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Structural Behavior Analysis of the Beam-Column Connections of Existing Steel Structure Buildings based on Finite Element Modeling-Idea StatiCa

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Abstract. In designing the structures of a building, the beam-column connections are a very important component that needs to be properly taken into account. Failure of these connections can cause total collapse of a building. With the assistance of finite element modeling (FEM) programs such as Idea StatiCa, connections to steel structural buildings can be evaluated quickly. The study was carried out on the Sarinah transformation parking buildings in Jakarta. Based on spectral response analysis, building has been reliable to the latest regulations. The building structure model was tested for horizontal and vertical irregularity factors, story drifts, P-Delta effect, stress ratio of beam and column elements, Strong Column-Weak Beam ratio (SC-WB) and the structure performance levels through pushover analysis, all of which met the requirements. Analysis results showed that based on the plastic moment data, maximum stress at plate was 400 MPa (for x- direction) and 377 MPa (for y-direction). Meanwhile, based on Idea StatiCa analysis, maximum stress at plate was found to be 199.8 MPa (for x-direction) and 81.3 MPa (for y-direction). The plate stress in plastic condition appears to be greater, this is because internal forces acting in this condition are also greater.

1 Introduction

Based on the geographical location, Indonesia is at the meeting point of the four world tectonic plates, namely the Eurasia plates, the Australia plates, the Philippine plates and the Pacific plates. Besides that, Indonesia also passes through two world earthquake belts, those are the Asia and Pacific earthquake belts. Pacific Earthquake belts were accompanied also by the presence of many active mountains, so it is known by the term the Pacific Ring of Fire. This condition makes Indonesia vulnerable to earthquakes, potentially causing damage or collapse of buildings.

In designing the structures of a building, whether it is intended for residence, business or special functions, it must be designed in accordance with applicable standards. This planning is intended to minimize the risk of structural failure. Neither buildings nor other buildings today must be planned not only with functional consideration, but must have the capacity to respond to the type of earthquake that occurs in each area according to the potential of the earthquakes. On the other hand, building codes are constantly being updated so old buildings need to be re-checked for reliability to the new regulations.

Kasapoglu et al. [8] investigated the prequalified seismic connections due to the cyclic load, where the bolted unstiffened and stiffened extended end plate moment (EPM) connections followed the AISC design procedure [2]. They disclosed that the link is applied in three different ways. A value of about 80% of the plastic moment capacity is obtained from two different connections. In the interim, a further variation can develop 110% of the beam's nominal plastic moment capability. Plate stiffeners near the end experience the first yielding. Local buckling of the beam flanges, beam web, and column web doubler plates was noted after complete yielding of the beam flanges and end plate stiffeners.

In the meantime, Osman and Mourad [1] created a numerical model to forecast the behavior of steel extended end-plate moment connections under blast-like and static stress using ABAQUS software. When a stiffener was added to the configuration under study, the plastic energy dissipation for blast loading increased by 45% when compared to the unstiffened connection. However, under static loading, the stiffened connection's plastic energy dissipation was 30% greater than the unstiffened connections.

Özkılıç and Topkaya [12] have reported that the end-plates' ultimate resistance was measured. The finite element approach was used to examine both stiffened and unstiffened T-stub models. The plastic and ultimate resistance were computed using expressions derived from yield line mechanisms. The analyses revealed that when the suggested expressions are used, the average test-to-predicted ratios for the plastic and ultimate resistance, respectively, are 1.06 and 1.17.

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Silalahi et al. [11] stated that after an earthquake, the strength of the connections determines whether a building would fail or collapse. Selecting the appropriate connection is essential to guarantee the presence of plastic joints in the beam region. This study uses ABAQUS software to analyze how steel connections of the Extended End Plate type behave under cyclic loads. When modeling results are compared with experimental data, there is little discernible difference.

Luo et al. [10] stated that, in high-risk areas, the expanded end-plate connectors perform exceptionally well in withstanding seismic loads. The method of putting displacement loads on the beam tip has been the focus of the majority of academic experiments and finite element research on this type of joint ; the way of applying displacement on the column side has not received as much attention. However, because not every joint fit under the design concept of "strong column - weak beam," the load transfer mechanism of this kind of connection is not entirely consistent in real engineering.

Related to designing, the connections must be stronger than the beam or column itself, so it is necessary to pay more specific attention to how to plan a strong and correct connection.

2 Analytical method

Before evaluating structural connections to existing buildings, it is necessary to first check whether the existing building structure already meets the requirements of the applicable provisions.

