

Seismic Isolation in Newly Built Bridges in Italy: Historical Development, Regulations, and Recent Applications

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Abstract: Seismic isolation is a well-mature technique to protect structures against earthquakes, allowing to achieve a level of safety not possible with conventional systems. The Somplago Viaduct on the Udine–Tarvisio highway, built in 1976, was the first seismically isolated bridge in Italy. Its good performance during the strong shocks, which hit the viaduct when it was still under construction, encouraged the use of seismic isolation in bridges. The development of applications in Italy was initially quite slow, due to the delay in considering this new technology in technical standards. Significant developments occurred following the major seismic events that affected the country. Today, seismic isolation is almost always used for new construction projects and, especially, in major cases such as those illustrated in this paper, whose aim is to document the Italian experience and illustrate applications.

Author keywords: Newly built bridges; Seismic isolation; State-of-the-art in Italy

Introduction

An appropriate anti-seismic protection system is fundamental to obtaining good performance of a structure during earthquakes. The choice depends on the structural characteristics of the bridge and the seismic hazard of the site. With these premises, seismic isolation is a well-mature technique to protect structures against earthquakes and can be used in most cases, allowing for a level of safety not achievable with traditional technologies.

It is well known that a seismic isolation system consists of a set of isolation devices placed between the substructure, which remains anchored to the ground, and the superstructure, which will be seismically isolated. The isolation strategies to achieve the reduction of the horizontal seismic response, regardless of the typology and structural materials of the structure, are:

- Increasing the fundamental period of vibration to bring it into a range with lower response accelerations.
- Limiting the maximum horizontal force transmitted.

In both strategies, the isolation performance can be improved by dissipating a significant portion of the mechanical energy transmitted from the ground to the structure.

After some non-engineered proposals and realizations in ancient eras and some pioneering devices patented at the end of the nineteenth century and the first decades of the twentieth century, seismic isolation started in Europe in the 1970s.¹ Interesting applications were realized in Italy in bridges. The very first one referred to the Somplago Viaduct, along the Udine–Tarvisio highway, in Friuli, Northeastern Italy. It was hit by two severe seismic events on September 15, 1976 ($M = 5.9$ and $M = 6.0$, respectively), with the epicenter just a few kilometers from the bridge. The viaduct was under construction, and its excellent behavior favored a rapid increase in the application of anti-seismic systems in newly built bridges and viaducts. Italy became a leading country in the field, with more than 150 applications by the beginning of the 1990s.²

Seismically isolated buildings appeared later in Italy. The first was the fire command building in Naples, completed in 1981. In order to leave as much space as possible on the ground floor for vehicle movement, the steel structure is suspended from reticular beams, which rest on reinforced concrete towers by means of neoprene supports. Floor dampers and shock transmitter units were also used. The second building was the Telecom Italia Centre at Ancona, completed in 1991. A release test was performed on one of the five buildings, with an initial displacement equal to 110 mm, to test the performance of the 297 high-damping rubber bearings isolation system.³

The good performance of seismic isolation systems has been demonstrated during strong earthquakes all over the world. In Italy, however, the behavior under low-energy

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earthquakes has pointed out the necessity of considering this condition in the design phase and checking the correct working of the different types of devices.⁴⁻⁹ Design criteria and optimization have also been developed for both elastomeric and sliding devices (SDs).¹⁰⁻¹²

The use of seismic isolation in Italy was slowed by the absence of a technical code. In the absence of a technical code that defines the rules to follow, it was not possible to implement seismic isolation. As usual, the seismic events have provided significant impulse to the development and issuance of new seismic standards. The first standard issued in Italy followed the 1997 Umbria–Marche seismic sequence and was not a proper code, which in Italy is legally binding, but simple guidelines for seismically isolated structures.¹³ These were issued in 1998 and required a very long and complicated approval process by a special committee of the Ministry of Infrastructures.

After the earthquake that struck the Molise region in 2002 ($M = 5.4$), with an ordinance of the presidency of the council of ministers (OPCM 3274),¹⁴ a new seismic code was issued, which accounted for the most recent European standards. It included design rules for seismic isolation and energy dissipation systems, whose use was from then on permitted without specific approvals. The new code encouraged the use of new anti-seismic technologies, especially in high seismicity areas and for structures for which a very high level of safety was required.

Finally, in 2008 the new Italian Technical Code for Constructions (NTC-2008)¹⁵ was issued, which included all the technical codes that had been issued separately in the past. Seismic isolation had become a common anti-seismic technique, the use of which was well regulated within the standards both in terms of design aspects and those regarding the devices to be used and the related materials. The Italian code was updated in 2018 (NTC-2018)¹⁶ and will probably be updated in the next years.

This paper traces the development of seismic isolation in bridges in Italy and reports the main regulatory aspects, highlighting the differences with buildings. The aim is to document the Italian experience and illustrate applications, rather than to provide new analytical and experimental insights. Finally, some of the major projects completed in recent years are illustrated as examples of the most commonly used types and devices.

Seismically Isolated Bridges in Italy

In Fig. 1, the development of the number of seismically isolated structures in Italy is plotted, classified as bridges, buildings, and other structures. It should be first noted that applications in bridges began earlier, and their number grew much more rapidly than in buildings and other structures.

