Use of the dissipator SL-B in the rehabilitation of health facilities in Cuba

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ABSTRACT: This work present the seismic evaluation and the rehabilitation proposal of one essential facility, specifically the "Guillermo Luis" hospital of the Moa city in Holguín. The authors intend to apply, for the first time, a non-conventional technique used in Cuba to seismic protection of facilities health. This solution is based on seismic energy dissipation mechanisms, by mean of shear link device. The Shear Link-Bozzo device, allows the "Giron" precast concrete systems to improve the inadequacies of behavior under earthquake lateral load by avoiding the undesired failure mechanism, such as: weak story and torsion due to great stiffness and mass asymmetries. All the above mentioned aspects drives us to take some alternative measures of seismic retrofit for this typical structures, based on the incorporation of the passive energy dissipation that allow the system behave in the elastic range of response. By means of this solution it is possible to reduce the interference during the rehabilitation works, and also to reduce the time of break services of the hospital.

INTRODUCTION TO THE PROBLEM

The international experience has demonstrated that adaptation, rehabilitation or design techniques that incorporate non-conventional of seismic energy dissipation or isolation devices are often the only way to achieve the level of performance required for certain buildings. What usually happens in many countries is that these systems are becoming more applicable in the rehabilitation of those buildings whose owners want higher seismic performance goals, and can pay the special cost associated with the design, manufacture and installation of energy dissipation devices. The opinion of the engineers in practice is that dissipation devices introduction in Cuba, could be applicable only for health facilities protection.

The construction of a large number of health facilities is very common in the eastern region of Cuba, using the prefabricated system called GIRON, which is a structural system conceived since the 70´s decade. At the epoch, the state of the knowledge in relation to our levels of seismic hazard originated that, in many of the regions of our country, no especial requirements of the earthquake design and structural conception were dictated. Thirty years later, the revision of the conceptual design and the evaluation of preliminary resistance brings to the light some deficiencies that still subsist in these structural systems, like: heavy weight, low redundancy, weak floor, short columns, big torsional problems and little ductile capacity, according to that, they may prove to be very inefficient to achieve an adequate seismic behavior.

This investigation intend as a main objective to contribute with the necessary criteria to demonstrate the feasibility of the incorporation in Cuba, the innovative techniques of energy dissipation employed at an international scale to improve the performance demanded to the essential buildings such as facilities health.

The building subject to study was selected from the interest of the investor in the provincial dependence of the Health Department located in Holguín. It is the Clinical-Surgical Hospital "Guillermo Luis" in Moa. The building was fragmented in parts for its study, making good use of the existence of expansion joints that set apart the different blocks. It was established as priority the assessment and retrofit of the part of the structure corresponding to the building of hospitalized patients, called Block 2. The information collected for the initial works proved to be essential in the development of the later stages, related with the computations of vertical loads and seismic horizontal actions. More than 600 files of the original layout (architectural and structural drawings) of the Block 2 was consulted. Several visits were made to the site in order to know the current condition of the structure, its technical state and the modifications made during its service life, being detected serious modifications to the original layout, besides the location of medical equipment that implies significant weights to the structure.

a) b) c)

Figure 1. a) Regional location of the building at the Moa city, Holguin province, Cuba; b) Aerial view of the “Guillermo Luis" hospital. c) Building area of hospitalized patients, Block 2.

DESCRIPTION OF THE STRUCTURAL SYSTEM

The "Giron" system is a structure of precast reinforced concrete frames, conformed by unidirectional frames and precast concrete shear walls. The structure obey to a basic grid of 6,00m x 6,00m and 6.00 m x 7.50 m and height between structural levels of 3.30 m. Shear walls could be placed in both directions since they were conceived originally to take the horizontal wind and earthquakes loads. As the figure 2 illustrates, the existence of a structural first floor supported only on pedestals (short columns) of 40cm x 60cm and, could yield structural instability due to the great inertial forces generated above this floor level (weak story mechanism) during earthquakes.

