RETROFIT OF BUILDINGS IN ITALY THROUGH SEISMIC ISOLATION

Placido LUCA’ TROMBETTA¹, Maria Gabriella CASTELLANO² and Davide COCCHIO³

ABSTRACT

The number of seismic isolated buildings in Italy is continuously increasing since 2003 and even more since 2009. In the last years, seismic isolation technique is increasingly used for the seismic retrofit of existing buildings, especially in buildings severely damaged by the 2009 L’Aquila earthquake. The use of seismic isolation technique allows a significant reduction of intervention on the superstructure, compared to traditional techniques; in effects, when using seismic isolation, most of the interventions are concentrated at the isolation floor level and on the substructure.

In recent seismic retrofit interventions either elastomeric isolators or curved surface sliders are used. With the latter it is easy to achieve a high period of isolation, necessary to reduce as much as possible the forces transmitted to the superstructure, not only in heavy structures but in relatively light-weight structures such as low-rise buildings as well; this because the fundamental period is not largely dependent on the supported mass but mainly on the curvature radius of the devices themselves. On the other hand, in case the isolation system is based on elastomeric isolators, it is almost always necessary to combine them with multidirectional bearings in order to achieve sufficiently high fundamental period.

This paper describes the typical phases of the installation procedure of isolators in existing buildings, with particular reference on some examples of retrofitted buildings.

INTRODUCTION

The use of seismic isolation in Italy is continuously increasing since 2003, the year in which the seismic codes introduced for the first time a chapter on seismic isolation, thereby eliminating previous requirements on design review of seismic isolated structures by the Public Work Council. The use of seismic isolation was rapidly increased after the tragic seismic event on the 6th of April 2009 in L’Aquila. Until that time most of the seismic isolated buildings were public and often strategic buildings. In the last years, however, this technology has also been used in private buildings, mostly in high seismic areas, where the cost of seismic isolation can be partially or fully compensated from the superstructure cost saving. Moreover, lately, seismic isolation technique is increasingly used for seismic retrofit of existing buildings, mostly in reinforced concrete frame structures.

It is well known that seismic isolation is used for seismic retrofit of existing structures since the 80’s of the past century [Bayley and Allen, 1989]. In Japan, the total number of seismic isolated buildings is more than 2600 [Takayama and Morita, 2012], about a hundred are seismically retrofitted through seismic isolation, of which approximately one-third are public office buildings and 18% private office buildings [Masuzawa and Hisada, 2012]. In Italy, the first buildings retrofitted through

¹ Structural Engineer, FIP Industriale S.p.A., Selvazzano Dentro, Italy, placido.lucatrombetta@fip-group.it
² Structural Engineer, Ph.D, FIP Industriale S.p.A., Selvazzano D., Italy, maria.gabriella.castellano@fip-group.it
³ FIP Industriale S.p.A., Selvazzano Dentro, Italy, davide.cocchio@fip-group.it
seismic isolation were public buildings. On the other hand, in the last years, most of the seismic isolation retrofit interventions performed or designed, concerns private residential buildings, damaged and declared uninhabitable after the L’Aquila earthquake. Table 1 lists the interventions already been completed or in progress, in which isolators have been supplied, and in most cases installed as well, by FIP Industriale. The next sections describe some of these interventions, with particular attention to the procedure carried out during the vertical loading transfer and the installation of the isolators. It should be noted that seismic isolation retrofits of masonry buildings recently started in Italy as well [Vetturini et al., 2013; Mezzi et al., 2012].

The use of seismic isolation in an existing building allows to reach safety levels required by the seismic code for a newly constructed building, significantly limiting the strengthening interventions on the superstructure, compared to traditional techniques for seismic retrofitting.

