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# Analysis of building structure performance due to earthquake load with time history analysis method using ETABS (Extended Three-Dimensional Analysis of Building Systems) software (case study: the faculty of medicine building at IGM University)

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**Abstract.** The inability of a building to withstand deviations due to earthquake strength exceeding the required safe limit is one of the factors causing the collapse of the building. Mitigation efforts that can be made to overcome the impact of earthquakes include evaluating the performance of building structures. In this study, the Faculty of Medicine building at Indo Global Mandiri University was evaluated using the time history analysis method using ETABS V.18. The results of the analysis showed that for the El Centro (1940), Mentawai-West Sumatra (2007), and Chihuahua (2010) earthquakes, based on the value of inter-level drift and maximum inter-level drift on the effect of planned earthquake loads, the service limit performance was fewer than 0.017 meters and the ultimate limit performance was fewer than 0.080 meters, so it has met permit requirements according to the Indonesian standard (SNI 1726-2019) and is included in the safe category. Based on the performance of ATC-40 obtained for the El Centro (1940) and the Mentawai-West Sumatra (2007), it produced the performance level of the structure "Immediate Occupancy", while when subjected to the load of the Chihuahua (2010), it produced the performance level of the structure "Damage Control".

## 1 Introduction

Earthquakes are one of natural phenomena that occur due to the movement of tectonic plates along the fault lines of the earth's crust. Earthquakes can cause ground shaking, soil liquefaction, landslides, and potential tsunamis [1]. One of the countries with a reasonably high earthquake tendency is Indonesia because of its geological location at the convergence of two main earthquake pathways: the Pacific Circum and the Transasiatic Alpide [2]. Based on data from [3] throughout the period 1900 to 2022, it was recorded that Indonesia had more than 150 earthquake intensities of 7.0+ on the magnitude scale. Earthquakes can cause macro and micro losses depending on the intensity and duration of the earthquake, the local geology, and the design and materials of the building or industry used [4].

South Sumatra is one of the regions in Indonesia that is considered to have relatively low earthquake occurrence. Still, it is not entirely safe and is often affected by earthquake vibrations in adjacent areas, such as the one that occurred on November 2nd, 2014, measuring 4.8 magnitude and occurring 12 kilometers southwest of Pagar Alam City. Additionally, the Musi Fault triggered an earthquake in Kepahiang Regency, 6 kilometers northeast of Kepahiang on May 15th, 1997, with a magnitude of 5.0, which affected 65 buildings severely and lightly damaged, and four people died due to building rubble [5]. One of the factors causing damage and collapse due to an earthquake is a building not being able to withstand deviations due to earthquake forces exceeding the specified safety factor.

This research focuses on the Faculty of Medicine building at IGM University, which is currently under construction as an effort to develop services in the field of education. It is planned to consist of seven stories with a height of 28.50 meters, including high-rise buildings [6], and have higher structural complexity, making it very vulnerable to earthquake shocks. Therefore, it is necessary to evaluate the strength of the structure as an appropriate effort to overcome the impact of earthquakes disaster using the time history analysis method, which is reviewed based on the value of displacement, base shear, and drift ratio so that service limit performance, ultimate limit performance, and ATC-40 performance levels are obtained. This research is expected to provide benefits as a source of knowledge in the construction industry, especially in the structural analysis process, by optimizing the use of ETABS software to obtain maximum results.

### 1.1 Structural analysis

Structural analysis due to earthquake force consists of equivalent static and dynamic analysis (response spectrum and time history).

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### *1.1.1 Equivalent static analysis*

Equivalent static analysis is one way of analyzing structures in buildings due to the influence of earthquake forces, which are considered horizontal static loads or lateral loads obtained only by considering the response of the first variety of structural vibrations [7].

Equivalent static analysis can be done for straightforward and regular building structures. However, it's not advisable for complex and asymmetric (irregular) building structures because the load used in equivalent static analysis only imitates the actual earthquake's dynamic influence [8].

### *1.1.2 Dynamic analysis of time history*

Dynamic analysis is a type of analysis of building structures due to the influence of earthquake forces. It involves determining the distribution of seismic shear forces across each layer by considering the dynamic effects of ground movement caused by earthquakes on the evaluated structure [9].

