Application of Seismic Isolation System in an Existing Structure: Importance to Protect Schools

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SUMMARY
The paper describes the application of a seismic isolation system in schools (two particular cases in Avezzano-L'Aquila).
The problem connected to the high seismic risk increased during the last years and, particularly in Italy, this problem involves many structures made by concrete built around the 60s and 70s. Moreover these schools are located in the area where the big earthquake occurred in 2009. Basing on the new knowledge of the seismic events and construction technologies, those structures are not able to support the seismic requirement but, nevertheless, most of them represent a symbol or an important architectural element. The proposed operation was to insert an isolation system, with a particular system of clamps designed to temporarily support the structure during the intervention. Particular emphasis is given to the requirements of the main purchasers (Italian local administration): time and safety of the intervention and the durability of the system.

Keywords: old concrete building, retrofitting technologies, structure with a high social importance

1. INTRODUCTION

Italy, as for many others European countries, is in a very particular situation concerning the general condition of many of existing buildings and structures. Many building are related to an old concept from the construction technologies point of view, indeed a lot of them are concerning from 70's or still before until some centuries ago. Many of those mentioned structures, still now, cover an important rule from a strategic and cultural point of view; in fact, above to represent the historical-cultural heritage of Italy (as for others country), in some of them are placed of institutional offices, important for the efficiency of the country as: city hall, hospitals, schools, courts, etc.

One of the most relevant problems connected to the administration of those structures is connected to interface the real structural behaviour related to the new standards or technical improvement. Obviously from this point of view, a strategic importance is connected to the seismic risk. Just the seismic risk represent the main problem for a country as Italy; in fact, from the following picture (Figure 1.1.), is easy to see how this problem is relevant for all the country.

Due to those reasons, and also from the economical point of view, in most of cases is not possible or acceptable to demolish the buildings and so is interesting find some solution (Figure 1.2.) in order to adapt them with the new structural demand; generally speaking is possible to say that there are three main possibility and, case by case, is possible to chose the best solution considering the followings main aspect: structural reinforcement, install isolation devices or install a brace reinforcement system.
The purpose of this paper is to show how the solution with base isolation system will be the more suitable in order to adapt the behaviour of the structure reducing as much as possible the structural reinforcement. Insert a base isolation system can guarantee the complete efficiency of the structure without modify the general outlook; especially this aspect is important for the schools because can guarantee the not reduction of the available area for students. All that is possible because all the retrofit intervention are concentrated in one specified area of the buildings.

All those things will be described making reference to two projects where this system was applied.

