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# SEISMIC RETROFIT OF STRATEGIC MASONRY STRUCTURES WITH BASE ISOLATION TECHNIQUE: THE CASE STUDY OF "GIACOMO MATTEOTTI" SCHOOL BUILDING IN GUBBIO, ITALY

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## *Abstract*

Seismic retrofit of existing structures is an extremely important topic in the field of earthquake engineering. For strategic structures such as school and military buildings, bridges and infrastructures in general, the expected performance level is further raised compared to conventional structures to guarantee two fundamental targets: to resist the ultimate design seismic action corresponding to the life safety limit state and to guarantee immediate occupancy after an earthquake event. This means no damage to the structural elements as well as protection of internal equipment from excessive accelerations. Structure functionality is therefore the minimum acceptable level of retrofit for strategic structures.

In case of masonry buildings located in medium-high seismicity zones, conventional retrofit (i.e. wall-to-roof and wall-to-floor anchorage, out-of-plane wall bracing, diaphragm strengthening) does not allow to fully achieve the above objectives. Furthermore, the application of these techniques causes an important and invasive impact on the structure, distorting the building on both architectural and functional level.

Base isolation is a technical solution that allows to drastically reduce the seismic demand on the structure using special anti-seismic devices characterized by high horizontal flexibility.

This paper describes the application of seismic isolation technique to protect the "Giacomo Matteotti" school building, located in the city of Gubbio, Italy. The building was built in the 1940s, and it is made of cast stone and bricks and reinforced concrete-hollow tiles mixed floors. The building has three floors, a total area of 6.000 m$^2$, an inter-storey height of 4 m and a total volume of about 23.750 m$^3$.

The City of Gubbio (Umbria region, Italy), is located in an area where strong earthquakes can occur, with expected peak ground acceleration on rock soil equal to 0.29g for 475 years return period (i.e., 10% exceedance probability in 50 years).

For the base isolation system, Freyssinet has supplied 94 anti-seismic rubber isolators ISOSISM® type HDRB-H 550x155 and 93 flat sliders with confined elastomeric disc TETRON® type CD GL 3000.600.600 in order to reduce the eccentricity between centre of mass and centre of stiffness of the isolation system and consequently the torsional effects on the superstructure.

This paper describes the performance characteristics of the isolators with particular attention to the experimental dynamic response. A special focus is given to all the construction phases and details necessary to isolate a masonry structure.

*Keywords: masonry structure, seismic isolation, energy dissipation, anti-seismic rubber isolators, retrofit procedure.*

## 1. Introduction

Seismic retrofit of existing structures is a very topical issue in the field of seismic engineering. Moreover, strategic structures such as school and military buildings, bridges and infrastructures in general, must not only be protected against earthquakes but must ensure immediate occupancy and full functionality after a seismic event. In case of masonry buildings located in medium to high seismicity areas and designed for static loads only, conventional retrofit (e.g. wall-roof and wall-floor anchoring, out-of-plane bracing, diaphragm reinforcement) does not allow to protect the structure from the design

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seismic action (i.e. damage of structural elements is allowed without collapse), therefore not being able to guarantee immediate occupancy after a seismic event. Furthermore, the application of these techniques alters the building from an architectural and functional point of view. Therefore, seismic isolation is often the best strategy for the seismic protection of structures.

Nowadays, seismic protection through base isolation represents a consolidated technique of protection against earthquakes. This strategy is extensively applied on existing structures, due to the fact that it does not require any interruption of the building use and occupants' dislocation. Essentially, it consists in decoupling the superstructure motion from the ground one by installing anti-seismic devices characterized by low horizontal stiffness. The fundamental natural period of the superstructure is therefore lengthened, thus reducing the lateral acceleration demand, with a consequent increase of lateral displacement at the isolation level.

The dynamic response of an isolated building strictly depends on the characteristics of the isolation devices and having the combined function of building re-centering after an earthquake event and dissipating the seismic kinetic energy. Different typologies of anti-seismic devices may be applied and combined among them such as elastomeric isolators, curved surface sliders, elasto-plastic dissipators. General studies and applications with these devices for isolation buildings may be found in [1, 2, 3, 4] and specific applications on existing buildings having also historic value may be found in [5, 6, 7, 8].

