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Research paper

Performance Evaluation of Low-Rise Steel Structures Using Pushover Analysis (Case Study of Jeep Indonesia Brand Center Alam Sutera Showroom Building)

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ABSTRACT

Purpose: Indonesia is a country prone to earthquakes, and earthquakes can cause significant losses such as damage to infrastructure, buildings and loss of life. The objectives of this research are: (1) to determine the structural performance level of the Jeep Indonesia Brand Center Alam Sutera showroom building based on the ATC-40 method, (2) to determine the structural performance of the Jeep Indonesia Brand Center Alam Sutera showroom building based SNI 1726: 2019 regulations.
Methods/Design: The methods used in this research are: (1) 3D structural modeling using ETABS software, (2) calculate and determine the load on the structure based on SNI 1727: 2020, (3) perform earthquake load analysis to check the deviation between permit levels (Δ) according to SNI 1726: 2019 regulations, (4) perform pushover analysis using ETABS software to obtain performance points, (5) evaluate the structural performance level using the ATC-40 method from the calculation of the drift ratio obtained from the performance point results.
Findings: The results showed that: (1) based on the performance points obtained, the maximum total deviation value for x direction = 0.01011 and y direction = 0.00858. While the maximum inelastic deviation value for the x direction = 0.00811 and y direction = 0.01085.
Practical implication: This shows that the performance level of the Jeep Indonesia Brand Center (JIBC) Alam Sutera showroom building structure based on the ATC-40 method is Damage Control (DC), namely the building suffered minor damage due to the earthquake, but the damage can be repaired at an affordable cost and the risk of human casualties is very small, (2) the performance of the building structure still meets the requirements according to Table 20 of SNI 1726: 2019 which is indicated by the value of drift or deviation between floors that is not more than the deviation between permission levels (Δ).

INTRODUCTION

According to (Choerudin, 2008), Indonesia is a country that is very prone to earthquakes. This is because Indonesia is located in a meeting area between three large tectonic plates, namely the Indo-Australian, Eurasian and Pacific plates. Earthquakes in Indonesia often occur and cause significant losses such as damage to materials, infrastructure, buildings and fatalities. (Warsono & Budianto, 2019). This shows the need for structural performance evaluation and better earthquake prevention efforts. (Satria, 2022). Evaluation of the level of structural performance is a process carried out with the aim of determining the ability of a building to withstand earthquake loads and perform its functions properly during and after an earthquake. (Aldo & Pratama, 2019).

In addition, this evaluation aims to provide information about the condition of the structure and assist in making decisions about necessary repairs or renovations to ensure optimal performance in the long term. (Comartin, 1996). Evaluation of structural performance can be done by conducting earthquake load analysis using non-linear static analysis, namely pushover analysis. According to (Nuraga et al., 2021), Pushover analysis is one method in analyzing building structures with the aim of being able to determine the nature of the collapse of a building structure. Pushover analysis is carried out by giving the building structure a form of lateral load, then gradually increasing it so that it reaches a target displacement in the building. (Dewobroto, 2005). The primary purpose of a pushover analysis is to determine whether a building meets required performance specifications, such as safety and skill levels, and to provide information about structural weaknesses and strengths to assist in planning repairs or renovations. (Hakim, 2013). Pushover analysis is an important part of structural performance evaluation and is very useful in ensuring that buildings can function safely and effectively in earthquake situations. (Hakim et al., 2014).

According to (SNI 1726, 2019), regarding Earthquake Resistance Planning Procedures for Building and Non-building Structures, drift values (Δ) or the deviation between floors must meet the requirements and must not exceed the permitted deviation limit between levels (Δ) that has been determined. The deviation between floors is obtained by conducting static and dynamic earthquake load analysis. Based on (Ismaeil et al., 2015), The building must calculate its drift ratio value to obtain the building risk category calculated based on the performance point value obtained from the pushover analysis results. Based on the drift ratio value, the building is divided into four conditions, namely Immediate Occupancy, Damage Control, Life Safety, and Structural Stability. (Khouy et al., n.d.).

