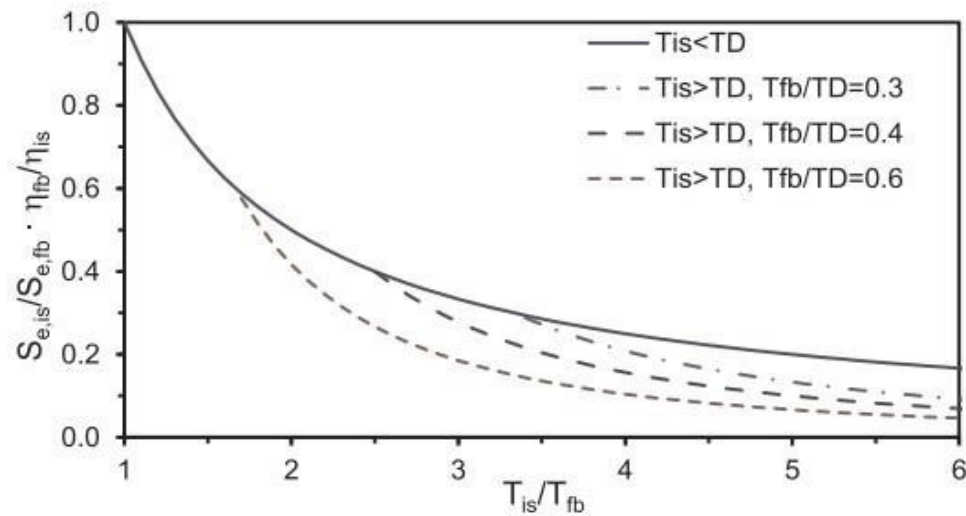


Fig. 2- Elastic spectra ratios $S_{e, is}/S_{e, fb}$

The first modern application of seismic isolation in Italy dates 1976 and concerns the Somplago Viaduct of the Udine-Tarvisio freeway (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 epicenters only a few kilometers from the viaduct. This was without any damage, in contrast to most other structures located in the epicentral area.



Fig. 3. The seismically isolated Somplago viaduct of the Udine-Tarvisio freeway, after its completion, Italy.

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 antiseismic 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.



Fig. 4. The first seismically isolated fire-command building in Naples, Italy

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 at 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).

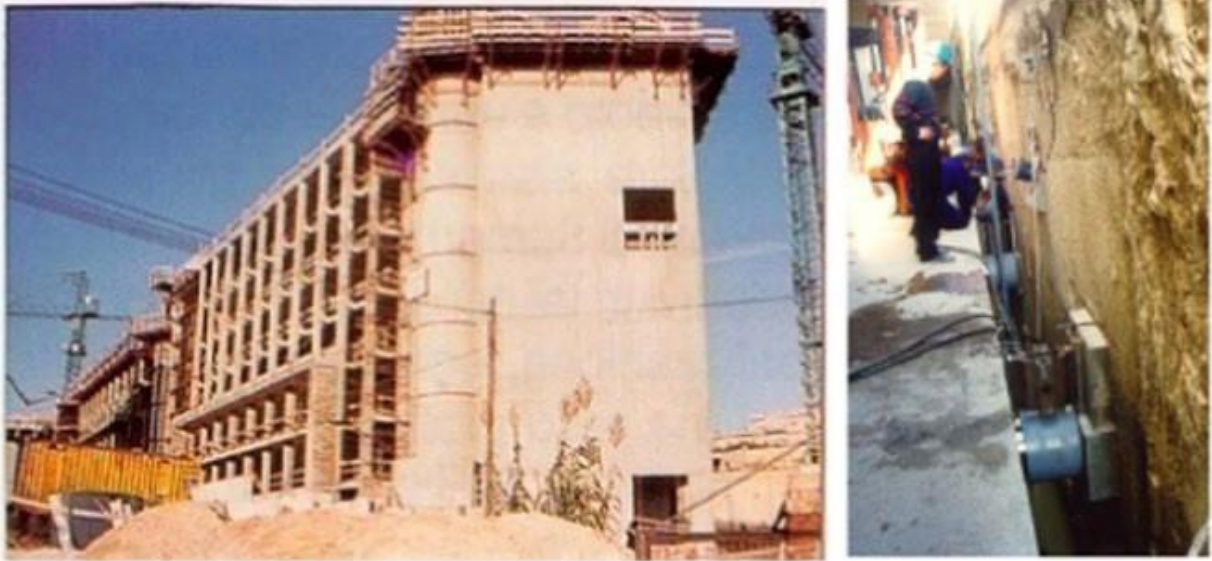


Fig. 5. The Telecom Italia Centre in Ancona, completed in 1992 and subjected to a release test.

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. 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. 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 center of the isolation system should be almost coincident with the projection of the center of gravity to minimize torsion effects. Lead Rubber Bearings (LRBs), which enable a higher damping (up to an equivalent damping ratio of 25–28%), are used especially for bridges and viaducts. Finally, single and double Curved Surface Sliders (CSSs) were introduced in Italy after the 2009 L'Aquila earthquake ($M = 6.3$) and are now widely used in buildings. In this course, a state-of-the-art on seismic isolation in buildings in Italy is presented. The evolution of the seismic code is first traced, and then an overview of the most interesting applications follows. The importance of structural monitoring to improve knowledge under different loading conditions is finally emphasized.

1. The Importance of Design Codes in the Seismic Isolation of Structures

As already mentioned, Italy was among the first countries in the world to apply seismic isolation, especially to bridges and viaducts. In spite of this, a suitable design code was missing until 2003. This was the main reason for which the use of seismic isolation was very limited before that year. Due to the absence of specific rules for structures with seismic isolation in the Italian Technical Code, all designs of such structures had to be submitted for approval to a special committee of the Ministry of Infrastructures. The first technical reference in Italy containing the design rules for seismic isolation, the so-called “Guidelines for the design, execution, and testing of seismic isolated structures”, was issued in 1998. The guidelines did not constitute an effective code, so the approval