This paper describes the application of seismic isolation to protect the "Giacomo Matteotti" school institute, an existing masonry building located in the city of Gubbio, Umbria region, Italy. The building was designed for vertical loads only since at the time of construction (1940), the Italian standard (Regio Decreto n. 193 del 18 Aprile 1909) for structures did not include anti-seismic design procedures.

The isolation system at the base of the building consists of 94 High Damping Rubber Bearings ISOSISM® type HDRB-H 550x155 and 93 flat sliders with confined elastomeric disc TETRON® type CD GL 3000.600.600 supplied by Freyssinet, a world reference in specialist civil engineering.

This paper reports the performance characteristics of the isolators with attention to the experimental response. A special focus is given to all the construction phases and details necessary to isolate a masonry structure.

## 2. Case study description

### 2.1 Seismic vulnerability of "Giacomo Matteotti" school building

The chosen case study is the "Giacomo Matteotti" masonry school building located in Gubbio, a medieval city belonging to the Province of Perugia, Italy.

Figure 1. Identification of the building.

The construction of the building dates back to the late 1930s, with construction beginning in 1937 and inauguration in 1940, after only three years.

Figure 2. Historical photos of the opening day.

The building is made of cast stone and bricks and reinforced concrete-hollow tiles mixed floors. The building has three floors, a total area of 6.000 m$^2$, an inter-storey height of 4 m and a total volume of about 23.750 m$^3$.

The structure is characterized by a high seismic vulnerability determined by the following factors:

- low number of structural masonry walls in relation to the global surface of the building;
- large rooms;
- inter-storey heights of 4 m or more;
- four levels above the ground;
- geometric irregularity both in plan (the building has a large E shape extremely disadvantageous in seismic conditions) and elevation;
- large corridors along the longitudinal side without transversal walls clamped to the facade perimeter walls;
- absence/low number of transverse resisting masonry.

Therefore, it is clearly perceived that the building has a simple and effective static concept. The foundations are continuous and always made of masonry which rests on loose soils. The seismic vulnerability of the building is clearly related to the high seismic hazard of the construction site. Indeed, the City of Gubbio is characterized by medium-strong earthquakes, with expected peak ground acceleration on rock soil equal to 0.29g for 475 years return period (i.e. 10% exceedance probability in 50 years). The building is very stiff, with a fundamental period of vibration of about 0.27 sec which corresponds to a design horizontal acceleration equal to 1.20g. It has been estimated that the building is able to resist only 25% of the design earthquake. Fig. 3 shows the design elastic acceleration spectra for the collapse limit state (1950 years return period, as per Italian Standard NTC 2018).

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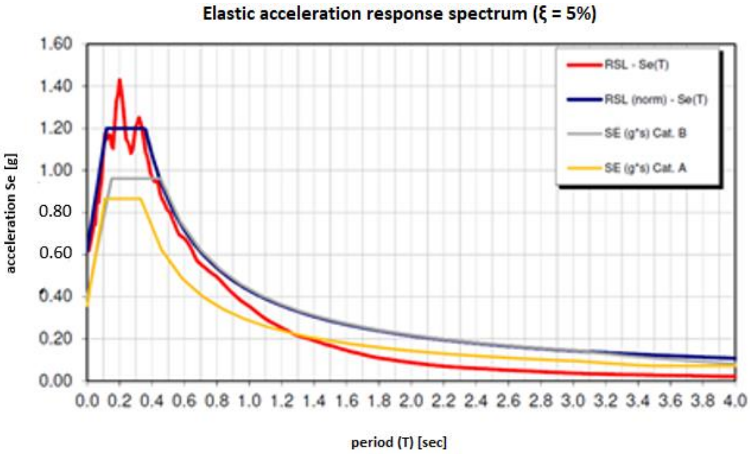

Figure 3. Design elastic acceleration spectra for 1950 yrs return period (SE = design elastic spectrum, RSL = site response spectrum)

The school building has a strong monumental value, therefore the retrofit strategy must increase the seismic safety level by at least 3-4 times without having a major and invasive impact on the building itself. In fact, conventional retrofit procedures such as construction of new structural walls, metal hoops and/or strengthening with fibre reinforced polymers allow to reduce the seismic vulnerability of the building, but they are in contrast with the reasons for architectural protection and conservation. Finally, a traditional retrofit strategy would not guarantee the absence of damage (both structural and non-structural) and therefore the functionality of the structure after a seismic event.