The types of seismic isolators most used in existing and new constructed buildings in Italy are elastomeric isolators and curved surface sliding isolators or friction isolation pendula [Castellano and Infanti, 2010]. With the latter it is easier to reach high values of fundamental period (necessary to reduce, as much as possible, the accelerations transmitted to the superstructure) in relatively light-weight structures, such as low-rise buildings, since the fundamental period is not substantially dependent on the supported mass, but mainly on the radius of curvature of the devices themselves. On the other hand, in case the isolation system is based on elastomeric isolators, in order to achieve a sufficiently high fundamental period, it is almost always necessary to combine them with multidirectional bearings. This is precisely why almost all Italian buildings isolated with elastomeric isolators comprise a number of multidirectional bearings as well.

Table 1. Retrofit of buildings in Italy through seismic isolation (supply by FIP Industriale and in many cases installation as well).

<table>
<thead>
<tr>
<th>Building name and/or address</th>
<th>City</th>
<th>Structure type</th>
<th>Year</th>
<th>Isolator type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apartment house - via Pave, 2</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2014</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>Apartment house - Colle Capo Cioce</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2014</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Fortuna 4&quot; Apartment house - via Pasteur</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;S.Maria degli Angeli&quot; School</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>Apartment house - via Pratola Peligna, 2</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;SORIN GROUP&quot; Office building</td>
<td>Mirandola</td>
<td>r.c.</td>
<td>2013</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>Industrial Building - University of Catania</td>
<td>Catania</td>
<td>precast r.c. + steel</td>
<td>2013</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;DOvidio&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Acine&quot; Apartment house - Building D1</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Montecalvo 1&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Paolucci&quot; Apartment house</td>
<td>L'Aquila</td>
<td>masonry + r.c.</td>
<td>2013</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Prato Verde B&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;La Quercia&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Prato Verde A&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2013</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;La Silvestrella&quot; Villa</td>
<td>L'Aquila</td>
<td>masonry</td>
<td>2013</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Andromeda&quot; Apartment house - via S Giustino de Jacobs, 1</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>Former magistrates’ court</td>
<td>Pescia</td>
<td>r.c.</td>
<td>2012</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Del Beato&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Leonardo&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Acine&quot; Apartment house - Building C2</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Barattelli&quot; Apartment house - via G Vincenzo, 23</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Amiterno&quot; Apartment house - Via Sila Persichelli 1/B</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Borgo dei Tigli&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Il Melograno&quot; Apartment house</td>
<td>Potenza</td>
<td>r.c.</td>
<td>2012</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Aguglia&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Fortuna 2&quot; Apartment house - via Pasteur</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2012</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Habitat&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2011</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Domus Prima&quot; Apartment house</td>
<td>L'Aquila</td>
<td>r.c.</td>
<td>2011</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Cindy&quot; Villa</td>
<td>Treviso</td>
<td>masonry</td>
<td>2010</td>
<td>Double concave curved surface sliders</td>
</tr>
<tr>
<td>&quot;Q Albanese&quot; School</td>
<td>Tolve</td>
<td>r.c.</td>
<td>2010</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>Hospital - &quot;intrameonia&quot; building</td>
<td>Avellino</td>
<td>r.c.</td>
<td>2009</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;S Quasimodo&quot; School</td>
<td>Riposto</td>
<td>r.c.</td>
<td>2007</td>
<td>Elastomeric isolators</td>
</tr>
<tr>
<td>&quot;Madonna delle Lacrime&quot; Church</td>
<td>Sticosa</td>
<td>r.c.</td>
<td>2005</td>
<td>Flat surface sliders with steel hysteretic</td>
</tr>
<tr>
<td>&quot;IACP&quot; Apartment houses</td>
<td>Solano</td>
<td>r.c.</td>
<td>2003</td>
<td>Elastomeric isolators</td>
</tr>
</tbody>
</table>
INTERVENTION TECHNOLOGIES FOR THE INSTALLATION OF THE ISOLATORS IN CONCRETE BUILDINGS

In the seismic retrofit design of an existing building through seismic isolation, the intervention technology constitutes a fundamental part which influences the design and is influenced by the design itself. Every fixed-base building of course misses all the details needed for an isolated building: the same details that become design requirements in case of a seismic retrofit with base isolation.

