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Structural Behavior and Performance Level of Reinforced Concrete Under the Cyclic Loads

Dendi Sephanie[1*], Retno Anggraini[2], Desy Setyowulan[2]

[1] Postgraduate Program, Engineering Faculty, University of Brawijaya, Malang, Indonesia.

[2] Lecture on Civil Engineering Departemen, Engineering Faculty, University of Brawijaya, Malang, Indonesia

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Corresponding Author:
Dendi Sephanie
dendisephanie2@gmail.com

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Abstract: This study evaluates the applicability of ASCE 41-17 and ATC-40 for assessing the performance of existing structures in Indonesia, where current regulations focus on force-based rather than displacement-based evaluation. The analysis results indicate that all displacement ratios remain below the target performance level for Risk Category 2 structures. Strength values of 1.8943 and 2.9624 for the x-axis and y-axis, respectively, were found to be lower than the maximum allowable values, confirming that the pushover analysis meets the required criteria. The formation of plastic hinges initially in beams and later in ground-floor columns validates the Strong Column–Weak Beam principle, ensuring structural ductility. The study suggests that the Pushover method can be applied to more complex structures with additional stories. Furthermore, SeismoStruct, in combination with other software, offers an efficient alternative for nonlinear static pushover analysis, optimizing computational resources. The findings highlight the potential adoption of ATC-40 and ASCE 41-17 in Indonesia's structural assessment practices, enabling more accurate performance evaluations and enhancing seismic resilience. Future research should explore broader applications of these codes for various structural types to improve earthquake preparedness and mitigate potential risks.

Keywords: ASCE 41-17; ATC-40; Pushover Analysis; SeismoStruct; Strong Column–Weak Beam; Structural Performance

Introduction

The evaluation of existing structures is a crucial post-construction phase to determine structural safety and performance levels, ensuring they meet the necessary requirements. Existing structures can typically be investigated either directly through visual inspections or based on final project reports. This assessment provides valuable insights into the future performance of the structure and helps determine whether corrective measures or repairs are needed after certain events.

In construction building, reinforced concrete frame systems are one of the most commonly used structural types today (Astarini & Utomo, 2020). Based on past earthquake events, most frame structures have sustained damage following the Strong Column–Weak Beam pattern. To ensure earthquake resistance, design principles prioritizing the Strong Column–Weak Beam concept are essential and require further study. Structural failure in frame systems due to earthquakes can occur in two primary modes: plastic hinge formation in beams or columns (Ismail, 2014). If plastic hinges form in columns, the lateral displacement between floors increases significantly, leading to instability and compromising the structure's ability to support vertical loads. Therefore, earthquake-resistant design approaches must ensure that failure mechanisms occur in beams rather than columns, resulting in a more ductile structure. However, in some earthquakes, plastic hinges form at the column ends instead of the beam

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ends, reducing the overall ductility of the structure (Huang, 2020).

Currently, the Performance-Based Design (PBD) approach commonly utilizes nonlinear analysis methods, which simulate structural behavior under large-scale seismic impacts, accounting for material yielding and eventual failure. This method highlights the necessity of further developing Indonesia's building codes and regulations, which still rely on the force-based design concept. Unlike performance-based design, force-based design does not explicitly define the structural performance criteria that need to be achieved (Kuria & Kegyes-Brassai, 2023).

This research is essential to evaluate whether the ASCE 41-17 code remains applicable and whether ATC-40 can still be utilized and adopted in Indonesia, where there is currently no specific regulation governing the performance assessment of existing structures. Given the increasing need for reliable evaluation methods, it is crucial to explore whether these established international standards can effectively address structural performance concerns in Indonesia (Wibawa, Tubuh, & Prawira, 2021). This study will specifically implement the requirements outlined in ASCE 41-17 to determine the applicability of Pushover Analysis as a viable assessment method for existing structures. Additionally, the use of the SeismoStruct application will be explored as an alternative tool for evaluating structural conditions, providing further insights into its effectiveness in assessing performance and identifying potential vulnerabilities. By incorporating these methodologies, this research aims to contribute to the development of more comprehensive structural evaluation guidelines in Indonesia, ensuring that existing buildings can be assessed accurately and systematically (Dewi, 2020).