Time history dynamic analysis is recommended in asymmetrical and complex high-rise building structure configurations [10]. Still, it can also be used in symmetrical building structures to obtain analysis results close to the actual situation with a relatively high level of accuracy [11]. The time history method is carried out by providing a record of earthquake history in the form of ground motion from earthquake events, which are then numbered so that the response of building structures to lateral forces can be calculated step by step at particular time intervals [12].

### 1.2 Structure loading

Loading on the structure aims to determine the response of structural behavior to the loading involved in the analysis process so that analysis results that meet applicable loading standards are obtained. The loading used, based on Indonesian standards, includes:

1. Dead Load (DL) in PPPURG, 1987 [13]
2. Live Load (LL) in SNI 1727-2020 [14]
3. Earthquake Load (EQ) in SNI 1276-2019 [15]

### 1.3 Structural performance

The performance of structures at the service limit of a building is determined based on the drift between levels due to the influence of a planned earthquake, which should not exceed the following equation:

$$\Delta s = \frac{0{,}03}{R} x\, H \quad (1)$$

The performance of structures at the ultimate limit of a building is determined based on the drift between the maximum levels of building structures that occurs due to the influence of a planned earthquake in conditions on the verge of collapse and must not exceed the following requirements:

$$\Delta m = 0{,}02\; x\; H \quad (2)$$

Based on [16], which classifies the level of structural performance based on the maximum value of the total displacement on the roof story relative to the overall height of the structure, the amount of index drift depends on the magnitude of the loads arising on the building structure [17]. The following equation can determine the index drift:

$$Index\ drift = \frac{\Delta d}{H_{total}} \quad (3)$$

Where,

$\Delta s$ = Service limit permission requirements;
$R$ = Coefficient of modification;
$H$ = High level – x;
$\Delta m$ = Ultimate limit permission requirements
$\Delta d$ = Maximum deflection magnitude (m)
$H_{total}$ = Height of portal structure (m)

According to the Applied Technology Council 40, levels of structural damage are classified as follows:

1. Immediate Occupancy (IO): The structure's condition is stable, with a vertical and lateral force-bearing system on the building structure that can still bear the earthquake force that occurs. Minor damage may occur, but strength and rigidity are maintained.
2. Damage Control (DC): This level can limit and control structural damage to buildings better than the Life Safety (LS) level.
3. Life Safety (LS): The building structure has suffered significant damage but has not yet reached the point of collapse. The building can still be used if repairs are made.
4. Structural Stability (SS): The structure's ability to withstand lateral forces has been reduced and weakened, resulting in partial or total damage to the structural and non-structural elements of the building until it reaches the brink of collapse.

### 1.4 ETABS

ETABS (Extended Three-Dimensional Analysis of Building Systems) is an engineering software program used to analyze and design multi-story buildings. Building structure modeling, code or number-based structure loading, and analysis methods are all integrated with ETABS to conduct the analysis and evaluation process statically and dynamically on the building structure reviewed [18].

## 2 Materials and methods

Material is a collection of information and data requiring subsequent processing and analysis through the employed methodology. Researchers execute research methods as scientific phases to derive outcomes from the analysis process grounded in the collected material data. The following are the materials and methods that will be used in this study:

## 2.1 Materials

The data used in this study is secondary data obtained from the shop drawing of the Faculty of Medicine Building at IGM University. The part of the building to be analyzed is from As 1 to As 4, as shown in **Figure 1.**

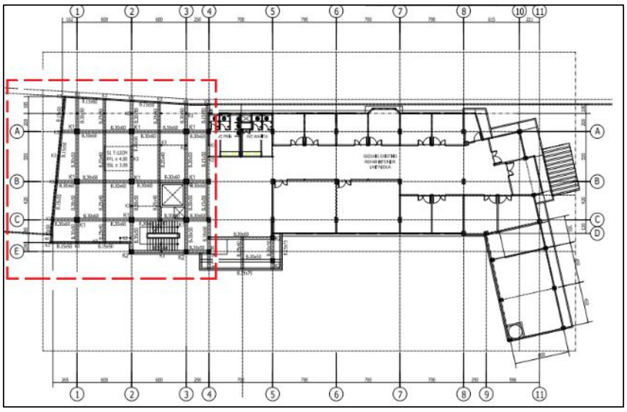

**Fig. 1.** Building plan

Structural data is used as a reference in the process of structural analysis due to the influence of earthquake loads, namely:

### *2.1.1 Building data*

Building data presents some general information that includes several things, as shown in Table 1.

