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ANALISYS OF THE BEHAVIOR OF A FLEXIBLE BUILDING WITH SINGLE AND DOUBLE SEISMIC ISOLATION

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Abstract

It is analyzed the seismic response of a 19 levels building for residential use typical from Mexico, said building structured with frames and wall made of reinforced concrete. It is also analyzed the seismic response of the building with a fixed-base and design alternatives were suggested adding seismic isolation in order to lessen the seismic response. Said alternatives were to add seismic isolation to the base using rubber isolators and friction isolators; also the response with double interface was analyzed using friction isolators in the buildings base as well as in the 7th floor´s base, with this the building behaved like two rigid blocks. The responses of each system are analyzed to determine advantages and disadvantages in each system to be used in a flexible building with 63.5 m height. The response of the structure is obtained via non-linear time-history analysis. Responses show problems when the rubber isolators where used due to the lack of post-fluency sturdiness necessary to return the structure to its original position after the quake. This problem was not present when the friction isolators were used, although, uplifting was present in 11 from 28 of the installed isolators in the structure. As an alternative to those situations it is studied the building´s response with a double interface isolation. The obtained result shows a significant reduction in the models with seismic isolation, reducing to a large degree the reinforcing steel in the sections.

Keywords: Flexible Building; Seismic Isolation; Double Interface.

1. Introduction

The traditional philosophy of the seismic resistant design accepts to reduce the elastic resistance demand of a structure being the main objective to avoid the collapse when facing a high magnitude seism. In other words, it is accepted the damage in the structural elements, which implies that the structure may be temporary out of service. In the last 30 years techniques that reduce the seismic impact have been developed with the ultimate intention of avoiding structural damage. One of the aforementioned techniques is seismic isolation, this consisting in the introduction of a laterally flexible interface between the foundation and the superstructure, to elongate the natural vibration period of the structure filtering the high frequency ground movement. (Ref. Seguin et al, James Kelly et al) Generally seismic isolation systems include energy dissipation, which increases the system´s efficiency. Currently seismic isolation is in masification stage all around the world due to the broad theoretical and experimental research, having been validated during high intensity seismic movements. (E.g. Kobe, 1995; Northridge, 1994; El Maule, 2010). Every country with seismic activity has now specific regulations for seismic isolation systems (E.g. International Conference of Building Code ICBO, “Earthquake Regulations for Seismic Isolated Structures”, UBC 1991. Federal Emergency Management Agency FEMA. Nch 2745 of 2003, Análisis y diseño de edificios con aislación sísmica, INN Chile. Manual de diseño por sismo de la Comisión Federal de Electricidad CFE 2008, México). However the use of seismic isolation has been mainly performed on rigid, generally low to medium height building, where the response reductions could be up to 90% which essentially implies an elastic response of the superstructure.

As for flexible structures, it is assumed that the most appropriated technique is energy dissipation. (Ref. T.T Soong) This technique is capable of response reductions that rarely reach over 30%, which implies that for the model earthquake the main structure will enter in a non-elastic range (Ref. Aguirre et al)

Perhaps one of the biggest challenges in seismic engineering these days is to implement seismic isolation systems in flexible buildings. In this study it is analyzed the seismic response of a flexible building made of reinforced concrete where the traditional solution (fixed base) is compared against different seismic isolation system alternatives. The provisions from the Manual de obras civiles de la Comisión Federal de Electricidad CFE, 2008 México have been considered. The objective of this study is to define the advantages and disadvantages of each system and determine the best seismic isolation system for a flexible building according to Mexican regulations.

2. Model description

The model of the analyzed building has the typical geometry of a residential from México, structured with concrete frames and walls. Said walls are located in the elevator and stair zones, as well as in the edges of the building, in the shortest directions.

The building has a regular floor with a side length of 30.90 m x 20.53 m, with a total area of 635 m^2. The column sections area represents a 1.97% of the floor, while the walls represent a 2.22%. The building´s height is 65.4 m with a total of 19 levels, two basements, one ground floor and 16 apartment levels. The base/height relation is 1:2.15 on the X axis and 1:3.18 on the Y axis. The geometry of the model is represented in **figure 1**.

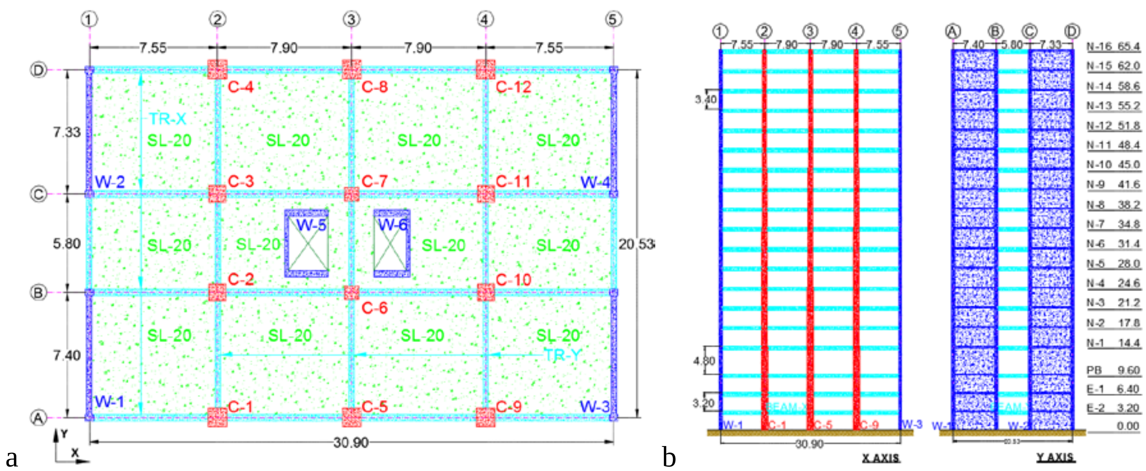


Fig. 1 – Building´s geometry. a) Floor view; b) Height view.