Method

The concept of Performance-Based Design first emerged along with the capacity spectrum method (Dewobroto, 2005). This method was first introduced by Freeman in 1975 as one of the evaluation methods to assess the safety of buildings on the working earthquake force. Then, the capacity spectrum method was officially used for the first time in the ATC-40 document in the form of graphics. This graphic is what helps engineers and structural designers in determining the performance point of the structure which is a combination of structural and non-structural performance(Choudhury, 2024).

The previously mentioned Performance Level serves as an indication of failure or damage in structural elements or the overall structure. The performance level itself can be determined by the plastic deformation occurring in structural elements, which may include plastic rotation in beams, columns, and walls, as well as cracks in beams and beam displacements. The performance level is represented by discrete points within a specific range. The diagram below illustrates force-induced deformation in an element, where the extent of plastic deformation determines the performance level of the element (O'Reilly & Calvi, 2019).

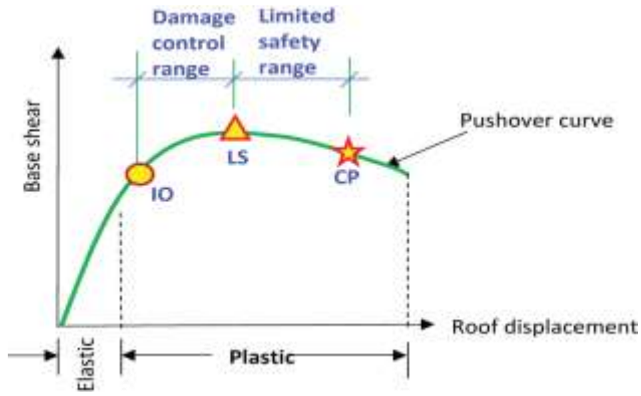

Figure 1. Performance Level of Structure
Source: Choudhury, 2024

The performance level of the structure presented in the curve below is the result of the plot between the basic shear force and displacement on the roof of the building. This curve is called the pushover curve which will be discussed further in the next sub chapter (Setiawan, Suryanita, & Djauhari, 2017). In this curve, after the structure or structural element passes the elastic endpoint, the performance level is at Immediate Occupancy (IO) where at this point the damage that occurs is quite small and the structure is still at a safe level; the next point at the top of the curve is Life Safet (LS), this level of performance is quite large but not life-threatening; Furthermore, the endpoint is at Collapse Prevention (CP), which is the point where damage has almost occurred to all structural elements or structures but has not yet collapsed (Purwanto & Yanto, 2010).

Table 1. Deformation limit

Deformation	Performance Level			
	Immediate Occupancy	Damage Control	Life Safety	Structural Stability
Maximum Story Drift	0.01	0.01 – 0.02	0.02	$0.33\frac{V_i}{P_i}$
Maximum Inelastic Story Drift	0.005	0.005 – 0.015	No limit	No limit

(source: ATC-40,1996)

The limits that have been determined on the ATC-40 for each performance point have been set and described as follows: (1) Immediate Occupancy (IO), Structural elements suffer minimal damage and there is no threat of casualties; (2) Damage Control (DC), damage to structural and non-structural elements is at a minimum level but the building's operational facilities cannot be partially used and there is no threat of casualties. Minor repairs are needed before the building is reused; (3) Life Safety (LS), structural damage occurs but does not cause collapse and non-structural components cannot be used but can be reused after repairs; (4) Structural Stability, the threat of casualties is quite high due to the possibility of structural failure or collapse of non-structural elements. Structural elements at this stage are expected not to collapse so that they can minimize the possibility of casualties (Asmara, Isneini, & DWSBU, 2021).

The research on structural performance evaluation based on ATC-40 and ASCE 41-17 has important significance in the theoretical context of the development of civil engineering science, especially in the field of earthquake-resistant structure engineering. An in-depth comparative study between these two standards fills an existing knowledge gap on how differences in analytical methodologies can affect the results of structural performance evaluations. This research also contributes to a more comprehensive understanding of the advantages and limitations of each standard, especially when applied to building structures in regions with different seismic characteristics such as Indonesia (Mamesah, Wallah, & Windah, 2014).