Figure 1. Jeep Indonesia Brand Center Alam Sutera Showroom Building

The Jeep Indonesia Brand Center (JIBC) showroom building is a three-story building with a steel structure located in Alam Sutera, South Tangerang, Banten. The Jeep Indonesia Brand Center Alam Sutera showroom building is a building that functions as a commercial building for Jeep vehicles and is used as an office on the second and third floors. In this building, it is necessary to carry out an earthquake load analysis and evaluate the structural performance level using the pushover analysis method with the help of ETABS software. (Scandura, 2009). The evaluation was carried out using pushover analysis to determine the performance of the building structure during an earthquake and to determine which areas are vulnerable to the structure. (Hutama, 2021).

METHODS/DESIGN

The object of the study is the Jeep Indonesia Brand Center (JIBC) showroom building located on Jl. Jalur Sutera Boulevard Kav. 30, Alam Sutera, South Tangerang, Banten. The Jeep Indonesia Brand Center building is a steel structure building with a height of three floors and a roof. The data used in this study are secondary data.

Table 1. Building Description

Biulding Name	Jeep Indonesia Brand Center
Vulding Function	Office and commercial buildings
Number of floor	3
Typical floor heght	4 m
Height from ground level	14.95 m

The research was conducted by conducting an analysis using non-linear static analysis, namely pushover analysis using ETABS software to obtain the level of building structure performance. The procedure used in this study uses the ATC-40 method and refers to the regulations (SNI 1726, 2019). This research was conducted by carrying out several stages as follows:

1. Collecting data on the structure of the Jeep Indonesia Brand Center showroom building. The data collected is in the form of shop drawings and construction management data used based on existing data.
2. Retrieval of spectrum response design data on the page https://rsa.ciptakarya.pu.go.id/
3. Three-dimensional structural modeling of the Jeep Indonesia Brand Center showroom building using ETABS software.
4. Carry out calculations and determine dead, live and wind loads with reference to (SNI 1727, 2020) and earthquake loads with reference to (SNI 1726, 2019).
5. Conduct pushover analysis using ETABS software and calculate data using the ATC-40 method and referring to regulations. (SNI 1726, 2019).
6. Evaluation of the structural performance level based on the drift results obtained from the ETABS software according to the ATC-40 method.

7. Make conclusions based on the results of analysis and discussion.

Evaluation of the level of structural performance is carried out based on the results of the pushover analysis. The stages of pushover analysis in this study are as follows (Muntafi, 2012) :

1. Create a nonlinear case in the form of gravity loading and lateral loading as a pushover load in the x and y directions.
2. Modeling and inputting hinge properties data for beam and column elements into ETABS software.
3. Running a pushover analysis program to obtain the building structure performance point from the intersection of the capacity curve and the demand spectrum.
4. Obtain capacity curve data at each step to determine where plastic hinges occur in the building.
5. Conduct evaluations and determine the performance level of building structures by calculating the drift ratio based on the ATC-40 method.

FINDINGS

The structural modeling of the Jeep Indonesia Brand Center Alam Sutera showroom building was carried out in 3D using ETABS software by modeling all elements of columns, beams, plates, and roofs. The results of the building modeling in 3D are shown in Figure 3. The technical data of the building used in the modeling and analysis of the building structure are as follows:

a. Location of the building : Tangerang
b. Building construction : Steel structure
c. Type of building : office and commercial buildings
d. Material specifications
- Profile steel quality : ST-37
- Concrete quality (fc') : 35 MPa