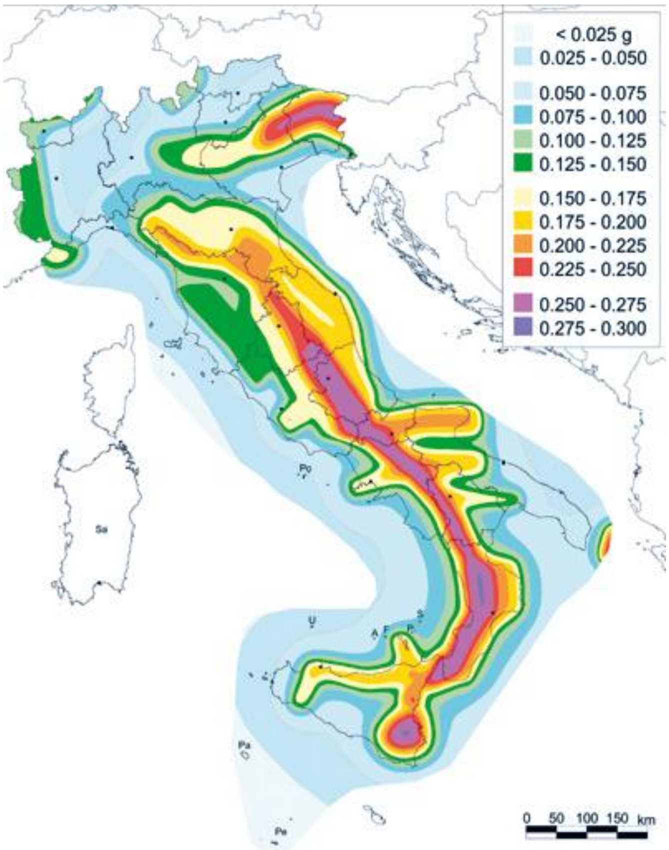

Figure 1.1. Map of the seismic risk in Italy

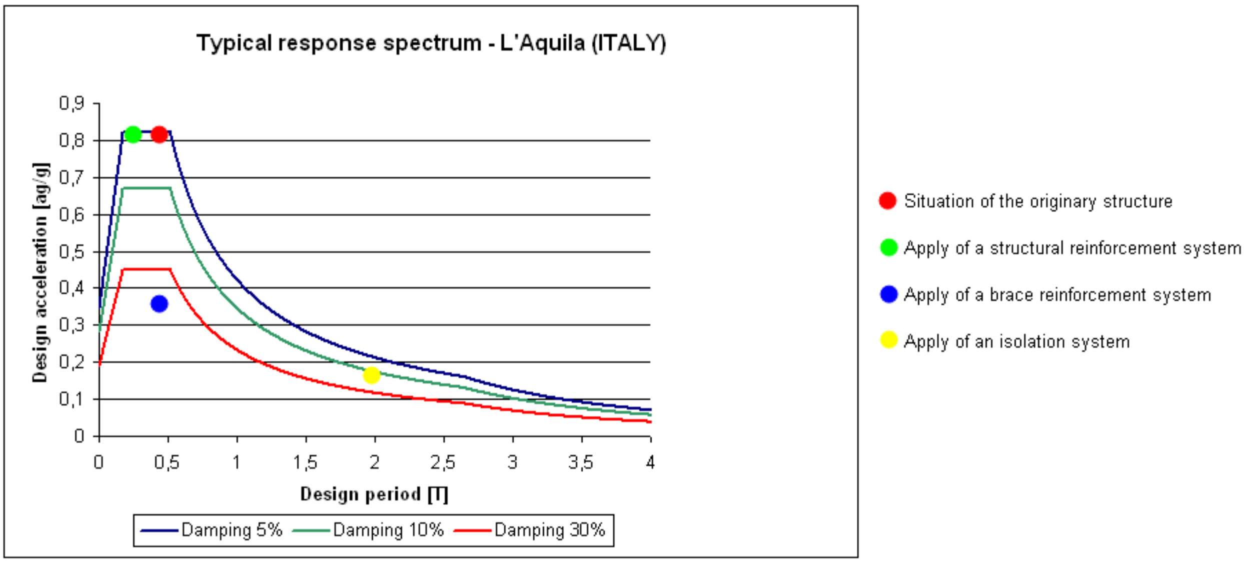

Figure 1.2. Different effects due to the application of different retrofitting system

2. ADVANTAGES OF A BASE ISOLATION SYSTEM AS RETROFIT TECHNOLOGY IN THE MENTIONED PROJECT: TWO SCHOOLS IN AVEZZANO (L'AQUILA)

The project from which will begin the study and the application of the base isolation system is the retrofit of two public schools in Avezzano (L'Aquila - Italy); after the earthquake occurred the 6th April 2009 the seismic emergency becomes relevant for all the area around L'Aquila (epicentre of the seismic event). At the beginning the first problem tackle was to find a temporary housing solution for all the people with a damaged or destroy house.

After this first step, while the reconstruction of the city proceed slowly due to many internal problems, the local administration decided to focus with a strong involvement to the retrofit of some public buildings that could take as example for all the reconstruction activities and, generally speaking, for the restart of the normal life in the area.
Following this intent were chosen some schools (Figure 2.1. and Figure 2.2.) where apply an efficient retrofit system; the main required qualities were: the velocity and the safety of the intervention and the strong and of long duration system.

In the following chapters it will be described how the installation of a base isolation system can fully feel those requirements. In particular will be studied two relevant cases (Figure 2.1. and Figure 2.2.).

Figure 2.1. Project number 1: institutes "G. Galilei" and "L.B. Alberti" in Avezzano

Figure 2.2. Project number 2: institute "A. Serpieri" in Avezzano

All the checked schools have the peculiarity to have a story between the foundation level and the ground level; moreover in the both schools this mezzanine floor is dedicated to place laboratory and school depository. For all the described reasons this floor looks suitable for the installation of a base isolation system: in this way all the interventions can be localized in only one area of the institutes and in particular in the one where problems connected to the architectural and functional aspects are less relevant. Nevertheless in the upper structure the safety of the structure can be guarantee without any structural intervention.

