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ISOLATED LONG OVERHEAD VIADUCTS: A SOLUTION FOR IMPROVE CITIZENS' MOBILITY IN HIGH SEISMIC COUNTRIES

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ABSTRACT

Big Cities with high density of population, especially when the growing of population is fast, are always in a difficult situation due to the increase of vehicular traffic. One solution for flowing the traffic and ease the movement of the people from one side of the city to the other is to move the traffic on overhead highways or railways. Of course, in high seismic areas this solution need a particular care to avoid damages to the structures below the viaducts as well as interruption of the service, especially in case of railway viaducts. The use of isolators instead of rigid bearings on top of the piers is a well-known technique that allows to increase the safety level reducing in the same time the cost of realization.

The paper presents two case studies. The first case is the Mexico-Puebla highway, a 19 km long viaduct able to serve 11 million vehicles has been built in 2016 in Mexico in the areas of Puebla, Veracruz, Tabasco, Tlaxcala, Chiapas, Oaxaca and Distrito Federal. This viaduct is supported by piers from 7 to 19 m with 4 carriageways and has been isolated with 676 lead rubber bearings supplied by Freyssinet. The second case is the Light Train Railway in Jakarta, Indonesia, a 42 km viaduct consisting of 903 million dollars of investment fully isolated with 4280 lead rubber bearings supplied by Freyssinet.

Keywords: Long Viaducts; Seismic Isolation; Lead Rubber Bearings; Full Scale Tests

1. INTRODUCTION

The growing of the world population and the global economy brings millions of people to move from country to big cities. This concentration of population in small areas has a consequence the need of new infrastructures for improving population mobility from one side of the city to the other.

To make the infrastructures and people mobility efficient with such sudden growing of population and to limit the traffic congestion at ground level, one solution is to build transport routes laying at different overhead levels, this is of course applicable to routes, highways or railways.

Overhead viaducts and intersections are an optimum solution to this issue, sometimes with complex layout. Care must be considered to not only protect what is on top of these infrastructures and guarantee service condition to the railway or highway, but also secure what is laying at the lower

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level. As a matter of fact, roads at the ground level should be considered, but also, in complex solution, other viaducts or even buildings. Moreover, in case of seismic areas, the effects of earthquakes could seriously damage the infrastructure itself including its collapse over the underlying structures or just making it out of service.

The best solution to protect from earthquake effects these viaducts is for sure the use of seismic isolators. The use of isolators instead of rigid bearings on top of the piers is a well-known technique that allows to increase the safety level reducing in the same time the cost of realization.

This technology allows to easily reduce the seismic acceleration on top of the piers by shifting the natural frequency of the rigid structure composed by deck and piers to a lower frequency which is typical of a structure where springs with quite low stiffness connect the deck to the piers. In addition to the frequency shift, isolators provide damping to the isolation system, reducing hence further the acceleration (Figure 1).

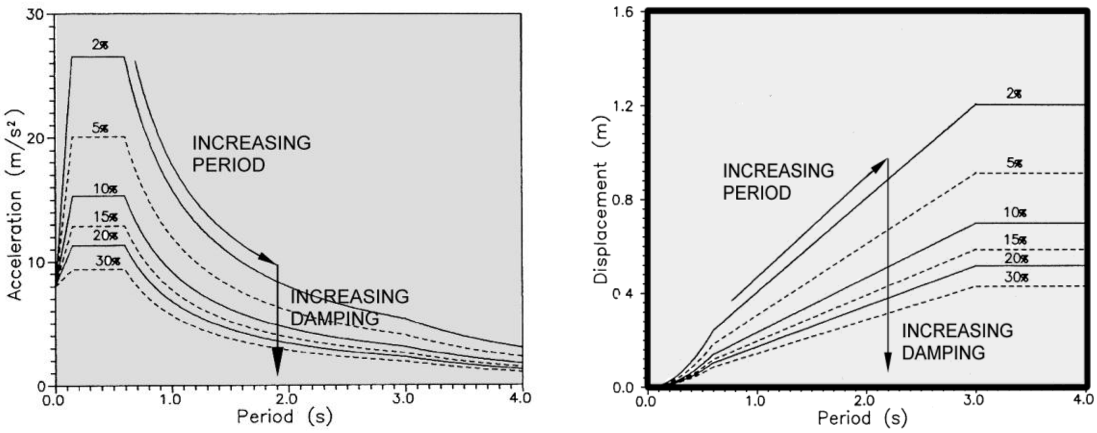

Figure 1: Reduction of seismic acceleration by period shifting and increased damping