**Table 1.** Building data.

| No | Building data | |
|---|---|---|
| 1 | Building functions | Lecture building |
| 2 | Types of structures | Reinforced concrete |
| 3 | Structure system | Special moment frame |
| 4 | Soil type | Soft soil |
| 5 | Number of stories | 7 stories |
| 6 | Inter-story height | - $1^{st}$, $4^{th}$ to $7^{th}$ story = 4 meters<br>- $2^{nd}$ to $3^{rd}$ story = 4.25 meters |
| 7 | Max elevation | 28,50 meters |

### *2.1.2 Material quality*

**Table 2.** Quality of materials used.

| No | Material | Quality |
|---|---|---|
| 1 | Reinforced concrete | K-300 or fc' = 25 MPa |
| 2 | Reinforcement<br>- Plain reinforcement<br><br>- Screw reinforcement | fy = 240 MPa for a diameter of < 12 mm (BJTP-24)<br><br>fy = 400 MPa for a diameter of > 13 mm (BJTD-40) |

Material quality is one of the data needed for the analysis process, as seen in Table 2.

### *2.1.3 Dimensions of structural elements*

The dimensional data of the presented structural elements are columns, beams, and plates, as follows:

a) Column dimensions

The dimensions of the column structure elements are presented accordingly in Table 3.

**Table 3.** Column dimensions.

| No | Column Type | Dimension (mm) |
|---|---|---|
| 1 | K1 | 500x500 |
| 2 | K2 | 400x400 |
| 3 | K3 | 100x150 |

b) Beam dimensions

The dimensions of the elements of the beam structure are presented accordingly in Table 4.

**Table 4.** Beam dimensions.

| No | Beam Type | Dimension (mm) |
|---|---|---|
| 1 | B 30/60 | 300x600 |
| 2 | B 30/50 | 300x500 |
| 3 | B 25/40 | 250x400 |
| 4 | B 15/50 | 150x500 |
| 5 | SL1 | 300x500 |
| 6 | SL2 | 250x400 |

c) Plate dimensions

The dimensions of the elements of the plate structure are presented accordingly in Table 5.

**Table 5.** Plate dimensions.

| No | Plate Type | Thickness (mm) |
|---|---|---|
| 1 | S1 | 12 |

## 2.2 Research analysis methods

The study utilizes the dynamic analysis of the time history method to analyze the structural performance. The process involves entering accelerogram data from recorded earthquakes and matching them with the studied locations in ETABS V.18. This yields analysis results closely aligned with actual conditions, allowing for an assessment of structural performance at both service and ultimate limits according to SNI 1726-2019 and ATC-40-based structural performance levels.

To ensure optimal outcomes, the researcher performs the analysis stage meticulously. This stage is divided into several steps, outlined as follows:

### *2.2.1 Data processing*

This research processes data using Excel 2016 and the SeismoSignal application. These tools simplify data processing to obtain data results that can guide further study. After the appropriate data processing, the results are inputted into the ETABS V.18 software. This software then conducts further analysis following the analysis method, producing numerical results that convey information about the analyzed structure.

### *2.2.2 Structural modeling*

3D modeling is only done on reinforced concrete structural components such as plinth beams (sloofs), columns, beams, and plates. Conversely, non-structural components don't undergo 3D modeling because it has no significant influence. The structure of the Faculty of Medicine building at IGM University is modeled as depicted in **Figure 2.**