## 2.2 Retrofit strategy with seismic isolation

As already described in the introductory chapter, seismic isolation is actually a design strategy largely applied all over the world either for designing new buildings or for retrofitting existing ones. Thanks to the decoupling of the superstructure motion from the ground one by installing anti-seismic devices with low horizontal stiffness, the fundamental period of the structure is strongly lengthened, thus allowing to significantly reduce the seismic accelerations on the superstructure. In this way the superstructure elements damage may be nullified thanks to the drastic reduction of the interstorey drifts and floor shear. Fig. 4 shows the comparison between the response of the original structure (fixed base) and that with seismic isolation at the base.

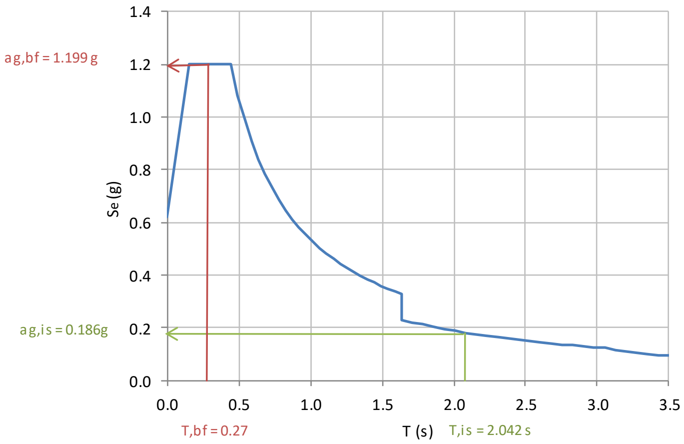

Figure 4. Spectral acceleration comparison between fixed base building (red line) and isolated one (green line).

Analysing Fig. 4 it is possible to quantify the main benefits obtained from seismic isolation:

- drastic reduction (up to 6 times) of seismic acceleration transmitted to the superstructure;
- system damping increase up to 16% with further reduction of acceleration transmitted to the building and of displacements at the isolation level;
- very high decoupling of superstructure motion from the ground one (isolation ratio $T_{,bf}/T_{,is} = 7.6$).

For the isolation system of the building, Freyssinet has supplied 94 high damping rubber bearings ISOSISM® type HDRB-H 550x155 and 93 flat sliders with confined elastomeric disc TETRON® type CD GL 3000.600.600. Fig. 5 shows a rendering of the isolation system implemented at the base of the structure.

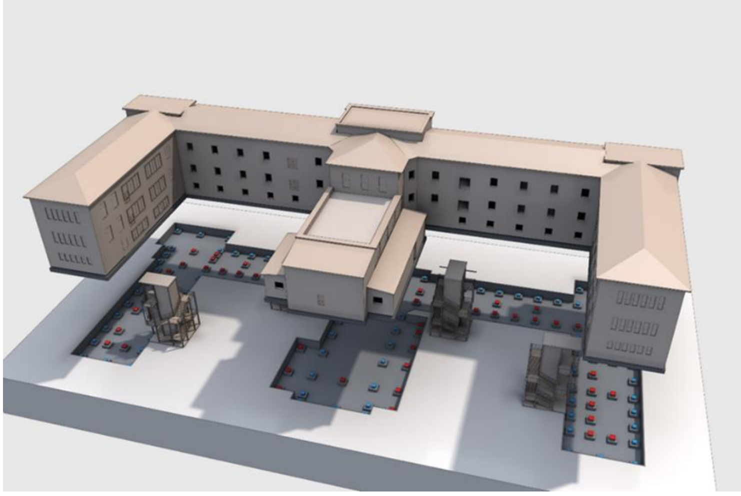

Figure 5. Rendering of the isolation system at the base of the building.

Isolators and flat sliders are positioned to achieve excellent centering between centre of mass and stiffness, thus reducing torsional effects during a seismic event. The layout of the devices is shown in Fig. 6.