The properties of the materials that form the beams, columns and walls are:

a) Concrete: compression resistance after 28 days $F´c=350\ kgf/cm^2$, specific weight $\gamma=2400\ kg/m^3$.

b) Reinforcement steel: Steel A630-420H was used; having a yield stress of $F_y=4200\ kgf/cm^2$ and a final resistance of $F_u=6300\ kgf/cm^2$ with an specific weight of $\gamma=7850\ kg/m^3$

On the X axis all the beams have a section of 40 cm x 60 cm with a value under 5.12% with nominal momentum $M_{n(+)}=3174\ tonfxcm$; and a top value of 9.21% with nominal momentum $M_{n(-)}=5237\ tonfxcm$. On the Y axis they have a section of 30 cm x 60 cm with a value under of 5.89% with nominal momentum $M_{n(+)}=2700\ tonfxcm$ and a top value of 11.22% with a nominal momentum $M_{n(-)}=5003\ tonfxcm$. Three columns where taken into consideration, all of them square shaped, with 110cm at the base (C-1, C-4, C-5, C-8, C-9, C-12 see figure 1); 100 cm (C-2, C-3, C-10, C-11) and 80 cm (C-6, C-7) all of them are reduced after a certain number of level by 10cm finishing at the last level with sections of 70cm, 60cm, and 50cm respectively. Two types of wall were considered on the Y axis (M-1, M-2, M-3, M-4) having a width of 30cm in the first 10 levels and 20cm in the last 9 levels, with edge columns; and another wall in "C" shape (M-5, M-6) with 40 cm flange (X axis) and a 20 cm web (Y axis) in the first ten level, for the rest of the levels the flanges were reduced 30 cm, maintaining the 20 cm web.

Three types of gravity charge were considered. First one is the structural elements weight itself. The second is the non-structural element weight corresponding this to the tiles, facilities, partition wall, plaster or decorative panel which are; a) 0 kg/m^2 in basements, b) 240 kg/m^2 in ground floor, c) 300kg/m^2 in levels 1 through 15; and d)200 kg/m^2 in level 16. The third one corresponds to live loads as defined in the construction and urban development regulations from Zapopan, Jalisco, said loads are: a) 250 kg/m^2 in basements, b) 350 kg/m^2 in ground floor, c) 190 kg/m^2 in levels 1 through 15; and d) 100 kg/m^2 in level 16.

The seismic analysis will be done for the location and mechanical properties in the ground on 4161 Pablo Neruda Av. Zapopan, Jalisco, Mexico, situated in the following geographical coordinates: *Lat: 20° 41.474' N; Long: 103° 24.656' W; Alt: 1610 m.a.s.l.*

The seismic demand is defined by the seismic chapter in the Manual de Diseño de Obras Civiles from Comision Federal de Electricidad 2008 acording to their PRODISIS program, said chapter gives the necessary parameter to generate the design's spectrum. Using the geographic coordinates previously defined, the following parameters are obtained: ground acceleration coefficient $a_o = 0.17\ g$; seismic coefficient $c = 0.64\ g$; plateau's inferior limit $T_a = 0.1571\ sec$; plateau's superior limit $T_b = 0.6\ sec$; descendent branch beginning period $T_c = 2\ sec$; ground's dominant period $T_s = 0.33\ sec$; critical dampening factor $\zeta = 5\ \%$.

An acceleration record was generated, this is compatible with the design spectrum calculated through an domain in frequency calculation (Ref. Clough and Penzien). In **figure 2** the acceleration record for the X and Y axis is shown adjusted to the design's spectrum. For this analysis said record was amplified in 1.3 for the isolated models, as stipulated in the CFE design manual 2008.

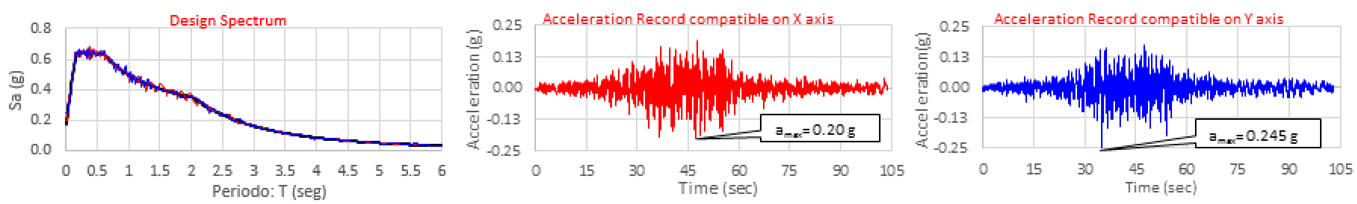


Fig. 2 - Acceleration record compatible to design´s spectrum.

3. Considered models

The structured models were developed with the SAP2000 program (ref. Edward L. Wilson, computer & -structures Inc. CSI). Beams and columns were modeled as frame elements; while the walls and slabs were modeled as shell elements, discretized in square elements with a maximum size of 100 cm. It is assumed that the shell elements are kept in elastic range. In contrast plastic hinges were considered at both edges of all beams and under the base of the basement columns, using non-linear flexural elements type LINK with a degree of freedom with the capabilities indicated in section 2.

In total 4 structural models were developed (i) fixed-base model (FB); (ii) model with isolation interface at the base and rubber isolator (RI); (iii) model with isolation interface at the base and frictional pendulum isolators (FPI1); and (iv) model with double isolation interface, at the base and in level 7 with frictional pendulum isolators (FPI2). The seismic response was evaluated through non-linear time-history dynamic analysis using the algorithm kwonw as Fast nonlinear analysis (FNA, ref. Wilson 2002)

3.1 Fixed base model (FB)

In this section the main properties of the fixed base model (FB) are described, said model is the reference to be compared with the models using seismic isolation. **Figure 3** show the first three vibration modes on model FB. The first vibration mode has a period of $T_1 = 1.893\ sec$, corresponding to travel on the X axis. The second vibration mode has a period of $T_2 = 1.51\ sec$. corresponding to travel on the Y axis. The third mode is torsional, with a period of $T_3 = 1.18\ sec$. A Rayleigh damping was considered, assigning a 5% critical dampening in models 1 and 3.

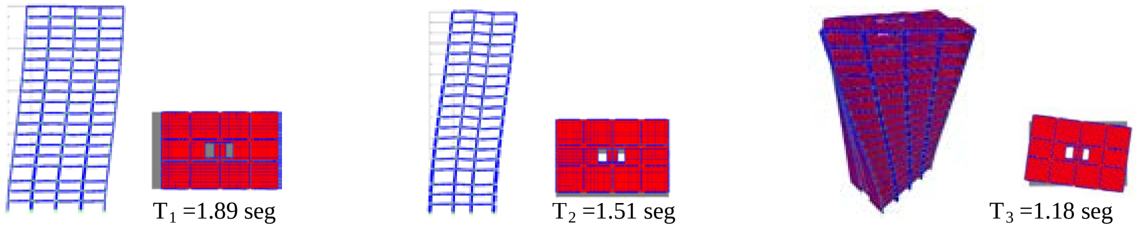


Fig. 3 - First three vibration modes on the fixed base model.

Figure 4 shows the history responses over time of the vertical reactions on the supports 1, 11 and 6 (see figure 1). At support 1 a maximum vertical reaction of 2590 tonf in compression was produced, with 1705 tonf in traction due to such support is located in a corner of the building. Support 11 (M-5 corner wall) presents a maximum compression of 2258 tonf and a maximum traction of 1172 tonf. Lastly, support 16 has a maximum compression of 1215 tonf, without showing traction due to the location in the building's central zone.

