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# Análisis estático no lineal (push over) con aisladores sísmicos en los talleres de la Universidad Técnica de Ambato

## *Nonlinear static analysis (push over) with seismic isolators in the workshops of the Technical University of Ambato*

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**Palabras claves:** Análisis estático, push over, aisladores, sísmicos talleres

## Resumen

En el presente artículo se realiza un análisis del comportamiento estructural de dos estructuras con y sin la utilización de aisladores sísmicos. La una estructura se encuentra en el taller de la Facultad de Ingeniería Civil y Mecánica (FICM) mientras que la otra está en el taller de la Facultad de Ingeniería en Sistemas, Electrónica e Industrial (FISEI), las dos pertenecientes a la Universidad Técnica de Ambato. Las estructuras tienen un sistema estructural de pórticos especiales sismo resistentes de acero laminado en caliente con diagonales rigidizadoras. Primeramente, se realizó un marco metodológico. Posteriormente, para el análisis del comportamiento estructural se muestran los resultados del período fundamental de vibración, validación del análisis dinámico, derivas de piso, análisis estático no lineal, curva de capacidad, punto de desempeño, características del aislador elastomérico con núcleo de plomo, modelamiento en el software de ingeniería ETABS, comparación de resultados del período de vibración, comparación de derivas inelásticas, comparación de los desplazamientos, entre otros. Se concluye que, para el taller de la FICM la estructura empotrada presentó un desplazamiento máximo para un sismo de diseño de 1.162 cm, en la estructura con base asilada se redujo un 50.76% con un desplazamiento de 0.572 cm; mientras que, para el taller FISEI la estructura empotrada presentó un valor de 1.294 cm, y con la implantación de aisladores se reduce un 63.49% con un valor de 0.473 cm. Por lo tanto, con la incorporación de aisladores sísmicos las estructuras tienen mayor capacidad de disipación de energía.

**Keywords:**Static analysis, push over, isolators, seismic workshops

## Abstract

In this article, an analysis of the structural behavior of two structures with and without the use of seismic isolators is carried out. One structure is located in the workshop of the Faculty of Civil and Mechanical Engineering (FICM) while the other is in the workshop of the Faculty of Systems, Electronic and Industrial Engineering (FISEI), both belonging to the Technical University of Ambato. The structures have a structural system of special earthquake-resistant hot-rolled steel frames with stiffening diagonals. First, a methodological framework was created. Subsequently, for the analysis of structural behavior, the following are presented: the results of the fundamental period of vibration, validation of the dynamic analysis, floor drifts, nonlinear static analysis, capacity curve, performance point, characteristics of the elastomeric insulator with lead core , modeling in the ETABS engineering software, comparison of vibration period results, comparison of inelastic drifts, comparison of displacements, among others. It is concluded that, for the FICM workshop, the embedded structure presented a maximum displacement for a design earthquake of 1.162 cm, in the structure with a fixed base it was reduced by 50.76% with a displacement of 0.572 cm; while, for the FISEI workshop, the embedded structure presented a value of 1.294 cm, and with the implementation of insulators it is reduced by 63.49% with a value of 0.473 cm. Therefore, with the incorporation of seismic isolators, the structures have a greater energy dissipation capacity.

## Introduction

Ecuador is located in a region with a high danger of seismic and volcanic events, with the last event occurring on April 16, 2016 in the provinces of Manabí and Esmeraldas with a magnitude 7.8 earthquake. The earthquake caused around 700 deaths, more than 7,000 injuries, 22,000 refugees, destroyed or uninhabitable buildings, and economic losses of around three billion dollars (Geophysical Institute – EPN, 2020).

At the University Campus of Valle de los Chillos, Rumiñahui Canton, Pichincha Province, there are structures with seismic isolators. The construction has an area of 23,338 square meters and is composed of 8 architectural blocks, of which 6 include FPT friction triple pendulum seismic isolators. According to the research of Aguiar & Pazmiño (2016), it is expected that the experiences carried out will be useful for structural designers, since the presence of seismic isolators has contributed to the development of Earthquake Resistant Engineering.

In the country, industrial workshops do not comply with all current construction standards. This situation makes it conducive for structural engineers to take into account the importance of using base insulators, even more so if the Equator is located in the Pacific ring of fire.

The lack of studies and evaluations of the moment of occurrence of a seismic activity has made it necessary to apply nonlinear static analysis criteria in the workshops of the

Faculty of Civil and Mechanical Engineering and the Faculty of Electronic and Industrial Systems Engineering. , using specialized finite element software (ETABS), based on current construction regulations. A nonlinear static analysis is used to approximately understand how structures function when subjected to seismic movements and exceed their elastic capacity.

Carrying out a structural evaluation is essential, therefore, a non-linear static analysis was carried out through the use of finite element software (ETABS), a review of all aspects related to the design and the current state of the workshops of the Faculty of Civil and Mechanical Engineering (FICM), as well as the Faculty of Systems, Electronic and Industrial Engineering (FISEI), complying with the Ecuadorian construction standard NEC 2015, as well as international standards such as AISC 360 , FEMA 440 and AISC 358.

In the investigation, the structural plans were compared with the in situ structures, non-destructive tests were carried out, the weld beads were inspected and measured, penetrating inks were applied to detect discontinuities on the surface, welded components were inspected using ultrasound tests and performed hammer tests.

The simulation used an elastomeric lead core (LRB) insulator with interlayers of neoprene and steel plates with a cylindrical lead core in the center. The steel plates provide vertical rigidity to resist vertical loads, while the lead core provides horizontal rigidity to prevent movement during service loads and dissipates energy as heat upon deformation.

Based on the Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications Standard (ANSI/AISC, 2016), the welded joints of the welded flange without reinforcement and welded web (WUF-W) connections were analyzed. In addition, with the information collected, the structures were simulated using the ETABS 2018 software.

Finally, a comparison of the structural behavior of the FICM and FISEI workshops was carried out, which are currently built under a system of special earthquake-resistant hot-rolled steel frames with stiffening diagonals and pre-qualified connections (welded flange connection without reinforcement and welded core (WUF-W).

In the present investigation, a design was carried out using seismic isolators in the steel structures, since they improve their behavior and consequently the lives of all occupants are protected.

The objective of this research is to carry out a nonlinear static analysis (push over) with seismic isolators in the workshops of the Technical University of Ambato.