This result comes from the concept that one building made with construction technologies of 30 or 40 years ago is designed with a reduced level of seismic area; as example the horizontal load to be applied in those structures during the original design phases is equal to the 7% of the seismic mass. In order to adjust the structures with the actual construction rules, where the horizontal load is calculated from a precise response spectrum, is possible to proceed in two different ways: the first is to increase the capability of the structure until rich the required seismic action and the second is to reduce the seismic action until the limit endurable for the structure introducing a base isolation system (Figure 2.3.). This technology can fully guarantee that, also after a seismic event, no structural damages will occur in the buildings (without apply concept connected to the capacity design)

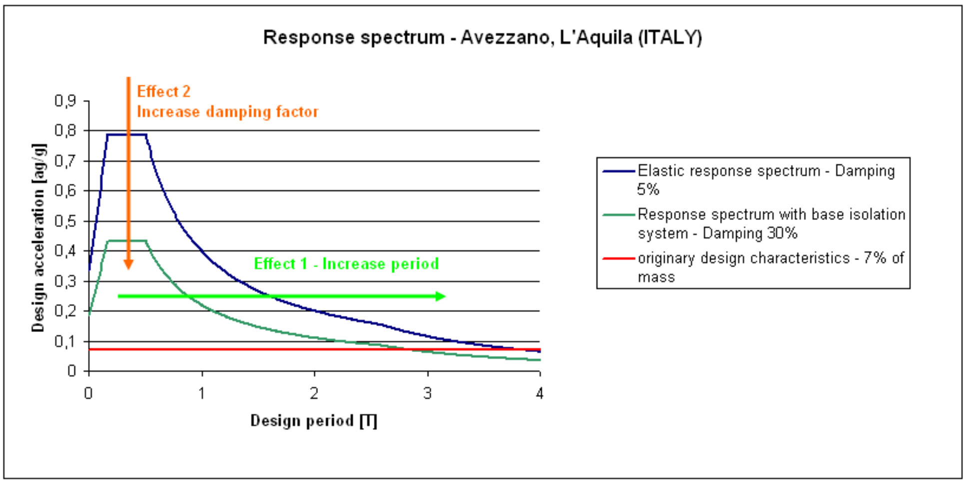

Figure 2.3. Response spectrum in Avezzano

From the technical point of view is possible describe the behaviour of a base isolation system with two effects: the increasing of the effective period (T_{eff}) of the structure and the increasing of the effective damping factor (ξ_{eff}). Is possible to say that originally the structure follows the behaviour in Eqn. 2.1:

$$\begin{aligned} T_{eff} &\approx 0{,}5\,\text{sec} \\ \xi_{eff} &\approx 5\% \end{aligned} \tag{2.1}$$

Following this particular response spectrum the target of the base isolation system is to keep the behaviour in Eqn. 2.2.

$$\begin{aligned} T_{eff} &\geq 2{,}85\,\text{sec} \\ \xi_{eff} &\approx 30\% \end{aligned} \tag{2.2}$$

Following those characteristics is possible guarantee that the horizontal load applied on the structure is less then the limit originally used for the design; is possible guarantee that is not necessary apply any reinforcement on the upper structure and in this way is possible to guarantee the perfect functionality of the schools after the retrofit project.

3. ISOLATION SYSTEM DEVICE: CURVED SURFACE SLIDERS

As isolation technology there are several type of devices, for the described projects was chosen the curved surface sliders (pendulum system); the peculiarity of those devices is that they can surely guarantee to reach the expected behaviour; in fact the dynamic behaviour is belong to two mechanical characteristics (effective radius -R- and friction coefficient -μ-) and others characteristics belong to the structure and to the interaction with the spectrum (seismic mass -M-, seismic load -V-, effective stiffness -K_{eff}- and dynamic displacement -D-), from which is possible define the effective period and the effective damping ratio as shown in Eqn. 3.1.

