Proposal of Isolated Basis for Low-Rise Buildings.

Oliver Ubando Franco
Ubando Engineering SA de CV

Manuel E. Ruiz Sandoval Hernández
Universidad Autónoma Metropolitana

SUMMARY

There are many construction projects in the Mexican Pacific coast. In this area occur seismic events of great magnitude due a subduction phenomenon. Building codes limit the height and number of floors, thus resulting in structures with short periods. The design spectrum has the maximum acceleration where these structures are located. An option to reduce the seismic forces is throughout the use of an isolated system. The main disadvantage of this technology is their cost.
With the occurrence of a high intensity earthquake the structure will have some damage. The cost to repair it could be considerable and may be produce the building closing. The use of an isolated system could decrease the damage in the structure, as well as to keep it under continuous operation.
This paper made a comparative cost in the construction of a typical structure in the Mexican Pacific coast, with and without isolated system.

Keywords: base isolated system, low-rise buildings, construction costs.

1. INTRODUCTION

Mexico is located in North America. It has a coastline on both Atlantic and Pacific Ocean. On the Pacific coast there are three important seismic plates in contact: the Pacific, Cocos and the Caribbean. Subduction is a present phenomenon between these plates. There exists an important liberation of energy in the zone.

In the majority of the Mexican seashores exists important tourist centers. In general, there are continuous developments of different types of resorts. This may include hotels, condominiums and nautical infrastructure. These constructions will be subject to large earthquake forces due to the high seismicity of the zone. Accelerations up to one time the gravity is not uncommon in this area.

In this paper is presented the analysis and design of a new condominium building located in the coastline city of Huatulco, Oaxaca, under two assumptions: traditional design and with the use of an isolation system. It is proposed a methodology for the design of isolated elements. A comparison of the construction cost (only for the core elements) of both design buildings is presented. Finally, it is shown the possible length and location of structural damage after the occurrence of an earthquake.

2. SEISMIC DESCRIPTION OF THE CONSTRUCTION ZONE

Figure 1 presents the seismic regions of Mexico according with the Manual of Civil Construction proposed by the State Electric Company (CFE in Spanish 1993). It can be distinguished four zones: A through D. The spectrum values are presented in table 1. Besides the seismic zone, a subdivision is shown in the table according to ground type. Type I is a firm terrain, Type II is a medium soil and Type III is a soft soil. In figure 2 are presented the design spectrums for each of the zones and type of soils.