In the development of this research topic, an applicative and descriptive methodology was used, because it used computational tools to carry out structural diagnoses in the event of seismic events of the two structures to be studied. The investigations and tests were carried out in the FICM and FISEI workshops, located on the Huachi Campus of the Technical University of Ambato.

### Methodological framework

### Hypothesis

The structural behavior of the FICM and FISEI workshops, with the inclusion of seismic isolators, through nonlinear static analysis (PUSH OVER), will be better compared to the behavior of those same structures without the inclusion of seismic isolators.

### Population

The study and tests were carried out in the FICM and FISEI workshops, located on the premises of the Technical University of Ambato, Huachi Chico Campus.

### Information collection

Field work was carried out where structural information from the workshops was collected in situ. The research selected in the course of the development of the research project helped in the interpretation of the results obtained.

### Information processing

The information that was collected, selected and processed was used to carry out the structural designs of the workshops. The designs were simulated using a PUSH OVER analysis in ETABS 2018, with and without the inclusion of seismic isolators. The purpose of the simulation was to determine the current state of the structures and, with the inclusion of seismic isolators, analyze their behavior.

### Results achieved

In the structural analysis, the level of risk presented by the FICM and FISEI workshops was determined. The structural characteristics in the event of a possible seismic phenomenon were also calculated.

### Architectural plans

The respective architectural plans and structural plans were obtained from the FICM and FISEI workshops. The plans were provided by the Physical Infrastructure Directorate of the Technical University of Ambato.

Figure 1 Render of the FICM workshop model shows the structural design carried out in the ETABS 2018 software.

**Figure 1**. Render of the FICM workshop model

**Source:** Own elaboration based on (ETABS, 2018)

Figure 2 Render of the FISEI workshop model shows the structural design carried out in the ETABS 2018 software.

**Figure 2**. Render of the FISEI workshop model

**Source:** Own elaboration based on (ETABS, 2018)

## Results

### Results of the analyzed structure with fixed base

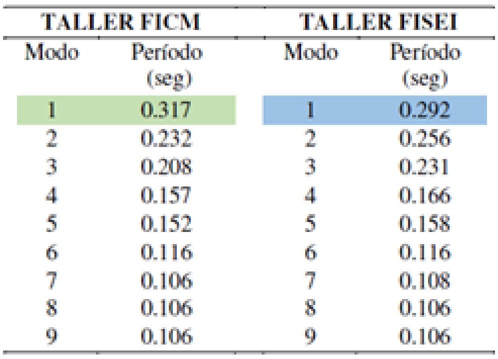
### Linear analysis of the structure in its current state

The ETABS software was used to model the FICM workshop and the FISEI workshop. The linear analysis was carried out following the standards established in the Seismic Hazard Standard Earthquake Resistant Design (Ecuadorian Construction Standard, 2014).

**Fundamental period of vibration:**

When verifying the vibration period (T), it must be verified that the value of T obtained by method 2 through linear analysis, as presented in Table 1 Fundamental Period Method 2, does not exceed the value of 30%. Ta obtained from method 1

**Table 1**. Fundamental Period Method 2

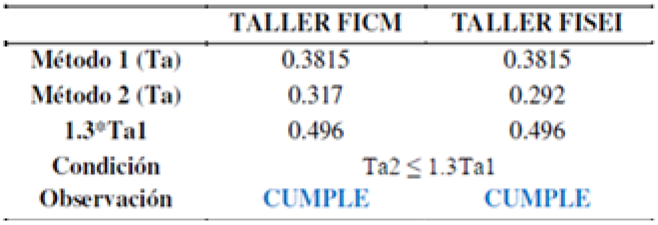


| TALLER FICM | | TALLER FISEI | |
|---|---|---|---|
| Modo | Período (seg) | Modo | Período (seg) |
| 1 | 0.317 | 1 | 0.292 |
| 2 | 0.232 | 2 | 0.256 |
| 3 | 0.208 | 3 | 0.231 |
| 4 | 0.157 | 4 | 0.166 |
| 5 | 0.152 | 5 | 0.158 |
| 6 | 0.116 | 6 | 0.116 |
| 7 | 0.106 | 7 | 0.108 |
| 8 | 0.106 | 8 | 0.106 |
| 9 | 0.106 | 9 | 0.106 |

**Source:** Own elaboration

Because the value of the period is less than 30% of the period obtained by method 1, the two workshops comply with this structural analysis as shown in Table 2 Verification of the fundamental period.

**Table 2**. Verification of the fundamental period



| | TALLER FICM | TALLER FISEI |
|---|---|---|
| **Método 1 (Ta)** | 0.3815 | 0.3815 |
| **Método 2 (Ta)** | 0.317 | 0.292 |
| **1.3*Ta1** | 0.496 | 0.496 |
| **Condición** | Ta2 ≤ 1.3Ta1 | |
| **Observación** | CUMPLE | CUMPLE |

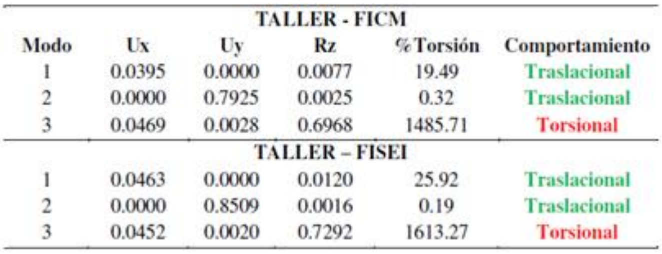
**Source:** Own elaboration

**Modal mass share**

It is necessary to verify that the first two vibration modes have a translational movement and that the third vibration mode is expected to be torsional for the structure to function correctly.

The two structures show translational behavior in the first two vibration modes and torsional behavior in the third vibration mode, therefore, there are no torsion problems. Table 3 shows the nodal mass and % torque participation factors.