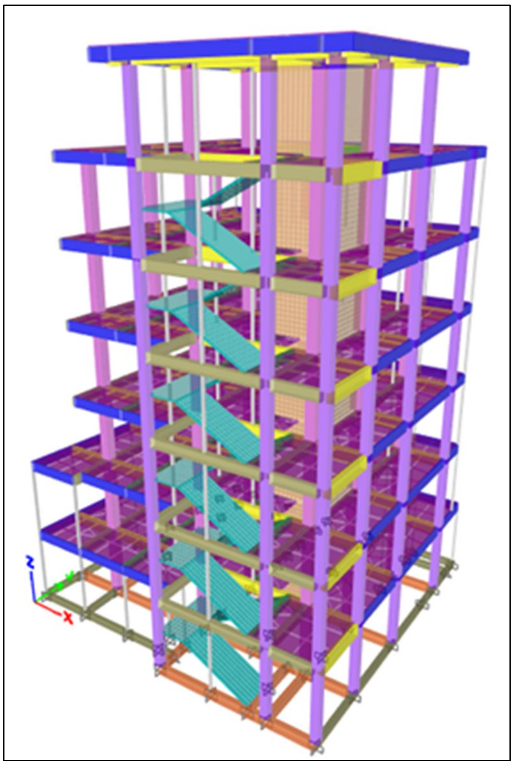

**Fig. 2.** Structural modelling.

### *2.2.3 Loading input*

The ETABS V.18 program automatically calculates dead loads during the process of 3D modeling and defining materials and dimensions within the building structure so that the input of dead load doesn't need to be done. In contrast, for Superimposed dead loads, live loads, and earthquake loads, it is necessary to input them manually into the software by the data obtained. The loading calculation results to be entered are detailed below:

a) Superimposed dead load on the story

Superimposed dead loads acting on each level are presented in Table 6.

**Table 6.** Superimposed dead load on the story.

| Area | Load |
|---|---|
| 7th to the top story | 1.01 kN/m$^2$ |
| 2nd to 6th story | 2.10 kN/m$^2$ |
| Stair landing | 1.1 kN/m$^2$ |
| Stair plate | 2.5 kN/m$^2$ |

b) Superimposed dead load on the wall

Loading on walls is divided into interior and exterior categories, as shown in Table 7.

**Table 7.** Superimposed dead load on walls.

| Area | Load |
|---|---|
| **Interior walls** | |
| Base story | 8.75 kN/m' |
| 2nd to 3rd story | 9.375 kN/m' |
| 4th to 7th story | 8.75 kN/m' |
| **Exterior walls** | |
| Base story | 5.25 kN/m' |
| 2nd to 3rd story | 5.625 kN/m' |
| 4th to 7th story | 5.25 kN/m' |
| 7th story fence | 3 kN/m' |

c) Live load on the 7th story to the top story

The 7th to Top story will receive a portion of the rain load (R), defined as the direct load. The rain load is considered to have reached the maximum water depth, so the value of R = 0.5 kN/m$^2$ is taken.

The load due to tendons, assuming a tendon capacity of 2000 liters, is four pieces of 2.42 kN/m$^2$, while in anticipation of additional water capacity, the surrounding plates are planned to bear the same load, except in cantilever areas, where it is designed to carry only 0.96 kN/m$^2$ loads.

d) Live load on the 2nd story to the 6th story

The live load can be reduced, except in the multipurpose room area [14], so a reduction value of 0.75 is taken. The working live load is presented in Table 8.

**Table 8.** Live load on the story.

| Area | Load |
|---|---|
| Classroom | 1.44 kN/m$^2$ |
| Corridor above 2nd story | 2.8725 kN/m$^2$ |
| Corridors and stairs | 3.5925 kN/m$^2$ |

### *2.2.4 Time history analysis*

The study's location lies in Palembang City, categorized within zone II for earthquakes, with a maximum earthquake potential of 7.2 magnitude at a distance of 60 to 111 kilometers [5]. Consequently, the earthquake accelerogram utilized should be derived from the magnitude and source length of earthquakes adjacent to the response spectrum of the studied area. SNI 1726–2019 also mandates including at least three earthquake recording data sets in the analysis process.