In the following, two case studies are presented. They are on the opposite side of the world, but similar solutions have been found to solve the problem of efficient mobility of people in very big cities. The first case is the Mexico-Puebla highway, a 19 km long isolated viaduct able to serve 11 million people, built in 2016 in Mexico which suffered the earthquake of magnitude 7.1 on September 2017 without any damage allowing the transit of rescue vehicles even immediately after the event. The second case is the Light Train Railway in Jakarta, Indonesia, a 42 km railway viaduct. Both long viaducts were seismically isolated with Lead Rubber bearings supplied and tested by Freyssinet.

2. CASE-STUDY: MEXICO-PUEBLA HIGHWAY

The highway which links the two big towns in Mexico, will bring benefit to 1.5 million vehicles in the areas of Puebla, Veracruz, Tabasco, Tlaxcala, Chiapas, Oaxaca and the Federal District of Mexico improving the production and commercial area in South-East of the Country.

The viaduct of 19 km and 4 ways each direction has been designed by Euro Estudio, design company in Mexico D.F., and built in 2016 by the two contractors Pinfra and OHL. It is composed of a continuous deck made by pre-casted beams linked by a continuous slab casted in-situ, all laying on piers of height from 7 m to 19 m.

Between piers and decks, 676 Lead Rubber bearings (LRB) and 48 High Damping Rubber Bearings (HDRB) have been manufactured, tested and supplied by Freyssinet. In addition, more than 2000 m of expansion joints with seismic movement have been supplied by Freyssinet group.

Manufacturing have been carried out at FPC Rubber, the rubber factory of Freyssinet Group located in Italy. Prototype and Quality Control tests have been performed at Isolab, which is the Freyssinet testing facility located in Italy, while coordination of all the activities linked to production and testing has been carried out by FPC Italia. Final supply has been done by Freyssinet Mexico, the local branch of Freyssinet in the Country.

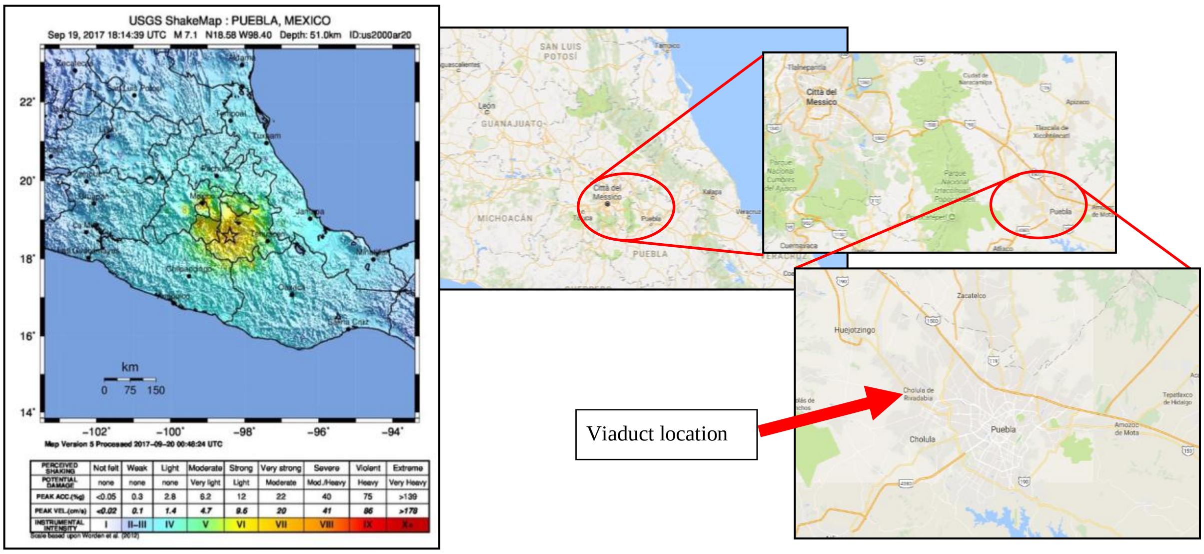

Figure 2: Location of the viaduct

Figure 3: The structure during construction phases and with isolators already installed

The isolation system is composed, depending on the spans and the ground characteristics, of two different types of Lead Rubber Bearings and one type of High Damping Rubber Bearing, as described in the Table 1.