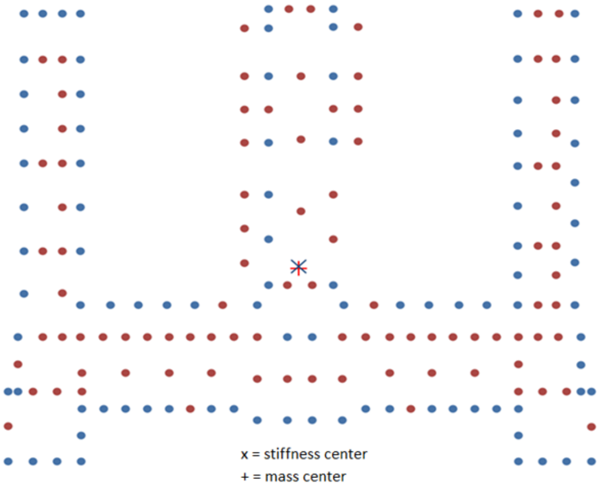

Figure 6. Plan arrangement of isolators (blue circles) and sliders (red circles).

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Finally, Fig.7 shows a global view of the finite element model of the building while Fig. 8 the first two vibration modes from which it is possible to appreciate that the total mass of the building is mobilized through purely translational behaviour.

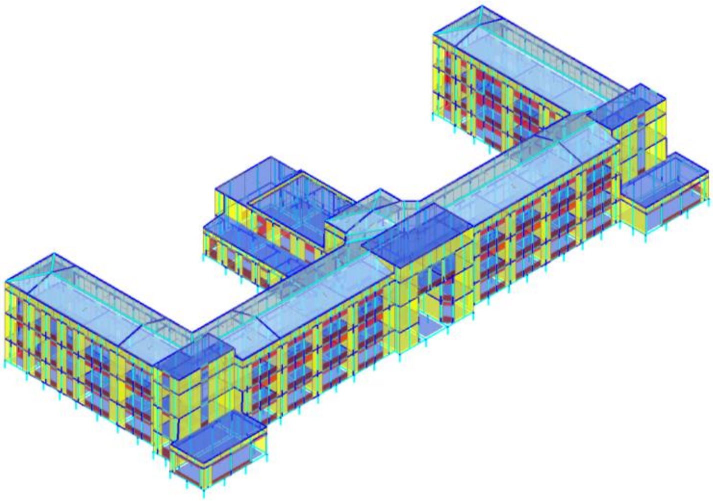

Figure 7. Finite element model of the building.

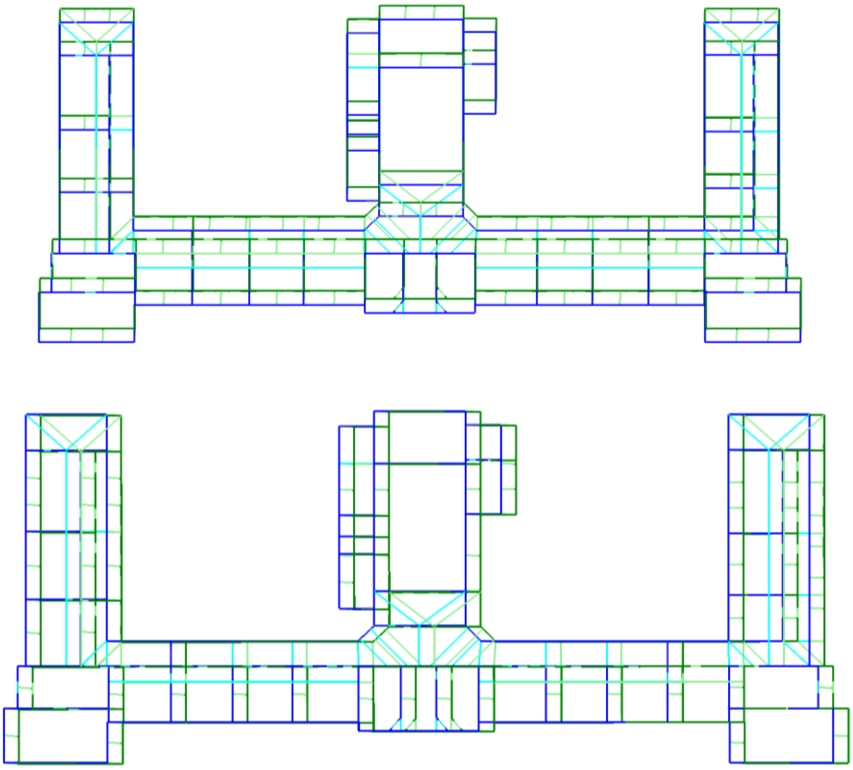

Figure 8. Top: 1st mode (T = 2.036 sec and $M_y$ = 99.8%); bottom: 2nd mode (T = 2.035 sec and $M_x$ = 99.7% ).