**Table 3**. Modal mass and % torque participation factors



| Modo | Ux | Uy | Rz | %Torsión | Comportamiento |
|---|---|---|---|---|---|
| **TALLER - FICM** | | | | | |
| 1 | 0.0395 | 0.0000 | 0.0077 | 19.49 | Traslacional |
| 2 | 0.0000 | 0.7925 | 0.0025 | 0.32 | Traslacional |
| 3 | 0.0469 | 0.0028 | 0.6968 | 1485.71 | Torsional |
| **TALLER – FISEI** | | | | | |
| 1 | 0.0463 | 0.0000 | 0.0120 | 25.92 | Traslacional |
| 2 | 0.0000 | 0.8509 | 0.0016 | 0.19 | Traslacional |
| 3 | 0.0452 | 0.0020 | 0.7292 | 1613.27 | Torsional |

**Source**: Own elaboration

### Modal mass accumulation

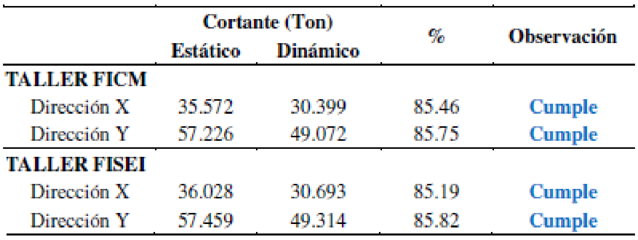
According to the Ecuadorian Construction Standard, all vibration modes must accumulate in each of the horizontal directions 90% of the total mass of the building. The accumulation of 90% of mass for the FICM workshop occurs in the eleventh mode of vibration for the two directions in Y direction. For both cases they comply since they are in the modes established for the analysis.

### Validation of dynamic analysis

The Ecuadorian Construction Standard establishes in section 6.2.2 the limit value of the dynamic shear when a dynamic spectral analysis is carried out. This value applied to the base of the structures should not exceed 80% for regular structures or 85% for irregular structures of the shear obtained by the static method.

Table 4 Validation of the Dynamic Analysis presents the dynamic basal shear in the X & Y direction, which exceeds 85% of the static shear for irregular structures, validating the dynamic analysis.

**Table 4**. Dynamic Analysis Validation



| | Cortante (Ton) | | % | Observación |
|---|---|---|---|---|
| | Estático | Dinámico | | |
| **TALLER FICM** | | | | |
| Dirección X | 35.572 | 30.399 | 85.46 | Cumple |
| Dirección Y | 57.226 | 49.072 | 85.75 | Cumple |
| **TALLER FISEI** | | | | |
| Dirección X | 36.028 | 30.693 | 85.19 | Cumple |
| Dirección Y | 57.459 | 49.314 | 85.82 | Cumple |

**Source**: Own elaboration

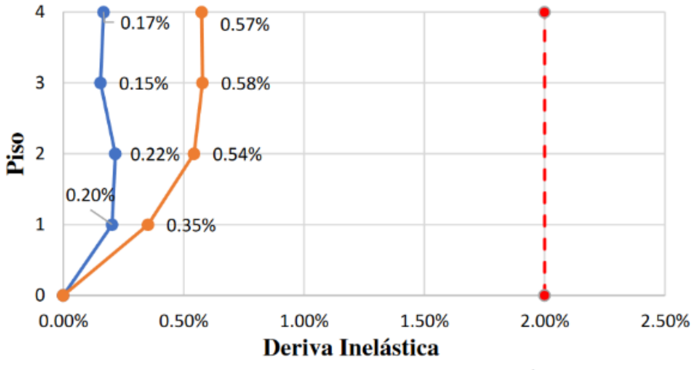
### Floor drifts

### Drifts caused by static shear

The inelastic drifts generated by the static shear do not exceed the maximum limit of 2%. Presenting a maximum value of 0.58% in the Y direction for the FICM Workshop and a maximum value of 0.61% in the Y direction for the FISEI workshop.

Figure 3 Inelastic drifts due to static shear of the FICM workshop shows the values of inelastic drifts due to static shear of the workshop structure.

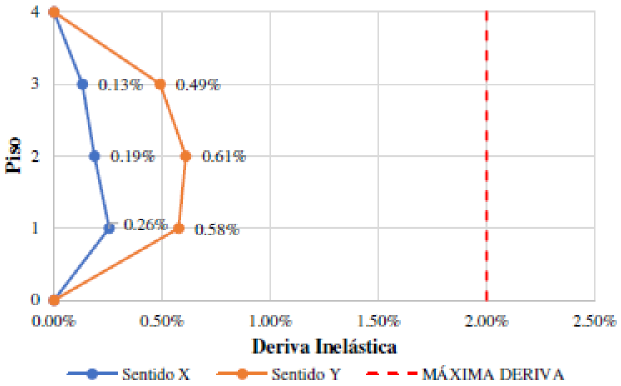
**Figure 3**. Inelastic drifts due to static shear from the FICM workshop



**Source**: Own elaboration

Figure 4 Inelastic drifts due to static shear of the FISEI workshop shows the values of inelastic drifts due to static shear of the workshop structure.

**Figure 4**. Inelastic drifts due to static shear from the FISEI workshop



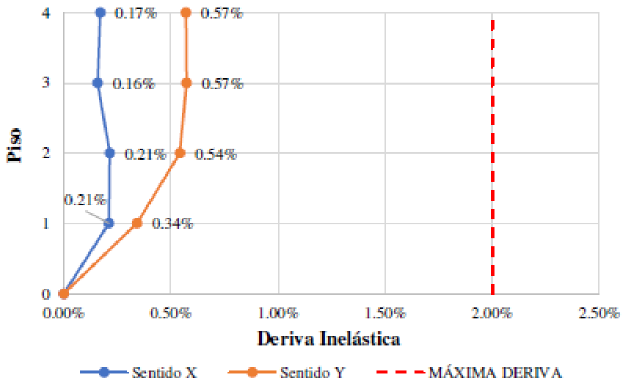
**Source**: Own elaboration

## Drifts caused by dynamic shear

The inelastic drifts generated by the dynamic shear do not exceed the maximum limit of 2%. Presenting a maximum value of 0.57% in the Y direction for the FICM Workshop and a maximum value of 0.57% in the Y direction for the FISEI workshop.

Figure 5 Inelastic drifts due to dynamic shear of the FICM workshop shows the values of inelastic drifts due to dynamic shear of the workshop structure.