The existing building heritage diversity, even though limited to concrete structures, means that each case should be carefully analyzed; multiple factors, specific for each building, suggest to the engineer the best solution in relation to:
- Positioning of the isolation level;
- Method of temporary transfer of the vertical load.

In respect to this, every choice made is mainly influenced by the following aspects:
- Intended use of the floor in which the isolators are installed (typically ground floor or basement);
- Adjacent constraints to the building;
- Type of existing foundations;
- Detail of stairwells and elevators.

The positioning level of the isolation system on the top of the columns is often practicable on parking floors or other technical areas where the presence of the horizontal joints and the enlargement of the existing columns, when needed, do not compromise the floor’s function. Such a choice usually guarantees the stiffness required above the isolators, provided by the existing floor, without the need for further intervention. The same request of sufficient stiffness in the substructure, i.e. below the isolators, is satisfied, where necessary, with an enlargement of the columns. Such column enlargement is often useful also to satisfy the geometrical requirements of the overall plan dimensions of the isolators, which otherwise require the construction of a capital.

In the case in which the isolators are positioned at the base of the column, the same request of sufficient stiffness above and below the isolation level often introduce the necessity of a new constructed slab directly above the isolators. In this case, no additional stiff elements at the base are required since the isolators are found in correspondence with the foundation beams.

The position of the isolators on the upper part of the column simplifies the inspection and maintenance operations, which are imposed by current regulations. Conversely, in case the isolators are placed at the base of the column, it is necessary to carry out numerous floor hatches in order to ensure access to all the isolators (Fig. 7).

On the other hand, when isolators are positioned at the top of the column, especially those on the ground floor instead of the basement, often greater attention is needed on the horizontal joints, in particular in correspondence with the stairwell and elevator.

Another fundamental aspect concerns the method of the temporary transfer of the vertical loads during the cutting operation of the columns, the installation of the isolator and the possible future replacement operations.

The load transfer takes place between the different parts of each column or between column and foundation, by means of two or more hydraulic jacks placed opposing upwards on the superstructure (suitable reinforced if necessary) and downwards on the foundation (direct loading) or on the columns transferring the load to the foundation (indirect loading).

In case the isolators are placed at the base of the columns on the ground floor, a direct loading transfer is obtained by placing the jacks opposing downwards on the foundations and upwards on suitable steel brackets, attached to the columns; such steel brackets have a double function of temporary vertical load transfer and support of the new slab to be casted over the isolation level (Figs. 3, 4, 6).

In the case where the isolators are placed at the top of the columns, the jacks can oppose upwards on metal brackets, on adequate concrete blocks, or directly on the superstructure (suitably strengthened where necessary); the downward contrast is possible either directly on the foundations by means of steel props (Fig. 19, 20), directly on the columns (enlarged by a r.c. capital, if necessary) or
once again with removable structural steel brackets, used also for future maintenance operations (Figs. 8-17), transferring the load to the columns.

In some cases, regardless of the isolation level location, the installation of the isolators is achieved with the help of flat jacks. The flat jack is installed in series with the isolator allowing the loading of the isolator, thus avoiding excessive vertical settlements during the loading phase, and especially differential settlements between the isolators that could create problems to the superstructure. The use of the flat jacks is therefore strongly recommended especially for masonry structures, but can also be useful for other types of structure.

APPLICATION EXAMPLES

“Domus Prima” and “Barattelli” Residential Buildings

The “Domus Prima” and “Barattelli” residential buildings, sited in L’Aquila in G. di Vincenzo street, present almost identical constructional and architectural features. Both buildings are comprised of two distinct building parts, separated by 30 cm construction joint. Each building consists of 5 floors for residential use, attic equipment room and a garage basement. The structure is made of reinforced concrete frame in both principal directions with piled foundation, with pile caps connected by 40x100 cm r.c. strips. Both structures, after the earthquake in 06/04/2009, were considered uninhabitable. Seismic retrofit was performed by means of seismic isolation using isolator devices placed at the base of the basement columns.