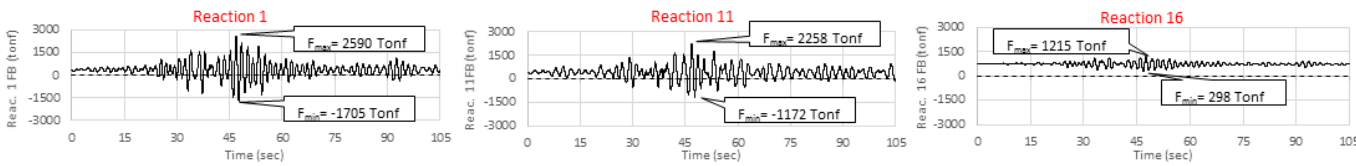


Fig. 4 - History of the supports 1, 11, 16 reactions from model FB.

3.2 Models with seismic isolation

The main purpose of the seismic isolation system design considered in this study is that of maintaining the superstructure in an elastic range, which will be verified analyzing the plastic hinges response. **Figure 5-a** shows schematically the isolators location in the floor. In **figure 5-b** is shown the axial force in each isolator, being distinguished 3 groups. The first formed by isolators 1 through 6 and 23 through 28 (in red); the second group formed by isolators 7, 8, 9, 10, 13, 16, 19, 20, 21 and 22 (in green); and the third group formed by isolators 11, 12, 14, 15, 17 and 18 (in blue).

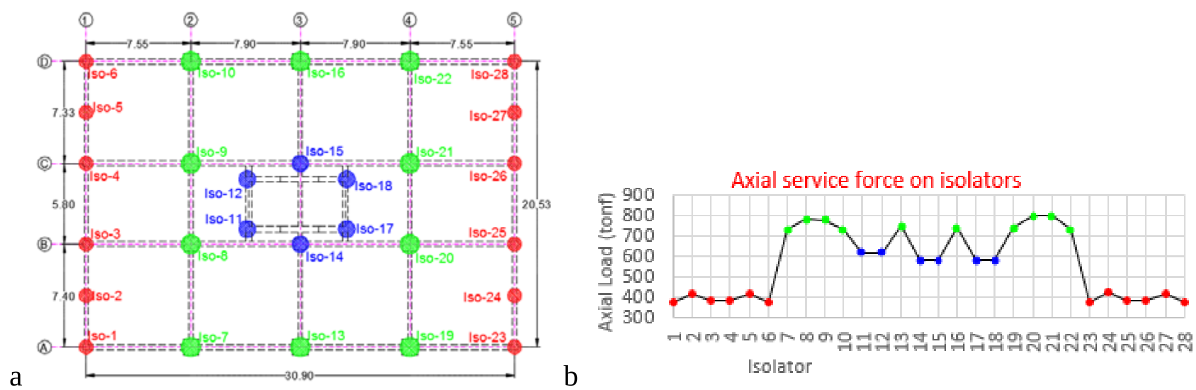


Fig. 5 - a) Isolators distribution and location in the floor. b) Axial service force in each isolator.

3.2.1 Isolated base model with rubber isolator (RI)

The Mexican code (ref. CFe-08,3.13.2.3.2.2) stablishes that the minimum post-flow stiffness that an isolation system must have, in order to guarantee the self-centering strength of the building, must satisfy the following equation:

$$(k)_p \geq 0.05 \text{ N}/x_{max} \qquad (1)$$

where N is the total building's weight; and x_{max} is the design's maximum displacement. Taking this limitations into account, an isolation period of *T= 4.09 sec*. was obtained, which corresponds to 2.15 times to the fixed base system period time. The sum of the plastic stiffness (post-flow of the rubber isolators) from all the isolators is $\Sigma(k)_p = 35.70$

tonf/cm, fulfilling the requirement in equation (1), plastic stiffness being minimal: $\Sigma(k)_p = 34.55$ *tonf/cm*. **Table 1** show the detais of isolation system from model FB.

Tab. 1 – Details of isolation system from model FB

	Axial Load (tonf)	Diam Ext (cm)	Diam Int (cm)	Elas. Stiff (tonf/ cm)	Plast. Stiff (tonf/ cm)	Efec Stiff (tonf/ cm)	Hyst damp	Efec damp	Fy (tonf)	Mod Elast (tonf /cm^2)	Rubber thick (cm)	Num rubbber	H rubber (cm)
Group1	392.87	110	12	9.79	1.08	1.48	0.16	0.21	10.37	24.40	0.8	55	43.97
Group2	759.90	130	12	13.72	1.51	1.91	0.13	0.18	10.37	35.37	0.8	55	43.97
Group3	595.28	120	12	11.68	1.28	1.69	0.15	0.20	10.37	29.63	0.8	55	43.97

Figure 6 shows the first three vibration modes from the structure, where it can be appreciated that the structural deformation is concentrated mainly in the isolation system. The first mode corresponds to the X axis, with a period of T_1*=4.09 sec.*; the second corresponds to the Y axis, with a period of T_2*=3.94 sec.*; and the third is torsional, with a period T_3*=3.46 sec*. A damping factor of 5% was considered for all the vibration modes, except for the first three, wich a damping factor of 0.05% was assigned.

Figure 7 shows the minimum and maximum axial loads on the isolators obtained from the dinamyc analysis. A critical situation is appreciated on isolators 1, 6 and 28 since they show tractions up to 200 tonf. This because those are the isolators located at the corners.

Figure 8 shows the history in time of the axial load on the 3 representative isolator of each group. The traction of 110 tonf on isolator 1 is shown, while the remaining two do not undergo traction. On isolator 16 in the third group, it is appreciated that its axial load is very stable due to the location in the building's center, with a difference of 447 tonf between its maximum and minimum axial load, unlike isolator 11 that suffers a variation up to 900 tonf.

Figure 9 shows the force-deformation relation on the X and Y axis on the studied isolators, where it is appreciated the same deformation of 17.8 cm on the X axis, and a deformation of 23cm on the Y axis. The maximum shear forces range between 28 tonf and 35tonf on the X axis, and between 34 tonf and 44 tonf on the Y axis.