Focusing on bridges, after a timid start between the second half of the 1970s and the first half of the 1980s, a significant increase in the number of seismic-isolated bridges was recorded starting in the mid-1980s. This was followed by a period of gradual but slow increase, primarily due to the mentioned reasons related to the lack of a standard. Then,

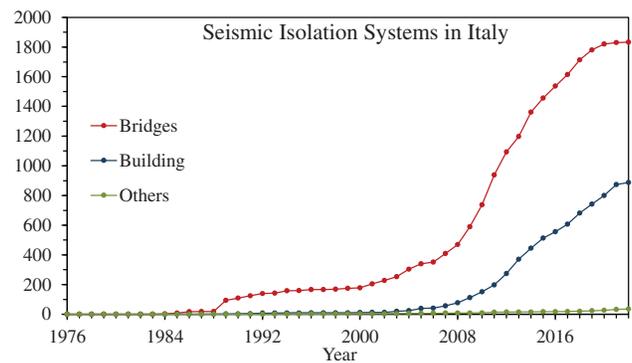


Figure 1. Development of the number of seismically isolated structures in Italy

after 2002, the year of the Molise earthquake and, above all, the issuance of OPCM 3274, a certain increase occurred. However, it was after 2009, the year of the L’Aquila earthquake and the definitive entry into force of the NTC-2008, that the number of applications increased significantly.

Nowadays, the application of new anti-seismic technologies in bridges is more than 2000 in Italy. The number of applications in existing bridges is quite low compared with the applications in new structures, but a significant number of applications has occurred in the recent years.¹⁷

SDs associated with dampers of different types were first used on a large scale in Italy, especially since 1988. Lead rubber bearings (LRBs) appeared in the same period, but their use has been limited. After 2004, high damping rubber bearings (HDRBs) were used extensively and then, after 2009, also curved surface sliders (CSSs). These are still the most common isolator types used.

Among the experimental tests conducted in Italy, noteworthy are those performed on a 1:5 scale model of a seismically isolated bridge span at the shake table laboratory of ENEA.¹⁸ Different isolation devices were used in the tests, such as rubber isolators and CCSs with varying friction coefficients, in addition to bearings made of simple neoprene simulating the original ones.

Notes on the Italian Standards for Seismic Isolation in Bridges

In bridges, isolation devices are usually inserted in place of the common support devices, between the vertical structures, that is, the piers and abutments, and the deck. Thus, the seismic actions that affect the deck are significantly reduced. Obviously, the substructure also benefits, because the seismic actions that the deck transmits to the vertical structures, and therefore to the foundations, will also be reduced. The set of devices defines the isolation interface. The choice and distribution of devices must optimize the distribution of horizontal seismic forces from the deck to the various support structures. The isolation system includes the connection elements and any additional constraints arranged to limit horizontal displacements due to non-seismic actions,

such as wind. The substructure, in general, cannot be considered infinitely rigid, contrary to what normally occurs in buildings.

As for buildings, also for bridges the superstructure and the substructure must remain in a substantially elastic range even for the actions to be considered for the check at the ultimate limit state (ULS). A higher reliability is required for the isolation devices due to their critical role.

Unlike buildings, the effects of accidental eccentricity of the masses in isolated bridges can usually be neglected. To allow the free movement of the different parts, and thus the correct working of the isolation system, the separation joints between the different portions of the deck and between the deck and the substructure must be correctly sized. Furthermore, the spatial variability of the ground motion must be taken into account as specified for non-isolated bridges.

As regards the mechanical properties of the isolation system and the modelling of the substructure and superstructure, the same requirements apply as for buildings. Linear dynamic analysis can be used if the device behavior can be modelled with its equivalent characteristics; otherwise, the nonlinear dynamic analysis is to be preferred and sometimes mandatory. Linear static analysis is allowed only if specific conditions are satisfied, while nonlinear static analysis cannot be used. In the case of linear analysis, a behavior factor $q = 1$ must be assumed.

The check at the ULS of the isolation devices subject to the combinations inherent in the horizontal variable actions (such as wind) must be carried out and could sometimes be decisive. Particular attention must be paid to avoid hammering between different adjacent parts of the structure.

Referring to construction, maintenance, and replaceability issues, and the testing phase, there are no additional requirements with respect to buildings.

It should be noted that seismic isolation is also particularly suitable for the retrofitting of existing bridges, where often the only replacement of the existing bearings with seismic isolators could be sufficient for the seismic retrofit. In both cases, seismic isolation allows obtaining very high

performance, in accordance with the new severe design standards, and is becoming a must in the construction and retrofit of bridges.

Recent Notable Newly Built Bridges

Bearing manufacturers and construction companies, as well as engineering firms, were invited to provide information on the main applications of seismic isolation systems in newly built bridges in Italy in recent years. Thanks to their contribution, some of these are described in the following paragraphs.

San Giorgio bridge

The San Giorgio Bridge in Genoa (Fig. 2) replaced the Polcevera Viaduct, designed by Riccardo Morandi, which partially collapsed on August 14, 2018, and was then demolished in June 2019. It was designed, built, and tested in only sixteen months. This result was achieved thanks to its structural simplicity but also by optimizing all the phases, ensuring rapid and high-quality work. It was opened to traffic on August 3, 2020.

The bridge is a continuous beam, with a total length of 1067.17 m, consisting of 19 spans. The three main spans are 100 m each; all the others are 50 m, except the last two, which are 40.9 and 26.27 m, respectively. The deck is composed of a steel multi-box beam, which has the shape of a ship hull, and a reinforced concrete slab (Fig. 3).¹⁹

The 18 hollow reinforced concrete piers have an elliptical cross-section with maximum dimensions in plan of 9.50 × 4.0 m to improve aerodynamic properties against wind action (Fig. 3). Their height varies from 32.0 to 39.0 m, except for the first pier P1 and the last pier P18, whose heights are 19.50 and 11.0 m, respectively. The bridge foundations are deep, resting on 1.50 m diameter piles.