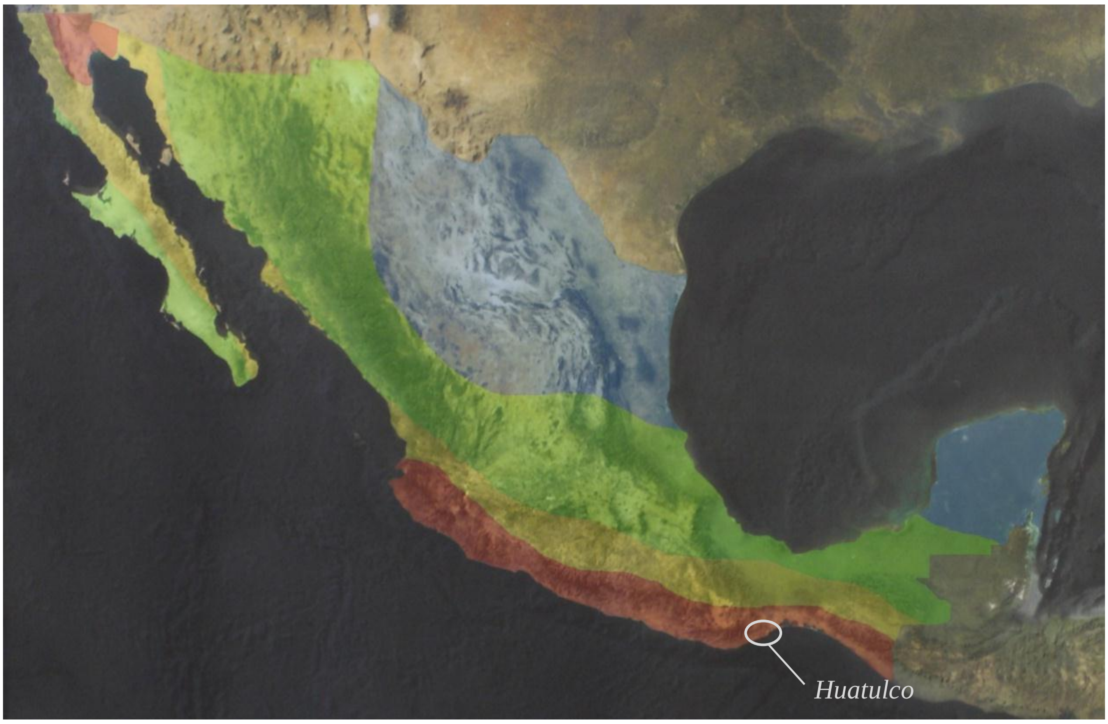


Figure1. Seismic regions of Mexico

Table 1. Spectral properties for each region.

Zone	Ground type	C g's	a_0 g's	T_a Sec	T_b Sec	r
A	I	0.08	0.02	0.20	0.60	½
	II	0.16	0.04	0.30	1.50	$^2/_3$
	III	0.20	0.05	0.60	2.90	1
B	I	0.14	0.02	0.20	0.60	½
	II	0.30	0.04	0.30	1.50	$^2/_3$
	III	0.36	0.05	0.60	2.90	1
C	I	0.36	0.36	0	0.60	½
	II	0.64	0.64	0	1.40	$^2/_3$
	III	0.64	0.64	0	1.90	1
D	I	0.50	0.50	0	0.60	½
	II	0.86	0.86	0	1.20	$^2/_3$
	III	0.86	0.86	0	1.70	1

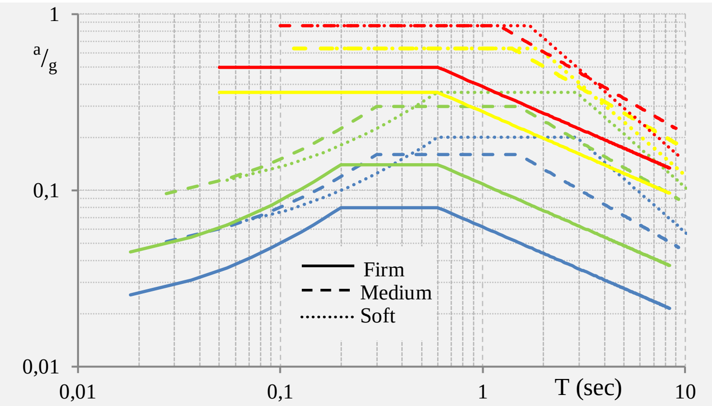


Figure 2. Spectrum designs according with CFE (1993).

Huatulco is located in Zone D according with CFE. Local authorities have established a construction code that limits the height of the buildings (4 levels or 15 meters) it in order to avoid the excessive urban exploitation.

The most common structural system in this region is based on load walls and flat slabs. A diverse variety of masonry ranging from ceramic to concrete block is employed. In figure 3 it is shown the typical types of structural walls used as a support system.

3. STRUCTURE DESCRIPTION

The building studied in this paper consists of 4 levels with a total of 14.50 m in height, and 30 x 15.50 meters of a plant size. It allocates two departments per floor of 175m^2. Each apartment has three bedrooms, lounge and dining room, as well as a terrace and kitchen. This distribution is repeated in 4 levels (figure 4).

a) Masonry walls

b) Link column between walls

c) Concrete shear walls.

d) Load walls

Figure 3. Construction details.

