Journal of
Advanced Civil and Environmental Engineering
Vol.5, No.2, 2022, pp 94-102
ISSN: 2599-3356
DOI: http://dx.doi.org/10.30659/jacee.5.2.94-102

Performance of The Existing Building Under Earthquake Loads Based on Current Indonesian National Standard

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(**Received:** 17th October 2022 ; **Revised:** 31st October 2022 ; **Accepted:** 11th November 2022)

Abstract: This paper presents the results of an assessment of the existing 5-storey building built in 1980, which aims to determine the level of safety against the most recent standards. The method used is non-destructive testing, collecting planning data in the form of as built drawings and implementation data. The assessment of the existing structure consists of an evaluation of the condition of the material, structural system, and analysis of the structure using the latest load standards. The test results of the existing structural material show that the compressive strength of the concrete still meets the requirements based on SNI-2847-2019. The results of the evaluation of the structure against earthquake loads show that the performance of the structure has a mass participation of 100% and the dynamic base shear force (V) reaches 100% of Vstatic therefore it meets the requirements in SNI 1726-2019. The results of the evaluation of the performance of the structure show that the lateral drift and P-delta effects still meet the requirements of the most recent standards. Horizontal and vertical structural irregularities are found in the existing structural system. The structure's overall performance level (X and Y direction earthquakes) is Damage Control. These results are still permitted for structures with a priority factor (Ie) 1.50, with an earthquake return period of 2500 years.

Keywords: Assessment; Testing; Concrete Structures; Earthquake Analysis

1. Introduction

Changes in standards that have occurred in Indonesia are relatively fast in the last two decades. In the most recent earthquake SNI (SNI-1726-2019) there is a change in parameter values from the parameters in the previous standard. These changes include the acceleration of the MCE spectral response from the earthquake map in the short period (Ss) and the parameter value of the MCE spectral response acceleration from the earthquake map in the 1 second period ($S1$). These changes affect the value of the acceleration spectral response parameter in the short period and the value of the acceleration of the spectral response of the MCE in the 1 second period, which are referred to as SDS and $SM1$respectively. Another change is the values of SDS and $SD1$ which are defined as parameters of the acceleration of the spectral response in the short period and the parameter of acceleration of the spectral response in the period of 1 second. Another change is the site coefficient for a short period of 0.2 seconds (Fa) and the site coefficient for a long period of 1 second (Fv). The consequences of the changes mentioned above will affect the value of Cs , or what is often referred to as the seismic coefficient to the determination of the basic shears force. Another significant change is the form of the design response spectrum, where SNI-1726-2019 accommodates a long period of time in the structure if the structure is categorized as a slender building. With these changes, structural analysis of earthquake loads using the most recent standards is very important, because it will affect the seismic performance and stability of the existing structure.

2. Metodhology

2.1. Material Investigation

The building under review was constructed of reinforced concrete. Although data based on As built Drawing are available, it is necessary to carry out material testing to ensure the condition and quality of existing materials for analysis purposes. The investigation of the quality of the concrete was carried out by the Hammer Test Method. The reinforcing steel is assumed to be of U-39 quality for deform bars and U-24 for plain reinforcement.

2.2. Earthquake Analysis

2.2.1. Loading and Structural Modeling

The loading of the structure refers to SNI-1727-2020 and ASCE-7-16 [10,11]. The outline of the procedure to analyze building structures against earthquakes refers to the literature [12,13,14,15]. The building being reviewed, as shown in Fig. 1 above, was modeled using the software as shown in Fig. 2 and Fig. 3.Based on article 4.1.1 of SNI 1726 2019, the earthquake design is defined as an earthquake with a probability of exceeding the magnitude during the life of the 50-year structure by 2% because the building have been built long before the latest earthquake regulations took effect. Buildings are defined according to the type of building use to determine the risk category of the building (Article 4.1.1 of SNI 1726 2019). Site class is determined based on geotechnical data a minimum depth of 30 meters according to article 5.1 of SNI 1726 2019. The definition of site class is divided into several classes including SA, SB, SC, SD, SE, and SF site classes according to article 5.3 of SNI 1726 2019.