At the east end of the viaduct, a three-span ramp accessing the bridge is connected to the main structure. It is composed of three spans of 35.1, 44.79, and 37.82 m,



Figure 2. View of the San Giorgio Bridge

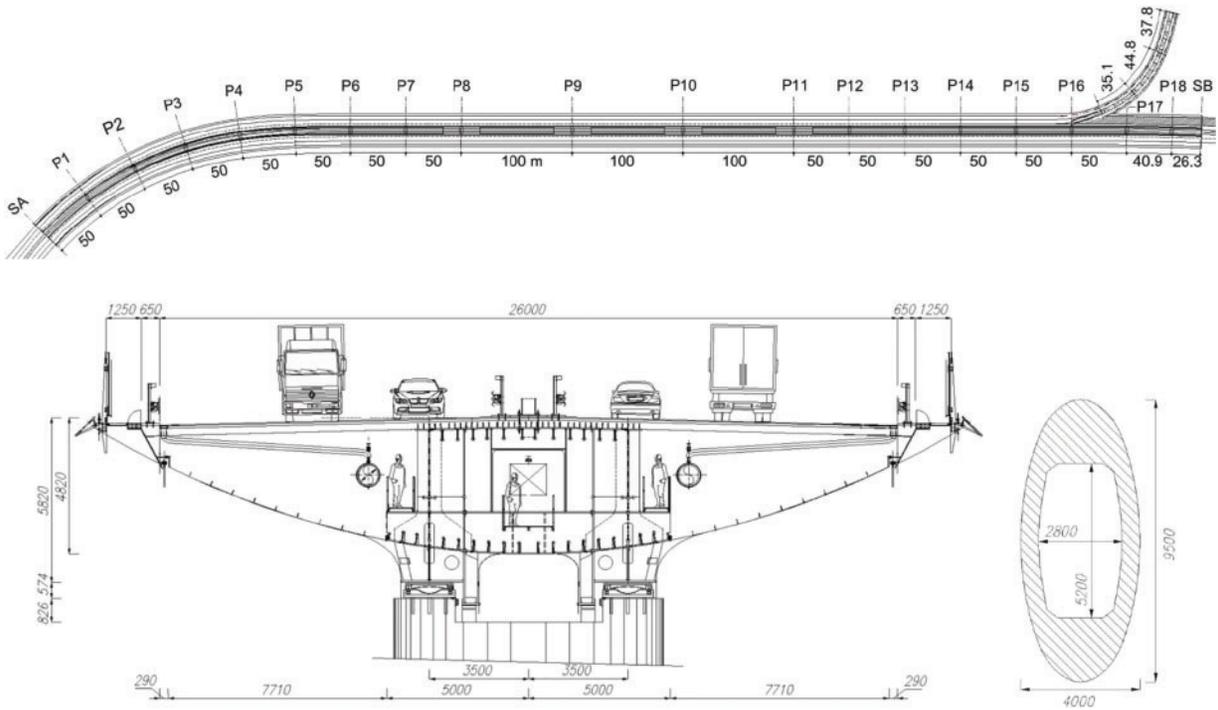


Figure 3. San Giorgio Bridge: Plan, cross-section of the deck and the piers

respectively, having a total length of 117.71 m. The ramp is supported by an abutment and three piers, 11.55, 26.3, and 35.8 m high, respectively, and has dimensions in plan of 4.75×2.10 m. The last pier is very close to the main deck.

The designer conceived a slender bridge with narrow piers to emphasize the lightness of the new structure. For this reason, the distance between the upper surface of the piers and the deck intrados is 1.4 m, greater than the conventional one.

The San Giorgio Bridge is also an example of advanced technology. It was designed to be an efficient and smart structure, with its integrated monitoring system, which allows:

- The monitoring of the service facilities, the environmental conditions, the structural behavior, and the degradation phenomena.
- The automatic inspection of the deck condition and the washing of the windbreaks and the solar panels.
- The creation of a database to better schedule the maintenance.

The isolation system is made up of 51 devices, two for each pier and three for each of the three abutments. The main bridge is seismically isolated by means of 42 devices, whose characteristics are shown in [Table 1](#):

- At each of the two abutments: Two multidirectional bearings and one longitudinal prismatic guide.
- At both end piers P1 and P18: Two multidirectional bearings.
- On each of the piers from P2 to P7 and from P12 to P17, which support the 50 m spans: Two single CSSs (i.e., with a single surface, in total 12 of B type and 12 of B + S type).

- On each of the central piers from P8 to P11, which support the 100 m spans: Two single CSSs with a higher vertical load capacity (in total 4 of A type and 4 of A + S type).

The deck of the accessing ramp has nine devices:

- On the abutment: Two multidirectional bearings and one elastomeric bearing.
- On each of the three piers: Two single CSSs.

The cross-section of the deck ([Fig. 3](#)) has a total width of 29.8 m, while the spacing between the devices is 7.0 m. The structural analysis proved the good performance of the isolation system both in static and dynamic conditions. The use of single CSS allowed optimizing the project. All checks, including the overturning one, were satisfied.