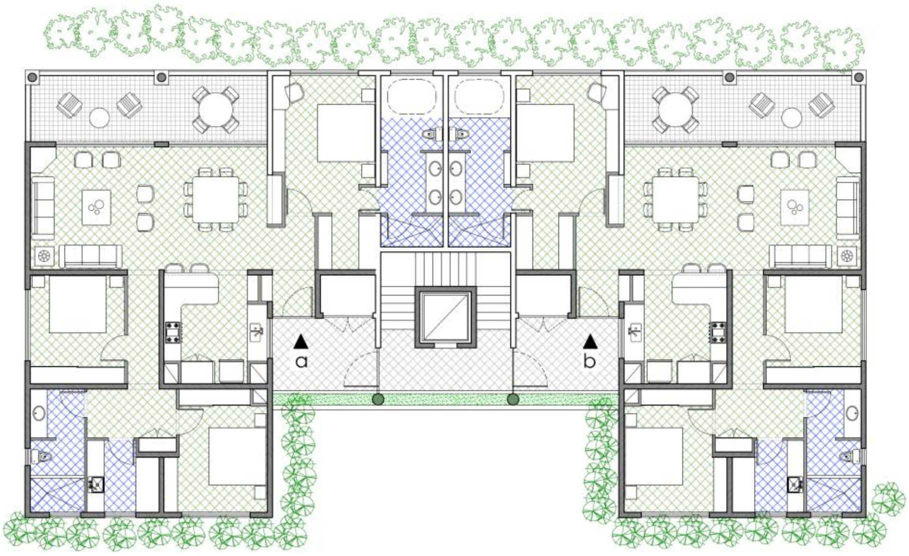


Figure 4. Architectonic space distribution

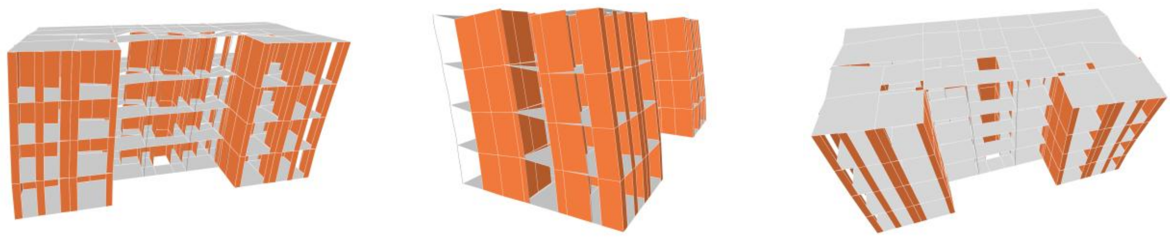
The walls are of two types: reinforced concrete and reinforced masonry. The slabs are of concrete. The soil in the area is mostly sand, therefore the foundation was designed using piles linked with a pile caps, link beams and a slab. Table 2 shows the materials properties used in each of the elements.

A mathematical model that represents the building was developed. The software used was ETABS (2012). The mode shapes for the rigid base model are presented in figure 5.
It was performed the analysis and the design of the building. The final distribution of the walls and their resistance in each direction was calculated (figure 6). Also, a modified version of the model was done to

include the based isolated system. The period of the structure was move up to four times the original period (figure 7), as suggested by Naeim and Kelly (1999). A set of construction drawings, as well as catalogs of the volumes and costs for the construction were developed for the both types of design buildings.

Table 2. Materials properties

Elements	**f'c** (MPa)	**E_c** (MPa)
Slabs	25	22136
Links beams & columns	15	9798
Columns, beams y walls	25	22136
Floor slab	10	
Piles	25	22136
Bottom beams & Pile caps	25	22136