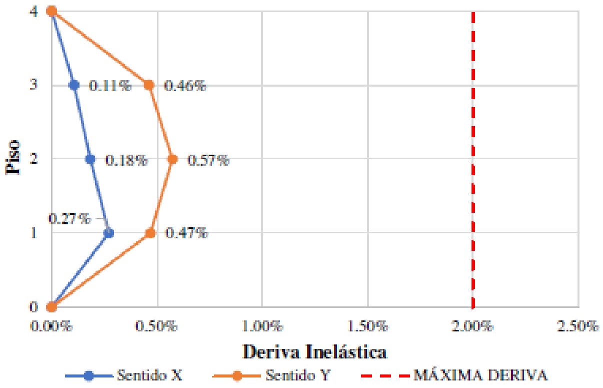
**Figure 5**. Inelastic drifts due to dynamic shear from the FICM workshop



**Source**: Own elaboration

Figure 6 Inelastic drifts due to dynamic shear of the FISEI workshop shows the values of inelastic drifts due to dynamic shear of the workshop structure.

**Figure 6**. Inelastic drifts due to dynamic shear from the FISEI workshop



**Source**: Own elaboration

## Nonlinear static analysis

First, a nonlinear static analysis was carried out to evaluate the seismic performance of the two structures. The objective of the analysis is to determine the capacity curve and obtain the performance point for the seismic threat levels referenced in the Ecuadorian

Construction Standard. To achieve this objective, the methodology established in the Standard Improvement of Nonlinear Static Seismic Analysis Procedures FEMA 440 (Federal Emergency Management Agency, 2005) is used.

For the beams, columns and braces, which are elements that resist lateral loads, plastic ball joints are placed at the ends of each one, indicating the area where yielding of the section is expected, which allows defining the individual capacity of each section that comprises it. the structure. According to the Prestandard and commentary for the seismic rehabilitation of buildings FEMA 356 (Federal Emergency Management Agency, 2000), it is between 5% and 95%.

**Plastic ball joint assignment**

The plastic hinges are assigned to each element that resists lateral loads such as beams, columns and braces. These are located at the ends of each one where the yielding of the section is expected, which allows defining the individual capacity of each section that makes up the structure. In accordance with the StandardPrestandard and commentary for the seismic rehabilitation of buildings FEMA 356 is located at 5% and 95%.

Plastic hinges for beams: Their assignment is taken from whatdescribed in the article ASCE 41-13: Seismic evaluation and retrofit rehabilitation of existing buildings (Pekelnicky et al., 2012), taking into account that these elements have bending behavior.

Plastic brackets for columns: Their assignment is taken from whatdescribed in the article ASCE 41-13: Seismic evaluation and retrofit rehabilitation of existing buildings (Pekelnicky et al., 2012), taking into account that these sections behave in flexo-compression.

Plastic strut ball joints: Their assignment is taken from whatdescribed in the article ASCE 41-13: Seismic evaluation and retrofit rehabilitation of existing buildings (Pekelnicky et al., 2012), taking into account that these elements have tension and compression behavior.

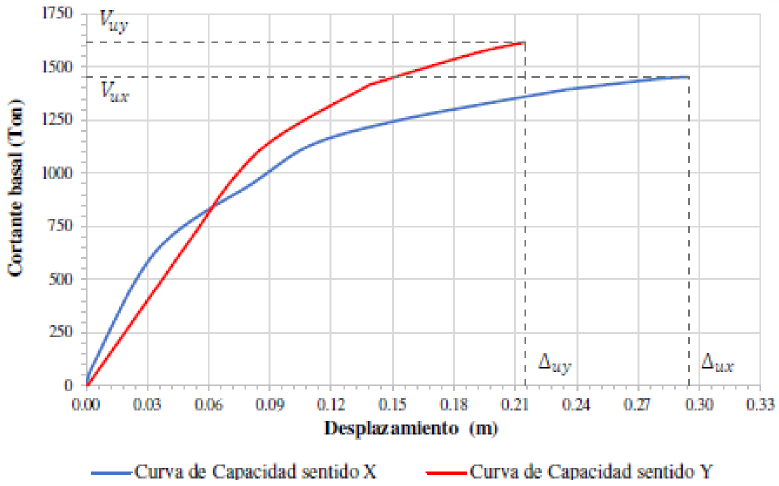
**Nonlinear Static Pushover Analysis Results**

**Capacity curve**

As a result of the nonlinear analysis, the capacity curve is determined for the two directions of analysis for each structure. This curve represents the relationship of the total shear at the base with its respective displacement of the top floor, until the building reaches collapse.

Figure 7 represents the capacity curve for the FICM Workshop, where the curve in the ultimate displacement of 21.45 cm. The values represent the maximum capacity of the structure, once it passes this limit it will cause its collapse.

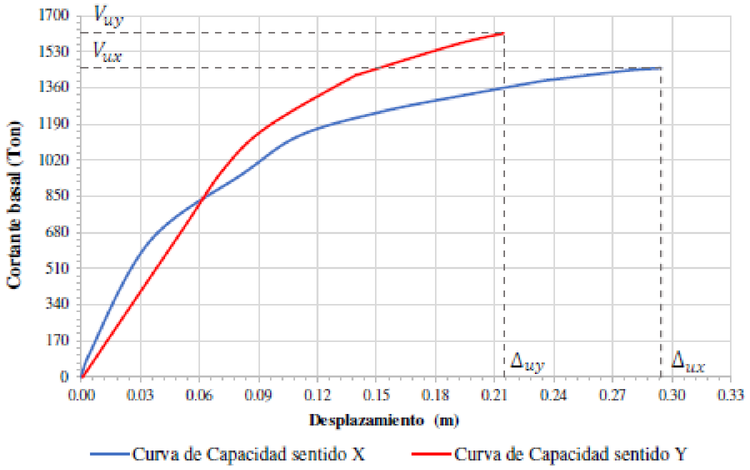
**Figure 7**. FICM Workshop capacity curve



**Source**: Own elaboration

Figure 8 Capacity curve of the FISEI workshop shows in the . The values represent the maximum capacity of the structure; once this limit is exceeded, it will collapse.

**Figure 8**. FISEI workshop capacity curve



**Source**: Own elaboration

### Performance point

Through the equivalent linearization method proposed by the Federal Emergency Management Agency Standard (2005), the performance points are determined. The method consists of a graphic procedure that compares the capacity of the structure to resist lateral forces with the seismic demand. The displacement and cutting force values of each performance point were obtained from the ETABS 2018 software.