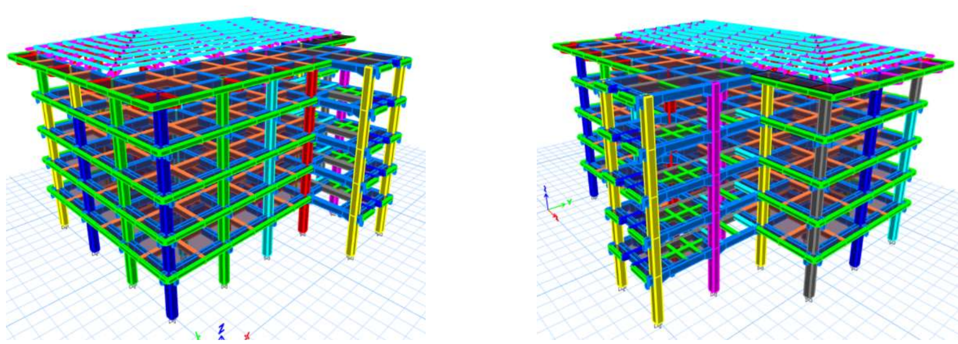
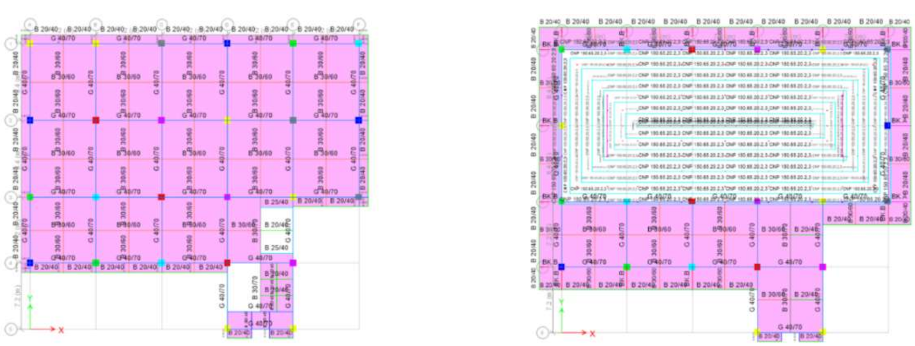


Fig.1 : Three Dimensional Model Structure



(a) Typical floor plans 1st-5th floor (b) Roof Plan

Fig.2. Building structure plan

2.2.2. Earthquake Parameters

The earthquake level uses an earthquake of 2500 years, which is a 2% probability of a design earthquake being exceeded within 50 years of the building's life. In evaluating the structure of this building, the earthquake loading used for analysis represents the analysis of response spectra with data on the location of the building structure in Semarang. The analysis was carried out with the ETABS software. The parameters used in the analysis of response spectra were obtained based on data from the Department of Public Works website according to the coordinates of the location taken.

The parameters used in the response spectral analysis consisted of: site class D (soft soil based on soil test results), S_s = 0.811g, S_{D1} = 0.357g, F_a : 1.239, F_v : 2.562, S_{DS} : 0.67, S_{D1} : 0.61, Building priority factor, Ie: 1.5, risk category: type IV (educational facilities). Based on the response spectra of the design, an analysis was carried out using the scale factor value according to the following equation:

$$\text{Scale Factor} = \frac{g \; x \; I_e}{R} \tag{1}$$

where :
g = Acceleration of gravitation (9.8 m/s^2)
I_e = Occupancy Factor = 1.5
R = Response modification factor= 8

Based on SNI 1726 2019, the ultimate value of the dynamic response of the building structure to the nominal earthquake load due to the influence of the planned earthquake in a certain direction, must be no less than 100% of the value of the first variance response. In addition, the analysis must include the number of variances to obtain a mass participation of 100% of the mass of the structure. The Seismic Design category is determined according to SNI 1726 2019 article 6.5. Based on the S_{DS} and S_{D1} values, the building being reviewed belongs to Seismic Design Category D. Furthermore, the structural system is determined according to the KDS, namely the Special Moment Bearing Concrete Frame System, where several parameters are taken based on SNI 1726 2019 article 7.2.2.