One of the reason of the choice of seismic isolation as a retrofit intervention method is the limited invasiveness, especially on the upper floors that were only slightly damaged. In both buildings the new structural configuration after the intervention was constituted by a unification of the two structural bodies in correspondence with the joint. The latter, although is adequate for the actual state of the buildings (fixed-base), would not have been sufficient to ensure the movements of the two isolated structures (to be on the safe side, the joint dimension should be two times the design displacement of each structure).

The designer decided to put the isolation level at the base of the basement columns, designing a new steel-concrete floor deck over the isolators, on the basis of the following issues: i) the need to maintain the structural continuity from the basement floor to the upper floors, without affecting the garage utilization; ii) the presence of a shaft on almost the entire perimeter of the building; and iii) the adequate dimensions of the foundation strips, that create a sufficient volume for future inspection. In effects, the inspection and maintenance operations of the isolators are guaranteed through suitable floor access hatches, that give the access to technical areas underlying below the new slab of the garage, and through a lateral shaft running along the perimeter of the building. The interventions were completed with the installation of double concave curved surface sliders characterized by reduced height dimensions (when compared with elastomeric isolators), resulting to an increase of the garage floor deck of only 16 cm.

The fundamental period of the structure in fixed-base condition was approximately 0.85 s (considering separately the two buildings); the installation of the seismic isolators has allowed to obtain a fundamental period of about 3.4 s; that is 4 times that of the fixed-based structure.

The installation works of the devices were assigned to FIP Industriale, requesting the following:
– Demolition of all non-structural elements on the garage floor, including the excavation of the filling material between the foundation beams until the foundation footing is reached (Fig. 1);
– Core drilling of the column; grouting of threaded rod anchors and subsequent fastening of the metal brackets at the base of the column (Fig. 2);
– Loading of the hydraulic jacks, opposing between the metal brackets and the foundation, in order to remove the unloaded segment of the column;
– Diamond wire cutting and removing of the cut section of the column (Figs. 3 and 4);
– Insertion of the isolator, screwing of the upper part of the isolator to the metal brackets, mortar casting for the completion of the lower anchorage process, followed by the removal of the jacks and the loading of the isolator (Fig. 5);
Assembly of the steel beams and the corrugated floor deck sheets above the metal brackets at the base of the column and casting of the new concrete slab (Figs. 6 and 7).
“Leonardo” Residential Buildings

The Leonardo residential building, located in L'Aquila, is a building complex consisting of three building parts, each with four storeys and a basement. The two main lateral buildings are connected to the central building housing the elevator shaft. The three building parts are structurally independent to each other, arranging an approximately "L-shaped" building.

The bearing structure is made of reinforced concrete frames and reinforced concrete and hollow tiles mixed floor. The foundations are made of 70x70cm beams, that connect in both directions the columns of the superstructure.

As a result of the earthquake in 06/04/2009, the building was declared uninhabitable. The structure exhibited widespread damage to masonry in fill walls especially on the ground floor, cracking at the joints due to hammering and limited capillary cracks at the nodes of the r.c. frame.

From the analysis of the current state and the vulnerability results of the building, it was decided to pursue the seismic retrofit by seismically isolating the entire complex inserting double concave curved surface sliding isolators at the top of the basement columns. This technique was considered by the Engineers as the most suitable, able to limit the intervention zone at the lower levels of the structure, where large-scale intervention on the infill walls was essential. Otherwise, the strengthening and stiffening of the r.c. frames with traditional methods would require a large-scale action at all floor levels, and consequently the dismantling of the infill on the upper floors as well, where no damages were detected. The seismic isolation technique also enabled to secure the heavy infill from the risk of expulsion and overturning, significantly limiting the inertial forces associated with the event of an earthquake. The natural period of the structure was brought up to 2.75 s, starting from 0.75 s for the fixed-based structure.