a) First mode T=0.45s, Longitudinal direction

b) Second mode T=0.27s, Transversal direction

c) Third mode T=0.24s, Torsion

Figure 5. Modal shapes of the traditional building

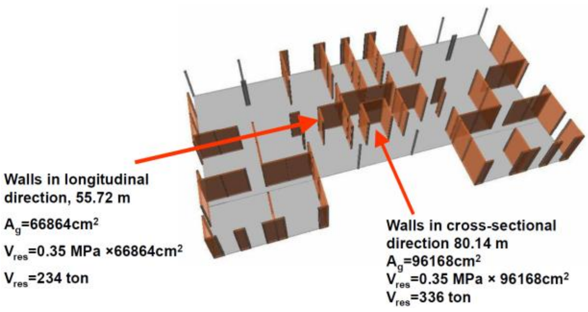


Figure 6. Distribution of walls

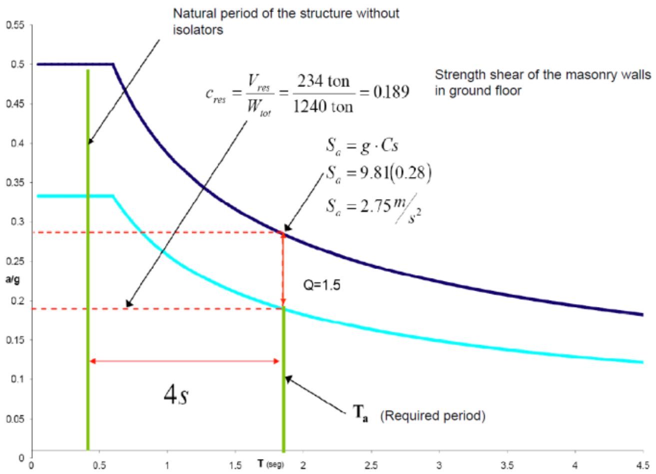


Figure 7. Spectral design, traditional structure period and the proposed isolated building period

4. PROPOSED METHODOLOGY FOR THE BASED ISOLATED SYSTEM

Figure 8 shows the proposed methodology for the design of the based isolated system. This is divided in four blocks.

a) Design of the isolated layer; The first step in this block is to distribute the based isolated elements across the foundation. The criterion used for its placement was the point of intersection of load walls and columns (figure 9). Once distributed, it is then proposed the material (type of rubber) and area of the elements. The isolated elements subject to large displacements will have lead in their core; this will help in providing energy dissipation to the structure. Finally, the isolated elements are arranged in similar groups. Four types of isolated members are proposed.

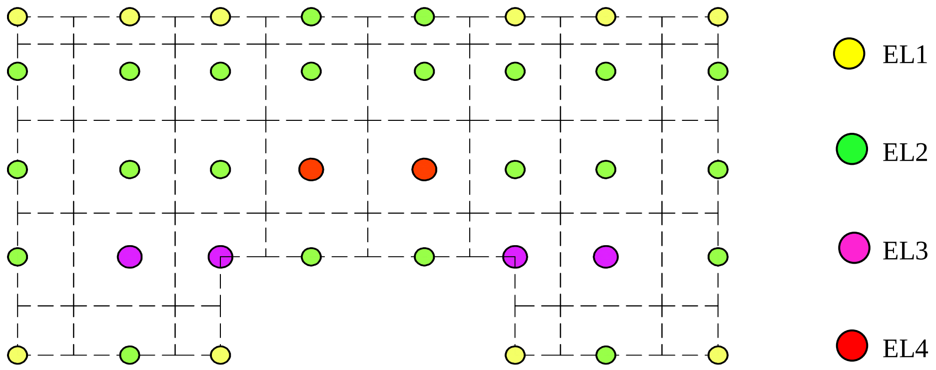


Figure 9. Isolated distribution and tributary areas to each four define types of isolated systems.

b) Vertical design of isolated elements; The second block is related to the design of the isolator in the vertical direction. It is verified that the allowable deformation of the element lies within the limits of the material. These limits are in function of the diameter and height (slenderness) of the isolator. Also, it is verified that the isolator does not fail because of the rolling of the layers of the isolator.

c) Design of isolated elements with lead core; In the third block, the isolators with lead core are designed. These contribute to the damping of the system. Different area sizes are proposed according with the initial and effective stiffness, shear and damping required for of each isolator.

d) Analytical model analysis; Finally, with the defined properties for each isolator, a mathematical model is constructed. Table 3 shows the characteristics of each of the 4 types defined for the based isolated system. This includes dimensions, drawings, physical properties, hysteresis diagrams, hysteresis ratio diagrams (deformation and shear), and the cost per piece.