At the structure design verification stage of existing buildings, the loading taken includes Dead Load (DL), Super Imposed Dead Load (SIDL), Live Load (LL), Rainwater load (R), Wind load (W) and Earthquake load (EQ). The verification carried out were the periods of structure, shape and number of mode shape, modal participation mass ratios, base shear, force scaling, base shear comparisons, horizontal and vertical irregularities, story drift, P-Delta effect, stress ratios of beam and column elements, Strong Column-Weak Beam ratios (SC-WB) as well as structural performance levels through pushover analysis.

This research uses the quantitative data analysis method, where the data is numerical. Forces in the earthquake load result were obtained from the running results of the ETABS v.21 program, in addition to the manual calculation of the connection condition in a plastic stage. Connection analysis using the FEM software Idea StatiCa v.21. The building codes used in this analysis refer to SNI-1726 [4], SNI-1729 [5], SNI-7860 [6], and SNI-7972 [7].

3 Results and discussions

In this study that was reviewed were steel structural buildings with Special Moment Frame (SMF), fifth-floor, irregular buildings as shown in Figure 1. The building is designed according to SNI-1726 [4] is a Sarinah transformation parking building. The building is located in the city of Jakarta, the classification of the site is soft soil (SE). The moment connection on this building uses type 4 (four) Bolted Unstiffned Extended End Plate Momen Connection.

In the connection evaluation, take the connection point as shown in Figure 2, where the x-direction is reviewed on the B.2 axis and the B.D axis for the y-direction.

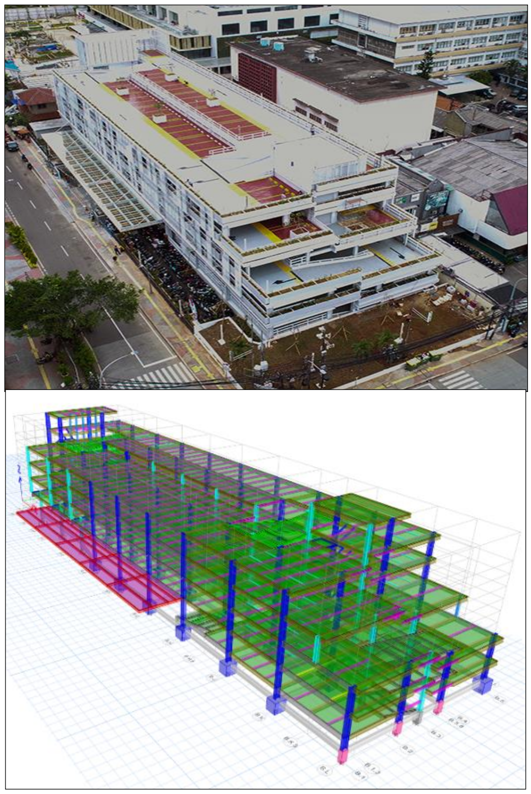

Fig. 1 Sarinah parking buildings & structural models (Courtesy of Sukamta [9])

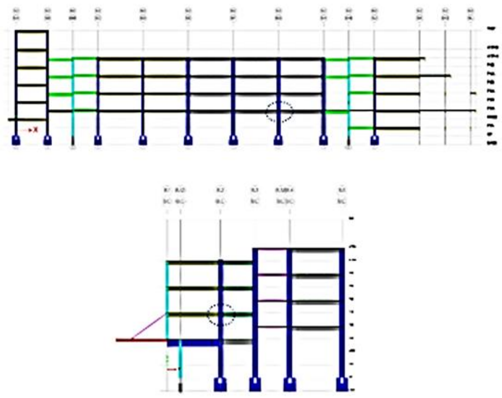

Fig. 2 Connection points reviewed in x and y directions

The connection is modeled with the FEM program Idea StatiCa v.21. Figure 3 below shows the connection model for x and y directions.

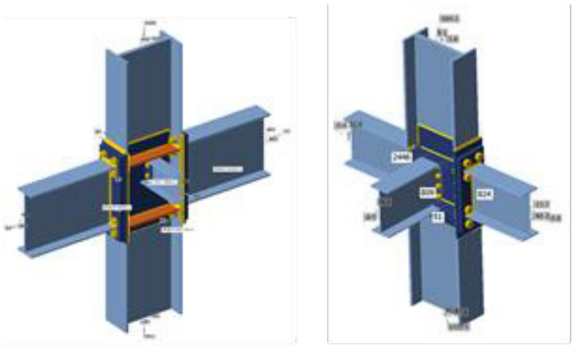

Fig. 3 Existing steel connection and modeling of x and y direction

3.1 Respons spectrum design

A graph of the response spectrum at the location can be seen in Figure 4. The response shows that once period of 1 second, the ground acceleration continues to decrease in value.

