ARCHITECTURE AND BASE ISOLATION

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Abstract

This paper reports on an investigation into how base isolation can produce benefits to the architectural design of buildings.

Architecture must incorporate passive protection against any threat from natural forces. Architects are partially responsible for the behavior of a building when facing an earthquake because they design its form and configuration. If a relatively new technology such as base isolation can be coupled with interdisciplinary collaboration from the inception of a project, it is possible to achieve not only an improvement in seismic performance, but also in its architectural design and performance.

The methodology adopted for this research consisted in identifying the architectural implications of the use of base isolation in hospitals, commercial and buildings for religious purposes. The three basic architectural qualities: Firmitas (structure), Utilitas (function) and Venustas (aesthetics) that comprise the Vitruvian Triad for buildings were analysed in these buildings. Thus Utilitas, optimization and functional use of space was studied. Regarding Firmitas, the more complex configurations that base-isolation can allow while meeting the seismic performance needs of the project were analysed. Finally, from the point of view of Venustas, the way base-isolation has allowed more complex volumetric massing and greater creative expressive design was considered.

As a milestone example in the history of the anti-seismic construction in Argentina, the IHEM building is presented as a case-study. Located in Mendoza, it is the first large base isolated building in Argentina.

The paper concludes that the use of base isolation in the IHEM building studied has increased the overall quality from conception architectural design process itself the seismic safety in case of earthquake maximum expected in the region, never reached goals achieved all together in a building of Mendoza.

Keywords: base isolation; seismic conception design; architectural structural design

1. Introduction

Among the different dangers that threaten human beings, earthquakes are causes completely out of control of people. They cannot avoid them. They can just take preventive measures against them to diminish their effects.

The architect conceives and designs the building configuration and therefore influences on the seismic behavior of buildings [1, 2]. Architects therefore are in a crucial position to influence the seismic safety of buildings [3].

As an all-embracing discipline the Theory of Architecture must take into consideration the principles of seismic-resistant structural design [4] and be updated with regard to the advances in seismic protection technologies in the same way it does with regard to sustainability, resilience, resource consumption, recycling and other modern issues.

New technologies of seismic protection are great advance in engineering that reduce the effects produced by earthquakes on works of architecture. But few architects have a thorough knowledge about the possibilities offered by this technology, and able to integrate both disciplines allowing new projects to take advantage of this technology.

The objective of this research is to demonstrate the benefits of developing an architectural project designed from the beginning of the process with base isolation (BI), taking as an example the architectural design of the IHEM building in Mendoza, Argentina

2. Development

Architecture should design buildings to function as the first system of passive protection against any type of threat. In case of earthquakes, should be The refuge where users must remain with the tranquility offered by the knowledge that the building is protected with advanced technologies. This architecture with seismic design should prevent any damage to its occupants, contents and maintain the functionality of the building.

Seismic isolation consists in inserting a soft layer between the building and its foundations. It comprises devices capable of absorbing energy during the deformation induced during ground shaking while increasing the horizontal flexibility of the building to decouple the ground motion and the building's response during a seismic event. The insertion of isolating devices that comprise this system, allows the building to remain almost stationary relative to the ground motion, resulting in a drastic reduction in damage to both the structural elements, nonstructural elements and building contents.

Conventional architectural seismic design admits an acceptable level of structural damage as part of the process to diminish the seismic risk in the building. It does not avoid damage. This leads to two conceptually different approaches to the problem (Figure 1).