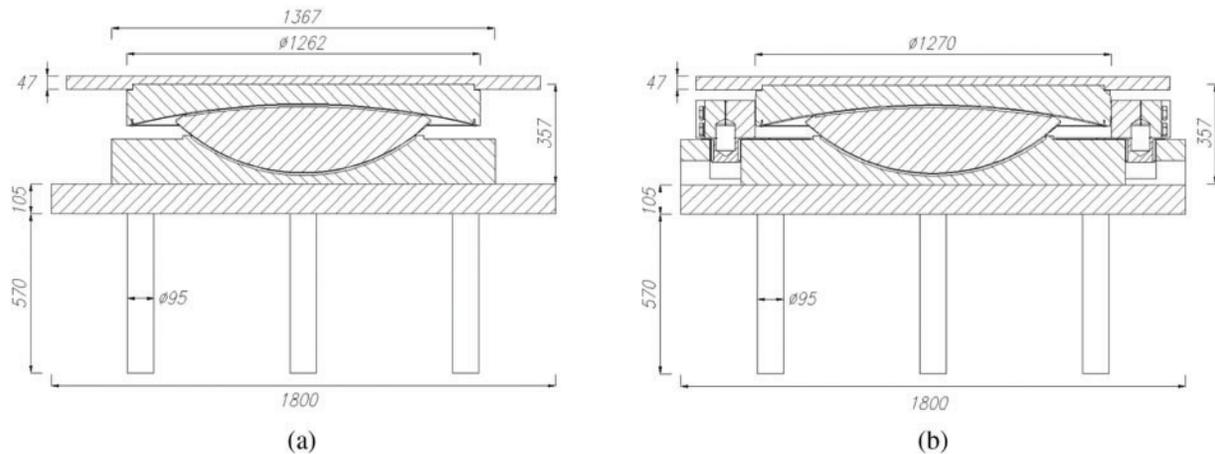
One of the two CSSs at each pier is equipped with a transverse fuse or S-plug (A + S and B + S CSS types), as shown in [Fig. 4](#), to avoid transverse movements of the deck in service conditions under non-seismic loads, such as wind action (i.e., ULS and service limit state). At the same time, longitudinal guides located in the same position allow expansion and contraction of the deck, also because the fuses are placed inclined with respect to the piers, to minimize the effects due to the thermal action.

The S-plugs will still be working in low-intensity seismic conditions (i.e., operation limit state SLO and damage limit state SLD, according to the Italian code), not allowing transverse movements nor modifying the dynamic response of the isolation system. The fundamental oscillation period is 2.0 s.

In extreme seismic conditions (i.e., life safeguard limit state SLV and collapse limit state SLC, according to the Italian code), all the S-plugs break, and the anti-seismic

Table 1. Main bridge: Characteristics of the devices

	Device type	Max vertical force (kN)	Max longitudinal horizontal force (kN)	Max trasversal horizontal force (kN)	Max longitudinal displacement (mm)	Max transverse displacement (mm)
SA abutment	Longitudinal prismatic guide	—	—	4000	±400	—
	Multidirectional bearings	15000	—	—	±400	±50
P1	Multidirectional bearings	35000	—	—	±375	±100
From P2 to P7	Curved surface sliders “B + S”	35000	—	3300	—	±350
	Curved surface sliders “B”	35000	—	1720	—	±350
From P8 to P11	Curved surface sliders “A + S”	60000	—	4400	—	±200
	Curved surface sliders “A”	60000	—	2450	—	±200
From P12 to P17	Curved surface sliders “B + S”	35000	—	3300	—	±350
	Curved surface sliders “B”	35000	—	1720	—	±350
P18	Multidirectional bearings	35000	—	—	±375	±100
SB abutment	Multidirectional bearings	15000	—	—	±400	±50
	Longitudinal prismatic guide	—	—	4000	±400	—

**Figure 4.** San Giorgio Bridge: CSS devices, (a) type A and (b) type A + S

protection is ensured by the devices, which have the following characteristics: Radius of curvature $R = 3.0$ m, fundamental vibration period $T_{is} = 3.0$ s, dynamic friction coefficient $\mu = 1\%$, and maximum displacement $d = \pm 350$ mm.

A + S- and B + S-type devices were designed to absorb the maximum shear force at ULS. This value is higher than the capacity of the S-plugs, which was determined by

SLV analysis in upper bound conditions. For A- and B-type devices, without S-plugs, the maximum shear force is obtained from the constitutive law of the devices and using the friction coefficient in upper bound condition.

The dynamic response of the structure was analyzed both with and without the contribution of S-plugs. For this reason, these elements were also subjected to fatigue checks

for a 300 kN force. The most severe condition is that at ULS, both in terms of stress and deformation. In fact, thanks to the use of the isolation system, the stresses on piers due to the seismic actions in the transversal direction are lower than those due to wind actions. In the same condition, longitudinal thermal displacements are also higher than the seismic ones. It is worth reminding that friction shall not be used to relieve this effect.

The re-centering capacity of the isolation system was verified. Inspection, maintenance, and replacement of the devices have also been guaranteed. For these reasons, vertical steel elements were placed (Fig. 5). These legs were designed to:

- Lift the deck with hydraulic jacks for isolator maintenance and replacement.
- Reposition the deck in case of imperfect re-centering of the isolation system after an extraordinary event.
- Guarantee a higher level of safety by acting as a constraint in case of displacements exceeding the design values, even if the CSS were dimensioned for the worst conditions.

Finally, at the shortest piers P1 (19.50 m) and P18 (11.0 m), only multidirectional bearings were located to make the stiffness characteristics of the entire structure as

uniform as possible and to guarantee the optimal behavior of the isolation system both in static and dynamic conditions.