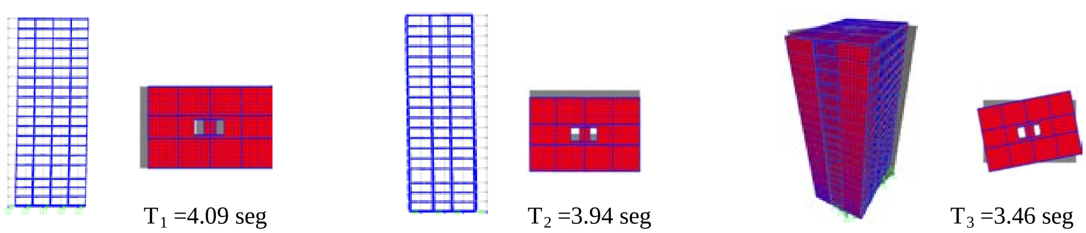


Fig. 6 - First three vibration modes in the structure with isolated base with rubber isolators.

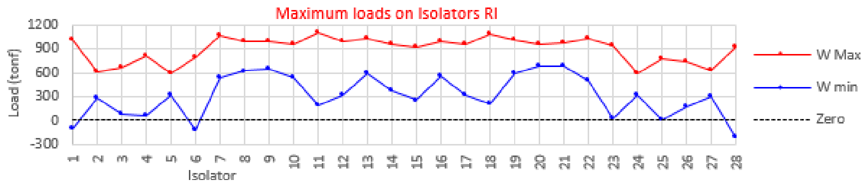


Fig. 7 - Maximum and mínimum load on RI isolators.

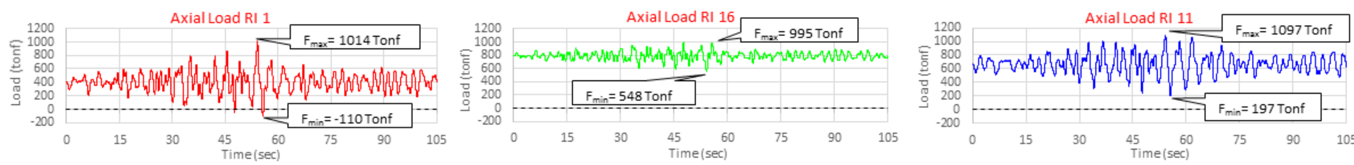


Fig. 8 - Rubber isolators' axial load through time.

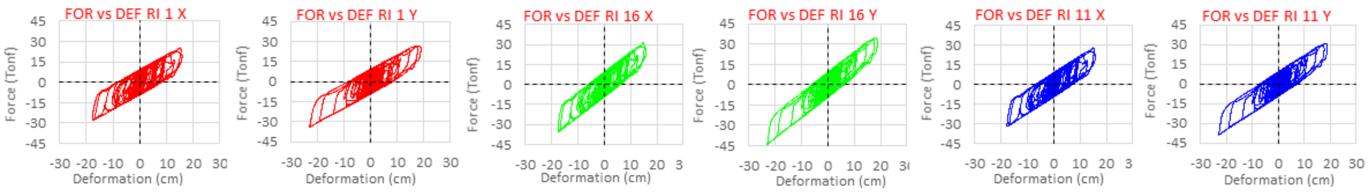


Fig. 9 - Force vs Deformation on rubber isolators RI.

3.2.2 Base isolation with frictional pendulum isolators model (FPI1)

Next is presented the base isolation interface model formed by frictional pendulum isolators (ref. Zayas et al Almazan et al). The same three group of bearings defined for the RI model were considered. The design procedure lead to a nominal isolation period of *T=4.76 sec*. that is to say 2.51 times the fixed base period, which achieves the objective of moving away the fixed base period 2.5 times at least. It is important to emphasize that the frictional pendulum does not have the self-centering strength limitation given by equation (1), consequently it is possible a larger flexibility of the structure. The curvature radius of all the isolators is equal to *R=561 cm*. A constant friction coefficient was used, equal to μ= 0.04. **Table 2** shows details of isolation system from model FPI1. **Figure 10** shows the three first vibration modes of the structure. First mode corresponds to the X axis with a period of $T_1=4.76$ *sec.*; the second mode is on the Y axis with a period of $T_2=4.60$ *sec.*; and the third is torsional, with a period of $T_3=4.27$ *sec*. As in the FB model a damping factor of 5% was considered for all the vibration models except for the first three (isolated models), to which a damping factor of 0.05% was assigned. **Figure 11** presents maximum and minimum loads on pendulum frictional isolators obtained in the dynamic analysis. It is appreciated that at some point during the seism an uplifting occurs in isolators 1, 2, 3, 4, 6, 11, 12, 23, 25, 26 and 28.

Figure 12 for its part shows history in the axial load on the isolators 1, 11, and 16. It is observed that isolator 1 is uplifted repeatedly, while in isolator 11 uplifting is produced only once, and isolator 16 has no uplifting at any moment. **Figure 13** shows force-deformation relation on the same isolators. It is observed the uplifting effect on isolator 1 on the Y axis. On the other hand an "ideal" behavior is presented in isolator 16 in both axes. Note that at any moment the impact generated after the uplifting generates significant axial loads, therefore no significant shear force was created either. The greater shear forces are created in synchrony with the greater compression efforts caused by the overturning momentum (ref. Almazan et al).

Tab. 2 – Details of isolation system from model FPI1

	Axial Load (tonf)	**Elastic Stiffnes (tonf/cm)**	**Plastic Stiffnes (tonf/cm)**	**Efective Stiffnes (tonf/cm)**	**Efective damping**	**Lateral Force (tonf)**	**Max Displacement (cm)**	**Diameter Pendulum (cm)**
Group1	421.93	337.54	0.75	0.75	0.35	30.53	18.29	50
Group2	821.29	657.03	1.46	1.46	0.35	59.43	18.29	70
Group3	643.90	515.12	1.15	1.15	0.35	46.59	18.29	60

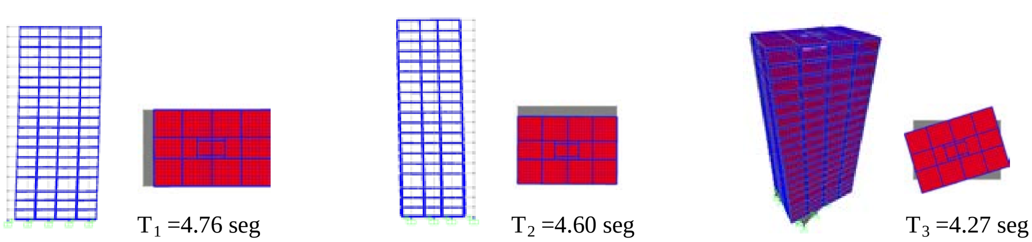


Fig. 10 - first three vibration modes of the isolated base structure FPI1.