5. EARTHQUAKE SELECTION

It was performed a selection of seismic events for the local design spectrum. The characteristics of the earthquakes consisted on: near the location, same soil type, maximum acceleration of the record and frequency signal content. A scale factor was calculated so the total of energy, over the total length of the record, is same for all. Table 4 presents the 6 earthquakes that were used.

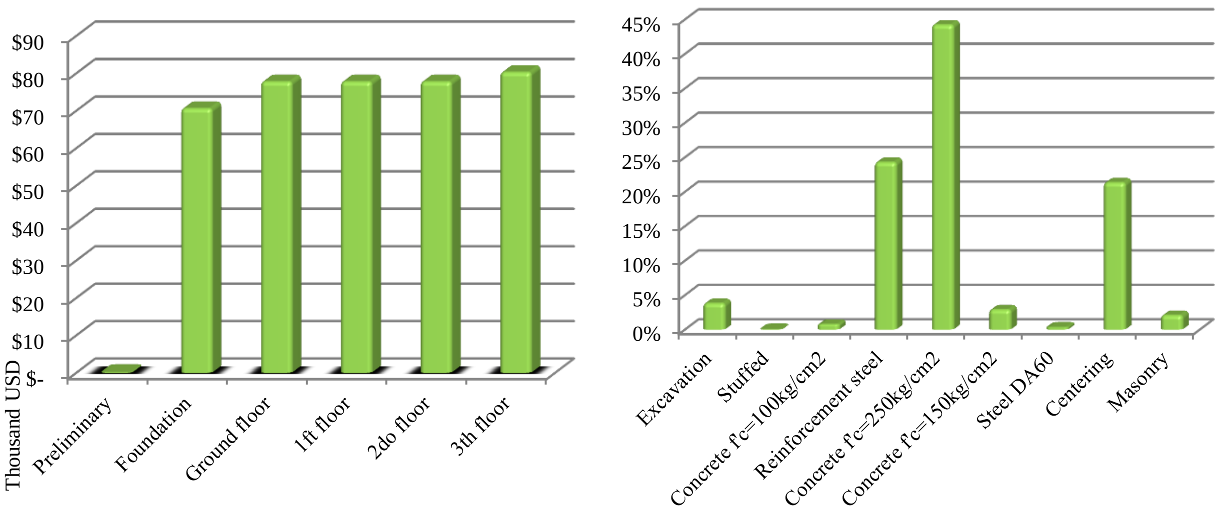
Table 4. List of earthquakes used.

Signal name	Magnitude	Max. Acceleration cm/s^2	$\sum_i^n a^2$	Reduced Time (s)	Num. points	Scale factor
HUIG9909.301 **H4X**	7.5	146.55	81422.86	65.6	5248	18
MZ019510.092 **M1X**	7.3	387.13	307954.21	108.6375	8691	1
UNIO8509.191 **U1X**	8.1	165.29	243986.09	94.5125	7561	2.1
UNIO8509.211 **U2X**	7.6	59.23	59735.36	75.875	6070	9.5
VILE8509.191 **V1X**	8.1	125.17	176922.90	117.675	9414	3
VILE9701.111 **V2X**	6.9	103.36	59206.79	89.5375	7163	11

6. COMPARISON OF COSTS BETWEEN THE TRADITIONAL AND ISOLATED STRUCTURE

As stated in the objective of this paper, only the cost for the core elements of the building was considered. The reason of this decision is because this amount could be considered common in each model.