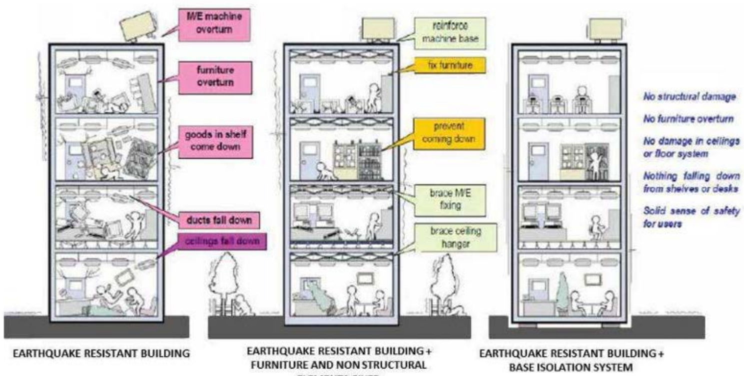

Figure 1: Conventional architecture with and without seismic isolation

One consists in controlling the damage by designing for it though not eliminating it. The other approach drastically reduces the damage by controlling the energy input. This may be achieved by the use of isolation devices. This second solution is very different and it requires an adaptation of design attitudes, which enable a new conception of damage reduction in buildings when a seismic event occurs. In this way, new technologies of seismic protection allow applications creating a new concept of architecture. Base isolation technology has been proven worldwide in numerous earthquakes, showing a level of structural performance that has never been reached before. In 2014 more than 24,000 structures, located in over 30 countries, had been protected by passive anti-seismic (AS) systems, mainly by the seismic isolation (SI) and energy dissipation (ED) [5].

2.1. Seismic Architecture

Seismic Architecture can be considered as the combination of principles related to architectural design and earthquake engineering. It combines the necessary elements from both fields and establishes new conceptual interlinks in the field of architecture. Earthquake resistant construction requirements are often seen as causing negative pressure on artistic freedom and a restriction on the adoption of architectural ideas coming from non-seismic areas in the world. However, the main problem is that these restrictive views reflect a lack of awareness of how to develop seismic-resistant structural designs through an adequate, creative, bold, safe and sustainable architecture.

2.1.1. Architectural Qualities

In the field of Architecture Theory, one of the starting points for analyzing Architecture Qualities are those qualities defined as Utilitas, Firmitas and Venustas by Marcus Vitruvius Pollio, Roman architect, writer, and engineer from second century B.C. Over time, these qualities have evolved along with the complexity acquired by architecture [6]. Venustas refers to beauty as an aesthetic element, the meaning and communication of a message. Utilitas means the function the building will be used for, the organization and distribution of the architectural spaces, and Firmitas represents the concepts of durability, firmness, stability, permanence, resistance and configuration, among others. With engineering, architecture shares the “Firmitas” quality and thus there is a contact area where architecture and engineering join. Therefore, it is necessary to identify the common components so as to have a wider and more complex view of the architectural and structural design, which is critical in seismic areas

2.1.2. Seismic Architectural Qualities

Firmitas is one quality representing the possibility of designing in an appropriate way an architecture that is suitable for seismic high risk areas, using base isolation (BI) as a strategy of damage reduction. BI becomes of vital importance and must be present from the conception of the architectural design (AD) [7].

2.2. Analysis of Buildings with Base Isolation

The methodology which is applied to the analysis of IHEM Instituto de Histología y Embriología “Dr. Mario Burgos” building design consisted of identifying the most outstanding architectural aspects of the building. It was then possible to discover the architectural potentialities arising as a consequence of the use of base isolation from the beginning of the architectural design process [8].

2.3. Analysis of Seismic Architecture qualities and architectural implications of the IHEM building:

The construction of this building is significant for Argentina, because it is the second base isolated building and the first large building with elastomeric isolators [9].

The building, located in Mendoza, the most active seismic zone of Argentina, has a rectangular plan of 21m x 72m and is 15.20 m high. It has five floors (basement for parking, ground floor, and three levels, built in a reinforced concrete and steel structure (Figure 2).

The simplicity of the seismic resistant structure meant that internal partitions and side walls were constructed with lightweight dry construction elements. The floors of the three levels above ground consist of concrete on steel-decking supported by steel beams which allowed rapid implementation and high flexibility of usage.

Figure 2: Instituto de Histología y Embriología “Dr. Mario Burgos” north facade

2.3.1 Regarding UTILITAS

IHEM headquarters was designed to house important creative scientific activities in reproduction biology and neuroendocrinology, cellular and molecular biology.

The architectural function is laboratories, auxiliary facilities and a library. It was built from 2012 to 2014 on the campus of the National University of Cuyo.