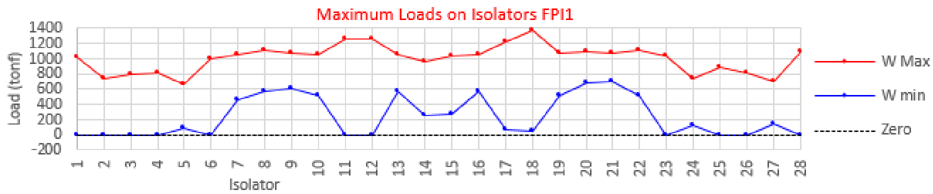


Fig. 11 - Maximum and mínimum loads on the isolators in FPI1

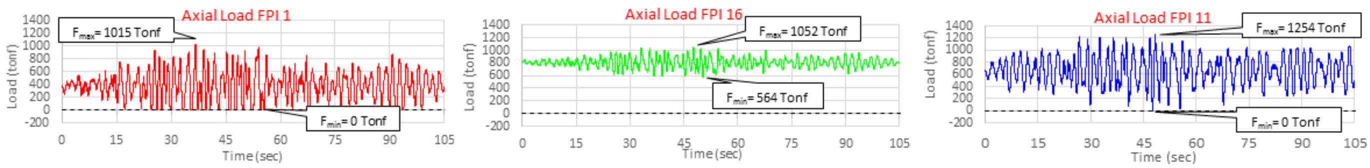


Fig. 12 - Axial load through time on isolators in the FPI1 model.

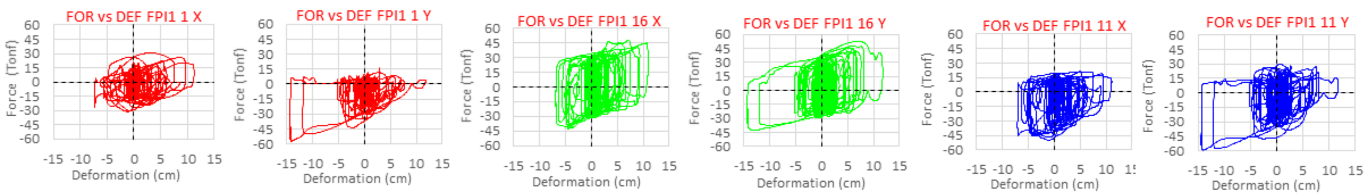


Fig. 13 - Force vs Deformation on friction isolators FPI1.

3.2.3 Double interface isolation model with frictional pendulum isolators (FPI2)

In this chapter is presented the building's response using double interface isolation, where the building has been subdivided into two blocks with approximately the same height, between levels 6 and 7, as is shown in **figure 14-a**. This model represents a peculiar case of structure segmentation. For this occasion frictional pendulum isolators were used in both interfaces, from the fact that this device allows higher structure flexibility. **Figure 14-b** shows the isolators' distribution in the floor in the intermediate interface. **Figure 15** shows the static axial loads on both interfaces isolators; being the same three groups in the base level defined for the FB and FPI1 models. Furthermore 3 groups were added corresponding to the middle interface: the fourth group consisting of isolators 29 to 34 and 51 to 56 (in yellow); the fifth group formed by isolators 35 to 41 and 44 to 50 (in magenta); and least group 6 consisting of isolators 42 and 43 (in grey). **Table 3** show details of isolation systems from model FPI2.

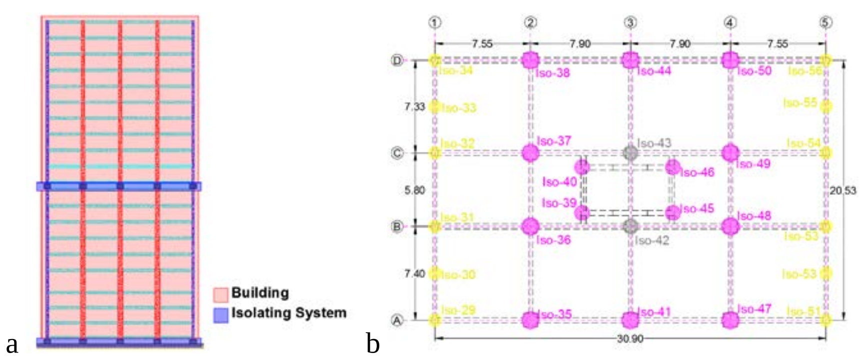


Fig. 14 - a) Double interface isolating system. b) Middle interface isolators floor distribution.

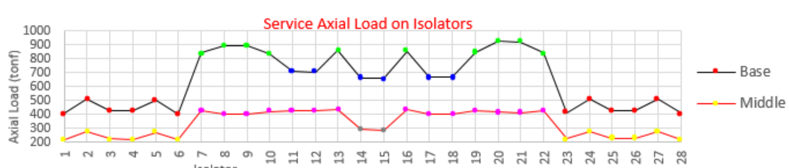


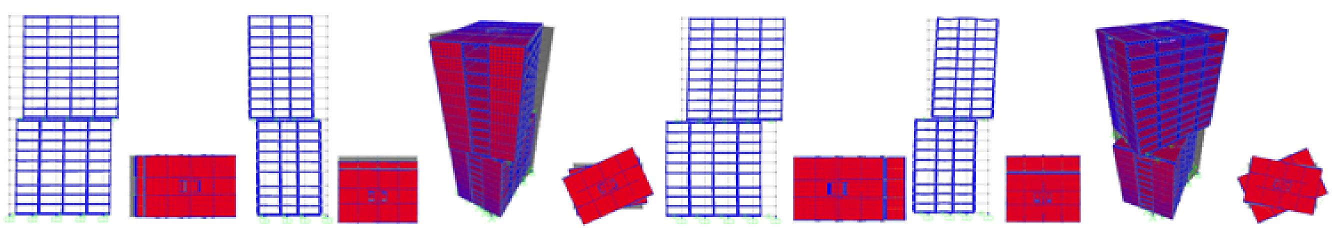
Fig. 15 - Service axial loads on each isolator in both interfaces in model FPI2.

Tab. 3 – Details of isolation system from model FPI2

	Axial Load (tonf)	Elastic Stiffnes (tonf/cm)	Plastic Stiffnes (tonf/cm)	Efective Stiffnes (tonf/cm)	Efective damping	Lateral Force (tonf)	Max Displacement (cm)	Diameter Pendulum (cm)
Group1	443.5	266.1	1.01	1.01	0.30	28.7	15.22	50
Group2	866.4	519.8	1.98	1.98	0.30	56.0	15.22	75
Group3	672.8	403.7	1.53	1.53	0.30	43.5	15.22	65
Group4	234.9	187.9	0.69	0.69	0.38	15.9	9.44	35
Group5	415.0	332.0	1.22	1.22	0.38	28.2	9.44	50
Group6	367.6	294.0	1.08	1.08	0.38	24.9	9.44	45

From the procedures outcome on the isolators design, in which was used a curvature radius of R= 438 cm for the base interface and a curvature radius of R= 340 cm for the intermediate interface, a nominal fundamental period T=5.52 sec. was obtained, corresponding to 2.92 times the period in the fixed base structure.