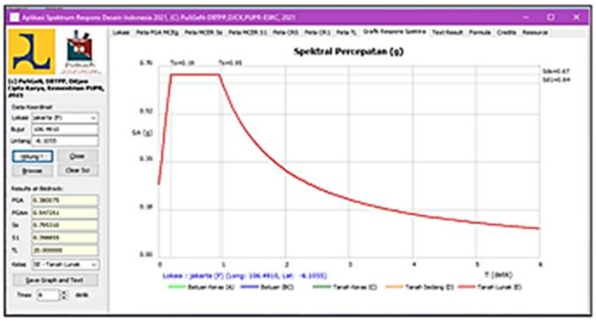

Fig. 4 Response spectrum design curve of soft soil (SE), Jakarta City

3.2 Category of Seismic Design (CSD)

Based on value of the design spectrum accelearation parameter at short period (Sds) of 0.670(g) and at period of 1 second (Sd1) of 0.639(g), as mentioned in SNI-1726 [4], location of building is in CSD-D.

3.3 Seismic force bearing factors

For the category of buildings with steel frame bearing special moment values the response modification coefficient (R) is 8, the strength factor over the system (Ω_0) 3 and the amplification factor of deflection (Cd) is 5.5 according to SNI-1726 [4].

3.4 The period of structure

The period of the x-directional structure is 0.885 seconds, while that of the y-directional structure is 0.707 seconds.

3.5 Shape and number of mode shape

Shape mode is taken 24, where mode 1 and 2 are translation directions.

3.6 Modal participation mass ratios

Modal participation mass ratios in the x direction is 91.30% and the y direction is 90.40%. Both are more than 90% or close to 100%.

3.7 Seismic base shear forces

Based on the analysis results using Etabs on the related building, it was obtained that seismic base shear force of 3017.547 kN.

3.8 Force scaling

The x-directional earthquake force scale is 1587.44 mm/s^2 and the y-direct is 1697.77mm/s^2.

3.9 Base shear ratio

The ratio of the dynamic base shear to the static base shear obtained is 100%.

3.10 Horizontal and vertical irregularities

The building has torque irregularities, internal corner, soft level stiffness and also weight (mass), so in the analysis of the reduction factor structure (ρ) should be taken 1.3, unexpected torque moment magnification should be applied as well as the permissible method of analysis is the response spectrum and time history.

3.11 Story drift

The maximum inelastic story drift that occurs at the top floor is 21.63 mm (direction x) and 28.22 mm (direction y), which is still smaller than the required 50 mm.

3.12 P-Delta effect

The maximum stability coefficient that occurs is on the P2B floor, namely 0.031 (x direction) and 0.014 (y direction). These two values are still smaller than the structural stability limit of 0.091 and the P-Delta effect limit of 0.1.

3.13 Stress ratios of beam and column elements

Stress ratio can be defined as a comparison between working stress to capacity stress of structural element. Usually, the value is below one. In the meantime, all beams and columns in this building have the stress ratio values below one. So, it means all these element in safety condition.

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3.14 Strong Column-Weak Beam (SC-WB) ratios

The SC-WB ratio of the x direction is 1.018 and the y direction is 2.952. Both of these values are still greater than 1(one). It is in line with the limits prescribed in SNI-7860 [6].

3.15 Pushover Analysis

The plastic hinge mechanism that occurs on the beam first, then followed on the column. The pushover results in the x and y directions indicate that the occurrence of plastics joints on the base column occurs at 3rd step, as can be seen in Figure 5, where as the performance point is shown in Figure 6.