$$
\begin{aligned}
&R = 4000mm \\
&\mu = 3\% \\
&D = 141mm(SLV) \\
&T_{eff} = 2\cdot\pi\cdot\sqrt{\frac{M}{K_{eff}}} = 2\cdot\pi\cdot\sqrt{\frac{V}{\left(\frac{V}{R}+\frac{V\cdot\mu}{D}\right)\cdot g}} = 2{,}95\sec \\
&\xi_{eff} \approx \frac{2}{\pi}\cdot\left[\frac{\mu}{\mu+\frac{D}{R}}\right] = 29\%
\end{aligned}
\tag{3.1}
$$

With this kind of devices, in accordance to the Eqn. 3.1, is possible to use a dynamic linear analysis (Figure 3.1.) and obtain a result that can guarantee the efficiency of the intervation:

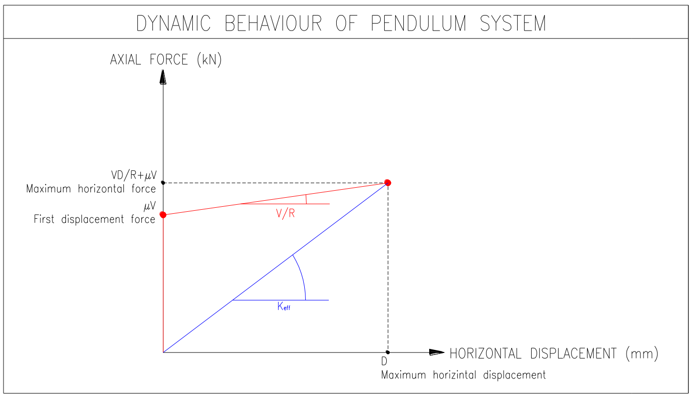

Figure 3.1. Sketch of the dynamic behaviour of the devices

Moreover, within the different types of curved sliders, the chosen one was the double surface device. The main advantages of the double surface device are: reduction of the plant dimension of the devices (Figure 3.2.) and the shear of the secondary effects (eccentricity) between the lower and the upper structure (Figure 3.3.).

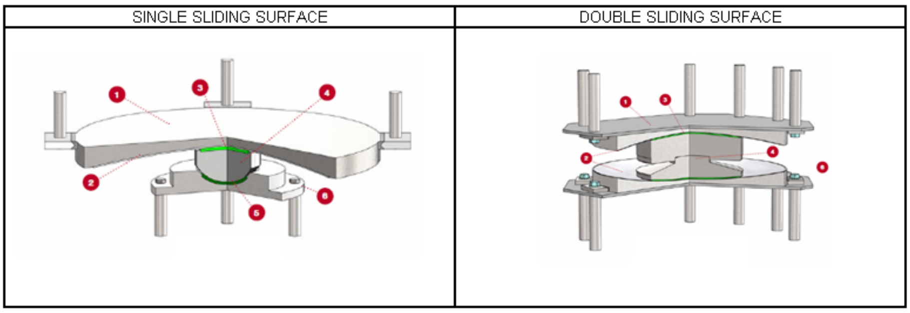

Figure 3.2. Sketch of single and double curved surface slider (pendulum)

In an existing structure is very important to find the devices not only in accordance with the technical point of view; is necessary to check the installation capability and, for this reason, is important to reduce as much as possible the plant dimensions: more details of this characteristics will be described in the next chapter.

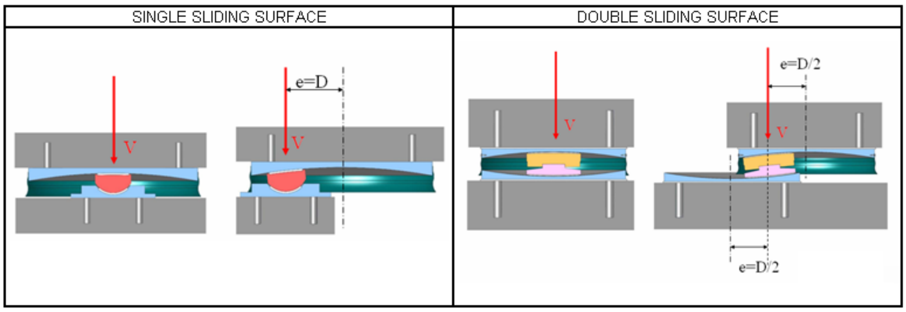

Figure 3.3. Eccentricity effects in single and double curved surface slider (pendulum)

Introducing an isolation system in an existing structure is necessary to guarantee the structural capability of the connection elements of the buildings: the upper part of the column (first upper story) and the lower part of the column (foundations): more details of those reinforcement will be described in the next chapter.