Several high-intensity earthquakes that have occurred in recent years have seen that seismic risks are increasing. The high level of seismic risk after an earthquake requires scientists to develop new approaches and methods in solving the problem of earthquake-resistant building structures. Performance-Based Earthquake Engineering (PBEE) was the beginning of the development of the Performance-Based Seismic Design (PBSD) method which was then adopted by documents such as ATC-40, FEMA 273, FEMA 350 and other documents (Dalal Sejal, Vasanwala, & Desai, 2011).

Table 2. Performance level existing structure

Risk Category	Seismic Hazard Level	
	BSE-1E	BSE-2E
I and II	Life Safety	Collapse Prevention
III	Damage Control	Limited Safety
IV	Immediate Occupancy	Life Safety

Source: ASCE 41-17

The Performance-Based Seismic Design method offers several levels of performance in the design process or in the evaluation process. Some of the documents that have begun to implement these performance level limits include ASCE 41-17. In this document, several levels of performance are determined according to the elements that function as structural or non-structural elements, in addition this document also regulates the limits for existing structures according to the function and purpose of the building used. This restriction is also used in the design process as one of the preventive measures to avoid large expenses during repairs and maintain the safety and comfort of building residents (Hassanzadeh, Moradi, & Burton, 2024).

Immediate Occupancy, When an earthquake occurs, the potential for damage to structural elements is so small that structural elements that function as a buffer against vertical and lateral forces can still maintain their function and strength. Damage Control, this level of performance limits structural and non-structural elements so that they do not suffer severe damage. The damage that occurs at this level is arranged in such a way that the building can still function properly but does not need huge repair costs.

Life Safety, aims to protect the lives of building occupants during earthquake disasters with a very small level of damage to structural and non-structural elements. The damage that occurred to the building made the building uninhabitable, but residents could still be evacuated. Limited Safety, a condition where the building is almost damaged but does not exceed the condition of structural stability. Some opinions provide information that this level is at the level of life safety when the level is not effective or only critical damage to some structural elements occurs. Structural Stability, is a level where the structure is no longer able to withstand the working loads so that very severe damage occurs. The damage that occurs is not only to structural elements but also to nonstructural elements. Not Considered or Collapse Prevention is a condition where the structure has undergone complete destruction and cannot be reused so that at this stage only seismic evaluation can be carried out.

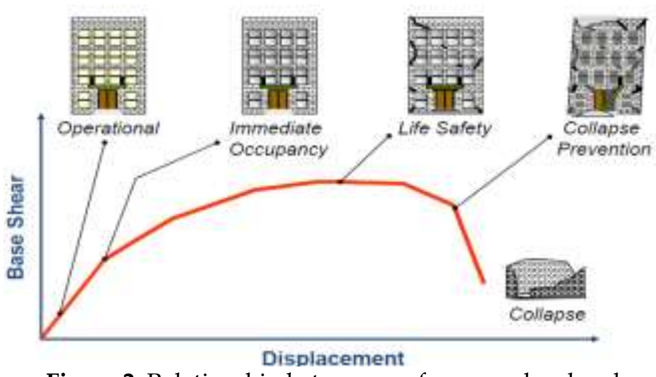

Figure 2. Relationship between performance level and structure respons (Kam & Jury, 2015)

Pushover Analysis

Nonlinear pushover static analysis is a static analysis used to evaluate the capacity of building structures in facing and withstanding lateral loads in the form of earthquake loads. This method applies a lateral load given to the center of mass on each floor of the building which will be continuously increased until it reaches the first melting point on the building structure and continues to increase until it reaches an inelastic condition . In this method, the stiffness in the structure is updated as there is an increase in load to cope with the changes caused by the nonlinear conditions. Some methods of pushover analysis are then simplified in such a way that they can be applied to structural systems with reinforced concrete materials. Pushover analysis applies the Beam Sway Mechanism collapse mechanism or better known as Strong Column Weak Beam. The method applied to reinforced concrete structures allows the estimation of lateral displacement profiles to be effectively used as a guide for various melting mechanisms on columns and beams (Sullivan, Saborio-Romano, O'Reilly, Welch, & Landi, 2021).