Table 1: Characteristics of LRB and HDRB for The Mexico-Puebla viaducts

Type	qty	d_{max} (mm)	TDD (mm)	Static ULS N_{stat} (kN)	Seismic ULS N_{seism} (kN)	F_{max} (kN)	K_{eff} (kN/mm)	Energy dissipated per cycle (kNm)	Damping (%)
LRB 0.4-10 760x160	596	402	322	8669	5123	621	1.93	423	33.7%
LRB 0.8-10 700x144	80	362	290	8308	5100	795	2.74	523	36.1%
HDRB 1.4-16 700x70	48	140	110	3141	5500	847	7.70	94	16.0%

The stiffness and energy dissipated by the isolation system allows to reduce considerably the acceleration transferred from the piers to the deck despite the high ground acceleration, as shown in the Figure 4.

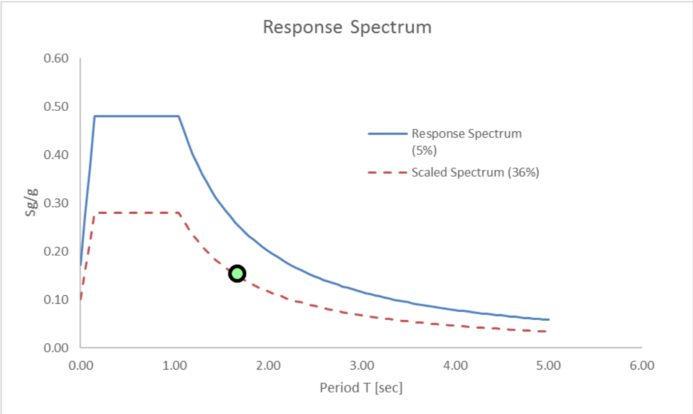

Figure 4: Seismic response of the Single Degree of Freedom

The required characteristics of stiffness and damping are in fact easily provided by High Damping Rubber Bearings and Lead Rubber Bearings. These devices, designed, tested and supplied by Freyssinet, are composed by a series of layers of dissipative elastomer and steel plates. The lead core placed in the center of the Lead Rubber Bearings allows to dissipate energy thanks to hysteretic cycles developed during the movement.

These devices, in addition to the characteristics of stiffness and damping needed for the seismic isolation, have also the major function of carrying the vertical loads, both in static and seismic conditions. Figure 5 shows a typical Lead Rubber Bearing with corresponding hysteretic cycles obtained by experimental tests.

Both LRBs and HDRBs have been designed and tested according to AASHTO Guide Specification for Seismic Isolation Design. Prototype tests for LRBs have been performed at Eucentre (European centre for training and research in earthquake engineering) in Pavia, Italy, while prototype tests for HDRBs have been performed at Isolab (Freyssinet Testing Facility) in Montebello della Battaglia, Italy. All quality control tests have been performed successfully at Isolab.

In addition to the huge quantity of Lead and High Damping Rubber Bearings provided for the viaduct, more than 2000 m of expansion joints type SFX 700/320 has been supplied to complete the bridge equipment and to make the single spans of the viaduct collaborating in the proper way. Single beams have been connected by a concrete slab cast in-situ. Anyway, every few spans an expansion joint has been installed to allow thermal movements of the structure.

A special type of expansion joint was installed, able to cover the gap between two adjacent spans even during seismic events. The joint is composed of reinforced rubber with a bridge plate to ensure the continuity above the gap also during the seismic event. It works like a classic rubber expansion joints for service movement, absorbing it by rubber deformation. The design service movement is ±160 mm in all the plan directions. During the earthquake, it is able to resist to much higher deformation, up to ±350 mm thanks to the wide bridge plate vulcanized in the central part of the rubber. The Figure 6 shows a section view of the seismic expansion joint while Figure 7 shows the joint during and after installation.