For time history analysis in this study, the earthquake recording data were procured from the PEER (Pacific Earthquake Engineering Research Center) site for the El Mayor-Cucapah (Chihuahua (2010)) earthquake [19]. Furthermore, earthquake accelerograms for the Mentawai-West Sumatra (2007) and Imperial Valley (El Centro (1940)) earthquakes were obtained from the SMC (Strong Motion Center) site [20]. These accelerograms were then utilized to calculate input ground movement. The ground motion data used in this research are depicted in **Figure 3.**

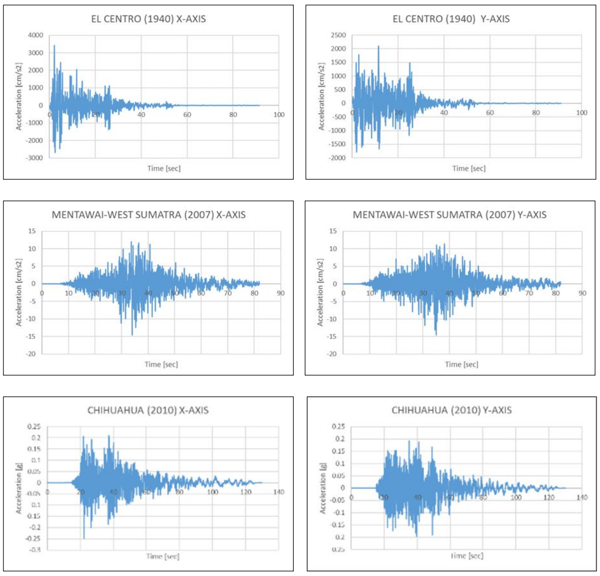


**Fig. 3.** Earthquake accelerogram.

The scale of earthquake intensity needs to be considered before the time history analysis process is carried out by scaling the acceleration of the original ground surface peak of the planned earthquake, which is defined as an input earthquake, to the nominal earthquake loading level. Based on the calculation results, scale factors for each earthquake were analyzed as in Table 9.

**Table 9.** Time history scale factor.

| Earth-quake | Peak Ground Acceleration of the Original Site ($PGA_0$) | $PGA_0$ ($m/s^2$) | $PGA_0$ (g) | Scale Factor ($mm/s^2$) |
|---|---|---|---|---|
| **El Centro (1940)** | | | | |
| X-Axis | 341.695 $cm/s^2$ | 3.4170 | 0.3484 | 1941.6431 |
| Y-Axis | 210.142 $cm/s^2$ | 2.1014 | 0.2143 | 3157.1485 |
| **Mentawai-*West Sumatra* (2007)** | | | | |
| X-Axis | 14.574 $cm/s^2$ | 0.1457 | 0.0149 | 45522.8733 |
| Y-Axis | 14.532 $cm/s^2$ | 0.1453 | 0.0148 | 45654.4423 |
| **Chihuahua (2010)** | | | | |
| X-Axis | 0.24849 g | 2.4369 | 0.2485 | 2722.5686 |
| Y-Axis | 0.19699 g | 1.9318 | 0.1970 | 3434.3423 |

### *2.2.5 Loading combination input*

The combination of loads based on [14, 15] can be inputted into the ETABS V.18 program as loads that are considered to work together over the life of the plan, so for analysis, it is necessary to consider the existence of such load combinations. However, wind loads aren't factored into combination loading as they don't exert significant influence over the structural elements within the reinforced concrete frames of the building site.

### *2.2.6 Running*

Running can be done in the ETABS V.18 program after all modeling and input loading stages are completed. The running results will show deflections observed within the 3D model, and the final results given are in the form of numbers that provide information related to the structure being analyzed.

## 3 Result and discussion

At the performance analysis stage, this structure includes service limit performance, ultimate limit performance, and performance levels based on ATC-40. The results of the analysis obtained are as follows:

### 3.1 Service limit performance

The analysis results yield displacement values and drift ratios, which are examined to determine if they satisfy the stipulated criteria according to the service limit performance mandated by applicable regulations. Service limit performance is presented in Tables 10 and 11.