In the following table are defined all the type of devices used in the two mentioned projects (Figure 3.4.):

Table 3.1.

Project	**Device load [kN]**	**Device displacement SLC [mm]**	**Number**
Institutes “G. Galilei” and “L.B. Alberti	1.500	+/-310	110
Institutes “G. Galilei” and “L.B. Alberti	2.500	+/-310	27
Institutes “G. Galilei” and “L.B. Alberti	4.000	+/-310	1
Institute “A. Serppieri”	1.500	+/-310	103

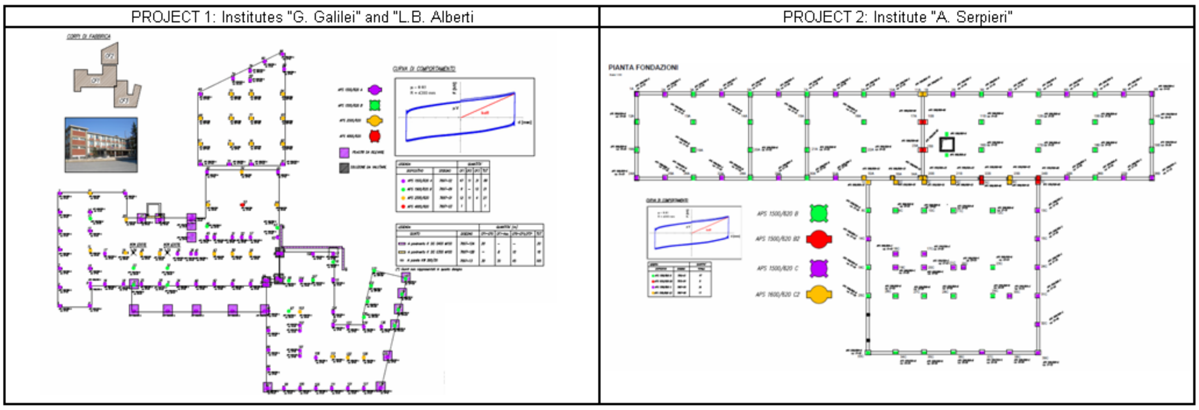

Figure 3.4. Plant of the two projects: distribution of the devices

4. INSTALLATION TECHNOLOGY

The installation procedure, specially for the retrofit projects, is very important in order to realize a safe work; moreover, due to the requirements given by the local authorities, another relevant aspect has to be the velocity of the procedures.
For fully respect those requirements the used system, studied with preliminary tests in laboratory, is realized by a double system of clamps connected for friction to the existing columns; the clamps are placed around the square columns and the tensile load is given by some post-tensioning bars. In particular is placed two sets of clamps: one upper and one lower respect the device placement. Each set is composed by two primary and two secondary clamps placed in two opposite sides of the columns; the bars, placed between each couple of clamps (primary or secondary) can be loaded in order to apply the friction load to the columns.

After the tensioning of the bars is possible to install four jacks between the lower and the upper clamps and active them in order to unload the internal part of columns. At column unloaded is possible cut it and insert the isolation devices (Figure 4.1.).

Due to this tricky installation procedure is necessary check that all the preliminary procedures are safety made; very important is the reinforcement of the columns and that is necessary because the columns have to guarantee to do not collapse with the tensile load applied by the clamps (minimum compressive stress on the column equal to 25 MPa). Is important to consider that the structural configuration of the isolated story is totally changed after the installation; for this reason is also necessary apply a structural reinforcement of the columns and moreover is important the reinforcement of the connection elements: between the columns and the devices and between the columns and the lower or upper structure. A detail, important from the safety point of view, is that all this process don't require any hole or the installation of any additional device; in this way is avoid to compromise the structural resistance of the columns during the operation phases.