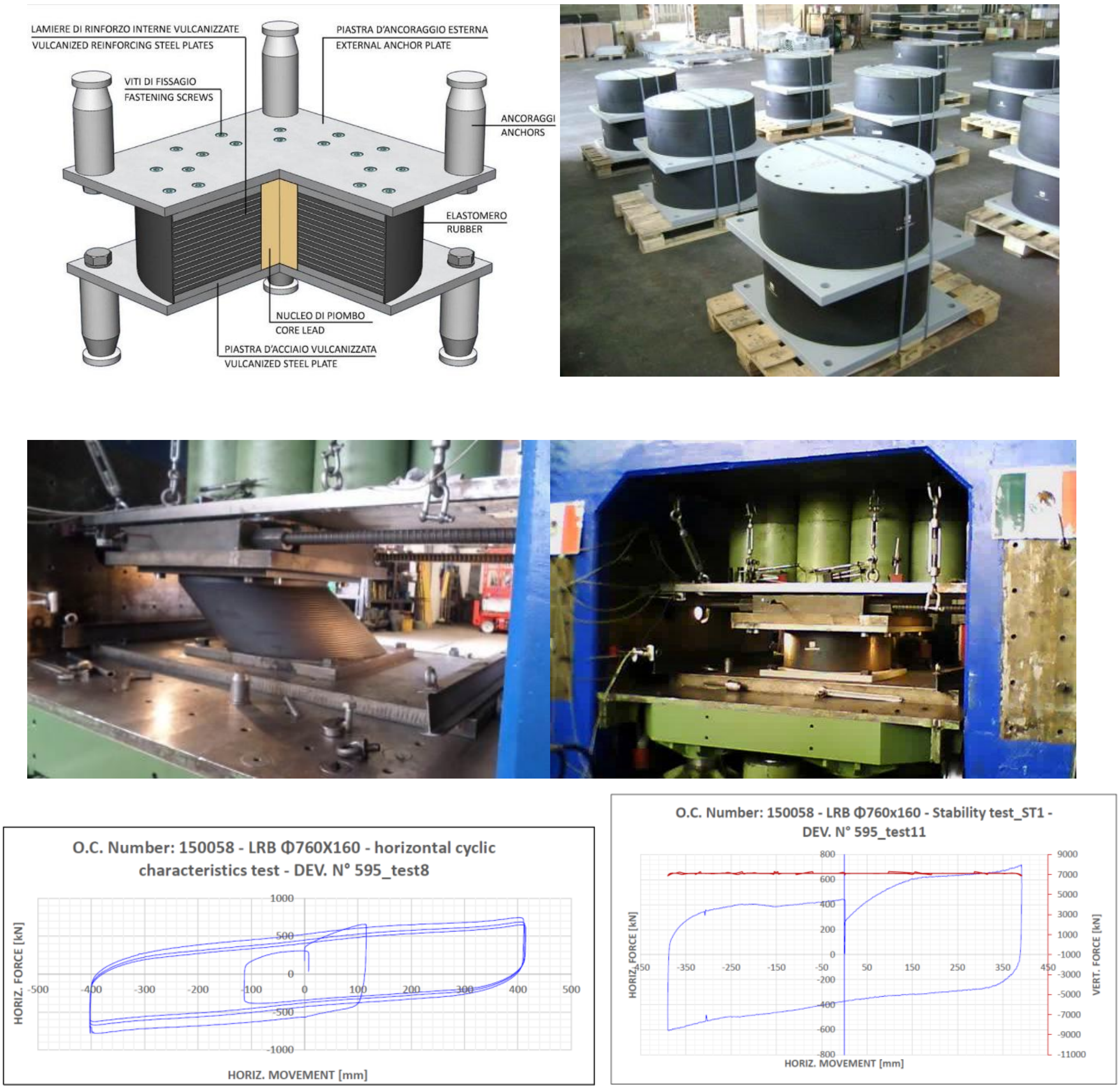

Figure 5: Tests at Isolab

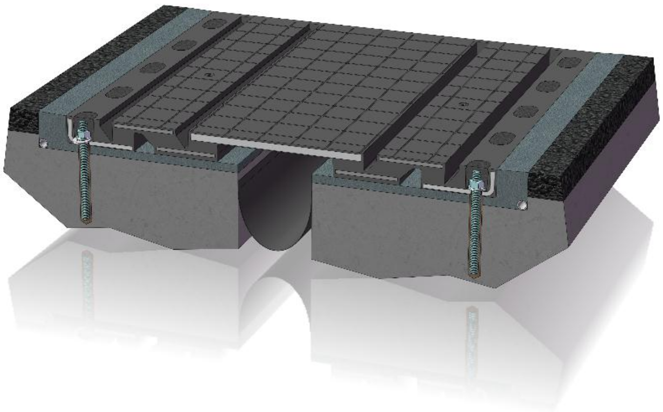

Figure 6: Section of the expansion joint

Figure 7: Expansion joint during and after installation

The viaduct, after few months from the opening to traffic, suffered an important earthquake of magnitude 7.1 in September 2017. The inspection on site showed no sign of damages demonstrating that the isolation system protected in a due way the overall structure. It was by fact perfectly working during and after the seismic event, allowing the traffic of rescue vehicles even immediately after the earthquake, helping population during those difficult days.

3. CASE-STUDY: LRT JAKARTA

The Greater Jakarta which topped 31 million inhabitants, is the fourth most populous metropolitan area in the world. A huge program has been launched to improve the urban transport in the capital city, including the construction of a Light Rail Transit (LRT).

The Jakarta LRT is a network of 6 elevated lines that will totalize 83 km. The phase 1 consists of the lines 1 and 5, with 43 km and 18 stations. The contractor PT Adhi Karya, was appointed in 2015 by Indonesian