The analysis procedure is carried out according to the seismic design category and building specifications according to SNI 1726 2019 article 7.7. The determined design period is in no less than the minimum period and shall not exceed the maximum period of the structure determined according to the type of structural system. The acceleration period of 1 second (S_{D1}) and the height of the building are calculated according to SNI 1726 2019 article 7.8.2. The basic seismic shear force V is determined according to the equation.

$$V = C_s \; x \; W \tag{2}$$

where V, Cs and W are respectively seismic base shear, seismic response coefficient and effective seismic weight. The analysis carried out includes the amount of variance to get a mass participation of at least 100% of the mass of the structure.

If the fundamental period of calculation results exceeds the value of $T_{max} = C_u.T_a$, , where C_u is the coefficient for the upper limit and T_a is the approximate fundamental period, the T_{max} value must then be used instead of the fundamental period in that direction. If the response combination for the base shear force (V_t) is less than 100% of the base shear calculated by the static equivalent (V) method, the base shear force must then be multiplied by (V/V_t). In the response spectrum calculation, the force response parameter is multiplied by (I/R), where I is the building priority factor and R is the response modification coefficient. The magnitude of the deviation is multiplied by (C_d/I), where C_d is the deflection enlargement factor.

The deviation between floors that occurs shall not exceed the allowable inter-floor deviation as specified in SNI 1726 2019 article 7.12.1 table 20. Control of structural stability against the P – Delta effect is calculated according to SNI 1726 2019 article 7.8.7 as follows :

$$\theta = \frac{P_x.\Delta s.I_e}{V_x.h_{sx}.C_d} \tag{3}$$

where Px, Δs, Ie, V, hsx and Cd are respectively axial loads without load factor, displacement between floors, building priority factor, shear force between stories, story height and deflection enlargement factor.

Furthermore, SNI 1726 2019 Article 7.3.2 explains that structures must be classified as regular and irregular. Structural irregularities include horizontal and vertical irregularities. The horizontal irregularities of the structure under consideration include Types 1A and 1B. Vertical irregularities are defined as Types 1A, 1B, 5A, 5B.

3. Result and Discussion

3.1. Concrete Material

The Determination of the quality of the concrete material is done by using the Hammer Test Method as an approach method. The compressive strength of the hammered concrete is shown in Fig. 3. The average compressive strength of the concrete produced is 24 MPa. This value is above the minimum compressive strength requirement for earthquake-resistant concrete material required in SNI-2847-2019, which is 21 MPa. Based on Fig. 3, conservatively for structural analysis, the value of the concrete compressive strength (fc') is 21 MPa. The steel reinforcement used and sampled for the tensile test were all threaded steel with diameters of 10, 16, 19. The results of the tensile test resulted in the yield stress value of steel (fy) in the range of 400 MPa.

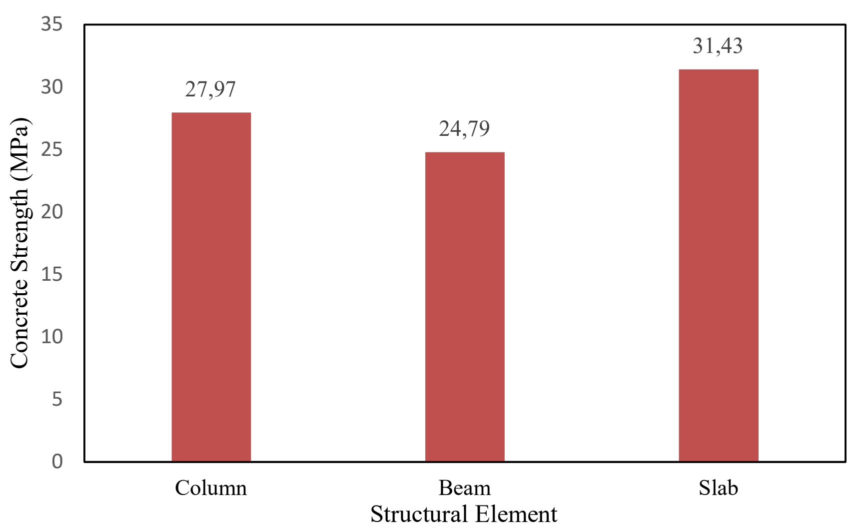


Fig.3. Concrete Strength Result

3.2. Earthquake Disaster Parameters

The results of the earthquake parameter analysis are shown in Table 1. Based on Table 1, the fundamental period of the structure for both the x and y directions are 0.971 and 0.996, respectively, where these values are still between the minimum and maximum fundamental period limits. The structure is quite flexible, considering the fundamental period has exceeded the value of 3.5Ts (Fig. 4).