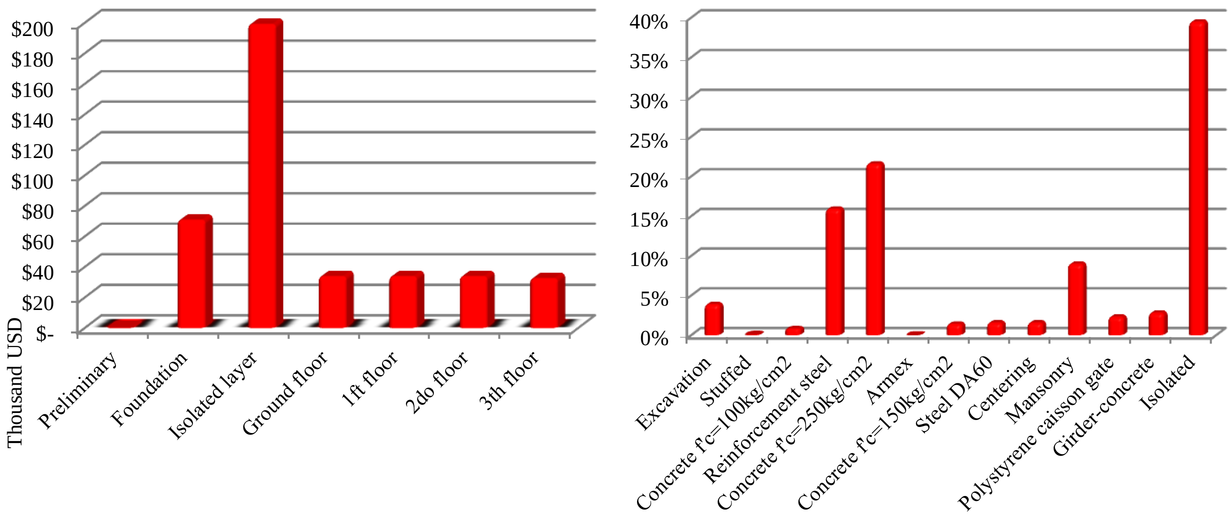
The traditional building, henceforth call Building A, has a construction cost of $ 385,000 USD. Each level of the structure (including the foundation) requires virtually the same amount of money. The distribution of cost is as follows: 44% is used for the concrete (piles, pile caps, link beams, walls, columns, beam and slabs); 24% is required for reinforcement steel and 21% in falsework, as seen in figures 10.a and 10.b.



a) Cost by level (USD)   b) Percentage of cost by concept

Figure 10. Building A

Base Isolated building, henceforth called Building B, has a construction cost of $ 403,000 USD. The most expensive items are: based isolated system (37%), concrete (20%); reinforcement steel (15%) and masonry walls (8 %). See figures 11.a and 11.b.



a) Cost by level (USD)   b) Percentage of cost by concept

Figure 11. Building B

Figure 12 show the comparison of the distribution of cost per level of structure. Figure 13 shows a comparison of the materials used between the structures. From figure 12 it can be notice that there is an important cost in the based isolated system. However, building B requires a less amount of concrete and reinforced steel, but there is an increment in the required masonry. This is mainly due to the reduction of concrete wall and its substitution for masonry because of the reduction of shear forces in the building.

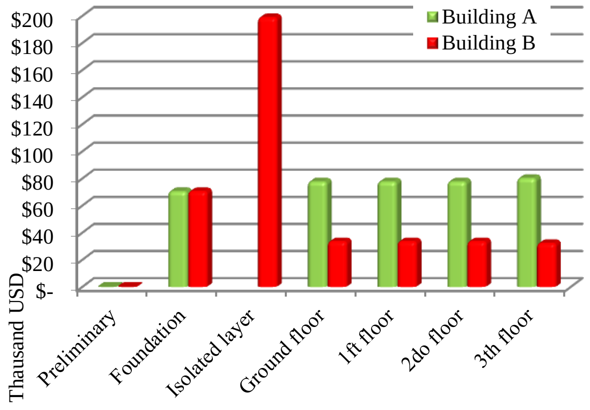


Figure 12. Construction cost by level for each building.