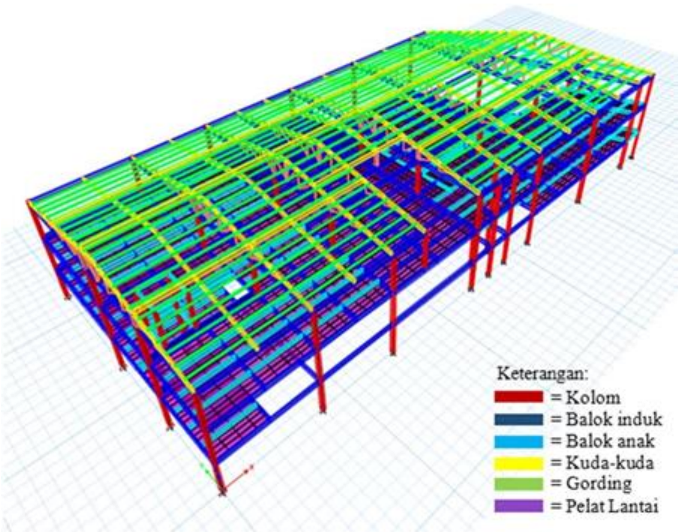

Figure 2. 3D Modeling of Building Structures

A. Earthquake Load Analysis

The static and dynamic base shear force values (base reactions) from the results of the structural analysis due to equivalent static earthquake loading and earthquake response spectrum are shown in Table 2..

Table 2. Basic Static and Dynamic Shear Forces

Output Case	Case Type	FX (kN)	FY kN
SX	LinStatic	-2272.1970	0.0004
SY	LinStatic	-0.0001	-2272.0470
DX Max	LinRespSpec	1215.6586	32.1301
DY Max	LinRespSpec	32.1111	1508.2062

Based on Table 2, the static base shear force value (V) due to equivalent static earthquake load in the x direction = 2272.197 kN and the y direction = 2272.047 kN. While the dynamic base shear force value (Vt) due to the response spectrum earthquake load in the x direction = 1215.6586 kN and the y direction = 1508.2062 kN.

Based on (SNI 1726, 2019) If the dynamic base shear force (Vt) is smaller than the static base shear force (V), then the scale factor must be increased by V/Vt. The calculation of the new scale factor is as follows:

- x – direction scale factor $= \frac{2272{,}197}{1215{,}6585} = 1{,}8691$
- y – direction scale factor $= \frac{2272{,}047}{1508{,}2062} = 1{,}5065$

Then the new scale factor in the x and y directions that have been calculated, multiplied by the previous scale factor by entering it into the ETABS software. After the scale factor is multiplied, then re-analyzed, so that a new dynamic base shear force value is obtained which is greater than the static base shear force shown in Table 3.

Table 3. New Dynamic Basic Shear Force

Output Case	Case Type	FX (kN)	FY kN
SX	LinStatic	-2272.197	0.0004
SY	LinStatic	-0.0001	-2272.047
DX Max	LinRespSpec	2272.2061	60.0548
DY Max	LinRespSpec	48.3742	2272.0576

The deviation between floors must meet the requirements based on Table 20 of SNI 1726:2019 concerning the Deviation Between Permit Levels. Based on the analysis results, the deviation values between floors of the Jeep Indonesia Brand Center Alam Sutera showroom building in the x and y directions have met the requirements and are not more than the deviation values between permit levels shown in Tables 4 and 5.

Table 4. Inter-Floor Deviation X Direction

Lantai	Deviation Direction X (mm)	Delta x (mm)	Delta Permission (mm)	Cek
4	28.098	0.8305	73.75	OK
3	27.947	15.9665	100.00	OK
2	25.044	68.8710	100.00	OK
1	12.522	68.8710	100.00	OK

Table 5. Inter-Floor Deviation Y Direction

Lantai	Deviation Direction X (mm)	Delta x (mm)	Delta Permission (mm)	Cek
4	28.098	0.8305	73.75	OK
3	27.947	15.9665	100.00	OK
2	25.044	68.8710	100.00	OK
1	12.522	68.8710	100.00	OK

Based on Table 4 and Table 5, it is known that the results of the inter-floor deviation for the x and y directions on each floor have met the permitted inter-level deviation (Δ) based on SNI 1726:2019 regulations.

B. Pushover Analysis

The output generated from the pushover analysis is in the form of a capacity curve, performance point, and mechanism of plastic hinge occurrence. The final result of the pushover analysis is in the form of determining the level of building structure performance calculated based on the ATC-40 method. The capacity curve from the results of the pushover analysis in the x and y directions are shown in Figures 3 and 4, respectively.