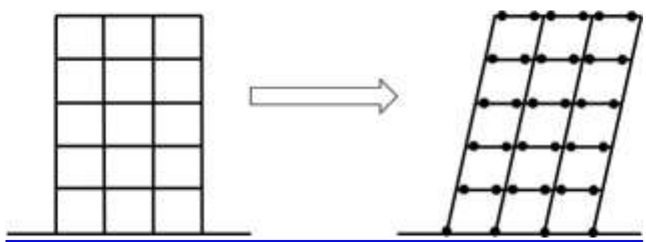

Figure 3. Beam Sway Mechanism

The procedure in pushover analysis begins with modelling the structure using a structural analysis application, in this case Seismostruct. Modelling begins with the definition of the materials used, the dimensions and shapes of the structural elements along with the repetition carried out in order to provide an overview of the rigidity of the structural elements. Modelling of reinforcement on structural elements becomes important to start pushover analysis in the hope that structural elements can work as they should, even if they only use computational modelling. In the next stage, the gravity load case is defined by reducing the live load factor by 50% which is then followed by the definition of pushover load for all x and y directions (Sucipto, Tanijaya, & Kalangi, 2023).

As mentioned earlier, after the analysis process is carried out, it is expected that each floor of the structure will experience plastic hinges to meet the concept of beam sway mechanism or SCWB. The first-time plastic hinges occurred was on the ground floor beam until it continued to creep up along with an increase in the number of steps until in the last step there was a plastic joint at the base of the column on the bottom floor. The results of the pushover can then provide an overview of the movements that occur during the pushover loading process. This displacement is then compared with the height of the structure to obtain the displacement ratio which will later be used as a value to determine the level of performance on the structure with reference to ATC-40 and ASCE 41-17 (Suwandi, 2019).

Capacity Spectrum Method (CSM)

The Capacity Spectrum Method or better known as CSM is a nonlinear static analysis approach used to evaluate the performance of structures during earthquakes. This method combines two main components in the analysis process; capacity curve and earthquake demand spectrum. The capacity curve is a graph that shows the deformation ability of the structure and the strength of the structure, while the demand spectrum is a picture of the spectral response of the earthquake. The intersection point that occurs between the capacity curve and the spectral response of the earthquake is a point known as the performance point. The performance point is the condition in which structural elements undergo deformation to meet earthquake demand. This method is fairly simple but useful to provide an overview of the inelastic response of building structures (Ing, Simatupang, & Setiawan, 2016).

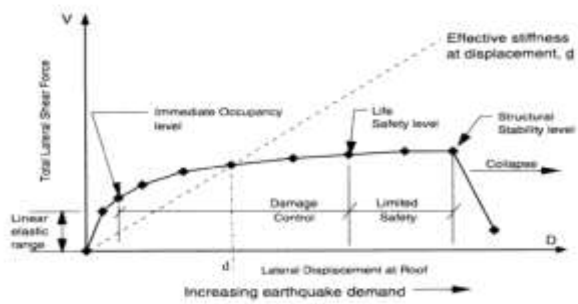

Figure 4. Capacity Curve

The first stage in the analysis process using the CSM method begins with the creation of a structural capacity curve. This capacity curve is a curve resulting from Pushover analysis by describing the displacement and basic shear forces on the structure. The pushover process has been described in the previous stage and the iteration is repeated continuously until it reaches the destruction of the structure which is characterized by the occurrence of plastic joints in the column area on the ground floor.

After the capacity curve is obtained, it is necessary to convert the curve into a spectral form or commonly called the capacity spectrum according to the demand spectrum. This conversion is performed by separating the effective mass of the structure using the parameters of the pseudo-acceleration (Sa) and pseudo-displacement (Sd) spectrum. The results of this transformation can provide a comparison between the capacity of the structure and the demand spectrum to obtain the performance point of the structure (ATC-40).

After converting from the capacity curve to the capacity spectrum, then a check is carried out on the capacity spectrum and demand spectrum to get the results of the performance points which can later provide an overview of the performance level (Golesorkhi, Joseph, Klemencic, Shook, & Viise, 2017).

Displacement Coefficient Method (DCM)

The Displacement Coefficient method is an approach used to determine the response of a structure to an earthquake, which is regulated in the ASCE 41-17 standard. This method adopts the principle of non-linear analysis to evaluate the behavior of the structure and assess its ability to withstand earthquake loads. In this method, the analysis is carried out considering displacement parameters that allow the evaluation of the performance of the structure based on the established criteria (Aksoylu, Mobark, Hakan Arslan, & Hakkı Erkan, 2020).