The use of multidirectional bearings and longitudinal guides on the main bridge abutments limits the transversal displacements, optimizing the joints' behavior (± 400 mm in the longitudinal direction). The maximum vertical load for this kind of device is 35000 kN at P1 and P18, while the longitudinal guides are designed for a transversal load of 4000 kN. With reference to the single CSSs, the devices of the 50 m spans are characterized by a vertical capacity of 35000 kN, a maximum horizontal force of 3300 kN, and a design displacement of ± 350 mm. For the isolators of the 100 m spans, the previous values become 60000 kN, 4400 kN, and ± 200 mm, respectively. On the ramp, due to the presence of elastomeric bearings on the abutments, the joint is bidirectional (± 400 mm in the transversal direction, ± 350 mm in the longitudinal direction).

The Albiano Magra bridge

The Albiano Bridge over the Magra River (Fig. 6) between the villages of Caprigliola and Albiano Magra in the town of Aulla, Tuscany, replaced the previous five-span arch bridge along the SS330 road, built in 1948 and suddenly collapsed on April 8, 2020. Due to the coronavirus quarantine then in

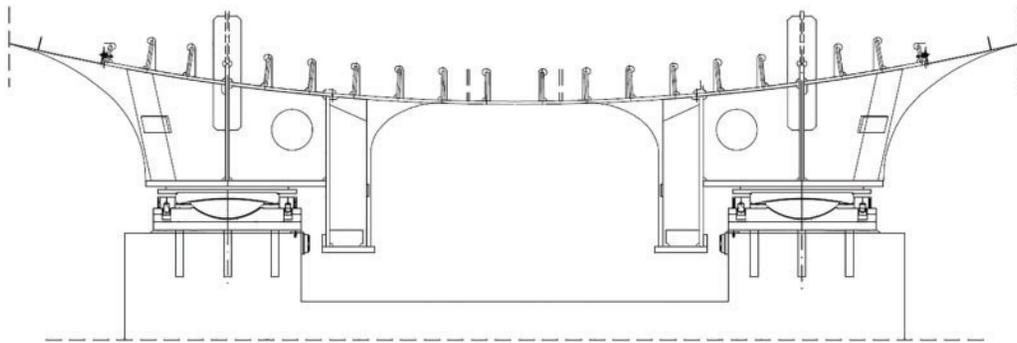


Figure 5. San Giorgio Bridge: Vertical steel “legs,” which are a safe system in case of displacements exceeding the design values but also allow lifting the deck with hydraulic jacks for maintenance and replacement of isolators, and the repositioning of the deck in case of imperfect re-centering after an extraordinary event



Figure 6. The Albiano Bridge over the Magra River

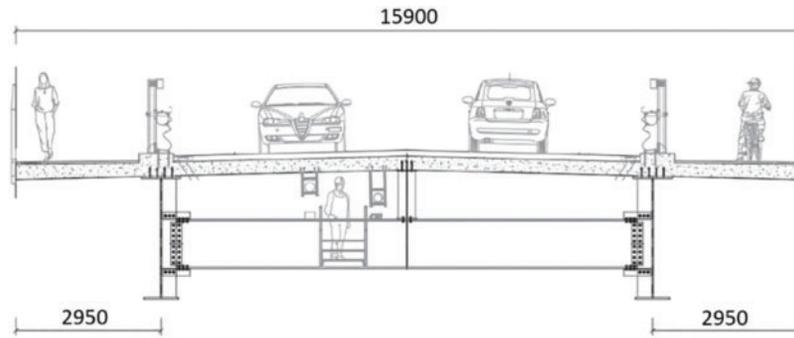


Figure 7. The Albiano Bridge: Cross-section

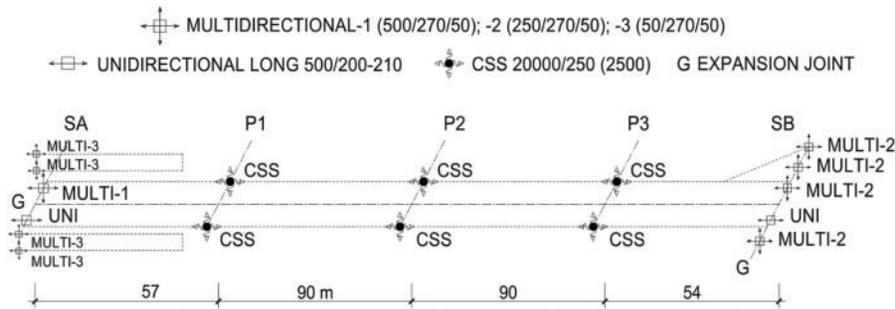


Figure 8. The Albiano Bridge: Anti-seismic devices

force, the traffic on the bridge was absent, so the collapse caused no injuries.

The new bridge, which was opened to traffic on April 30, 2022, has a continuous deck with a total length of 291.0 m and four spans. The two central spans have a length of 90 m, and the side ones are 57 and 54 m, respectively. The cross-section is composed of two main steel beams, having a variable height and spaced 10 m apart, a secondary beam between them, and a concrete slab. The deck, including the external pedestrian and cycle lanes, is 15.9 m wide at the piers (Fig. 7) and 27.0 m wide at Abutment B (Caprigliola side). Immediately after pier P1 and up to Abutment A (Albiano side), there are external lanes, independent from the main deck and running at different heights.²⁰

The isolation system is made of 13 devices for the bridge plus four for the external pedestrian and cycle lanes, deployed as follows (Fig. 8):

- Abutment A (SA): One confined elastomeric disc multidirectional bearing (MULTI-1) and one unidirectional longitudinal bearing (UNI).
- On both sides of Abutment A: Two multidirectional bearings for the external paths (MULTI-3).
- On each of piers P1, P2, and P3: Two double CSSs, with $R = 2.5$ m and $\mu = 0.055$.
- Abutment B (SB): Four confined elastomeric disc multidirectional bearings (MULTI-2) and one unidirectional longitudinal bearing (UNI).