## 3. Freyssinet anti-seismic devices

To achieve the seismic isolation objectives (acceleration reduction, damping increase, decoupling), Freyssinet has designed and supplied a total of 187 devices, half of which are rubber isolators and half are flat sliders.

### 3.1 ISOSISM® HDRB and TETRON® CD: design parameters

The elastomeric isolators ISOSISM® type HDRB are reinforced rubber bearings made up of alternating layers of hot vulcanized rubber and steel laminates. These devices are characterized by high vertical stiffness, low horizontal stiffness and a suitable damping capacity. These features allow, respectively, to resist to vertical loads without appreciable setting, to lengthen the fundamental period of vibration of the structure, and to limit the horizontal displacements of the isolation system itself.

For the seismic isolation of the school building, 94 ISOSISM® type HDRB were supplied, with a rubber compound characterized by high stiffness and damping capacity. Fig. 9 shows the 3D exploded view of the isolator while Table 1 reports the main design parameters.

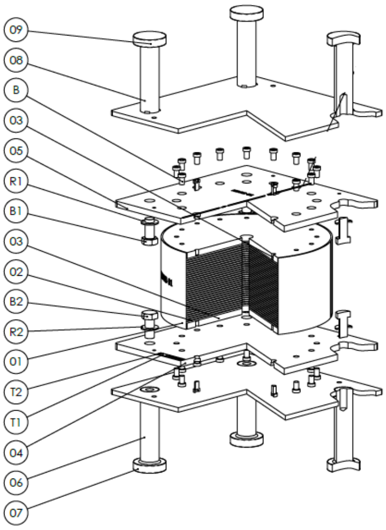

Figure 9. 3D exploded view of ISOSISM® HDRB-H 550x155.

Table 1 – Technical properties of ISOSISM® HDRB-H 550x155

| Parameter | Unit | Value |
|---|---|---|
| Rubber diameter, $D_r$ | mm | 550 |
| Rubber height, $T_r$ | mm | 155 |
| Total height, H | mm | 295 |
| Side length of outer steel plates, B | mm | 600 |
| Weight, W | kg | 488 |
| Maximum static vertical load, $N_{ULS,max}$ | kN | 3000 |
| Maximum seismic vertical load, $N_{Ed,max}$ | kN | 2500 |
| Design displacement, $d_{bd}$ | mm | ±153 |
| Displacement capacity, $d_c$ | mm | ±300 |
| Effective horizontal stiffness, $K_{eff}(d_{bd})$ | kN/mm | 1.76 |
| Vertical stiffness, $K_v$ | kN/mm | $\geq 800 \cdot K_{eff}(d_{bd})$ |
| Equivalent viscous damping, $\xi_{eq}(d_{bd})$ | - | 16% |

The isolators are then combined with flat sliders TETRON® type CD GL 3000.600.600 to minimize the eccentricity between centre of mass and stiffness. The confined elastomeric disc allows to increase the vertical stiffness of the slider. Fig. 10 shows the 3D exploded view of the slider while Table 2 reports the design parameters.

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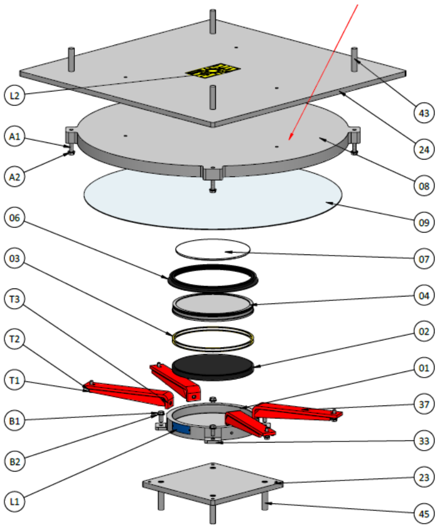

Figure 10. 3D exploded view of TETRON® CD GL 3000.600.600.