The first step in the application of this method is to create a model of the structure to be analyzed. Modelling should include all relevant structural and material elements and take into account the interactions between elements. The structure must be accurately modelled to depict real conditions in the field. Once the structure model is ready, the next step is to determine the appropriate displacement coefficient. This coefficient is used to account for the relative deformation that occurs due to earthquake loads. This coefficient is determined based on the desired performance criteria, as well as relevant data and analysis from existing standards (Nie, Zhang, Jiang, & Yu, 2020).

The purpose of using this method is to generate a displacement target when the structure receives an earthquake load at a certain frequency based on the spectral response reference that has been given. The building analyze by the DDBD method was modelled with a single degree of freedom (SDOF) with the calculation procedure starting by analyzing the displacement design.

$$n \leq 4,\ \delta_i = \frac{H_i}{H_n} \quad (1)$$

$$n > 4,\ \delta_i = \frac{4}{3}\left(\frac{H_i}{H_n}\right)\left(1 - \frac{H_i}{4H_n}\right) \quad (2)$$

The inelastic value of the mode shape (δi) in the frame system can be calculated based on the height on the first floor (Hi) with the total height of the overall structure (Hn). The displacement design (Δ) can be calculated by equations (3) and (4) which are affected by the drift design (θ)

For first floor, $\Delta_1 = \theta\ x\ H_i$ (3)

For next floor, $\Delta_1 = \delta_i \frac{\Delta_1}{\delta_1}$ (4)

Then, the level displacement design that uses multi degree of freedom (MDOF) must be converted into an SDOF system with a maximum displacement (Δd) equivalent to the MDOF level displacement design. The parameters used include mass at the level of i (mi) and displacement on the floor to I (Handana & Karolina, 2018)

$$\Delta_d = \frac{\sum_{i=1}^{n}(m_i \Delta_i^2)}{\sum_{i=1}^{n}(m_i \Delta_i)} \quad (5)$$

Result and Discussion

Before starting the analysis of the existing structure, the collection of data on the existing condition of the building, the condition of the soil around the building and supporting data such as details of structural elements must first be fulfilled. Data collection is carried out with the consent of related parties for the use of these data for academic activities. After all the data is met and the reference sources of the library are considered sufficient, the research continues to the analysis stage by modeling in 3D with the help of computing to assess the existing structure. Also, the cyclic setup must be considered before start the analyzing, cyclic setup shown under this.

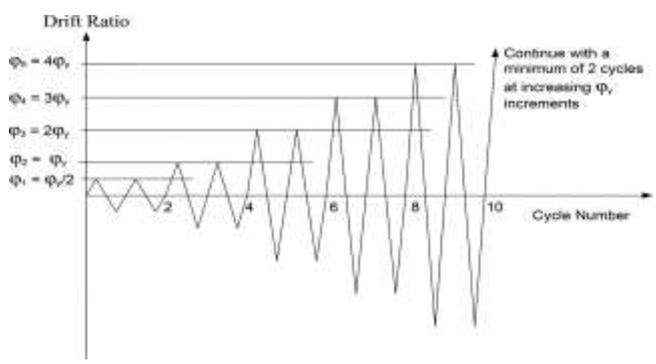

Figure 5. Cyclic Setup
source: ACI 374.2R-13, 2013

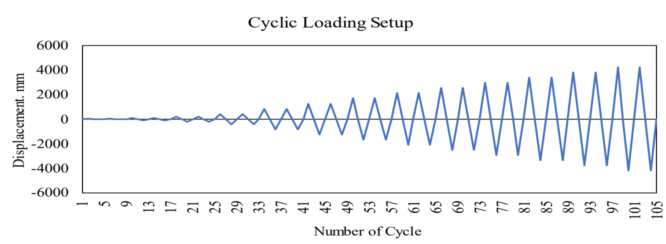

Figure 6. Cyclic Loading
Source: (ACI 374.1-05, 2005)

The building structure is modelled in 3D as in Fig. 8 using data from the final project report after the construction process. The model is then assigned a load for the super dead load (SDL) and the live load (LL) according to SNI 1727:2020, SNI 2847:2019 and SNI 1726:2019. In the beam element, reinforcement is defined at the base by entering the area of reinforcement according to the actual conditions. Meanwhile, in the column element, the rebar configuration is then adjusted to the actual conditions to determine the actual behaviour of the building structure.