The design of the new bridge had to consider the presence of multiple risks, such as hydraulic, structural, and seismic risks. For this reason, the anti-seismic devices were located at a height such as to be protected against 200-year design

floods and projected to guarantee their best behavior against wind and braking actions.

The main characteristics of the devices are shown in Table 2. In the longitudinal direction, the abutments are not loaded because of the presence of longitudinal and multidirectional bearings. Abutment B (Caprigliola side) is located on an unstable slope, subject to a monitored landslide. For this reason, the maximum displacement values obtained from the structural analysis were increased by ± 70.0 mm to prevent the risk of low movements of the slope. At the same time, low piers are only 2.0 m high with rounded edges in the transversal direction, to offer the minimal resistance to the river flow.

In the transversal direction, the choice was not to allow movements at the abutments to optimize the behavior of the joints and to guarantee a driving comfort. Even construction details benefit from this limitation. In fact, bridge parapets, gas and water pipes, telephone lines, and so forth, were designed to absorb only longitudinal displacements at lower costs. On the other hand, higher solicitations in the transversal direction do not cause problems in these elements. Transversal displacements at the piers are allowed by the deformability of the deck. According to the designers, the effectiveness of the isolation system in these conditions is guaranteed for bridges with more than three spans, as in the present case.²⁰

The CSS radius of curvature equal to 2.5 m allows re-centering in seismic conditions and absorption of braking and wind actions while neglecting friction.

A nonlinear dynamic analysis was performed, considering the local seismic response. In the lower bound design properties analysis (μ reduced by 20%), the fundamental

Table 2. Albiano Magra Bridge: Characteristics of devices

	Device type	Max vertical force (kN)	Max longitudinal horizontal force (kN)	Max trasversal horizontal force (kN)	Max longitudinal displacement (mm)	Max transverse displacement (mm)
SA abutment	Multidirectional bearing	5000	—	—	±200	±50
	Unidirectional bearing	5000	—	2100	±200	—
P1-P3	Curved surface sliders	20000		2000		±250
SB abutment	Unidirectional bearing	5000	—	2100	±270	—
	Multidirectional bearing	2500	—	—	±270	±50



Figure 9. The Filomena Delli Castelli bridge

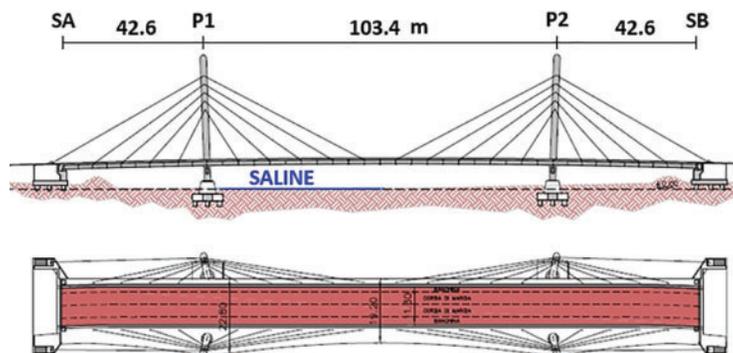


Figure 10. Filomena Delli Castelli Bridge: Longitudinal view and plan

period is 2.3 s in the longitudinal direction and 1.8 s in the transversal direction. In the upper bound design properties analysis (μ increased by 50%), the maximum forces acting on the piers are 1600 and 1150 kN, respectively.

The abutment multidirectional and unidirectional bearings are designed for a vertical load of 5000 kN with a

displacement capacity of ± 200 mm, considering the SLC seismic condition with a thermal effect increased by 50%. In the same condition, the maximum transversal force acting on unidirectional bearings is 2100 kN. About double CSSs, the maximum vertical load is 20000 kN with a horizontal displacement equal to ± 250 mm.

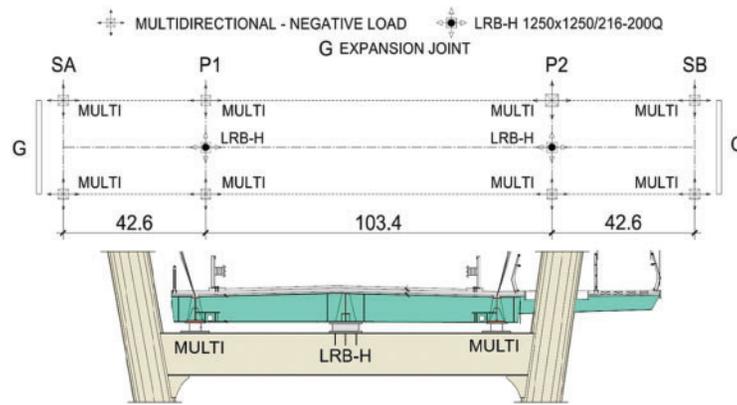


Figure 11. Filomena Delli Castelli Bridge: Layout of the constraints and detail at the pylons

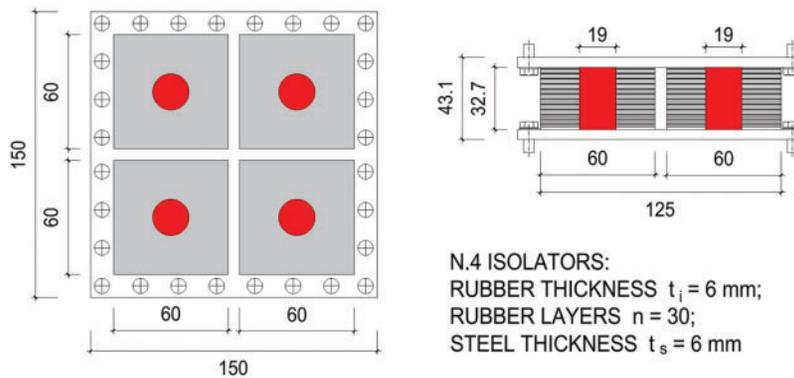


Figure 12. Filomena Delli Castelli Bridge: Elastomeric isolators

The Filomena Delli Castelli bridge

The Filomena Delli Castelli Bridge (Fig. 9), spanning the Saline River near its mouth at Montesilvano, Abruzzo, is a cable-stayed bridge with a central span of 103.4 m and two lateral spans of 42.6 m. Both the deck and the pylons are made of a mixed steel-concrete system (Fig. 10).