Unlike the conventional seismic isolation models, that is to say with a single interface in the base level, the double interface isolation model has 6 “isolated modes”. **Figure 16** shows this 6 modes which correspond to model FPI2. The first mode correspond to the X axis with a period of $T_1=5.52$ *sec*.; the second is on the Y axis with a period of $T_2=5.34$ *sec*.; the third is torsional with a period of $T_3=4.98$ *sec*.; the fourth again corresponds to the X and has a period of $T_4=2.12$ *sec*.; the fifth mode is on the Y axis with a period of $T_5=2.08$ *sec*.; the sixth one is torsional with a period $T_6=1.97$ *sec*.; note that in the first three modes both blocks in the superstructure move in the same direction (movement in phase), while in modes 4 to 6 move in opposite directions (movement in counter phase). As in the previous cases, a damping factor of 5% was used in the non-isolated modes (7th and on) and 0.5% for the isolated modes. (1st to 6th).



T_1 =5.52 seg T_2 =5.34 seg T_3 =4.98 seg T_4 =2.12 seg T_5 =2.08 seg T_6 =1.97 seg

Fig. 16 - First 6 vibration modes of the structure in model FPI2

The isolators analyzed in the base level are 1, 11 and 16 (same previously studied). The isolators analyzed in the intermediate interface are number 29 from group 4; number 42 that belongs to group 6; and number 44 belonging to group 5. In **figure 17** are presented the minimum and maximum axial loads on isolators in both interfaces. In **figure 18** presents history over time of the axial loads on the 6 representative isolators in each group. An uplifting is appreciated in isolators 1 in one occasion only, contrasting with model FPI1 where the uplifting is repeatedly presented. Isolators 16 and 11 in the first interface and none of the isolators in the second interface uplifting. In **figure 19** it is shown the force-deformation relation from the studied isolators on the X and Y axis. The isolators belonging to the first interface show a displacement of 8.61 cm on the X axis, and 12.54 cm on the Y axis. A reduction in displacement and force on the isolators in the base is observed, against the RI and FPI2 models. The isolators corresponding to the intermediate level show a displacement of 6 cm on the X axis, and 7.3 cm on the Y axis.

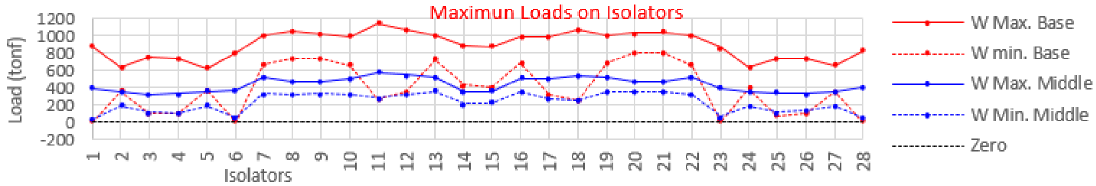


Fig. 17 – Maximum and minimun loads on isolators in both interfaces in FPI2 model

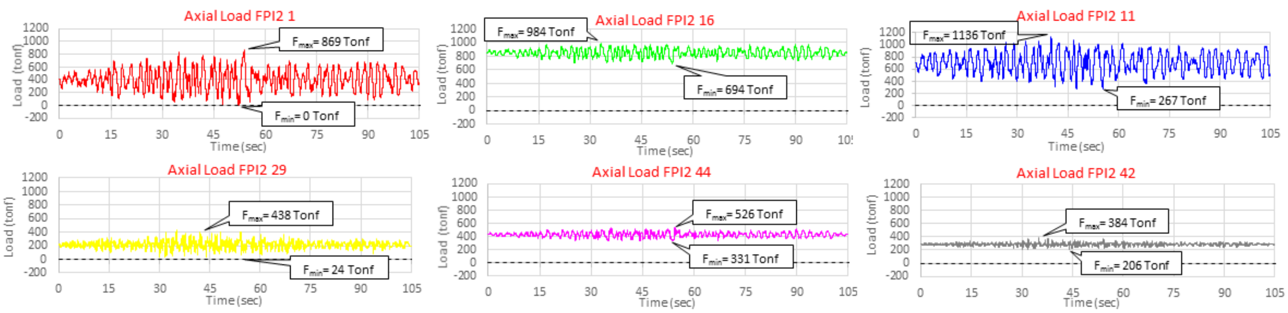


Fig.18 - Maximum and minimum loads on isolators in FPI2.

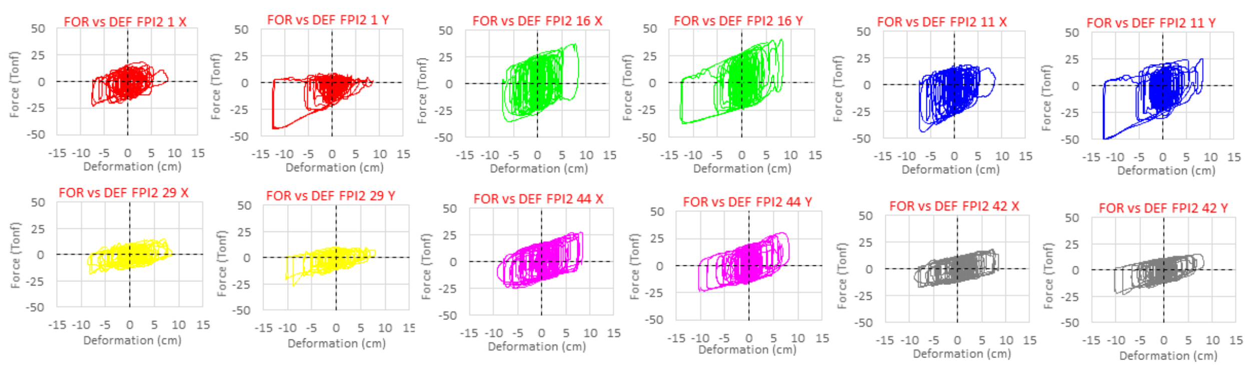


Fig.19 - Force - deformation relation on isolators in model FPI2.

4. Global and local responses comparison

In **figure 20** are presented the minimum and maximum vertical reactions on the supports in the four models obtained from dynamic analysis. Note that in model BF (fixed base) it is produced a maximum compression of 2587 tonf and a maximum traction of 1846 tonf, both in one corner of the building. This traction value will imply the use of special foundations (floor anchoring). However, and as it was expected, with the isolated models both the magnitude of the reactions, and the amount of tractions at supports were reduced. Maximum traction is 250 tonf on said corner of model RI.