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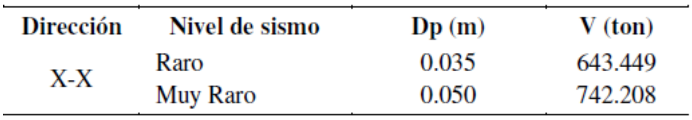
Table 5 Performance points in direction X of the FICM workshop show the values of each performance point for direction

**Table 5**. Performance points in direction X of the FICM workshop

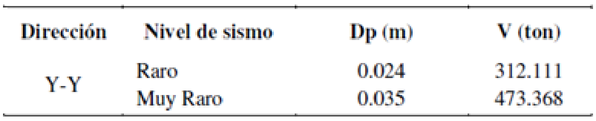


| Dirección | Nivel de sismo | Dp (m) | V (ton) |
|---|---|---|---|
| X-X | Raro | 0.035 | 643.449 |
|  | Muy Raro | 0.050 | 742.208 |

**Source**: Own elaboration

Table 6. Performance points in the Y direction of the FICM workshop show the values of each performance point for the Y direction, with its cutting force and displacement value that corresponds to each level of seismic threat.

**Table 6**. Performance points in the Y direction of the FICM workshop



| Dirección | Nivel de sismo | Dp (m) | V (ton) |
|---|---|---|---|
| Y-Y | Raro | 0.024 | 312.111 |
|  | Muy Raro | 0.035 | 473.368 |

**Source**: Own elaboration

Table 7 Performance points in direction X of the FISEI workshop show the values of each performance point for direction

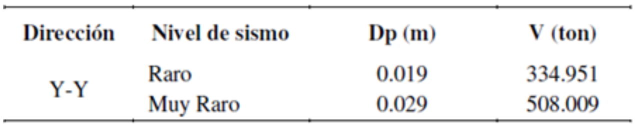
**Table 7**. Performance points in direction X of the FISEI workshop

| Dirección | Nivel de sismo | Dp (m) | V (ton) |
|---|---|---|---|
| X-X | Raro | 0.012 | 298.909 |
|  | Muy Raro | 0.032 | 689.675 |

**Source**: Own elaboration

Table 8 Performance points in the Y direction of the FISEI workshop present the values of each performance point for the Y direction, with its value of cutting force and displacement that corresponds to each level of seismic threat.

**Table 8**. Performance points in the Y direction of the FISEI workshop



| Dirección | Nivel de sismo | Dp (m) | V (ton) |
|---|---|---|---|
| Y-Y | Raro | 0.019 | 334.951 |
|  | Muy Raro | 0.029 | 508.009 |

**Source**: Own elaboration based

### Results of the structure analyzed with seismic isolators

### Characteristics of the elastomeric insulator with lead core for the FICM and FISEI workshops

For the seismic analysis, the elastomeric type insulator with a lead core will be used. Table 9 presents the geometric properties of the insulator.

**Table 9**. Geometric properties of the insulator

| Descripción | Símbolo | Valor |
|---|---|---|
| Diámetro de la goma | Do | 520 mm |
| Diámetro del núcleo de plomo | Di | 90 mm |
| Espesor total de la goma | H | 120 mm |
| Espesor de cada capa de goma | tr | 5 mm |

**Source**: Dynamic Isolation Systems supplier catalog

Table 10 presents the physical and mechanical characteristics of the elastomeric insulator with a lead core for the FICM and FISEI workshops, and the dynamic properties used for modeling in the ETABS 2018 software are also presented.

**Table 10**. Physical and mechanical characteristics of elastomeric insulator with lead core.

| Descripción | Valores | | Unidades |
|---|---|---|---|
| | Taller FICM | Taller FISEI | |
| Diámetro de aislador (DI) | 235.55 | 247.62 | mm |
| Altura del aislador sin planchas (HI) | 234.88 | 234.88 | mm |
| Rigidez efectiva (Keff) | 9.48 | 10.42 | T/m |
| Amortiguamiento efectivo (Beff) | 0.1395 | 0.1370 | |
| Rigidez elástica (Ke) | 73.30 | 81.07 | T/m |
| Fuerza de fluencia (Fy) | 1.386 | 1.496 | T |
| Radio de rigidez post fluencia (Kd/Ke) | 0.10 | 0.10 | |
| Carga axial ultima (Pumax) | 35.55 | 39.29 | T |
| Rigidez efectiva lineal (Kv) | 2998.88 | 3632.45 | T/m |

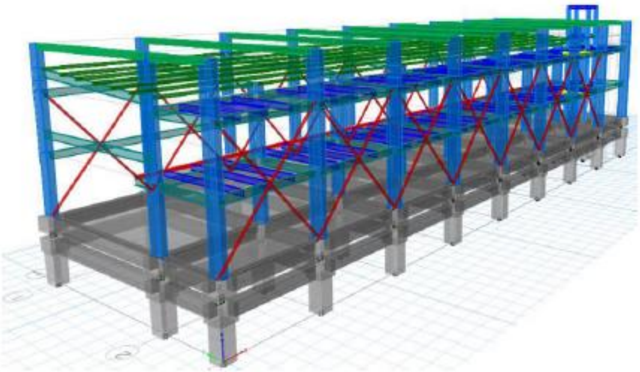
**Source**: Own elaboration

### Modeling in ETABS engineering software

The verification of the results with the implementation of the insulators is carried out through modeling in the ETABS 2018 software, for which the insulators are placed in the structure through a Link/Support properties,

Figure 9 Modeling of the isolated base FICM workshop shows the three-dimensional modeling with the ETABS structural engineering software.

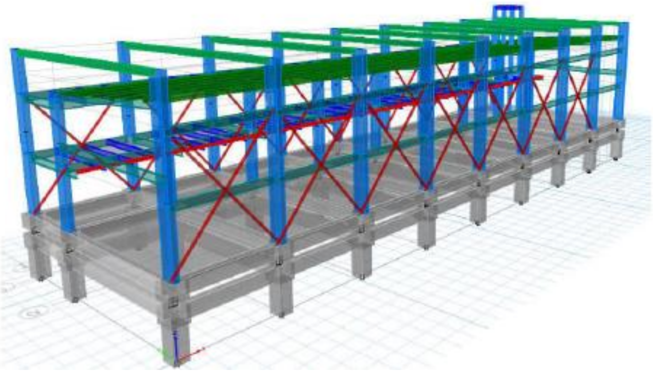
**Figure 9**. Modeling of the isolated base FICM workshop



**Source:** Own elaboration based on (ETABS, 2018)

Figure 10 Modeling of the isolated base FISEI workshop shows the three-dimensional modeling with the ETABS structural engineering software.