Figure 3. Curva Capacity Direction X

Figure 4. Curva Capacity Direction Y

The results of the pushover analysis on the pushover loading for the x direction stopped at step 20, namely when the displacement value = 162.741 mm and the base force value = 5522.023 kN. The results of the pushover analysis on the pushover loading for the y direction stopped at step 17, namely when the displacement value = 214.428 mm and the base force value = 10685.072 kN

The determination of the performance point on this building structure uses the ATC-40 capacity spectrum method. This method uses a capacity curve that is converted into the acceleration displacement response spectrum (ADRS) format that shows the relationship between Sa and Sd, as well as a seismic demand curve that is converted into the demand spectrum form (Ertanto et al., 2017). Curve conversion is done automatically in ETABS software. (Riantoby et al., 2014) The performance point is obtained when the capacity curve intersects the spectrum demand curve. After the performance point value is obtained, the drift ratio value can be calculated to obtain the performance level of the building structure by referring to the ATC-40 method. The performance point based on the results of the pushover analysis for the x and y directions can be seen in Figure 5 and Figure 6.

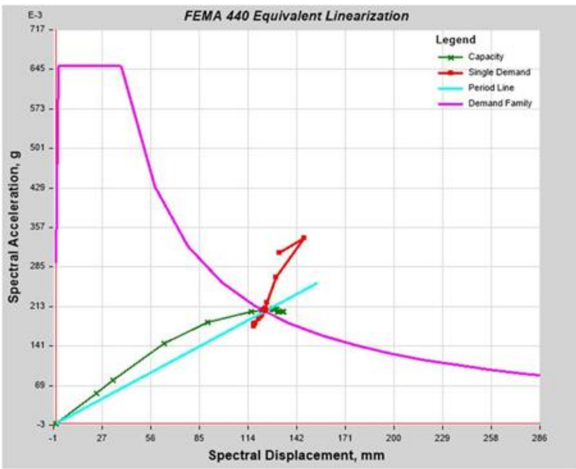

Figure 5. Performance Point in X Direction

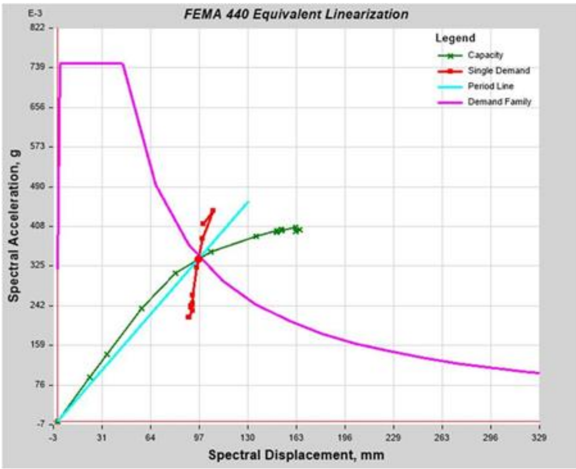

Figure 6. Performance Point in Y Direction

Based on Figure 5 and Figure 6, it can be seen that the capacity curve and demand spectrum have intersected, so that the performance point value can be known. The performance point value from the pushover analysis results in the x and y directions are shown in Table 6.

Table 6. Performance Points from Pushover Analysis Results

Performance Point	**Direction X**	**Direction Y**
Point Found	Yes	Yes
Shear (kN)	5577.82	8763.09
Displacement (mm)	151.191	128.285
Sa (g)	0.20784	0.33886
Sd (mm)	123.504	96.16
T secant (sec)	1.546	1.066
T effective (sec)	1.455	1.041
Ductility Ratio	1.81367	1.56279
Damping Ratio, βeff	0.0765	0.0636
Modification Factor, M	0.88518	0.95377

The drift ratio value according to ATC-40 for the maximum total deviation is determined from the comparison between the displacement value at the performance point and the total height of the building. The maximum inelastic deviation is determined from the displacement value at the performance point then reduced by the displacement value at the first step and then compared with the total height of the building. So the drift ratio value for the x and y directions are as follows:

Maximum Total Deviation:

X direction $= \frac{151,191}{14950} = 0,01011$ (*Damage Control*)

Y direction $= \frac{128,285}{14950} = 0,00858$ (*Immediate Occupancy*)