Table 1. Results of earthquake parameter analysis (SNI 1726-2019)

No	Parameter	Value
1	Risk Category	IV
2	Priority Factor	1.5
3	Mapped Spectral Acceleration	
	S_s	0.811
	S_1	0.357
4	Site Class	SE
5	Site Coefficient	
	F_a	1.239
	F_v	2.562
6	Spectral Response Acceleration	
	S_{ds}	0.670
	S_{d1}	0.610
7	Seismic Design Category	D
8	Response Modification Coefficient R	8
9	Overpower factor Ω_0	3
10	Deflection Magnification factor C_d	5.5
11	Structure Period	
	Building Height	23
	C_t	0.0466
	x	0.9
	C_u	1.4
	T Lower limit	0.783
	T Upper limit	1.097
	T_x Model	0.971
	T_y Model	0.996
12	Equivalent Statistic Analysis	
	Seismic Response Coefficient (C_s)	
	C_s, $S_{ds} / (R/I)$	0.126
	C_{sx}, $S_{d1} / (T^*(R/I))$	0.118
	C_{sy}, $S_{d1} / (T^*(R/I))$	0.115
	$C_{s\ min}$, $0.044^*S_{ds}.I_e$	0.044
	K_x, $0.5 < T < 2.5$	1.236
	K_y, $0.5 < T < 2.5$	1.248

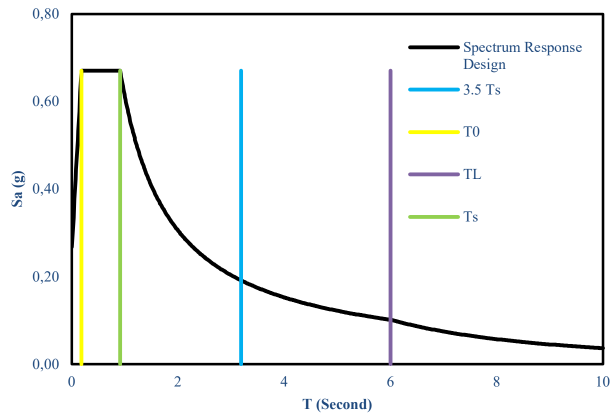


Fig.4. Spectrum Response Design

3.3. Cummulative Shear Force Nominal and Lateral Force Design

Fig. 5 represents the magnitude of the base shear that occurs at each level in the x and y directions. The base shear design is also shown in Fig. 5, and It in general shows the distribution of the base shear at each level in both directions is moderate. The following result is lateral drift that occurs in the building structure as shown in Fig. 6. Lateral drift at each level still meets the requirements (x and y directions), which is still below the lateral drift limit.