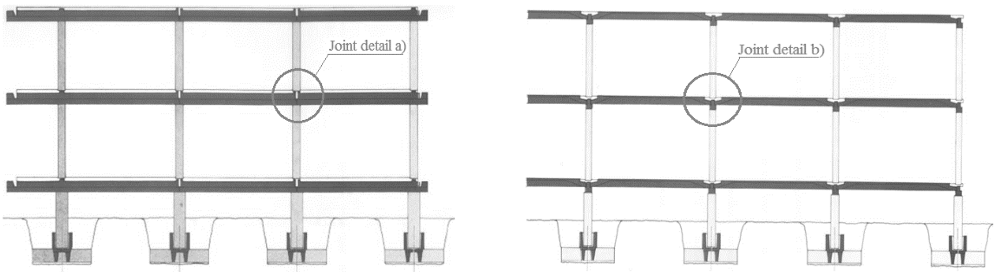


Figure 2. Tipical structural sections of Giron System. a) Frames in the beam direction (transverse frame), b) Frames in the direction of the double T slab (longitudinal frame).

The lack of symmetry in the shear walls disposition, characterizes the solutions observed in most of facilities health, conditioned by the requirements of the architectural drawings. This violation of the basics instructions given by the typical layout causes as a result the weakening of the structure. It is one of the reason for its assessment and retrofit become necessary. The figure 3 shows the shear walls disposition in structural drawings, at the level 1 to 5.

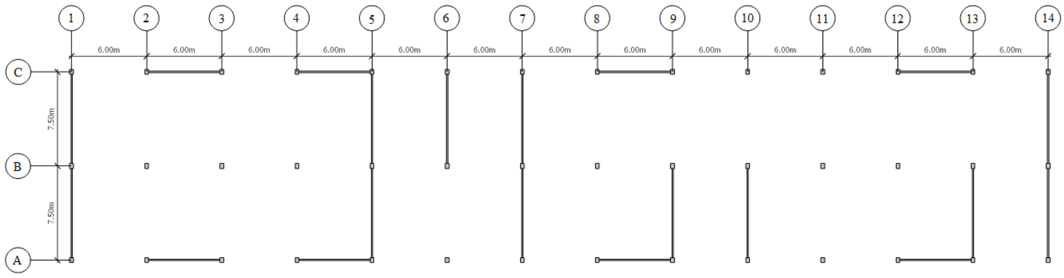


Figure 3. Structural plant of the hospitalized patients building. Block 2.

Connections of the system

The lacks of stirrups (transverse reinforcement) necessary to achieve the adequate confinement in the section core of beam-column joint, limit the column shear capacity at this zone, making weak the connection between members of the system for lateral forces. From figure 4 a) and b) it is noticed that the connection specifications does not allow to emulate a monolithic structure, behaving the system like pinned in the direction of the beams, and semi-rigid in the direction of the slabs**.** It is an additional weakness of the system to resist lateral forces.

Floor Diaphragms. Critical Points

The floors diaphragms conformed by prefabricated TT slabs units have disadvantages for the adequate seismic response, it is related to the weakness of longitudinal joints between TT slabs along the edges, which could tend to crack during the strong seismic shakes. Figure 4 c) gives the details of the joint between slabs to conform the floor diaphragm.

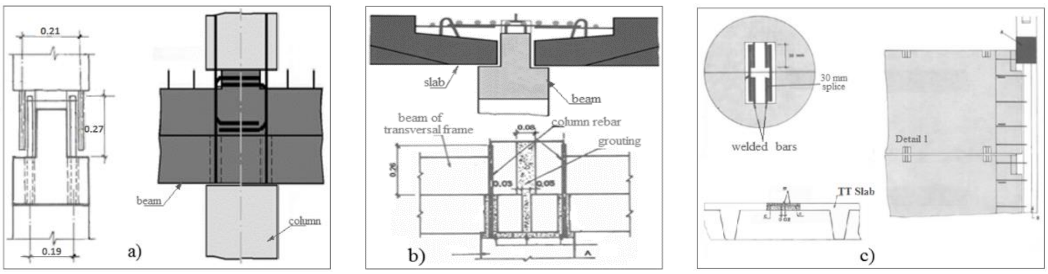
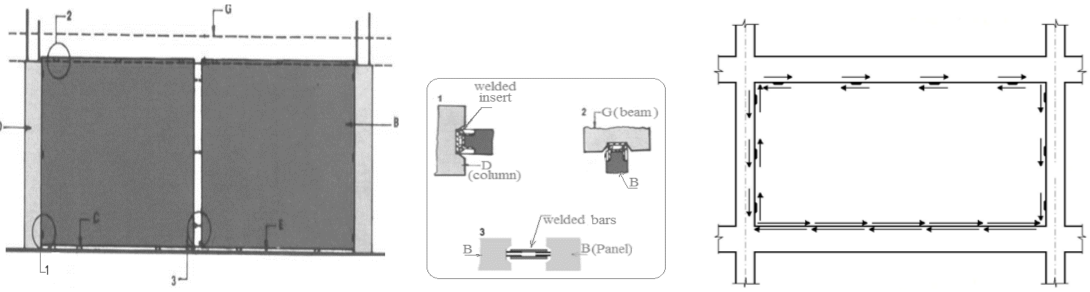