In order to ensure adequate stiffness of the substructure, all columns of the basement were enlarged and the isolators were placed at the top of each column.

The installation of the isolators, performed by FIP Industriale, required the following steps:

- Enlargement of the columns at the basement and simultaneous preparation of ferrules to be used for the anchoring of the lower lifting steel brackets and recesses to be used for the lower anchorage of the isolator with dowels (Fig. 8);
- Core drilling of the upper part of the column and provision of the ferrules for the anchorage of the upper lifting brackets (Fig. 9);
- Installation of metal brackets and placing of hydraulic jacks to unload the part of the column to be removed (Figs. 10 and 11);
- Diamond wire cutting, removal of the segment of the column, and levelling of the lower surface (Fig. 12 and 13);
- Insertion of the metal brackets for the anchorage of the upper part of the isolator (Fig. 14);
- Insertion and screwing of the isolator and subsequent grouting of the anchors and the collar with antishrinkage cement mortar (Fig. 15);
- Removal of jacks and consequent loading of the isolator (Fig. 16).
“Borgo Dei Tigli” Residential Building

The “Borgo dei Tigli” building, situated in L’Aquila, suffered seriously from the seismic events in 06/04/2009; the bad soil type, classified as type “D” according to Italian Standard, probably played an important role. The original building consists of three buildings, separated by a seismic joint, considered therefore as three detached buildings, each consisting of a three-floor superstructure, a basement and an attic. The plan geometry of the three buildings compose a particular irregular floor plan of “S”-shape; this particularity was studied in-depth, both on structural and architectural level, during the design of seismic retrofit. The bearing structure in elevation is formed of r.c. frames in the two orthogonal directions; the horizontal elements, including the roof, are made of concrete-brick; shallow foundations with reversed beams arranged on different levels.

The seismic retrofit project by means of base isolation, as seen in the previous examples, involved the elimination of the construction joints between the three building bodies and the realization of a seismic joint all around the building, in order to allow the horizontal displacements of the isolated complex. A total of 41 elastomeric isolators and 40 multidirectional sliding bearings were employed, to reach a period $T_a = 2.30$ s, compared to a value of about 0.5 s of the period for fixed-base structures (considered separately). The reduction of the acceleration transmitted to the superstructure, resulting from the increase of period, has permitted a considerable decrease of the interventions on the superstructure, which were mainly concentrated on the level directly above the isolation level.

As described in the previous paragraph example, also in this case the isolators were arranged at the top of the columns of the basement floor, suitably enlarged. In contrast to the “Leonardo” residential building, the temporary load transfer for the installation of the isolators was performed outside the columns. Hydraulic jacks were used and load-bearing metal frames, propping against a r.c. block, casted at the beam intersection. Another r.c. block was made at the foot of the column reinforcing the foundation footing plinth. In this case the dowels for the upper anchorage of the isolator are fixed to a metal counter-plate, cast together with the upper r.c. block.

The insertion phases of the isolators can be summarised as follows:
- Casting of the r.c. block in the beam intersection, including the metal counter-plate for anchoring the upper part of the isolators used as a formwork (Fig. 18);
- Strengthening of the columns and casting of foundation block;
- Vertical load transfer on the foundation with the use of hydraulic jacks and metal props outside the columns;
- Cutting with diamond wire, removal of the segment of the column and smoothing of the lower surface (Figs. 19 and 20);
- Insertion of the isolator and of a flat-jack below it; tightening of the upper part of the isolator;
- Loading of the isolator through the flat-jack; successive grouting of the jack and of the lower anchorages of the isolator with cement mortar and subsequent removal of the hydraulic jacks (Fig. 21).
CONCLUSIONS

The growing application in recent years prove that seismic isolation technology is by now mature not only for application in new buildings but also in existing ones.

ACKNOWLEDGEMENTS

The authors would like to thank the Structural Engineers and Site Engineers of the above-mentioned buildings for the information provided and the fruitful collaboration. The authors also thank Evina Pigouni for the cooperation.
REFERENCES