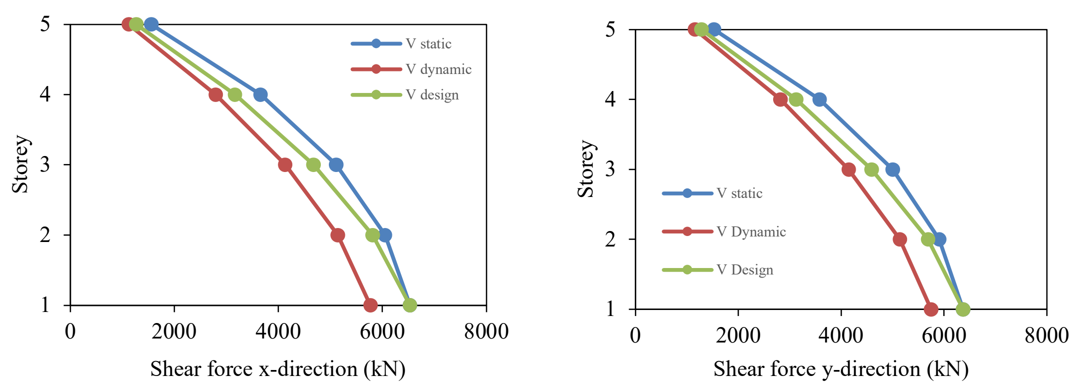


Fig.5. Cummulative Nominal Shear Force Diagram in the X and Y Direction

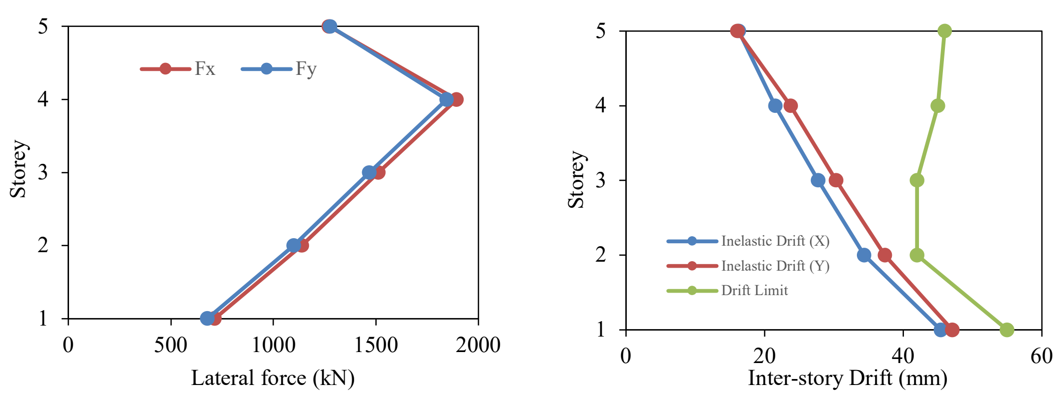
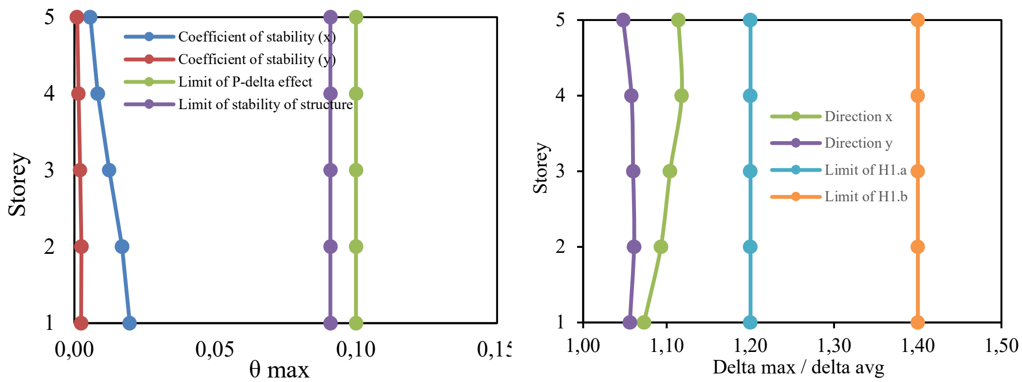


Fig.6. Design lateral forces and inter-story drift

3.4. P-delta effect and structural iregularity

The results of the analysis of the P-delta effect shown in Fig. 7a show that the structure still meets the requirements, where the stability coefficients in the x-direction and the y-direction are however far below the P-delta influence limit and the structural stability limit. Further results of the analysis of torsional irregularities are shown in Fig. 7b. It can be seen from Fig. 8b that the structure is still below the safe limit (H1.a limit and H1.b limit).



(a) P-delta effect (b) Torsion irregularity

Fig.7. P-delta effect and structural irregularity

The analysis is also carried out by checking the soft story stiffness irregularity, defined to exist if there is a story where the lateral stiffness is less than 70% of the lateral stiffness of the story above or less than 80% of the average stiffness of the three stories above. Table 2 shows the results of the analysis of the irregularity of the soft level structure, where there is no irregularity on all floors in both the x and y directions. Another assessment result is there is no lateral strength irregularity in the x-direction or y-direction level (Table 3). Heavy (mass) irregularity analysis is also carried out, where the irregularity exists if the effectiveness of all levels is more than 150% effective of the level above. The consequence is that the lighter roof on the floor below is unneeded to be favourably reviewed. As shown in Table 4, mass irregularities occur on the 3rd and 4th floors.