Figure 4. Details of the typical joints of the system: a) beam-column joint, b) the TT slab-beam joint, and c) longitudinal joint between TT slabs.

Lateral Bracing

The shear wall were detailed with mechanical shear transfer, so this allow a pure shear behavior to the horizontal actions, by transferring only shear forces to the beams and axial forces to the columns, like showed in figure 5 c).



a) b) c)

Figure 5. a) Dispositions of the inserts on structural elements, b) Detailed of the joints between shear walls and walls-frame, c) Shear walls behavior in the Girón system.

Conventional Methods proposed to Giron Structural System Rehabilitation

The solutions provided so far to improve the seismic response of the GIRON structural system have followed the intuitive strategy of strengthening the entire structure. They have being intended to eliminate weak floor mechanism, increasing section size of structural element of lateral loads resistant system, like columns, pedestals and foundations. To these measures bracing system, to stiffen the superstructure, is added. Another set of measures, such as, reinforcement of existing foundation elements in the critical areas, combining with the reinforcement of a limited number of columns and introducing seismic beams and bracing tensors at the level of pedestals and at the first structural level. All of these methods involve high costs of interventions, and entail too invasive strategies at the expense of long interruptions of the hospital service. To cite a specific example of this, the rehabilitation of Giron school buildings is about 405 084,46 $ USD.

Evaluation of the seismic hazard

The intra-plate bound that separates the Cuban Oriental Block from the rest of the island is one the main source of earthquakes hazard for the territory around the site, Chuy et al. (2005). Nevertheless, the greatest hazard comes from the Eastern Earthquake Zone, in which earthquakes of magnitude 8.0 can be occur. The city of Moa is located within a zone classified as a moderated seismic risk, it means that the seismic events can cause damages to the structures, and therefore some earthquake resistant measures have to be taken. This consideration will be applicable in all the structures as a function of its occupational category, and the level of seismic protection defined according to the probability of exceeding an earthquake design. The values of the maximum horizontal spectral acceleration of the ground, fall between 0.40 and 0.50 g for short periods (S_s) and from 0.15 to 0.20 g for long periods (S_1). In the Cuban standard NC 46:2013 for design of new structures, have been set the minimum levels of seismic protection. For instance, the 4.2.4.2 section of this standard define as a "severe earthquake" the one which have the probability 5% of been exceeded in 50 years, and it is used for structural design of "Important" and "Essential" buildings. According to this, an essential building has the same exceedence probability (earthquake design) as an important one, the acceptable lateral drift for each one of them, make the difference respect to seismic protection. The 4.2.4.3 section define as an "extreme earthquake" the one which have the probability 3% of been exceeded in 50 years, and it is used for structural design of critical buildings.

The seismic design spectrum generated for soil site D, at Moa city, corresponding to the earthquake design selected according to the seismic protection level defined by proposal of the Cuban Standard NC 46:2013 for the essential buildings, figure 6.