**Figure 10**. Modeling of the isolated base FISEI workshop



**Source:** Own elaboration based on (ETABS, 2018)

**Structural analysis results**

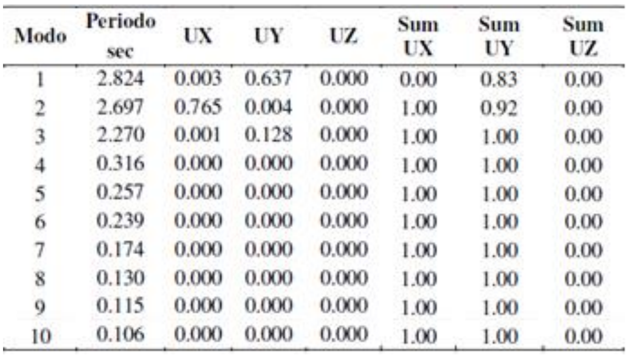
**Fundamental vibration period of the isolated structure:**

The following tables show high periods due to the use of base insulators. The masses that participate in the transportation modes must represent at least 90% of their participation. If they do not do so, a new distribution of their rigidities must be made.

The first two vibration modes of the workshops of the FICMThey have translational movement. The X direction and the Y direction have a share of more than 90% in the second mode. Furthermore, the analysis time is T = 2.824 s.

Table 11 shows the vibration modes and mass participation of the FICM workshop with isolators.

**Table 11**. Vibration modes and mass participation of the FICM workshop with isolators.

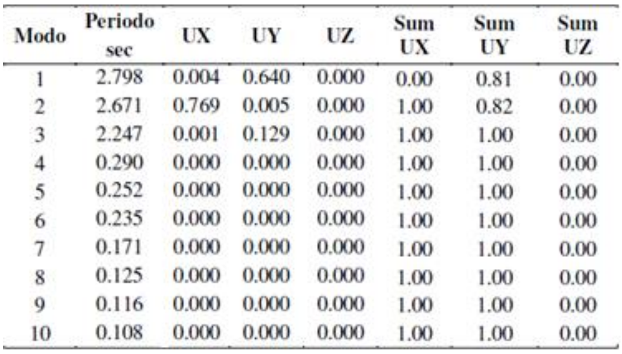


| Modo | Periodo sec | UX | UY | UZ | Sum UX | Sum UY | Sum UZ |
|---|---|---|---|---|---|---|---|
| 1 | 2.824 | 0.003 | 0.637 | 0.000 | 0.00 | 0.83 | 0.00 |
| 2 | 2.697 | 0.765 | 0.004 | 0.000 | 1.00 | 0.92 | 0.00 |
| 3 | 2.270 | 0.001 | 0.128 | 0.000 | 1.00 | 1.00 | 0.00 |
| 4 | 0.316 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 5 | 0.257 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 6 | 0.239 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 7 | 0.174 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 8 | 0.130 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 9 | 0.115 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 10 | 0.106 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |

**Source**: Own elaboration

The first two vibration modes of the workshops of the FISEI produce atranslational movement, while the third mode presents a participation greater than 90% for the X direction and the second mode for the Y direction. In addition, the analysis time is T = 2.798 s. Table 12 shows the vibration modes and mass participation of the FISEI Workshop with insulators.

**Table 12**. Vibration modes and mass participation of the FISEI Workshop with isolators



| Modo | Periodo sec | UX | UY | UZ | Sum UX | Sum UY | Sum UZ |
|---|---|---|---|---|---|---|---|
| 1 | 2.798 | 0.004 | 0.640 | 0.000 | 0.00 | 0.81 | 0.00 |
| 2 | 2.671 | 0.769 | 0.005 | 0.000 | 1.00 | 0.82 | 0.00 |
| 3 | 2.247 | 0.001 | 0.129 | 0.000 | 1.00 | 1.00 | 0.00 |
| 4 | 0.290 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 5 | 0.252 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 6 | 0.235 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 7 | 0.171 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 8 | 0.125 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 9 | 0.116 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |
| 10 | 0.108 | 0.000 | 0.000 | 0.000 | 1.00 | 1.00 | 0.00 |

**Source**: Own elaboration

**Results comparison**

- Comparison of vibration period results:

Table 13 presents the results of the vibration period of the two workshops for each structural system. As can be seen, an increase is generated in the vibration periods of the two workshops with the isolators, since this analysis considers the flexibility at the level where the isolator was located, forming a uniform coupling model between the base and the level of the insulator. This produces a more flexible model relative to fixed-based workshops.

**Table 13**. Vibration period for different structural systems

| PERÍODO (seg.) | | | | | |
|---|---|---|---|---|---|
| TALLER FICM | | | TALLER FISEI | | |
| Modo | Empotrado | Aislado | Modo | Empotrado | Aislado |
| 1 | 0.317 | 2.824 | 1 | 0.292 | 2.798 |
| 2 | 0.232 | 2.697 | 2 | 0.256 | 2.671 |
| 3 | 0.208 | 2.27 | 3 | 0.231 | 2.247 |
| 4 | 0.157 | 0.316 | 4 | 0.166 | 0.290 |
| 5 | 0.152 | 0.257 | 5 | 0.158 | 0.252 |
| 6 | 0.116 | 0.239 | 6 | 0.116 | 0.235 |
| 7 | 0.106 | 0.174 | 7 | 0.108 | 0.171 |

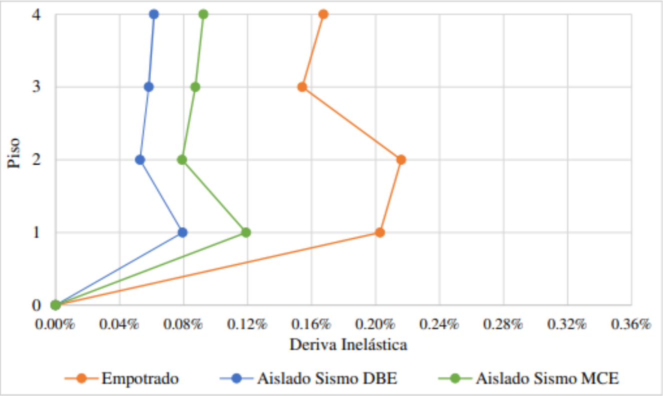
**Source**: Own elaboration

- Comparison of inelastic drifts:

To compare the two systems analyzed, the structure embedded in its base and the isolated structure, the floor drifts are a crucial parameter. The maximum floor drifts of the embedded system were determined by the design earthquake spectrum (DBE) and the maximum considered earthquake spectrum (MCE) for each direction of analysis. When comparing these drifts with those of the isolated system, it can be seen that there is a reduction in them.