Table 2. Check for soft level irregularities

Floor	Direction X Stiffness kN/m	Direction X Check	Direction Y Stiffness kN/m	Direction Y Check
5	304773.421		267856.396	
4	461051.834	OK	437371.563	OK
3	543814.565	OK	511086.284	OK
2	551815.336	OK	516762.45	OK
1	474748.82	OK	456219.49	OK

Table 3. Check for the level of lateral strength irregularity

Floor	Direction X Strength (kN)	Direction X Check	Direction Y Strength (kN)	Direction Y Check
5	1270.94		1277.06	
4	3163.90	OK	3121.88	OK
3	4675.27	OK	4588.70	OK
2	5814.59	OK	5687.79	OK
1	6527.66	OK	6365.77	OK

Table 4. Mass irregularity

Floor	Mass (kg)	Check
5	700619.8	OK
4	1942015.38	V.2
3	3164811.11	V.2
2	4383109.89	OK
1	5642605.62	OK

3.5. Structure Performance Level

To determine the level of performance of the structure, a ordinary method is used. The method used is a nonlinear static analysis method, which is looking for the intersection between the capacity spectrum method (CSM) curve and the reduced spectra response curve to estimate the maximum displacement. The basis used is ATC-40 and FEMA 356.

3.5.1. Performance Level of X Direction

With the help of the software, the relationship curve between demands vs capacity in the x direction is shown in Fig. 9. Based on the results of the force vs displacement plot, it is recognized that the maximum displacement in common is 337,382 mm, and the building height is 23,000 mm.

Building Performance Value = $\frac{x\ max}{H} = \frac{337.382}{23000}$ = 0.015

0.01 < 0.015 < 0.2 → *damage control*

3.5.2. Performance Level of Y Direction

For the y-direction structure, based on the results of the force vs displacement plot, the obtained maximum displacement is 372,251 mm, and the building height is 23,000 mm.

Building Performance Value = $\frac{x\ max}{H} = \frac{372.251}{23000}$ = 0.016 (*damage control*)

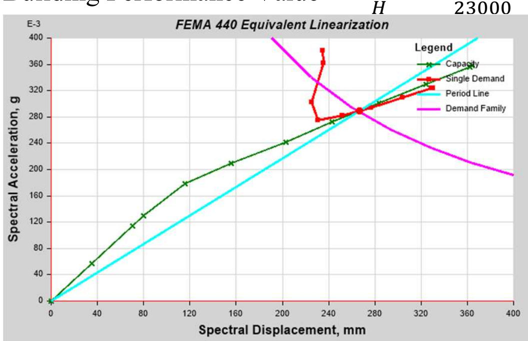


Fig.8.. Push Over x direction

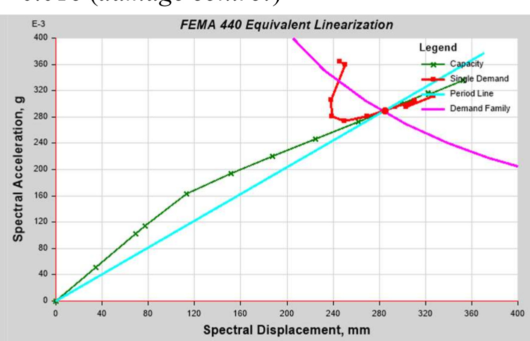


Fig.9. Push Over y direction

4. Conclusion

It has been described above regarding the assessment of the old building structure evaluated using the most recent standards, especially seismic performance based on SNI 1726-2019. The results of the existing concrete material still meet the requirements determined based on SNI 2847-2019, as well as the yield stress of the main reinforcement used is also still in accordance with the standard. A review of the results of the basic shear force, floor drift, and P-delta effects in the x and y directions that occur still meets the requirements of the most recent standards. The horizontal and vertical irregularities of the structure also never occured in the structure under review. However, there is a Heavy Irregularity (Mass) on the 3rd and 4th floors. The overall performance level of the existing structure (x and y direction earthquakes) is damage control. For structures with a priority factor of I=1.5, with an earthquake load of 2500 years return period, the structure is allowed to deform up to the life safety limit at the performance point.

Acknowledgements

Sincere thanks to PT. Arsi Granada Muda that have willingly provided facilities for the investigation.

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