The characteristics of the Institute's activities and its equipment led to using a seismic base isolation system, as it activities within the building are potentially dangerous and it contains very expensive equipment and other facilities.

It is a versatile building that can change its function according to the varying requirements in its lifetime without having to modify the structure (Figure 3-4).

The building has areas of different levels of biosafety to minimize the risk of exposure to workers or the environment to a chemical agent. Air pressures are controlled according to the specific needs of each local area, and air is filtered.

In addition to the basic facilities of any building, the IHEM has carbon dioxide installation, ultraviolet light, closed circuit water, compressed air, nitrogen and an emergency power unit. Both the north and south facades, as well as the roof, are composed of thermo panels ensuring excellent thermal insulation and durability. The windows are double hermetic glazed. Flexible services connections were placed in the basement to allow for the movement at the isolation plane and convenient inspection for maintenance was provided.

Figure 3: Large spaces that allow free division

Figure 4: Internal partitions are plasterboard

2.3.2 Regarding VENUSTAS

The emphasis in this section is on achieving a high level of building earthquake resistance. This is because this building represents the introduction of new technologies of seismic protection in Argentina.

The building adopts a simple shape, containing free plan and is morphologically adapted to the neighboring buildings of the faculty of medical science. The formal resolution is high visual impact with an applied ornament set with different colors, framed by massive reinforced concrete walls (Figure 5).

The building form deliberately lacks any plastic qualities so as to fit within its cultural and social context. A variety of styles make up the buildings of the University. They include cutting-edge trends from brutalism to the minimalist High Tech style.

Despite morphological freedom instigated in different areas of the Seismic World, base isolation was not used to transcend the limits of a bold and formal architectural design style (Figure 6).

Figure 5: North facade

Figure 6: South facade

2.3.3 Regarding FIRMITAS

The building has a regular configuration in plan and elevation. It has reinforced concrete structure for foundations, shear walls and the ground floor level. The structure of the upper floors is mixed concrete and steel, consisting of concrete-slabs over steel beams. The roof structure is of steel with preformed panels roofing.

The base isolation interface level is located in the basement where 32 rubber isolators Ø600 mm diameter and 200 mm high support concrete walls and principal columns, and 24 secondary supports on columns to reduce vertical flexibility of slab (Figure 7).