In Figure 11 Inelastic drifts of the conventional and isolated FICM workshop in the X direction, it is observed that for a built-in structure the maximum drift is 0.22% on the second floor. When the isolators are implemented, a reduction of 64% is observed in a design earthquake with a maximum value of 0.08%, while, for a maximum considered earthquake, the reduction is 45% with a maximum value of 0.12. %.

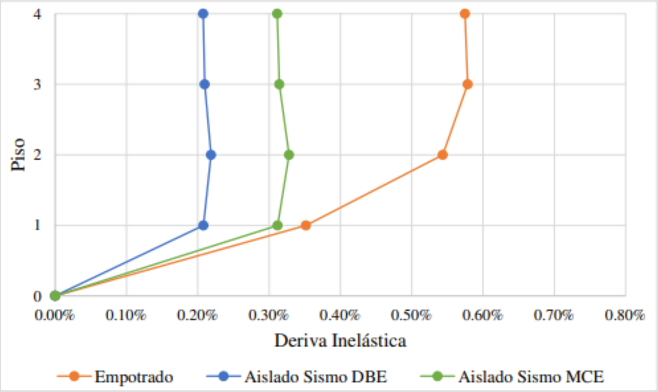
**Figure 11**. Inelastic drifts of the conventional and isolated FICM workshop in the X direction



**Source**: Own elaboration

In Figure 12 Inelastic drifts of the conventional and isolated FICM workshop in the Y direction, a maximum drift value of 0.58% is observed on the third floor for a built-in structure, while with the implementation of insulators a reduction in the 62% in a design earthquake with a maximum value of 0.22%, and a reduction of 43% in a maximum considered earthquake with a maximum value of 0.33%.

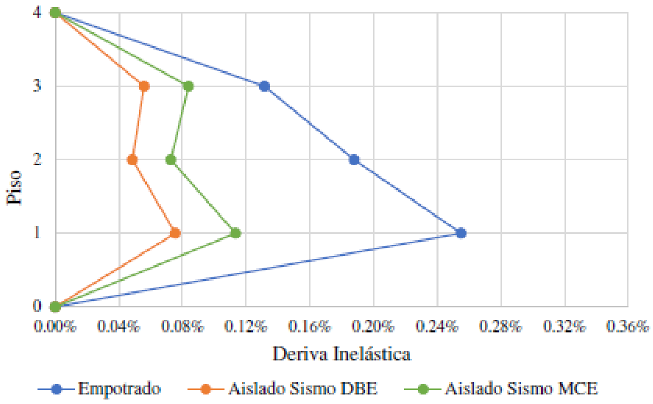
**Figure 12**. Inelastic drifts of the conventional and isolated FICM workshop in Y direction



**Source**: Own elaboration

In Figure 13 Inelastic drifts of the conventional and isolated FISEI workshop in the a design earthquake with a maximum value of 0.08%, and for a maximum considered earthquake it is reduced by 58% with a maximum value of 0.11%.

**Figure 13**. Inelastic drifts of the conventional and isolated FISEI workshop in the X direction

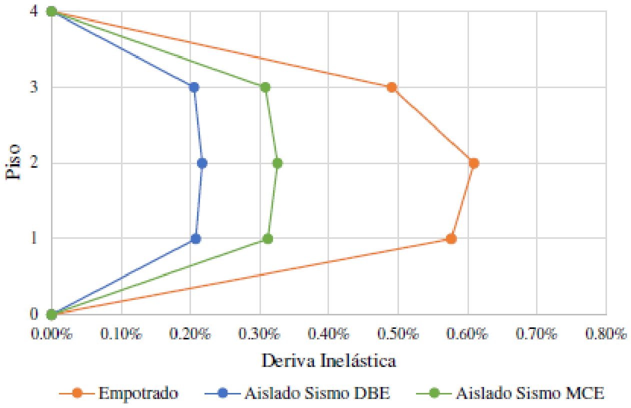


**Source**: Own elaboration

In Figure 14 Inelastic drifts of the conventional and isolated FISEI Workshop in the Y direction, it is observed that the embedded structure presents a maximum drift value of 0.61% on the second floor, while the implementation of insulators produces a reduction of 64%. % in a design earthquake with a maximum value of 0.22%, and a reduction of

46% in a maximum considered earthquake with a maximum value of 0.33%. All of these results comply with the values specified in NEC-15. 4.2.5.5.

**Figure 14**. Inelastic drifts of the conventional and isolated FISEI Workshop in the Y direction



**Source**: Own elaboration

- Comparison of maximum displacements

The maximum displacements obtained by the effect of the earthquake in the

In the following figures it can be seen that the displacements in the structure embedded in the base are approximately double compared to the isolated structure, both with the design earthquake and also for the maximum earthquake considered; allowing to obtain a better idea of the behavior of the structure in the face of an earthquake.

Movement of the FICM workshop:

In Table 14 Displacement in the maximum considered a maximum value of 0.858 with a reduction of 26.15%.

**Table 14**. Displacement in the X direction and percentage reduction with isolation system in the FICM workshop

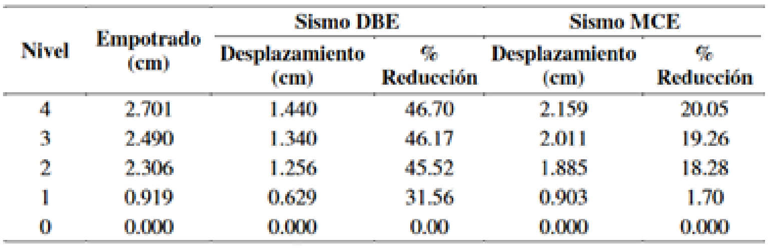
| Nivel | Empotrad (cm) | Sismo DBE |  | Sismo MCE |  |
|---|---|---|---|---|---|
|  |  | Desplazamiento (cm) | % Reducción | Desplazamiento (cm) | % Reducción |
| 4 | 1.162 | 0.572 | 50.76 | 0.858 | 26.15 |
| 3 | 0.872 | 0.351 | 59.75 | 0.576 | 33.90 |
| 2 | 0.831 | 0.244 | 70.59 | 0.467 | 43.86 |
| 1 | 0.481 | 0.028 | 94.26 | 0.141 | 70.62 |
| 0 | 0.000 | 0.000 | 0.00 | 0.000 | 0.000 |

**Source**: Own elaboration

In Table 15 Displacement in the Y direction and percentage reduction with isolation system in the FICM workshop with a design earthquake, a maximum displacement of

1,440 cm is obtained, reducing 46.70% compared to a built-in structure and for an earthquake. maximum considered a maximum value of 2,159 cm with a reduction of 20.05%.