Maximum Total Deviation:

X direction $= \frac{151,191-29,9}{14950} = 0,00811$ (*Damage Control*)

Y direction $= \frac{192,059-29,9}{14950} = 0,01085$ (*Damage Control*)

From the results of the drift ratio value calculation, it can be seen that the structural performance level of the Jeep Indonesia Brand Center showroom building according to the ATC-40 method is Damage Control (DC), namely the building experienced minor damage due to the earthquake, but the damage can be repaired at an affordable cost and the risk of human casualties is very small. The formation of plastic joints in building structures can be obtained based on the results of pushover analysis. The occurrence of plastic joints based on the results of pushover analysis shown in the ETABS software is marked by the appearance of colored dots on one or more structural elements. Each step of the pushover analysis, there are changes and additions to the plastic joint conditions that occur in the structural elements (Kairatun et al., 2019). Information regarding the occurrence of plastic hinges in structural elements is explained in Table 7.

Table 7. Description of the occurrence of plastic hinges(Marianda, 2016)

Description	Explanation
B	Shows the linear limit that causes an element in the structure to experience the first yielding.
IO	The stiffness of the structure is almost the same as the stiffness before the earthquake, and minor damage that is not significant to the structure begins to occur.
LS	The stiffness of the structure begins to decrease but still has a large enough threshold to reach a state of collapse, and damage begins to occur at a small to moderate level.
CP	The strength of the structure is reduced quite a lot, and quite serious damage to the structure begins to occur.
C	The maximum limit of shear force that can be resisted by a structure
D	The condition of the building became unstable and almost collapsed, and the rigidity of the structure experienced a significant decrease.
E	The collapse of a building occurs due to the inability of the structure to withstand the existing shear force.

In the structure of the Jeep Indonesia Brand Center (JIBC) Alam Sutera showroom building, the pushover analysis stops when there are many structural elements that experience plastic hinges in condition D. The occurrence of plastic hinges based on the results of the pushover analysis in the x and y directions is as follows:

1) Pushover X direction :

The first plastic hinge in the x-direction pushover occurs at step 2 which occurs in the column in condition B shown in Figure 7..

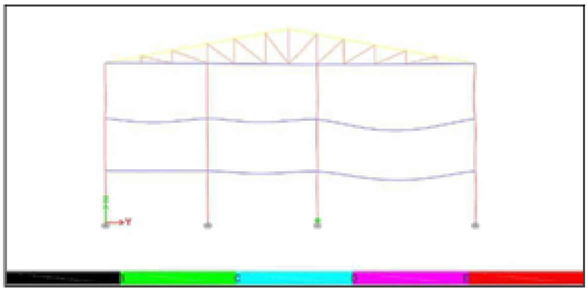

Figure 7. First Plastic Pushover Hinge X Direction in Step 2

Plastic hinges in condition IO begin to occur at step 4 as shown in Figure 9. Plastic hinges in condition C begin to occur at step 6, which is the maximum limit condition for shear force that can be withstood by the structure. Meanwhile, plastic hinges in condition D begin to occur at step 8.

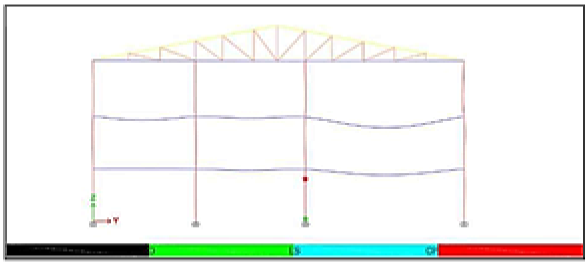

Figure 8. X Direction Pushover Plastic Joint in Step 4

At step 20, there are already many structural components that experience plastic hinge condition D, namely the condition of the building becomes unstable and almost collapses, and the stiffness of the structure experiences a significant decrease. The pushover plastic hinge in the x direction at step 20 is shown in Figure 9.