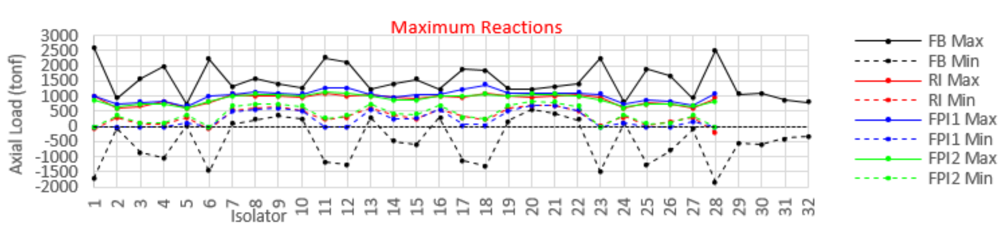


Fig. 20 - Maximum and minimum reactions in the four models.

Figure 21 show the maximum and minimum shear on the X and Y axes, for all the floors. **Figure 22 a**, **b**, and **c** show the maximum displacement per floor and the mezzanine deformation in addition of acceleration per floor respectively. It can be observed that the maximum displacement at the last level is practically the same for all models. However for the FB model the maximum deformation in the mezzanine is in the order of 6.5/1000, and too concentrated in a few levels. However for the isolated models the maximum mezzanine deformation does not exceed 2/1000 in none of the models, due to the fact that deformation is concentrated in the levels that have isolators.

Maximum total acceleration per level is presented in **figure 22**. Maximum acceleration of 0.30 g are shown on the X axis in the FB model, being the seismic isolation model RI the one that reports the least acceleration with 0.20 g; model FPI2 experiments an increase in acceleration at the middle of the structure, due to that there is located the intermediate isolation interface. On the Y axis accelerations are augmented up to 0.63 g in the FB model due to the walls on Y that return to the most rigid structure. In this sense the acceleration reductions with the isolation systems are substantial being 0.16 g, 0.26 g and 0.19 g the maximum accelerations for the models RI, FPI1, and FPI2 respectively. Accelerations on models with isolators FPI1 are greater than the ones produced in models with RI isolators, as a result of the pendulum isolators beginning to displace after the friction force is weakened, if this does not happen the model behaves like the FB model, precisely like a rigid base. On the other hand, the rubber isolators do not have an initial force to overcome, so they do not need a strong force to activate.

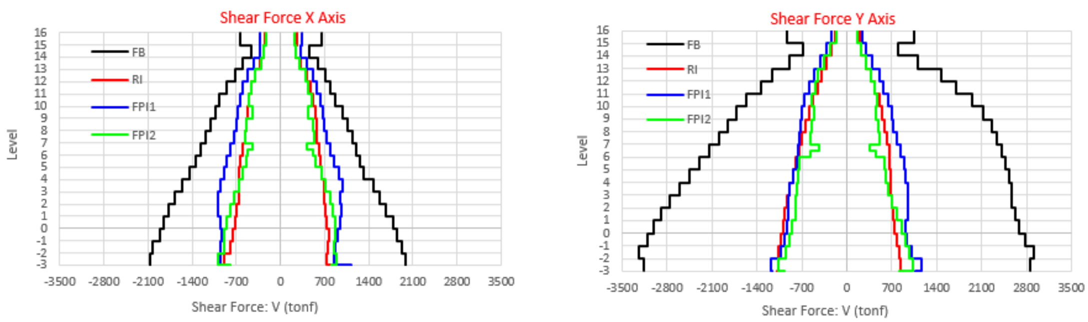


Fig. 21 - Maximum shear force per level on the X and Y axis in the four models.

The internal stresses in columns and beams are analyzed next. First column C-11 is studied at the second basement level where the maximum forces are applied. In **figure 23** are presented the combination between axial loads and flexor moment and the interaction curve. It is observed for the FB model that the combinations stay inside the interaction curve, as a result the column behaves elastically, with an utilization factor of approximately 80%. In contrast for the isolated models the utilization factor does not exceed 20% in none of the models. Using these results as a base, it is proposed a reduction of 0.20 ‰ in the amount of reinforcing steel for the models with seismic isolation. Hereof several reductions of reinforcing steel were made in various columns and walls all over the building, reaching a 63% total reduction in respect to the fixed base model. It is worth stressing that this changes occur in the steel reinforcing and not in the section's dimensions, maintaining this way the same mass, stiffness, and damping properties of the building.

a)

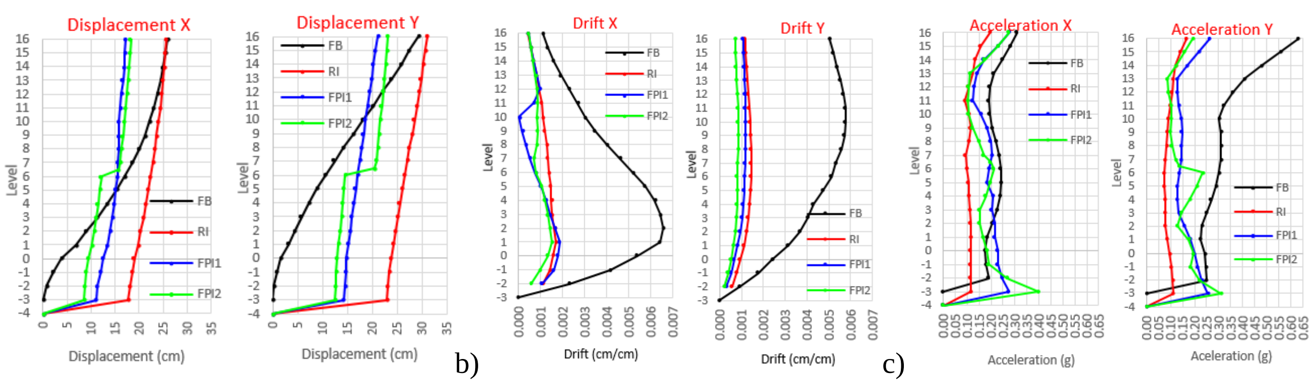


Fig. 22 - a) Maximum displacement on the X and Y axes in the four models. b) Mezzanine deformation DRIFT on the X and Y axes in the four models. c) Maximum mezzanine acceleration on the X and Y axes in the four models.

Now are presented the results on the beams with the highest demand (having FB model as a reference) on the X and Y axes. The beam analyzed on the X axis is the correspondent to level 5 between axes 3 and 4; while the beam analyzed on the Y axis is located in level 10 between axes C and D.

Figure 24 shows the beam's response on the X axis, where it can be appreciated that the flexor momentum reaches the limit of the plastic momentum for the FB model, forming a deformation in the corresponding plastic hinge with 0.009 rad. maximum deformation. On the other hand seismic isolated models, lack the presence of plastic hinge, consequently the relation momentum rotation is not present on the beam.