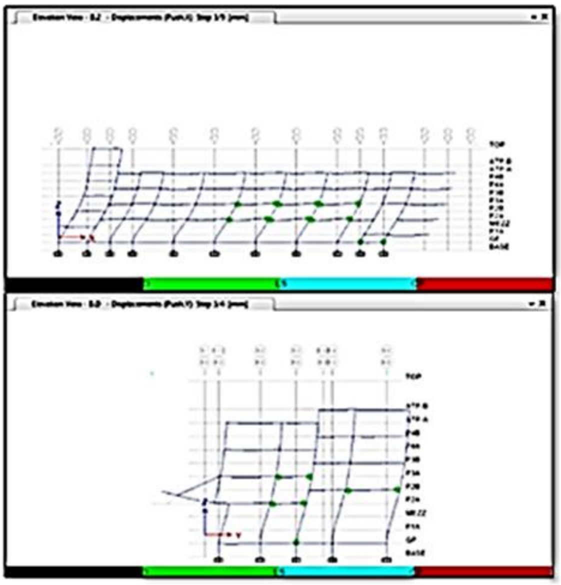

Fig. 5 Plastic hinge at the 3rd step

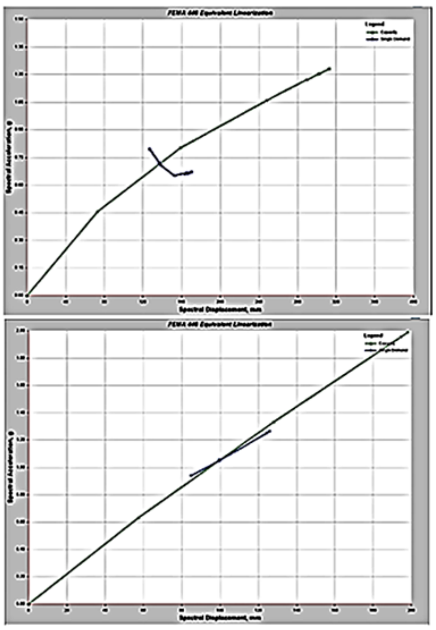

Fig. 6 Pushover curves in x and y directions

Furthermore, the total maximum total drift of the x direction is 0.0113 and the y direction 0.0101, where this value shows the level of performance of the structure. Then according to ATC-40 [3] the structure belongs to the level of category Damage Control (DO) which means the transition between the Immediate Occupancy (IO) SP-1 and the Life Safety (LS) SP-3. There is extremely little chance of human casualties from the earthquake because the structure is still able to withstand the earthquake and structurally sound.

3.16 Evaluation of x-directional connections

In evaluation of the x-directional connection, there are two conditions that are reviewed: the earthquake load condition and the plastic condition. The value of the earthquake load condition can be seen in Figure 7.

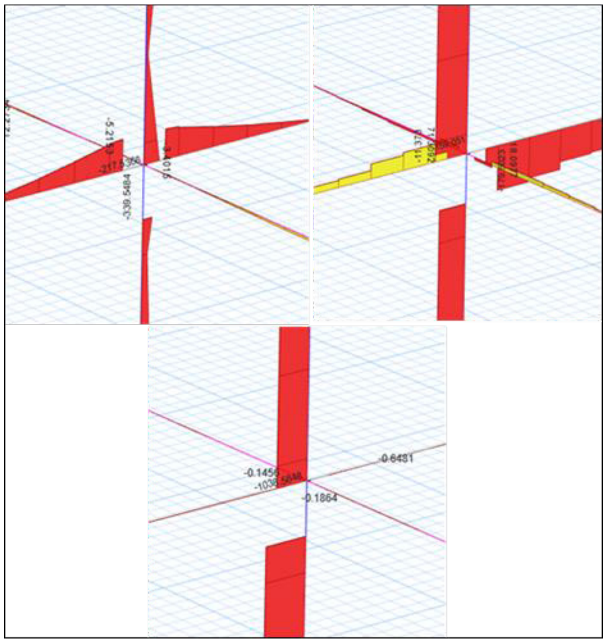

Fig. 7 Bending Moment, Shear and Normal due to earthquake load in x-direction

In plastic conditions, the value of bending moment and shear is:

$$M_{pr} = 1.1 * R_y * F_y * Z_x \quad (1)$$

$$V_{pr} = \frac{2M_{pr}}{L_h} \quad (2)$$

Where,

M_{pr} = Probable moment (kN.m)
V_{pr} = Probable shear (kN)
Z_x = Modulus of the plastic section of the beam WF600x200 (cm^3)
R_y = 1.5
F_y = Steel yield stress (MP_a)
L_h = Distance between two plastic hinge (m) = $L_b - d_c - 2S_h$
L_b = Beam span (m)
d_c = Column width (m)
S_h = Dist. from column face to plastic hinge (m)

$$M_{pr} = 1.1 * 1.5 * 240 * 2863 * 10^{-3} = 1134\ kN.m$$

$$V_{pr} = \frac{2 * 1134}{(7.8 - 0.6 - 2 * 0.3)} = 343.6\ kN$$

The steel plate stress values which are the result of running the Idea StatiCa v.21 program by 2 (two) conditions can be seen in Figures 8 and 9.