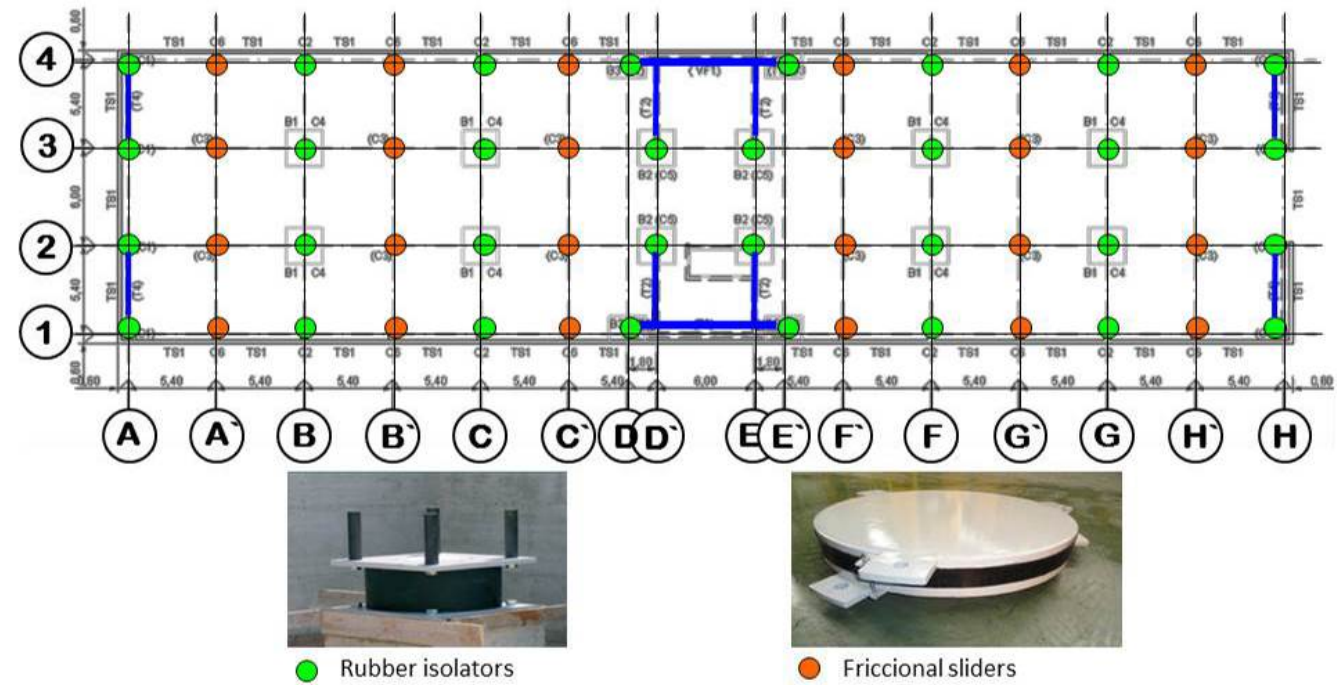

Figure 7: Base isolation interface level

The horizontal reaction of the building must be resisted by the isolators and transmitted to the foundation elements. If the isolators were located at the base of the columns would originate important flexion on the head of them, large bending moments would have to be resisted by the superstructure.

To avoid these stresses on the structure that would have required complicated construction and larger dimensions, the isolation system was designed unconventionally.

The columns´ isolators were placed immediately below of the first floor, thus the moments of the column are transferred directly to the foundation slab and the superstructure is free of additional bending moments (Figure 8). The isolators under the structural walls are placed at their bases, between the wall and the foundation slab (figure 9). The secondary columns were designed to withstand only vertical loads (Figure 10).

Figure 8: Isolators under the first floor

Figure 9: Isolators below the superstructure shear wall

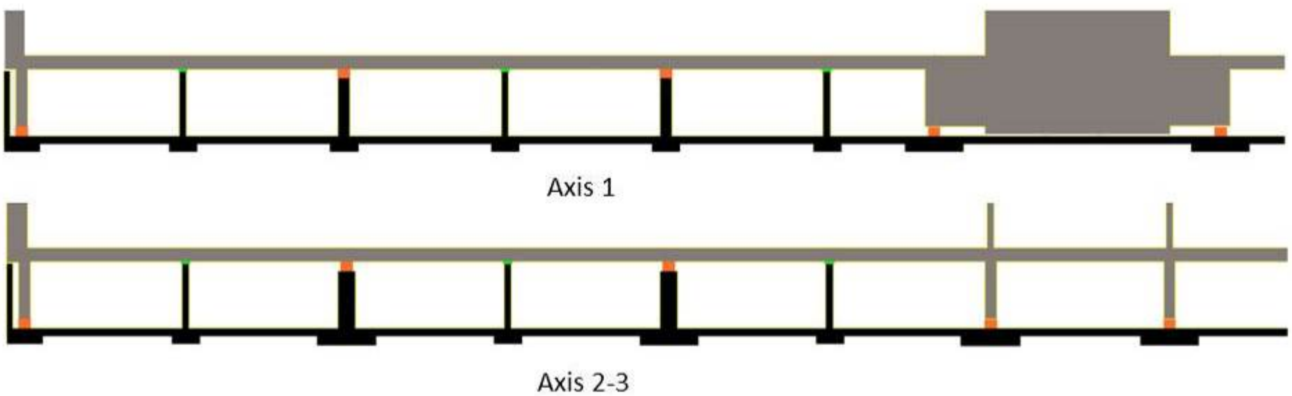

Figure 10: Unconventionally isolation system design, longitudinal section

The first slab is continuous of 15 cm thick with beams in both directions of 5.40 m span to decrease sensitivity to vertical vibrations. On this slab is housed the equipment most sensitive to vibrations.