**Table 10.** X-Axis service limit performance.

| Story | El Centro (m) | Mentawai (m) | Chihuahua (m) | Δs (m) |
|---|---|---|---|---|
| Top | 0.0046 | 0.0020 | 0.0068 | 0.017 |
| 7th | 0.0047 | 0.0020 | 0.0072 | 0.017 |
| 6th | 0.0047 | 0.0021 | 0.0070 | 0.017 |
| 5th | 0.0045 | 0.0020 | 0.0064 | 0.017 |
| 4th | 0.0041 | 0.0019 | 0.0058 | 0.017 |
| 3rd | 0.0028 | 0.0015 | 0.0042 | 0.018 |
| 2nd | 0.0012 | 0.0007 | 0.0018 | 0.018 |

**Table 11.** Y-Axis service limit performance.

| Story | El Centro (m) | Mentawai (m) | Chihuahua (m) | Δs (m) |
|---|---|---|---|---|
| Top | 0.0030 | 0.0023 | 0.0042 | 0.017 |
| 7th | 0.0034 | 0.0024 | 0.0013 | 0.017 |
| 6th | 0.0035 | 0.0021 | 0.0021 | 0.017 |
| 5th | 0.0032 | 0.0017 | 0.0042 | 0.017 |
| 4th | 0.0024 | 0.0017 | 0.0055 | 0.017 |
| 3rd | 0.0017 | 0.0010 | 0.0065 | 0.018 |
| 2nd | 0.0010 | 0.0004 | 0.0055 | 0.018 |

Based on Tables 10 and 11, It can be seen that the maximum service limit performance value of the X-Axis occurs on the 7th story, which is 0.0072 meters. In contrast, the maximum service limit performance value of the Y-Axis occurs on the 3rd story, which is 0.0065 meters, both of which are caused by the Chihuahua earthquake (2010) with an earthquake scale of 7.2 magnitude. A comparison graph of service limit performance is shown in Figure 4.

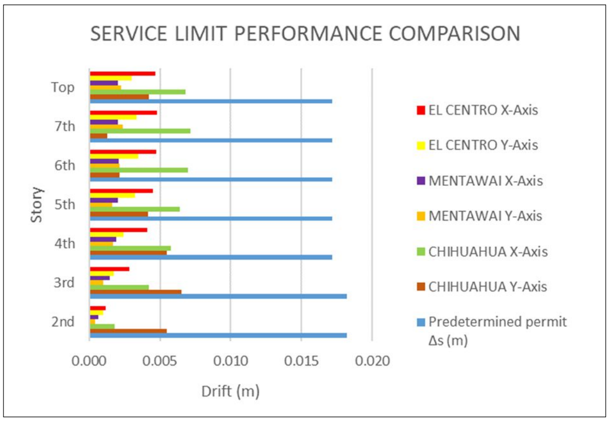


**Fig. 4.** Service limit performance comparison.

Figure 4 indicates that the inter-level drift values for all types of earthquakes utilized in the analysis process remain within safe parameters on the service limit performance. These values don't surpass the predetermined drift permit limit.

### 3.2 Ultimate limit performance

The analysis results yield displacement and drift ratio values for further checking the required ultimate limit performance. Ultimate limit performance is presented in Tables 12 and 13.

Based on Tables 12 and 13, the X-Axis maximum ultimate limit performance value occurred on the 7th story, which was 0.0351 meters. In contrast, the maximum ultimate limit performance value of the Y-Axis happened on the 3rd story, which was 0.0319 meters, both of which were caused by the Chihuahua earthquake (2010). A comparison graph of ultimate limit performance is shown in Figure 5.

**Table 12.** X-Axis ultimate limit performance

| Story | El Centro (m) | Mentawai (m) | Chihuahua (m) | Δm (m) |
|---|---|---|---|---|
| Top | 0.0226 | 0.0097 | 0.0334 | 0.080 |
| 7th | 0.0233 | 0.0098 | 0.0351 | 0.080 |
| 6th | 0.0231 | 0.0101 | 0.0341 | 0.080 |
| 5th | 0.0218 | 0.0098 | 0.0313 | 0.080 |
| 4th | 0.0200 | 0.0094 | 0.0284 | 0.080 |
| 3rd | 0.0137 | 0.0072 | 0.0207 | 0.085 |
| 2nd | 0.0057 | 0.0032 | 0.0087 | 0.085 |