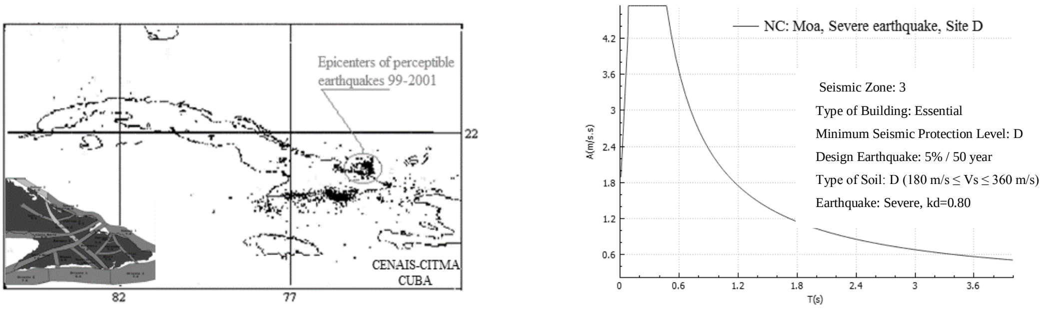


Figure 6. a) Earthquake Hazard, oriental zone of Cuba, and Geographical area of the Moa site where the hospital is located**,** b) Earthquake design defined in terms of Elastic Response Spectrum for the Cuban Seismic Standard, NC 46:2013 for the Moa City**.**

Phase of analysis of the structure without rehabilitation

The structural modeling was carried out in the 19 version of the software SAP2000, in which the main dynamic characteristics of the building were calculated, by means of a modal analysis. The period in the transverse direction, T_{1X}, is 0,962 s and in the longitudinal direction, T_{1Y}, is 0,756 s. These high values of periods yielded for a building with just 5 levels height, evidence the insufficient lateral stiffness in both directions at the structural first floor (formed only for short columns) and the lack of shear walls in both directions on the top floors.

Criteria followed for rehabilitation

Due to the limited ductility of the system, and to low shearing strength of the structural critical elements, the retrofit strategies was focused to three main goals:
1) To increase the global lateral resistance solving in a feasible way the most important mechanisms of failure detected in the structural system, these are:
a) Weak floor.
b) Brittle failure mechanism controlling the response of the earthquake lateral load resistant system, that is, shear capacity in shear walls and pedestals (short columns).
2) To take advantage of elastic response in the elements of the main structural system, canalizing the ductility demands to the energy dissipation devices by mean of yielding of SLB.
3) To be adjusted to the necessity of achieve the lower invasion as possible during the retrofit activities, in order to maintain the functioning of that area of the hospital.

Technical characteristics of the energy dissipation device SLB

The hysteretic dissipation devices of seismic energy have been largely used with excellent results in different parts of the world. These kind of devices have been used in some countries with high seismic risk, such as Peru, Mexico and Ecuador.

The specific type of dissipation device selected by us for the seismic rehabilitation, the Shear Link (SL), is suitable for seismic protection because it permit a significant reduction of the forces induced by a seism of severe intensity, but it also could yield to lower level of earthquake forces, what permit its use in zones of low and moderate seismicity. More specifically, the Shear Link-Bozzo device is based on localized increase of ductility in parts of the building, as the system concentrates the plastic response in a specific points that can be supervised and then replaced, unlike another traditional techniques of structural retrofit. The SL-B device guarantees two operating stages: (1) Before yielding of milled areas, in which it works according to a "shear mode", (2) After yielding and web buckling "bending mode". More details about works and the analytical model of shear link can be found in Nuzzo et al. (2014).