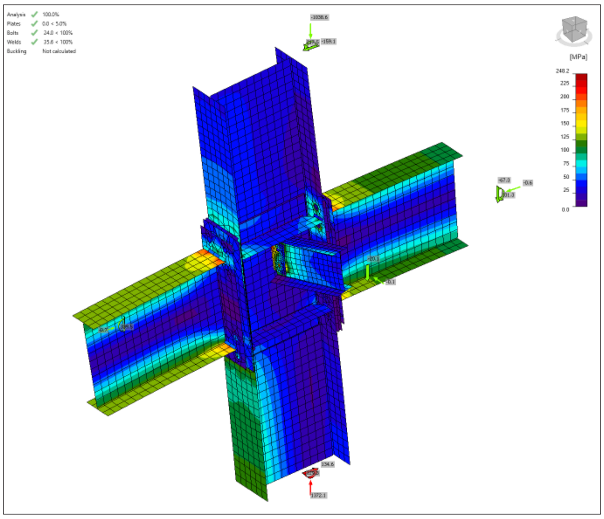

Fig. 8 Steel plate stress contour at the x direction joint due to earthquake loads

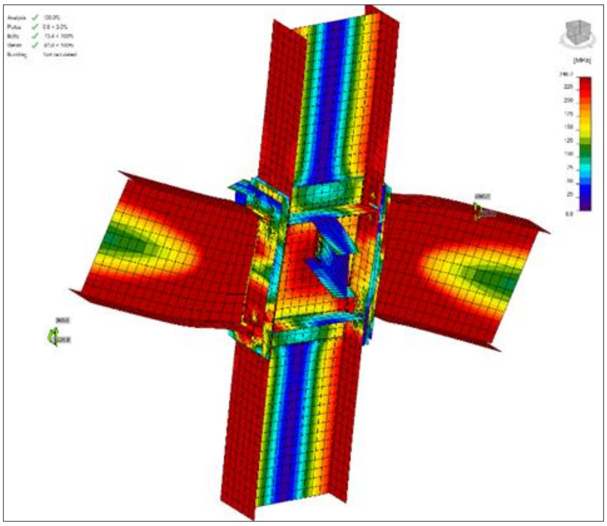

Fig. 9 Steel plate stress contour in x direction joint in plastic condition

The maximum stress that occurs in steel plates under load conditions due to earthquake loads is 199.8 MPa < 240 MPa (Fy). In plastic conditions, the stress that occurs is 400 MPa, this value is comparable to the ultimate allowable stress of steel (Fu = 400 MPa).

3.17 Evaluation of y-directional connections

To evaluate the y-direction connection, the forces considered are the same as in the x-direction. The value of the internal force from conditions due to earthquake loads can be seen in Figure 10.

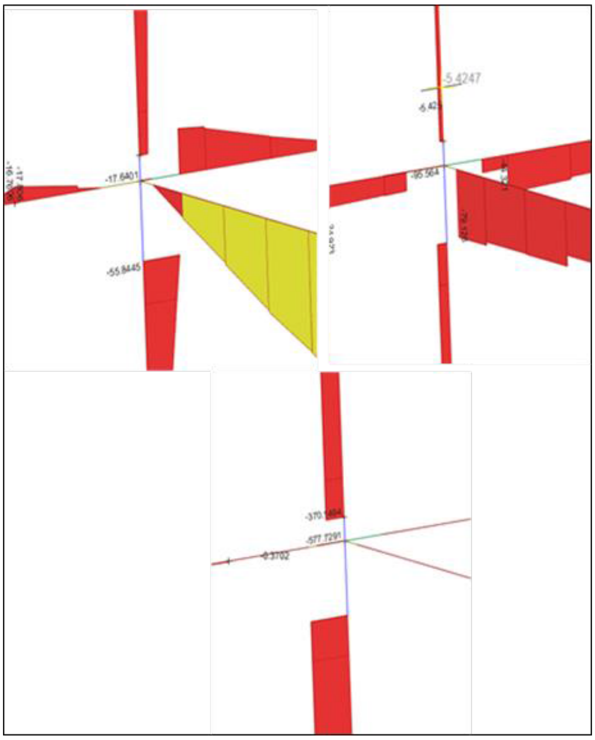

Fig. 10 Bending Momen, Shear and Normal due to earthquake load in y direction

In plastic conditions, the value of bending moment and shear is:

$$M_{pr} = 1.1 * 1.5 * 240 * 1624 * 10^{-3} = 641.9\ kN.m$$

$$V_{pr} = \frac{2 * 641.9}{(4 - 0.6 - 2 * 0.3)} = 435.2\ kN$$

Where, 1624 cm^3 is modulus of the plastic section of the beam WF450x200 (Z_x).