Table 2 – Technical properties of TETRON® CD GL 3000.600.600

| Parameter | Unit | Value |
|---|---|---|
| Pot diameter, $D_p$ | mm | 330 |
| Sliding plate diameter, $D_s$ | mm | 970 |
| Total height, H | mm | 106 |
| Weight, W | kg | 446 |
| Maximum vertical load, $N_{ULS,max}$ | kN | 3000 |
| Horizontal load, $F_H$ | kN | - |
| Displacement capacity, $d_c$ | mm | ±300 |

All the devices are equipped with upper and lower masonry plates for easy installation and replacement in the future, if required.

### 3.2 ISOSISM® HDRB: experimental response

The isolators were tested full-scale to check their performances. According to European Standard EN 15129:2009 and Italian Standard “Norme Tecniche per le Costruzioni 2018”, 20% of the production was subjected to vertical compression and horizontal dynamic tests to fully characterize the response of the devices and compare it with the theoretical behaviour. All tests were carried out by Politecnico di Milano (in charge of execution and certification) at ISOLAB laboratory (Montebello della Battaglia, Italy), the testing facility of Freyssinet. Table 3 illustrates the test protocol of the devices. Fig. 11 shows one device under testing and its experimental response.

Table 3 – Factory Production Control Test protocol for ISOSISM® HDRB-H 550x155

| test name | main dof [-] | max displ [mm] | max vel [mm/s] | load shape [-] | vertical load [kN] | cycles [-] |
|---|---|---|---|---|---|---|
| Compression stiffness | vert | - | 5.0 | ramp | 3000 | 1 |
| Horizontal characteristics under cyclic deformation | hor | ±155 mm | 200 | sine | 1425 | 3 |

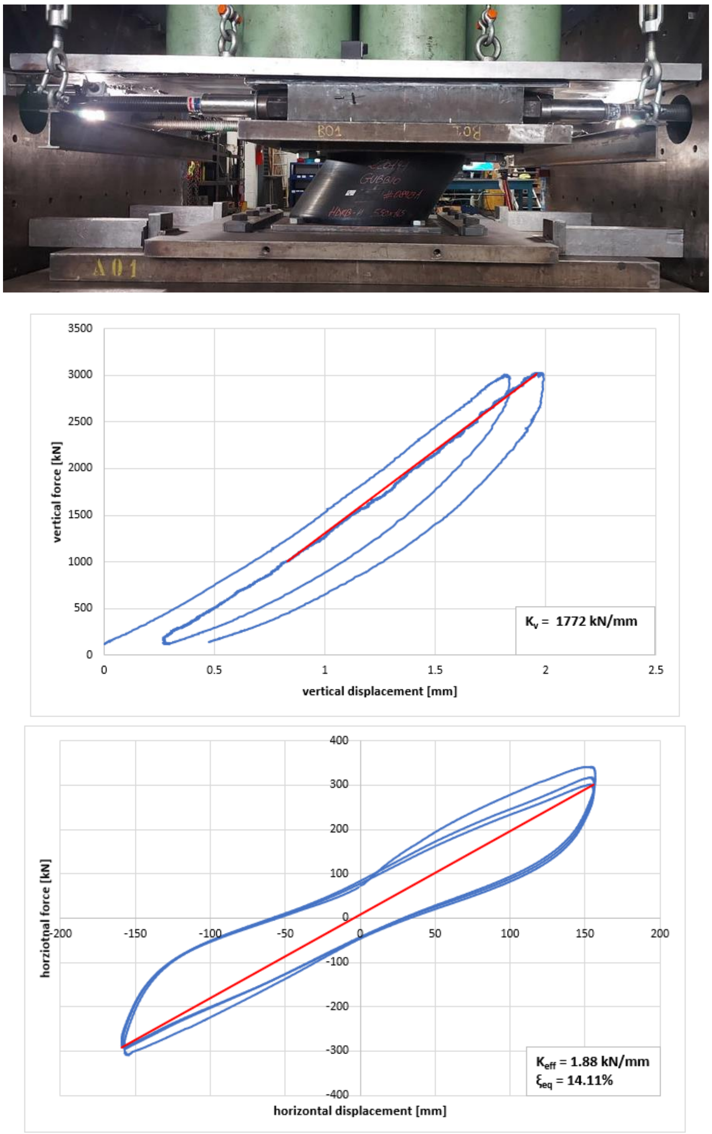

Figure 11. ISOSISM® HDRB-H 500x155 under testing (top), vertical (middle) and horizontal (bottom) response.