The deck has an overall width varying from 19.20 to 22.70 m. It consists of two longitudinal double-T steel beams, 1.20 m high and spaced 14.10 m apart, and a reinforced concrete slab with Predalles slabs arranged longitudinally on the transverse beams. These, with a height varying from 0.80 to 1.20 m, are placed at a longitudinal distance of 4.70 m in the central span and 4.26 m in the lateral ones and extend beyond the beams, cantilevering for a length varying between 4.00 m and 7.50 m at the upstream side and for 1.10 m at the downstream side.²¹

Each of the two pylons consists of two circular steel antennas with a diameter of 1.90 m and a height of 33.45 m at the upstream side and 36.40 m at the downstream side. The antennas are filled with concrete, reinforced with studs for the first 16 m of height. They are connected transversally by a steel transverse beam placed underneath the deck. Each antenna is inclined outward transversally by 10° for the upstream two antennas and 8° for the downstream two antennas, and longitudinally by 2°. At the base, each antenna is fixed to a truncated cone-shaped concrete element, which in turn is constrained to a foundation plinth supported by

nine piles (diameter = 1.20 m, length = 35 m). The plinths of the two antennas are connected by a concrete beam.

The stays are arranged in a semi-fan shape, anchored to the pylons on five levels, and to the deck spaced 9.40 m apart in the central span and 8.52 m in the lateral ones. The two pairs of outer stays are anchored to the abutment walls. The transverse distance of the anchor points increases from 14.10 to 26.10 m, thus ensuring a reduction in transverse bending.

The bearings of the main beams on the transverse beams connecting the two antennas and on the abutments are multidirectional PTFE bearings able to support negative loads.

One LRB is positioned between each transverse beam connecting the two antennas of each pylon and the corresponding transverse beams of the deck (Fig. 11). These bearings control the horizontal displacements of the deck and guarantee an increase in the vibration period and energy dissipation. For construction reasons, each bearing is composed of four isolators, each with a lead core and an equivalent horizontal stiffness of 4.25 kN/mm, thus ensuring a total equivalent horizontal stiffness of 17 kN/mm, equivalent viscous damping greater than 25%, and a maximum horizontal displacement of ± 200 mm (Fig. 12).

The Genzano Viaduct

The Genzano Viaduct (Fig. 13) is located near L'Aquila, at 722 m a.s.l., on a limestone rock geological site. It is part of the seismic retrofitting project that involves more than 20



Figure 13. View of the new Genzano Viaduct

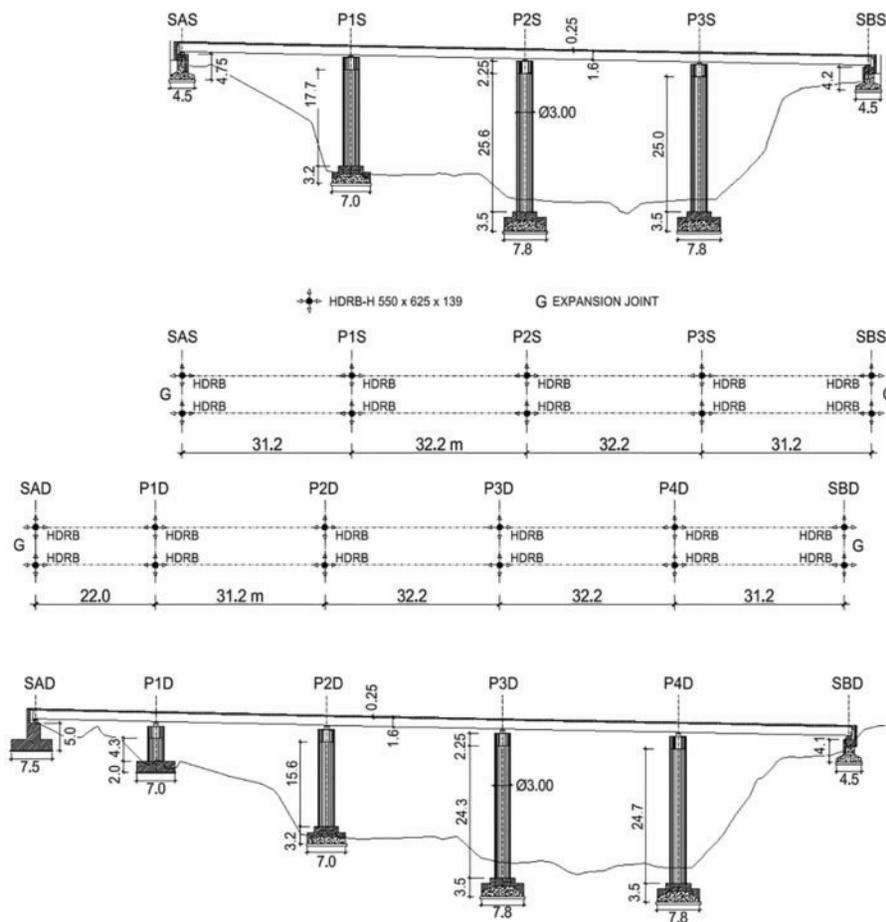


Figure 14. Genzano Viaduct: Longitudinal view and plan

viaducts along the A24 Rome–L’Aquila–Teramo highway. The design phase started at the end of 2017, so it was one of the first projects in accordance with the Italian Technical Code NTC2018. Furthermore, according to the indication of the Italian Ministry of Infrastructure and Transport, new viaducts had to guarantee a nominal life of 100 years due to their strategic importance for Civil Protection purposes, as demonstrated during the 2009 L’Aquila earthquake. This