government to build the whole project in a very tight schedule. The LRT must be commissioned in 2018, before the 2018 Asian games. In addition, the project is challenging because Jakarta is in a high seismic zone, soil conditions are difficult, and operability must be maintained after an earthquake.

In order to meet the tight schedule and reduce construction costs, Adhi Karya selected the U shaped viaduct solution developed by Systra and the seismic base isolation with Lead Rubber Bearings (LRB) developed by Freyssinet.

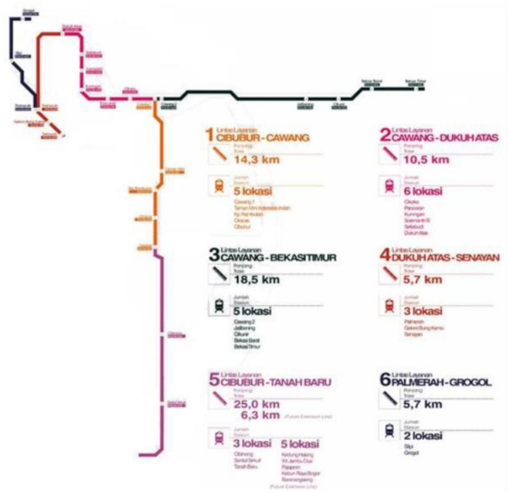

Figure 8: Light Rail Transit of the Greater Jakarta

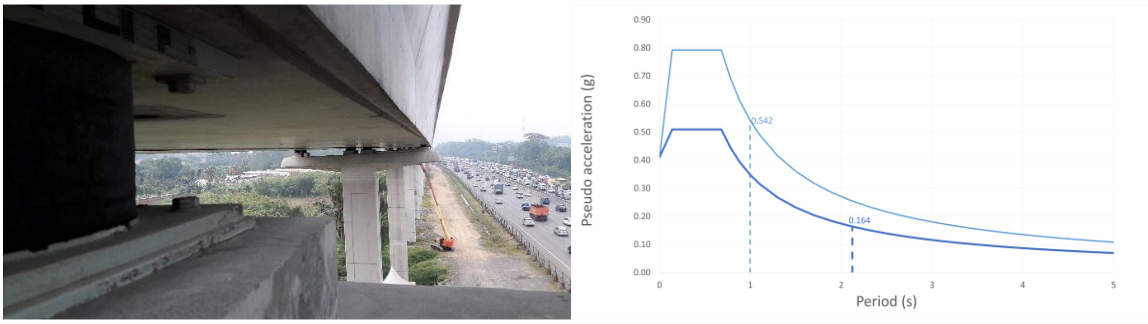

Figure 9: View of the LRB isolation level, between the precasted piers heads and the U shaped viaducts and the Response Spectrum of a span with and without isolation system

The non-isolated structure shows a first mode period of 1 s. The working point on a response spectrum is behind the peak acceleration part, which means that the non-isolated structure shows a substantial displacement during an earthquake. To make the isolation system efficient, a high flexibility and a high damping were required.