The steel plate stress values which are the result of running the Idea StatiCa v.21 program into two conditions can be seen in Figure 11 and 12.

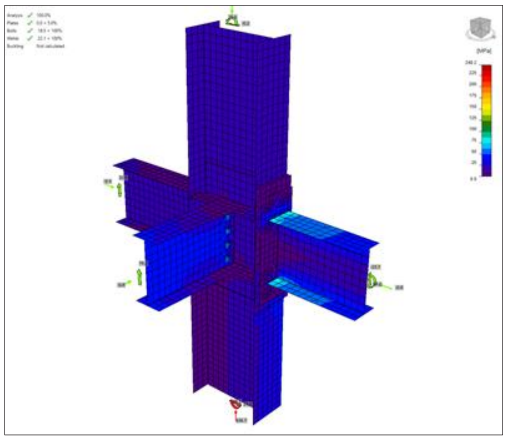

Fig. 11 Steel plate stress contour at the y direction joint due to earthquake loads

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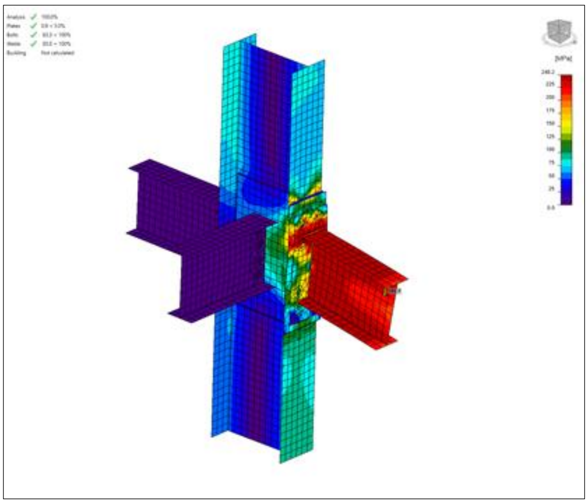

Fig. 12 Steel plate stress contour in y direction joint in plastic condition

The maximum stress that occurs in steel plates under load conditions due to earthquake loads is 81.3 MPa < 240 MPa (Fy). In plastic conditions, the stress that occurs is 377 MPa, this value is also smaller than the ultimate allowable stress of steel (Fu).

Figure 13 below shows a comparison of the four stress values on the steel plate

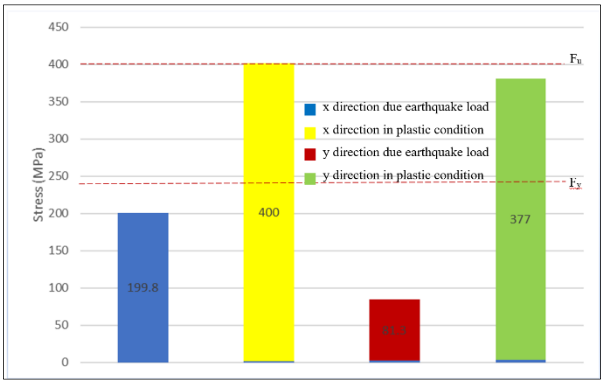

Fig. 13 Comparison of stresses at the steel plates

4 Conclusion

The parking building has reliability against the latest building regulations. In checking the period of the structure, shape and number of mode shape, modal participation mass ratios, seismic base shear forces, force scaling, base shear ratios, horizontal and vertical irregularities, story drift, P-Delta effect, stress ratios of beam and column elements, Strong Column-Weak Beam (SC-WB) ratios as well as the structural performance level, all values meet the requirements. Apart from that, the connection has sufficient strength to reach a plastic condition. For joint analysis based on plastic condition, the maximum stress in the plate was 400 MPa (x-direction) and 377 MPa (y-direction). Meanwhile, based on Idea StatiCa FEM analysis, the maximum stress on the plate was found to be 199.8 MPa (x-direction) and 81.3 MPa (y-direction). The plate stress in the plastic condition appears to be greater, this is because the internal forces acting in this condition are also greater.

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