**Table 15**. Displacement in the Y direction and percentage reduction with isolation system in the FICM workshop



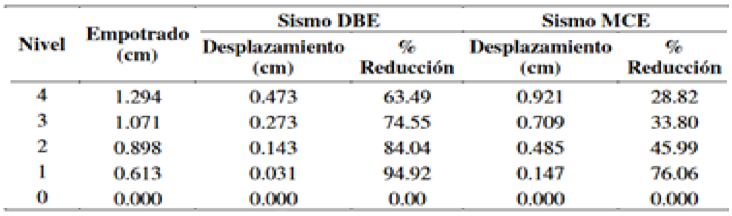
| Nivel | Empotrado (cm) | Sismo DBE | | Sismo MCE | |
|---|---|---|---|---|---|
| | | Desplazamiento (cm) | % Reducción | Desplazamiento (cm) | % Reducción |
| 4 | 2.701 | 1.440 | 46.70 | 2.159 | 20.05 |
| 3 | 2.490 | 1.340 | 46.17 | 2.011 | 19.26 |
| 2 | 2.306 | 1.256 | 45.52 | 1.885 | 18.28 |
| 1 | 0.919 | 0.629 | 31.56 | 0.903 | 1.70 |
| 0 | 0.000 | 0.000 | 0.00 | 0.000 | 0.000 |

**Source**: Own elaboration

Displacement of the FISEI Workshop:

In Table 16 Displacement in the maximum considered a maximum value of 0.921 cm with a reduction of 28.82%.

**Table 16**. Displacement in the X direction and percentage reduction with isolation system in the FISEI workshop



| Nivel | Empotrado (cm) | Sismo DBE | | Sismo MCE | |
|---|---|---|---|---|---|
| | | Desplazamiento (cm) | % Reducción | Desplazamiento (cm) | % Reducción |
| 4 | 1.294 | 0.473 | 63.49 | 0.921 | 28.82 |
| 3 | 1.071 | 0.273 | 74.55 | 0.709 | 33.80 |
| 2 | 0.898 | 0.143 | 84.04 | 0.485 | 45.99 |
| 1 | 0.613 | 0.031 | 94.92 | 0.147 | 76.06 |
| 0 | 0.000 | 0.000 | 0.00 | 0.000 | 0.000 |

**Source**: Own elaboration

In Table 17 Displacement in the Y direction and percentage of reduction with isolation system in the FISEI workshop with a design earthquake, a maximum displacement of 1,368 cm is obtained, reducing 53.85% compared to a built-in structure and for an earthquake. maximum considered a maximum value of 2,052 cm with a reduction of 30.78%.

**Table 17**. Displacement in the Y direction and percentage reduction with isolation system in the FISEI workshop

| Nivel | Empotrado (cm) | Sismo DBE | | Sismo MCE | |
|---|---|---|---|---|---|
| | | Desplazamiento (cm) | % Reducción | Desplazamiento (cm) | % Reducción |
| 4 | 2.965 | 1.368 | 53.85 | 2.052 | 30.78 |
| 3 | 2.941 | 1.341 | 54.39 | 2.012 | 31.58 |
| 2 | 2.757 | 1.250 | 54.66 | 1.875 | 31.99 |
| 1 | 1.336 | 0.628 | 52.98 | 0.942 | 29.46 |
| 0 | 0.000 | 0.000 | 0.00 | 0.000 | 0.000 |

**Source**: Own elaboration

## Conclusions

- For the FICM Workshop, the embedded structure presented a maximum displacement for a design earthquake of 1.162 cm, for the structure with a fixed base it was reduced by 50.76% with a displacement of 0.572 cm. While for the FISEI workshop it presents a value of 1.294 cm for the embedded structure, and with the implementation of insulators it is reduced by 63.49% with a value of 0.473 cm. Therefore, with the incorporation of seismic isolators, the structures have a greater energy dissipation capacity.
- According to the linear analysis carried out on the structure of the FICM workshop, it meets the requirements established by the Ecuadorian Construction Standard. Its fundamental vibration period is 0.317 seconds, less than 30% of the period obtained by method 1, and its translational behavior is adequate in the first two vibration modes.
- According to the linear analysis carried out on the structure of the FISEI workshop, the structure meets the requirements established by the Ecuadorian Construction Standard. Its fundamental period of vibration of the structure is 0.292 seconds, which is less than 30% of the period obtained by method 1. In the torsion check, the structure presents good translational behavior in the first two vibration modes.
- The capacity curve for the two directions of the analysis and the performance point were obtained from the nonlinear static analysis of the FICM and FISEI workshops. These results indicate that the two structures meet the threat levels established by the Vision 2000 Committee.
- The sizing of the elastomeric insulator with lead core LRB was determined with the specifications of the ASCE 7-16 standard, its properties are obtained from the catalog of the supplier Dynamic Isolation Systems with a rubber diameter of 520 mm, diameter of the lead core of 90mm, rubber thickness 120mm and the thickness of each rubber layer 5mm.

- The period of the structure with LRB insulator (Elastomeric with lead core) increased compared to the embedded structure, for the FICM workshop with an isolated period of 2.824 seconds and the FISEI workshop with a value of 2.798 seconds, therefore, The isolators are capable of reducing the seismic demand, with which it is possible to design elastic structures that no longer require entering the inelastic range.
- The floor drifts of the two structures are verified, concluding that for the FICM workshop with a design earthquake it was reduced by 64% compared to the embedded structure and for a maximum considered earthquake it was reduced by 45%, while for the FISEI workshop A reduction of 69% was obtained for a design earthquake and 58% for a maximum earthquake.

## Conflict of interests

The authors declare that they have no conflicts of interest.

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