A reinforced concrete shear wall is located along the basement perimeter, separated from the slab above. This space makes the vertical gap to allow for horizontal movement (Figures 11-12).

Figure 11: Basement perimeter, vertical gap

Figure 12: Basement perimeter, vertical gap

2.3.3.2 Earthquake resistant superstructure

In transverse direction (N-S) the building has shear walls that comprises the entire width at each end of the building and two shear walls on each side of the core that contains vertical circulation. Due to the seismic regulations in Mendoza at the time of the building design, seismic base shear was reduced by 30% as compared to the same building with a fixed base.

In longitudinal direction (E-W) a shear wall is on the south side of the vertical circulation core and on the north side two shear walls are coupled by deep beams (Figure 13). Longitudinal structure (adjacent to staircases and elevators nucleus on the southern side and the frame to the north) would not be enough for a fixed base building. The lesser amount of longitudinal structure is evident when walking around the university campus and comparing this structure with fixed base buildings of similar or lesser heights.

The lengths of the structural spans at higher levels (5.40 m slabs and 10.80 m) are important to achieve the necessary functional flexibility. The upper slabs are of steel deck with composite slabs of reinforced concrete, supported by secondary beams (IPN 180) separated by 2.7 m. The principal steel beams are of asymmetric section 500 mm high. All steel beams have connectors to achieve full composite action with the concrete slab. The columns are steel tubes of circular section 300 mm x 8 mm thick (Figure 14).

Figure 13: Shear wall west façade

Figure 14: Structural spans at higher levels

The superstructure is contained by the foundation box so that the maximum displacement is limited by stoppers. In addition the vertical space left by placing buffer stops allows jacks for eventual replacement of the devices.

Last but not least is that the simplification of structure due to isolation, basically steel deck and composite beams on steel columns, permitted faster construction with financial as well as economic savings

2.4 Special characteristics

Probably the most novel feature that occurred accidentally during construction is the method of mounting the isolators. The difficulties of importing the devices, due to bureaucratic obstacles, forced the contractor to build the superstructure on temporary supports. The isolation devices arrived when the entire structure was completed.

The temporary supports were built with the same overall geometry of the isolators so that they allowed installation of the anchor nuts in the final positions of the structure.

To insert the isolators the structure was raised with hydraulic jacks 2-3 mm. The temporary supports were removed and the isolators were slipped into position. The isolators for columns required lifting that area locally since the flexibility of the structure allowed it without inducing unacceptable structural actions (Figure 15-17).

Figure 15: Temporary support

Figure 16: Raised structure

Figure 17: Slider final location

Regarding the jacking, the end transverse shear walls, with four isolators, had to be lifted as one unit. The most critical case was the vertical circulation core, also with four isolators but with an approximate total weight of 400t (Figure 18-19). Despite initial fears of the builder and the IEHM´s authorities, workers quickly gained experience and the operation was completed in a remarkably short time.

Figure 18: Core shear walls lifted as one unit

Figure 19: Base isolators location

3. Discussion

After performing the analysis of the building, the following partial conclusions on the qualities of Seismic Architecture are:

3.1. UTILITAS: Benefits regarding the functions, increased by the use of base isolation in architectural design:

- The optimization of the area of use enables better architectural exploitation.
- The minimal structure in internal spaces allowed for adapting it for future performance of the laboratories. The flexibility of the plans allows the internal partitions and façade units to use dry lightweight construction elements with economic advantages.
- The functions of the IHEM building after severe seismic movements will not be disrupted.
- The deformation states and resistance are explicit and are known to the users, so the physical and psychological trauma generated by movement is reduced.
- The effect of an earthquake on the non-structural elements of the building and the equipment decreased drastically.