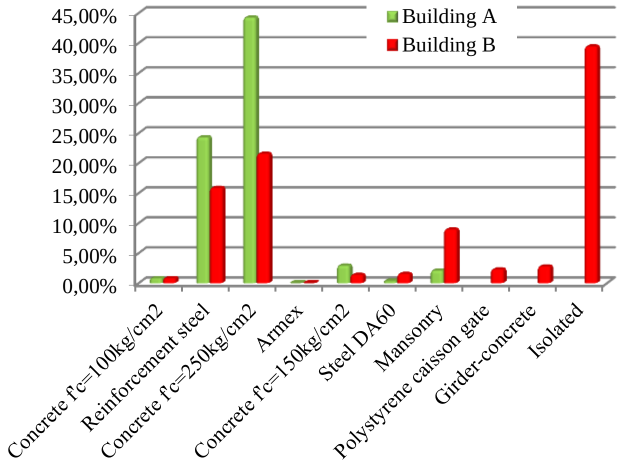


Figure 13. Participation percentage of materials.

7. ESTIMATED REPAIR COST AFTER AN EARTHQUAKE EVENT

During the life time of the building it is probable that will sustain a large earthquake event. After this occurrence, a number of repairs will be required. It is difficult, in an analytical study, to be certain of the type and magnitude of the damages produced by an earthquake. Based on the mathematical model estimated locations can be assumed.

Because of its importance, the retrofit of a building is a skilled job. The usual process begins with a technical inspection of the structure clearly indicating the damaged elements, as well as their type and extension. A retrofit proposal is later layout, so the correspondent elements could be brought up to the original security levels of operation.

Table 5 presents the estimated damages at the masonry walls (*MW*) and concrete walls (*CW*) according with the earthquake intensity: low, medium and high. It has been identify three types of damages: fissures, cracks and fractures. A Fissure is defined as a small superficial opening, not beyond the element, noticeable to the eye, and which do not produce the loosening of the surface material. A Crack is defined as elongated, narrow and non-uniform aperture produced on a surface beyond the element, this can be seen from the distance. Finally, fracture is defined as a total or partial rupture of an element, with or without displacement between its parts.

With the hypothesis presented in table 5, there will be some the repair costs associated to each damage level. In the case of low damage level some fissures will appear in the *MW*. The majority will be presented in the outside walls of the building. In case of medium damage level, both *MW* and *CW* will show cracks in the first and second level. For the rest of the levels *MW* and *CW* will present fissures. Finally, for the case of high damage scenario, some fractures will be present in the outer *MW* at the 1st and 2nd levels; cracks will be present in *MW* and *CW* in all three levels, and fissures in all *MW* and *CW*. The repair of these damages is an additional cost to the originally calculated. It is important to carry out these works since they represent the integrity and visual feature of the building.

Table 5. Qualitative description of damage according with the earthquake intensity level.

Type	Floor	Damage					
		Low		Medium		High	
		MW	*CW*	*MW*	*CW*	*MW*	*CW*
Fissures	1st	*ME & SI*	*SE*			*ME & MI*	*SE & SI*
	2nd	*SE*				*ME & MI*	*SE & SI*
	3rd	*SE*		*SI*	*SE*	*SE & SI*	*SE*
	4th			*SI*	*SE*	*SE &SI*	
Cracks	1st			*ME & MI*	*ME*	*ME & MI*	*ME & SI*
	2nd			*ME & MI*	*SE*	*ME & MI*	*ME*
	3rd			*SE*		*SE*	
	4th						
Fracture	1st					*SE*	
	2nd					*SE*	
	3rd						
	4th						
SE; some exterior, *SI*; some interior, *ME*; many exterior, *MI*; many interior.							

8. CONCLUSIONS

This paper focused to identify differences between a building design with and without based isolation system. The differences are not only the construction cost, but also the materials to be used, the construction process, final appearance and the short and long term maintenance.

The cost of the construction of the core of the structure represents about the 30 to 50% of the final value of the building. The cost of implementing a based isolated system represents the 4.6% of this cost, but, only represents from the 1.8 to 2.3% of the total cost of the building. Many owners do not appreciated this difference, and tend not apply new technology to their structures. However, beyond the initial cost, the performance of the structure during a seismic event reduces the demands over the structure. The damage sustained after an earthquake by a based isolated building could be small, and may be permit to continue to be in its operational state. Traditional building, although may have a lower initial cost, could have considerable damage and the loss of its operational state.

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