translates into considering a design seismic event having a return period of at least 950 years for the structure, and a design seismic event with a return period of at least 1950 years for the design of the isolation devices.

The new Genzano Viaduct consists of two separate structures that replace the previous ones (Fig. 14).

They maintain the position of abutments and piers and, therefore, the number of spans and their lengths, except for

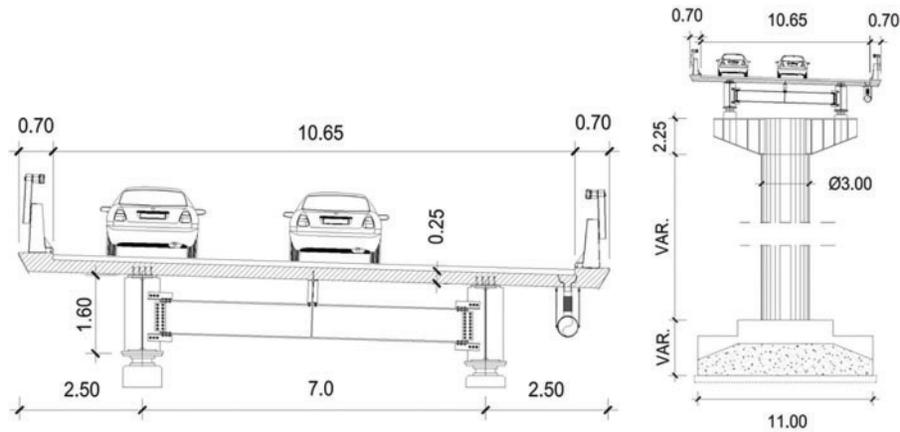


Figure 15. Genzano Viaduct: Transversal section and pier



Figure 16. Isolation devices of Genzano Viaduct: Panoramic view, scheme, and during deck launching

the first on the road toward Teramo, where a new abutment was realized to obtain a longer span of 22 m compared to the existing one of 18 m. The viaduct toward Rome has four spans, two of 31.2 m and two of 32.2 m, for a total length of 126.8 m. The viaduct toward Teramo has five spans, one of 22 m, two of 31.2 m, and two of 32.2 m, for a total length of 148.8 m.

Each deck is a continuous mixed steel-concrete girder made of two main beams spaced 7.0 m apart, with a secondary one in the central position and transverse beams. The new piers are full-section reinforced concrete and Cor-Ten steel. All the abutments are in reinforced concrete; the existing ones were retrofitted with tie rods to absorb the higher longitudinal forces transmitted by the new deck (Fig. 15). The direct foundations were retrofitted in all cases, except for the pier P1D, which was rebuilt.

The new structure was realized using crane trucks located at the base and the highway operation was always guaranteed thanks to the adjacent carriageway and to the night launching of the decks.

The seismic isolation system is composed of two HDRBs for each pier and abutment. The maximum vertical load in static condition is 6355 kN, while the maximum horizontal force in seismic conditions is 750 kN. Each device has an effective horizontal stiffness of 2.84 kN/mm and an equivalent viscous damping of 15%. A linear analysis, according to the Italian technical code, was performed obtaining a maximum displacement of 225 mm (Fig. 16).

The left carriageway was opened to traffic on June 29, 2021, and the right carriageway on June 10, 2022.

Conclusions

One of the world's first applications of seismic isolation in bridges was realized in Italy in 1976 with the Somplago Viaduct. Starting from this application, which is part of the history of seismic isolation, the development and application of this technology in Italy in the field of bridges and viaducts has been retraced. This process was linked to the development of appropriate technical standards that allowed its use, establishing the main rules to be observed in design, construction, and testing, and the use of new devices. Finally, four notable recent examples were selected and shown, each with unique characteristics, which demonstrate the potential of seismic isolation in protecting bridges against earthquakes.

The cases illustrated highlight how seismic isolation represents an optimal solution in various situations and for various structural, architectural, and functional needs that are difficult to achieve with traditional techniques. Among these, seismic safety must be foremost. Indeed, strategically important bridges must be operational even during and immediately after a strong seismic event.

Safety and rapid construction times are a perfect match for the San Giorgio Bridge, thanks also to its structural simplicity, characteristics that meet the need for an effective and safe infrastructure.

The same characteristics are found in the Albiano Magra Bridge and the Genzano Viaduct, structures located along major roads, subject to heavy traffic and connecting important and densely populated parts of the country.

But seismic isolation also allows for the right balance between functionality and elegance in naturalistic settings, always respecting the safety and resilience of the structure, as in the case of the Filomena Delli Castelli Bridge.

However, these are just a few examples of the multitude of seismically isolated bridges and viaducts present in Italy today from the perspective of documenting the Italian applications. Other challenges, not covered by this analysis, should be considered, such as maintenance, durability, and limitations, which will be the subject of a future paper.

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