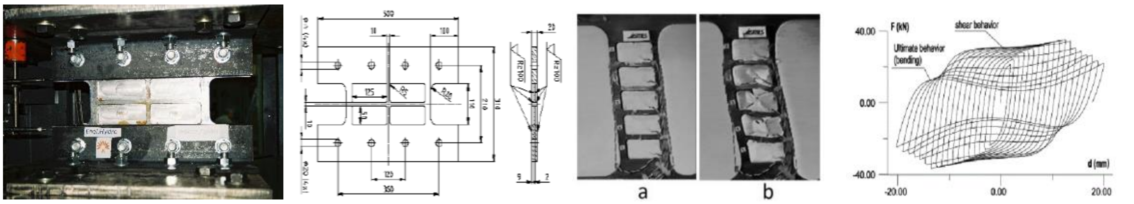


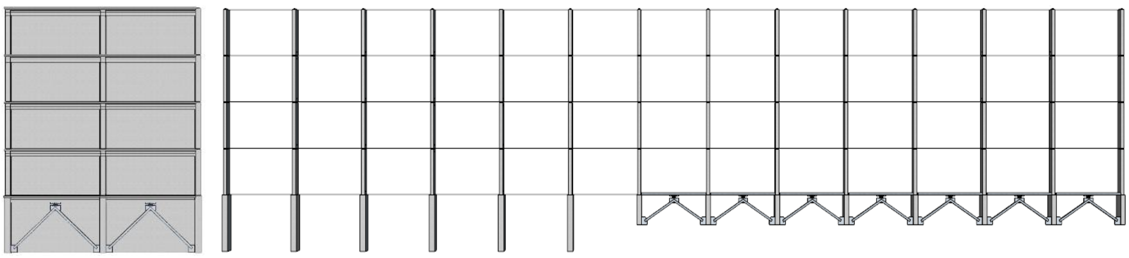
Figure 7. Seismic energy dissipation device type Sher link-Bozzo (SL-B)

Basics assumption of the structural modeling

The Linear Static Equivalent Analysis was used as a first step to find the value of elastic shear force in order to size the device. The elastic response spectrum was reduced by a factor R=1.5, regarding the low ductile capacity of the structural system and its low number of static indeterminacy. For the analysis, the shear wall was modeled like a bar impeded to take axial loads, simulating its shear behavior. This was carry out by creating a release in the frame element at the top (axial release) and a shear panel in the bottom. Then following an iterative process, "try and error" consisting of changing, in several positions the devices and running the model again, it was possible to avoid the failure mechanism of weak floor.

Dissipative braces

A combination of chevron-SL-B in strengthening shear walls capacity is shown in figure 8 a). In order to avoid weak story mechanism, metallic yielding device SL-B in series with steel elastic brace was the solution proposed as it is shown in Figure 8 b).



a) b)

Figure 8. a) Solution to strengthening shear walls capacity, b) Solution to avoid weakness of the structural first floor.

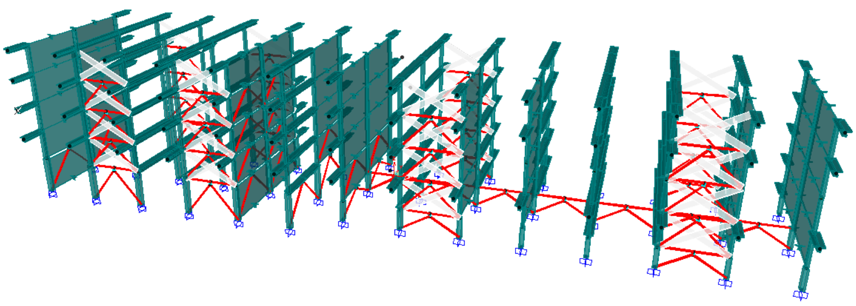


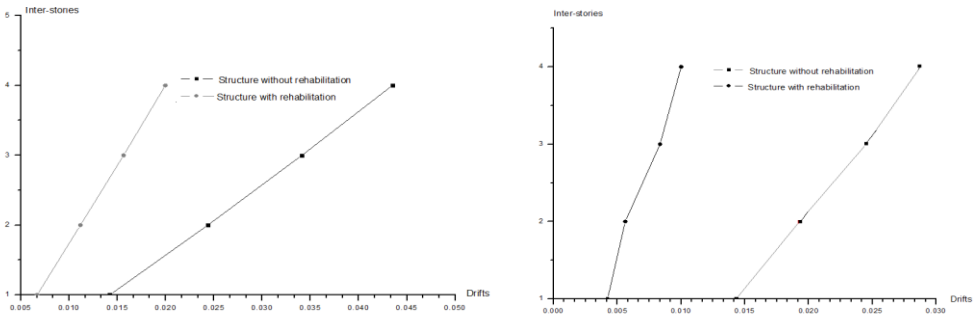
Figure 9. Schemes with the definitive positions of the devices SLB used in the building.