In order to develop these two characteristics, the best solution is the use of Lead Rubber Bearings with a large lead core and a soft rubber compound. The projects LRBs have been designed with a yielding force Fy equal to 8.5 % of the vertical weight, and a second branch stiffness krubber that is, per deck, 3.5 times smaller than the infrastructure’s stiffness.

This enabled to reach an isolation period of more than 2 s and a total damping of 22 %. The earthquake loads have been reduced by 70 %, while the displacement was increased by only 37 %.

Including the LRBs, the total project cost reduction only due to the base isolation was around 20 %.

For the project, depending on the ground characteristics and position of installation, different types of LRB have been designed tested and supplied by Freyssinet. Manufacturing have been carried out at FPC Rubber, the rubber factory of Freyssinet Group located in Italy. Type Tests and Factory Production Control tests have been performed at Isolab, which is the Freyssinet testing facility, located in Italy, while coordination of all the activities linked to production and testing has been carried out by FPC Italia. Final supply has been done by Freyssinet Indonesia, the local branch of Freyssinet in the Country.

The main characteristics of the Lead Rubber Bearings provided for the LRT Jakarta are summarized in the Table 2.

Table 2: Characteristics of LRB and HDRB for The LRT Jakarta viaducts

Project	Type	qty	d_{max} (mm)	d_{bd} (mm)	Static ULS N_{stat} (kN)	Seismic ULS N_{seism} (kN)	F_{bd} (kN)	K_{eff} (kN/mm)	Energy dissipated per cycle (kNm)	Damping (%)
Turnout	LRB 0.4-10 760x156	130	390	256	3500	1800	414	1.62	227	34%
Soil D	LRB 0.4-10 385x90	4014	214	140	1610	626	84	0.60	20	27%
Soil E	LRB 0.4-10 510x120	136	290	193	1610	626	160	0.83	56	29%

All the devices supplied are provided with CE mark allowing to ensure a high-level quality control. This is one of the first and for sure the widest application of CE marked seismic isolators outside Europe.

To apply the CE mark to a such huge number of devices, many tests have been performed at Isolab (Freyssinet Testing Facility) in Montebello dell Battaglia, Italy. Type Tests for all types of isolators supplied and Factory Production Control tests on 20% of the supplied quantity. This means in total almost 860 tests to be performed in a few months, in order not to delay the site activities.
A special testing equipment at Isolab (Figure 10) has been designed by Freyssinet at Freyssinet Product Company based in Italy and installed by Isolab engineers in only 6 months to be ready for the huge number of tests to perform. One of the primary input of the design for the testing equipment was to be flexible in changing test layout and in the same time to allow quick replacement of the devices to test. The goal has been completely reached since time for setting up a complete FPC test on a couple of devices (installation of devices, test, removing of devices) was of 30 minutes.

Figure 10: Isolab testing equipment for LRT Jakarta LRB and test performed

4. CONCLUSIONS

Two important case studies have been presented in this paper showing how overhead viaducts, both for highway and railway, can help the people mobility in big cities without impacting the ground vehicular circulation. On the contrary, the idea is to create more space on top to build new and safer infrastructures.

In high seismic areas, it can be very easy and cheap to protect structures against earthquake effects by using the seismic isolation, if properly designed for the ground characteristics and layout exigencies. Performing in a correct and industrial way tests on the seismic devices is also a key element for the success of the project. For the two case-studies, a huge quantity of tests has been performed to check the design isolators performances and their constancy along the full time of supply. Quality control and certification is of primary importance: if not tested and controlled under certification as CE mark, isolators could have not the expected properties and consequently not properly isolate the structure during an earthquake that could vanish the full investment.

5. REFERENCES

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