For all those reasons all the phases of the installation procedure are controlled by an electronic system and, moreover, the velocity of the intervention is guarantee by the utilization of many sets of clamps: is possible organize the work phases in order to optimize the procedures and install up to 3-4 devices per day.

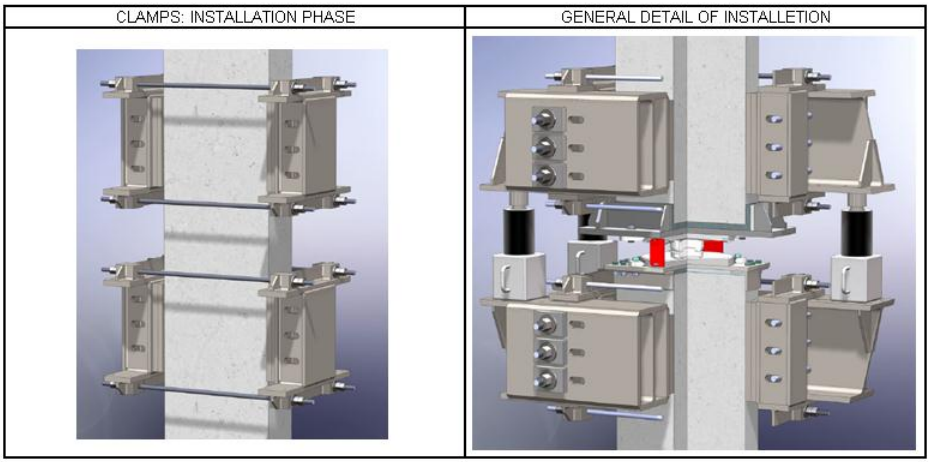

Figure 4.1. Two different sketch of the installation phases

Figure 4.2. Real phase of the installation procedure

From the upper picture (Figure 4.2.) is possible to see all the system as previously described: the red one are the primary clamps, the yellow one are the secondary clamps; between the clamps are installed the jacks and is also connected an electronic system for check and control all the installation phases. In this way is possible guarantee a correct and fast installation of the devices ((Figure 4.3.).

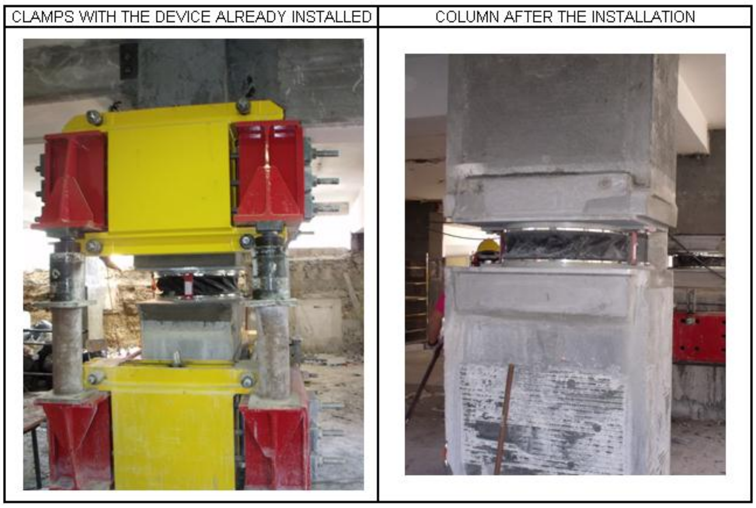

Figure 4.3. Real phases of the installation procedure

5. CONCLUSIONS

The introduction of a base isolation system can be a good solution in order to install an efficient and advanced technology for avoid any risk for the structural behaviour of an existing building during and after a seismic event. The installation of this system should take under consideration some peculiar phenomena, if those phenomena are neglected the general behaviour of the structure can be compromised. In this paper is described a particular solution of devices (pendulum system) and a particular technology for the installation; more in details the installation procedure is studied in order to fully combine the requirement of velocity and safety, for this reason the studied system provide many solutions for avoid any problem cause for any unknown technical characteristic of the structure. Another peculiarity of the system is that the phases are easy, checked and adaptable for any particular case.

Appling this solution are guarantee all the requirement given by the local administration and with less then three months of work around 250 devices were correctly installed and the schools could be open.

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