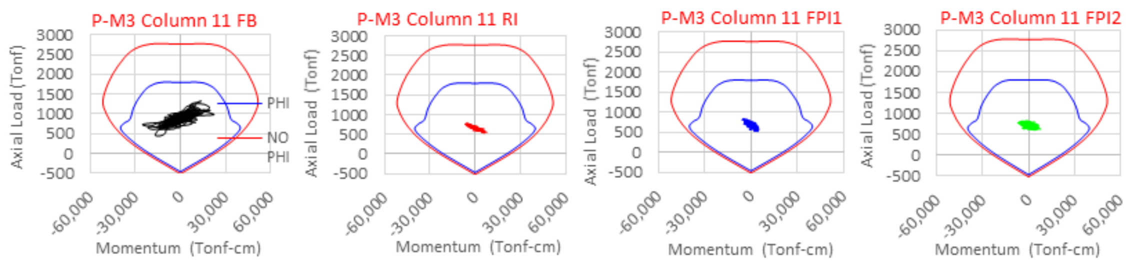


Fig. 23 - Interaction curve on the column C-11 of the four models.

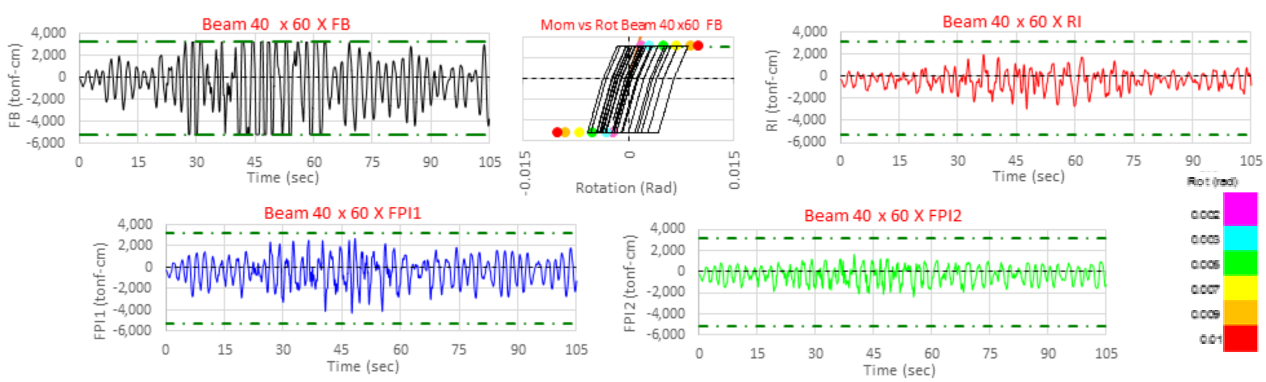


Fig. 24 - Momentum through time and momentum-rotation relation on the beams on the X axis in the four models.

5. Conclusions

In this study was analyzed the seismic response on from a concrete building with 19 levels in a real project, what allows to evaluate its economical and building advantages, in addition to the mathematical models and its responses. It was considered an original structure FB, and structures equipped with rubber isolators RI, frictional pendulum isolators FPI1 and double interface isolation using frictional pendulum isolators FPI2. The obtained results allow deducing the following conclusions:

About the FB system:

i) Beams show damage due to nonlinear behavior; ii) its maximum reactions are sizable and suffer uplifting forces in 19 from 32 supports, which requires a special and expensive foundation; iii) The proposed sections in the walls lack the requirements from the demand and plastic hinges are formed, damaging the structure presumably having the structure out of order for a time after the seism; iv) the building's energetic equilibrium is given basically by viscous dampening, which translates into damage.

About the RI system:

v) The desired period is not achieved due to the necessary self-centering force that do not allow enough flexibility to the isolator, restricting its use to flexible buildings, as in this case; vi) it reduces the energy input; vii) lesser mezzanine accelerations are presented; viii) Uplifting is produced in three of the building's supports; ix) The superstructure begins to show a minor drift, but the structures behavior is completely linear.

About the FPI1 system:

x) This system is capable to produce the desired period where is feasible to meet the self-centering force; xi) the energy input is increased; xii) uplifting is produced in 11 of the building's supports, nevertheless, this isolators are capable of withstand the uplifting generated; xiii) mezzanine deformation begins to occur, but the structure's behavior is completely linear.

About the FPI2 system:

xiv) exhibits the higher reduction on the seismic response among the models; xv) in regards to the single interface isolation models, the mezzanine deformations, uplifting in supports, basal shear, viscous damping, and the performing demand in beams and columns, is reduced; xvi) being the most flexible building, the least seismic exigency is presented; xvii) Deformation is distributed between the two interfaces; xviii) Implementing it is a generous alternative for high-rise buildings; xix) has problems with the elevator implementation, but solutions for said problems already exist; xx) uplifting was produced on the four corner's supports, but are presented in few occasions and the isolators are capable to control said uplifting; xxi) structure's behavior is completely linear, achieving the superstructure's behavior as two rigid blocks; xxii) To divide a building using a double seismic interface, comes out as a tendency for flexible tall buildings, showing adequate behavior, providing the benefits and advantages of the seismic isolation implementation, breaking the myth that is not possible to apply this system on tall buildings.

In general:

xxiii) The reduction on beams, columns and walls use of reinforcing steel on the isolated models allows to balance economics with the cost of the isolators; xxiv) On the models with frictional pendulum isolators, needing a force capable to overcome friction to begin oscillation, acceleration are incremented in regards to the model with rubber isolators, which need lesser forces to start moving; xxv) Seismic isolated systems reduce the maximum loads and uplifting that the structure shows, which involves a reduction in foundation making it cheaper and contributing to the expenses on the bearings in this way; xxvi) The behavior of the isolated systems is completely linear, which guarantees that after a seismic event the building will remain completely operational avoiding maintenance expenses; xxvii) breaking the myth and proving that it is possible to implement seismic isolation in tall buildings, carries a technological challenge to seismic isolators makers, manufacturing them with higher capabilities; xviii) the use of seismic isolation in tall buildings takes us to a high structure period, over 4 seconds. Seismic sensors deliver doubtful results for periods higher than 4 or 5 second. Due to that it is required that the normative incorporates higher certainty on the seismic demand above 4 seconds, because as a result flexible seismic isolation is limited. It has been proven that seismic isolation in flexible buildings works, now it is required that the normative evolves; xxix) It is convenient to use seismic isolation systems as far as possible, in one or more interfaces, according to height and flexibility, since the seismic response is lesser and the building suffers no damage.

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