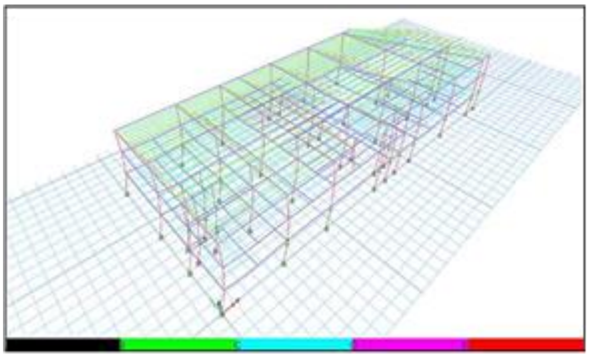

Figure 9. X Direction Pushover Plastic Joint at Step 20

2) Pushover Y direction

The first plastic hinge in the y-direction pushover occurs at step 2 which occurs in the beam in condition B as shown in Figure 10. Meanwhile, the first plastic hinge that occurs in the column occurs at step 3..

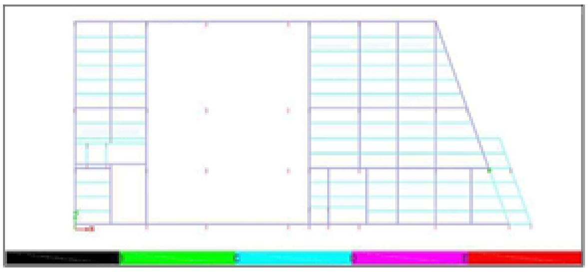

Figure 10. First Plastic Pushover Hinge Y Direction in Step 2

Plastic hinges in condition IO begin to occur at step 5 shown in 11. Plastic hinges in condition C begin to occur at step 7, which is the maximum limit condition for shear force that can be withstood by the structure. Meanwhile, plastic hinges in condition D begin to occur at step 8.

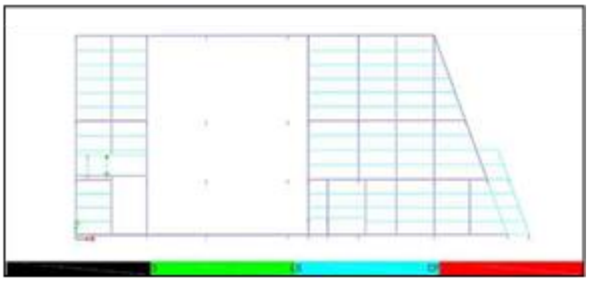

Figure 11. Y Direction Pushover Plastic Joint in Step 4

In step 17, there are already many structural elements that experience plastic hinge condition D, namely the condition of the building becomes unstable and almost collapses, and the stiffness of the structure experiences a significant decrease. The pushover plastic hinge in the y direction in step 17 is shown in Figure 12.

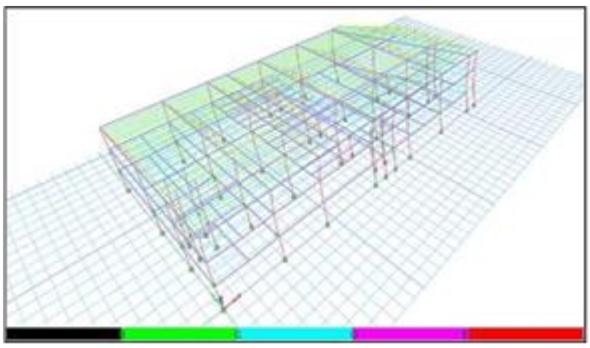

Figure 12. Y Direction Pushover Plastic Joint in Step 17

PRACTICAL IMPLICATION

Based on the performance points obtained, the maximum total deviation value for the x direction = 0.01011 and the y direction = 0.00858. While the maximum inelastic deviation value for the x direction = 0.00811 and the y direction = 0.01085. So that the performance level of the Jeep Indonesia Brand Center (JIBC) Alam Sutera showroom building structure based on the ATC-40 method is Damage Control (DC), namely the building experienced minor damage due to the earthquake, but the damage can be repaired at an affordable cost and the risk of human casualties is very small. The performance of the building structure still meets the requirements according to Table 20 of SNI 1726:2019 which is indicated by the drift value or deviation between floors which is not more than the deviation between permit levels (Δ).

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