**Table 13.** Y-Axis ultimate limit performance.

| Story | El Centro (m) | Mentawai (m) | Chihuahua (m) | Δm (m) |
|---|---|---|---|---|
| Top | 0.0148 | 0.0111 | 0.0208 | 0.080 |
| 7th | 0.0164 | 0.0115 | 0.0063 | 0.080 |
| 6th | 0.0171 | 0.0104 | 0.0105 | 0.080 |
| 5th | 0.0159 | 0.0081 | 0.0205 | 0.080 |
| 4th | 0.0120 | 0.0081 | 0.0268 | 0.080 |
| 3rd | 0.0085 | 0.0049 | 0.0319 | 0.085 |
| 2nd | 0.0048 | 0.0019 | 0.0269 | 0.085 |

Figure 5 demonstrates that the ultimate limit performance, evaluated by considering the maximum inter-level drift for all earthquakes analyzed, remains within the safe category. None of these drifts exceed the allowable limit.

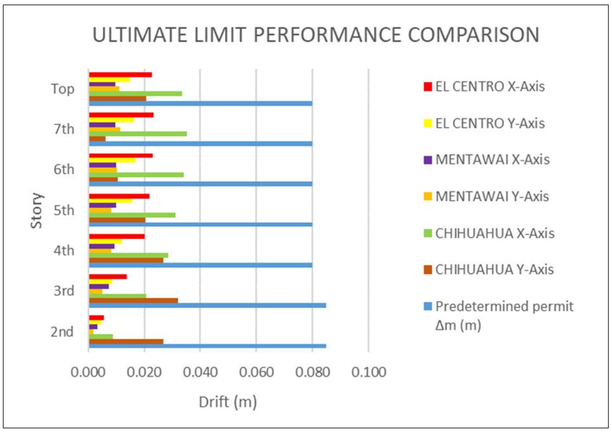


**Fig. 5.** Ultimate limit performance comparison.

### 3.3 ATC-40 performance

The calculation results based on ATC-40 to determine the level of structural performance in each earthquake included in the analysis process are presented in Table 14.

**Table 14.** Performance level ATC-40.

| Earthquake | $H_{total}$ (m) | $D_t$ (m) | $D_t/H_{total}$ (m) | Description of results |
|---|---|---|---|---|
| El Centro X-Axis | 28.5 | 0.02656 | 0.00093 | *Immediate Occupancy* |
| El Centro Y-Axis | 28.5 | 0.01823 | 0.00064 | *Immediate Occupancy* |
| Mentawai X-Axis | 28.5 | 0.01207 | 0.00042 | *Immediate Occupancy* |
| Mentawai Y-Axis | 28.5 | 0.01144 | 0.00040 | *Immediate Occupancy* |
| Chihuahua X-Axis | 28.5 | 0.03912 | 0.00137 | *Damage Control* |
| Chihuahua Y-Axis | 28.5 | 0.02931 | 0.00103 | *Damage Control* |

Based on the calculation results in Table 14, performance levels were obtained for each earthquake used in the analysis process based on the maximum drift ATC-40, namely for the El Centro earthquake (1940) with an earthquake strength of 6.9 magnitude and the Mentawai-West Sumatra earthquake (2007) with an earthquake strength of 7.0 magnitude on the X-Axis and Y-Axis included in the category of "Immediate Occupancy". It signifies that the structure remains safe and stable. Conversely, the Chihuahua earthquake (2010), with a magnitude of 7.2 along the X and Y axes, falls within the "Damage Control" category. It indicates that the structure might experience minor damage but remains capable of controlling structural damage caused by the influence of earthquake loads.

## 4 Conclusions

The analysis conducted concerning the structural performance of the Faculty of Medicine building at Indo Global Mandiri University under the influence of earthquake loads through time history dynamic analysis leads to the following conclusions: The performance of service limits and ultimate limits, based on the inter-level drift values and maximum inter-level drifts obtained for the El Centro, Mentawai-West Sumatra (2007), and Chihuahua (2010) earthquakes, is deemed safe and compliant with the stipulated requirements for both service and ultimate limits. In terms of the ATC-40 performance analysis focusing on the maximum drift values attained during the El Centro (1940) and Mentawai-West Sumatra (2007) earthquakes included in the category of "Immediate Occupancy". Conversely, the Chihuahua earthquake (2010) corresponds to the "Damage Control" category.

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