After testing, all devices were shipped for on-site installation.

## 4. Implementation of the isolation system: construction phases

The construction of the seismic isolation level at the base of a masonry building requires complex site activities that have to be planned in time.

First of all, the execution phases foresee the repair of the weaker masonry walls, through local reconstructions. Subsequently the soil is dug and removed inside the rooms of the building, for about two meters below the basement. Then parts of the foundations and soil under the walls are removed.

Through the use of props and jacks, two new reinforced concrete foundations are created: the first at the base (foundation slab), resting on the ground and the second, at the base of the masonry walls (curb beams). Devices are then installed between the two new foundations, thus realizing the seismic isolation of the building. Finally, at the location of the devices, the foundation slab will have short concrete

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columns (cap) to support the devices. Fig. 12 shows a rendering of the new elements at the base of the isolated building.

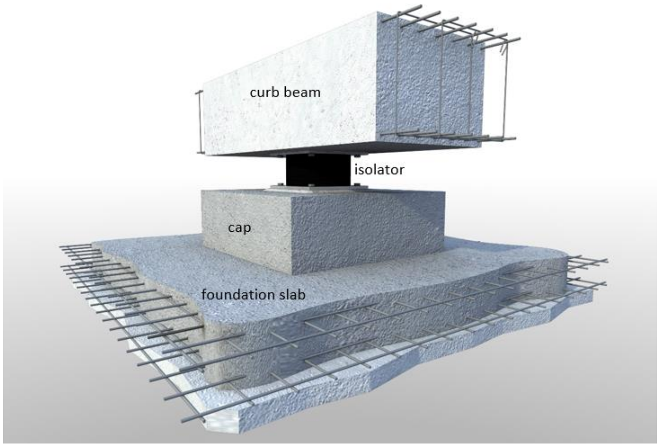

Figure 12. New elements at the base of the isolated building: foundation slab, cap, isolators, curb beams.

Flat jacks are installed underneath the devices. By injecting epoxy resin inside the jacks, part of the upper structure's load is transferred to the devices and the new foundation (cap and foundation slab) is also compressed. This procedure allows to eliminate differential settlements in the foundation due to a step-by-step construction.

By implementing seismic isolation at the base, the building needs to move with respect to the surrounding ground during a seismic event. This makes it necessary to have a perimeter cavity, which allows free relative movement between the ground and the building during an earthquake. This gap is covered by the perimeter sidewalk which completely hides the seismic joint. In fact, the sidewalk is a sort of overhang that allows relative movement between the surrounding ground and the isolated building. Fig. 13 shows typical construction details provided at the isolation level.

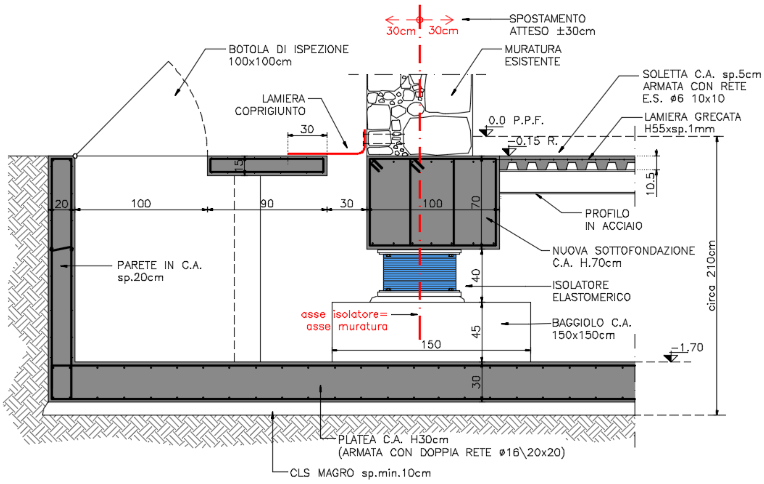

Figure 13. Construction details of the isolation level.

Fig. 14 groups together the main construction phases described above.

a) Demolition of existing foundation, new foundation reinforcement and support of masonry wall with props

b) Formwork for concrete casting of upper curb beams

c) Installation of flat jack

d) Installation of isolator

Figure 14. Base isolation construction phases.