Table 1. Number of devices demanded

Type of Devices	Number
SL 10-5	21
SL 10-3	12
SL 15-3	14
SL 5-5	8
SL 5-2	2
Total	57

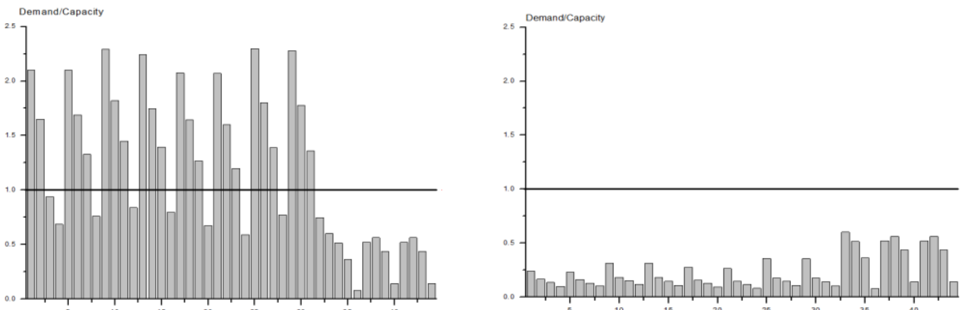
Evaluation of the effectiveness of the Proposal of Seismic Rehabilitation with energy dissipation using SL B

The structure in its original condition does not comply with the limit drifts of NC 46: 2013. After the rehabilitation with the use of the SLB device it was reduced to the acceptable values, figure 10. Another parameter used to evaluation of efficiency was the study of the relation demand/capacity of the structural elements involved in the seismic response such as: pedestals and shear walls. The shear walls demands were below capacity in all of the cases, figure 11. Similar results were possible for the case of pedestals, thus avoiding the weak floor failure mechanism, figure 12. The impossibility of changing the shear wall position leaves few alternatives for major modifications of the building torsional behavior. The use of the stiffening system allowed an acceptable reduction of the static eccentricity of 43%, 24%, 23% and 17% at the 1st, 2nd, 3rd and 4th story respectively.



a) b)

Figure 10. a) Drifts of the structure in transverse direction, b) Drifts of the structure in longitudinal direction



a) b)

Figure 11. a) Demand\Capacity relation in shear walls in the critical direction (longitudinal) of structure without rehabilitation, b) Demand\Capacity relation in shear walls in the same direction (longitudinal) of structure with rehabilitation using SL-B devices.

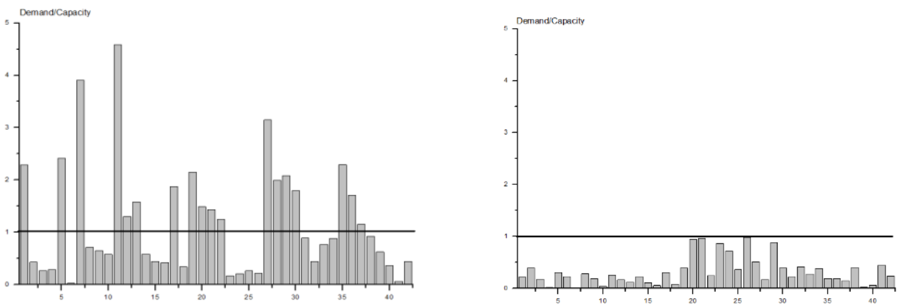


Figure 12. a) Demand\Capacity relation in pedestal, in the critical direction (transverse) of structure without rehabilitation, b) Demand\Capacity relation in pedestal, in the critical direction (transverse) of structure with rehabilitation, using SL-B devices.

The total cost of the SL-B rehabilitation proposal has been estimated to be about $ 19,500.00 to reduce the estimated total losses in the block under analysis amounting to $ 746, 935.75. All these aspects show the efficiency, from several points of view, of the technique of rehabilitation used with respect to the conventional ones.

Conclusions

The proposals of an innovative technique for the seismic retrofit, was used in the rehabilitation of Guillermo Luis hospital in Moa city. This technique was proved to be more feasible comparing to the traditional methods proposed in our country, from the point of view cost-benefit, that is, to be less invasive and less expensive than the traditional ones.

As can be shown, the former proposals analyzed have serious limitations due to the seismic structural conception. The fact is that traditional rehabilitation methods doesn't allow to reply the same solution for all the health facilities in the country because of the high cost involved and the particularities of each structure, while the proposals of this work give an unique philosophy that make easier the appraisal about the number, location and the different way of installing the energy dissipation device SL-B in structures subjected to seismic retrofit in the regions of moderated and high earthquake hazard of our island.

Acknowledgements

The authors are grateful in the first place for the valuable and disinterested collaboration shown by Dr. Ingeniero Luis Bozzo Rotondo, who offered all the technical assistance and documentation necessary to undertake this research.

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