3.2. VENUSTAS: Benefits regarding beauty, increased by the use of base isolation in architectural design:

- The shape respects its context in order to match with the surrounding environment. The potential for creative freedom in the aesthetic design of the building has not been exploited.
- A contemporary architectural language is achieved.
- Due to the fact that the architectural design developed with the use of base isolation devices from the beginning, more advanced cladding elements for enhanced sustainablility could have been used.
- The identity and history of the building will be protected through the years by preserving the architectural and cultural heritage, its meaning and identity, from earthquake destruction.

3.3. FIRMITAS: Benefits regarding the structure, increased by the use of base isolation in architectural design:

- The regular structural design configuration responds to the project needs.
- The resistant structure for horizontal loads is lighter and cheaper than that corresponding to the same building supported directly on the ground, thus resulting in economic savings (20%) that compensate for the cost of the base isolation system, and eliminates the harmful effects of micro vibrations in the building from vehicular traffic or similar actions in the environment.
- The deformations or distortions in the superstructure in case of severe seismic movements are reduced.
- Damage in the IHEM building during a severe seismic movement is drastically reduced, both in structural and non-structural elements.
- The damage to building contents is reduced (high-technology equipment, machinery, etc.).
- The building construction was noticeably faster than contemporary buildings, even some on campus of the National University of Cuyo. This is largely due to two characteristics: the reduction of earthquake resistant structure enabled by the seismic isolation system, and the use of composite structures of steel and concrete for slabs and columns. There was a very significant reduction of formwork, which also could be systematized.
- There was also a significant reduction in workforce (only 50 workers, as reported by the head of the construction company), reducing risks during the work.

4. Conclusions

Base isolated buildings, besides being more efficient, safe and functional, may achieve new design prospects in seismic regions. Integrated architectural-structural knowledge of the architectural implications of Seismic Architecture is essential to develop efficient and adequate works of architecture.

Seismic Architecture provides a means of passive protection against a potential earthquake. For such purpose, it should incorporate new technologies like base isolation, within its conceptual knowledge and then use it for a comprehensive protection system which will drastically reduce human losses and damage caused by an earthquake.

Creating a work of architecture which not only contributes to decrease the seismic vulnerability and environmental problem, but also provides other benefits gives the possibility of living together with our planet for a more promising future.

Sustainable and resilient architecture is possible in seismic prone areas, such as in Mendoza.

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5. References

[1] Arnold, C. and Reitherman, R. [1987] *"Configuración y Diseño Sísmico de Edificios"*, Editorial Limusa, México.

[2] Charleson, A. [2008] *"Seismic Design for Architects: outwitting the quake"*, Architectural Press, USA.

[3] Lupoi G., Lupoi A., Di Pasquale G., De Sortis A., Sanò T. [2001] "The Seismic Design of a new Base Isolated Hospital in Frosinone", *Proc. of the 7th International Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of Vibration of Structures, Assisi, Italy.*

[4] Tedeschi, E. [1978] *"Teoría de la Arquitectura"*, Ediciones Nueva Visión, Argentina

[5] Martelli, A., Clemente,P., A., Forni, M., Salvatori,A. [2015] "Worldwide state-of-the-art of development and application of anti-seismic systems based on the information provided at the ASSISi Sendai Conference in 2013 and later and conditions for their correct use", *Proc. of the 14th World Conference of Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures*, San Diego, California, USA

[6] Vitruvio, M. [1997] *"De Architectura"*, Editorial Alianza Forma S.A., España

[7] Charleson, A. and Guisasola, A. [2016] *"Seismic Isolation for Architects"*, Routledge, U.K.

[8] Guisasola, A. [2015] "How Base Isolation Benefits the Architectural Design of Buildings" *14th World Conference on Seismic Isolation, Energy Dissipation and Active Vibration Control of Structures (14WCSI)* University of California, San Diego California, USA

[9] Documentos Inéditos [2013] CONICET, memorias descriptivas de los arquitectos e ingenieros de la obra, Mendoza, Argentina

[10] "IHEM Mendoza, Aislamiento Sísmico", Vivienda, la revista de la construcción, 637 agosto 15, pag 48- 58, 2015, Buenos Aires, Argentina.

Website: http://fcm.uncuyo.edu.ar/ihem-instituto-de-histologia-y-embriologia