The last operation is the construction of the new base floor below which there will be the technical compartment for maintenance and inspection of the devices.

It is important to underline that this executive method allows the school to be fully operational, even if with a reduced usable surface. This type of construction framework allows to work in macro areas of the building that are temporarily unused and then re-occupied after installing the devices. Only the ground floor immediately above the isolation level cannot be used for the entire duration of the construction site.

## Conclusions

An application of seismic isolation at the base of an existing masonry building has been presented in this paper. The “Giacomo Matteotti” school building has been designed for vertical loads only, since at the time of the construction, no seismic design was required by law.

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The building is characterized by high seismic vulnerability due its static structural conception and due to the high seismic hazard of the site. The structure, in addition to being strategic, has a strong historical value. For these reasons, seismic isolation retrofit technique was adopted as an alternative to conventional strategy. In fact, this technique allows to protect the building from earthquakes and to be fully operational and it does not have an invasive impact on the building's architecture.

Seismic isolation therefore enable to drastically reduce (up to 6 times) the accelerations transmitted to the superstructure, to increase the system damping (up to 16%) and to strongly decouple the superstructure motion from the ground one ($T_{,bf}/T_{,is} = 7.6$).

The isolation system of the building consists of 94 anti-seismic rubber devices ISOSISM® type HDRB-H 550x155 and 93 flat sliders TETRON® type CD GL 3000.600.600 supplied by Freyssinet, a world reference in specialist civil engineering. 20% of the isolators were tested in accordance with EN 15129:2009 and NTC 2018 Standards, complying with relevant acceptance criteria.

The construction of the isolation system at the base of the masonry building required numerous and complex construction site activities, including the demolition of the existing foundation and the consequent construction of two new concrete foundations: a base slab resting on the ground and curb beams below the masonry walls. The devices were then installed between the two new concrete elements.

The building retrofit procedure was implemented progressively working in macro areas. This allowed keeping the school in operation during all phases of the construction site.

## References

[1] Braga, F., Faggella, M., Gigliotti, R., Laterza, M. (2005): Nonlinear dynamic response of HDRB and hybrid HDRB-friction sliders base isolation systems. *Bulletin Earthquake Eng.*, **3**, 333–353, doi: 10.1007/s10518-005-1242-2.

[2] Constantinou, M., Mokha, A., Reinhorn, A. (1990): Teflon bearings in base isolation II: modeling. *J. Struct. Eng.*, **116**, 455–474, doi: 10.1061/(ASCE)0733-9445(1990)116:2(455).

[3] Martelli, A., Forni, M. (1998): Seismic isolation of civil buildings in Europe. *Progress Struct. Eng. Mater.*, **1**, 286–294, doi: 10.1002/pse.2260010310.

[4] Kawamura, S., Sugisaki, R., Ogura, K., Maezawa, S., Tanaka, S. (2000): Seismic isolation retrofit in Japan, *12th World Conference of Earthquake Engineering*, Auckland.

[5] De Luca, A., De Mele, E., Molina, J., Verzeletti, G., Pinto, A.V. (2001): Base isolation for retrofitting historic buildings: evaluation of seismic performance through experimental investigation. *Earthquake Eng. Struct. Dynam.*, **30**, 1125–1145, doi: 10.1002/eqe.54.

[6] Tomazevic, M., Klemenc, I., Weiss, P. (2009): Seismic upgrading of old masonry buildings by seismic isolation and CFRP laminates: a shaking-table study. *Bulletin Earthquake Eng.*, **7**, 293–321, doi: 10.1007/s10518-008-9086-1.

[7] Castellano, A., Foti, P., Fraddosio, A., Marzano, S., Mininno, G., Piccioni, M.D. (2014): Seismic response of a historic masonry costruction isolated by stable unbonded fiber-reinforced elastomeric isolators (SUFREI). Key Eng. Mater., **628**, 160-167, doi: 10.4028/www.scientific.net/KEM.628.160.

[8] Petrovčič, S., Kilar, V. (2017): Seismic retrofitting of historic masonry structures with the use of base isolation – modeling and analysis aspects, *Int. J. Archit. Heritage*, **11**, 229-246, doi: 10.1080/15583058.2016.1190881.