Initial checks in accordance with SNI 1726:2019 were carried out on inelastic (Δ) transfers between levels. Displacement is reviewed at each level with a displacement constraint (Δ_{max}) according to the height of each level. This inelastic displacement will also be used as a check for the P-Delta effect with a stability limit (Θ_{max}) of 0.0909 and a P-Delta limit effect of 0.1.

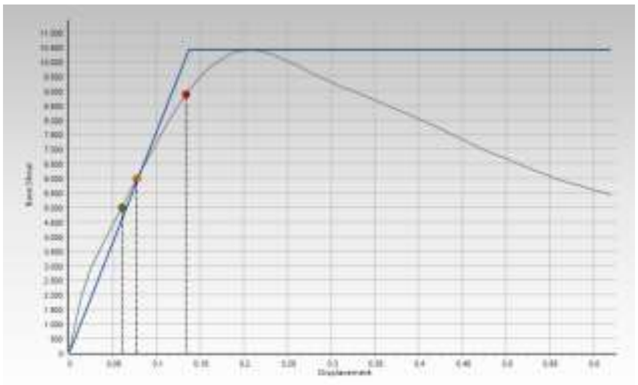

Figure 7. Pushover Curve

Performance Level Based on ATC-40

In assessing the performance of an 8-storey multi-storey building with a total height of 31 meters in an earthquake-prone area, the first step is to collect relevant structural data. The building uses reinforced concrete columns with a strength of f'c = 25 MPa and reinforcing steel with a strength of Fy = 420 MPa. The dimensions of the column are K1 = 60 cm x 60 cm, K2 = 40 cm x 40 cm, K3 = 30 cm x 30 cm, and K4 = 25 cm x 25 cm. The dimensions of the beam B1 = 40 cm x 70 cm, B2 = 30 cm x 60 cm, B3 = 30 cm x 40 cm, B4 = 25 cm x 50 cm, B5 = 25 cm x 40 cm and BA = 25 x 35 cm. With a zoning map showing a maximum acceptable acceleration (SDS) of 0.674 g, a 3D model of the building was created using Seismostruct structural analysis software.

After the model is completed, a non-linear static seismic analysis is carried out to evaluate the building's response to earthquake loads. From the simulation, the results show that the displacement is 1022.125 mm in the x direction and the same value in the y direction. The determination of the deformation value that occurs in the building can be determined using equation (1) by comparing the displacement (D) in each direction of the building to the total height of the building (H) from the ground floor to the top floor.

Performance Level Based on ASCE 41-13

The Displacement Coefficient Method (DCM) described in ASCE 41-17 is an approach used to assess the performance of building structures in the face of earthquake loads. In this stage, information regarding the dimensions of structural elements, material strength, and building geometry is essential. We must also determine the seismic conditions of the location, such as a zoning map that shows the maximum acceptable acceleration (S_{DS}). This model should include structural elements such as columns, beams, and sliding walls, with predefined parameters. Next, we perform a linear analysis to get an initial response to gravitational and lateral loads. The results of this analysis will provide information about the internal forces and deformations of the structural elements, which will be used as a basis for further calculations.

Table 3. Performance level for IO based ASCE 41-17

Level	X axis	Y axis
Roof	0.09%	0.11%
Rooftop	0.09%	0.09%
7	0.18%	0.17%
6	0.32%	0.28%
5	0.42%	0.36%
4	0.47%	0.41%
3	0.59%	0.49%
2	0.46%	0.40%

Table 4. Performance level for LS based ASCE 41-17

Level	X axis	Y axis
Roof	0.11%	0.11%
Rooftop	0.14%	0.13%
7	0.34%	0.36%
6	0.72%	0.75%
5	1.01%	1.03%
4	1.17%	1.21%
3	1.35%	1.29%
2	1.03%	0.94%

The process of running Seismostruct takes approximately one hour for pushover analysis on both the x and y axes. The result provided by the pushover analysis is in the form of a capacity curve and some data that can be used as a reference to determine the performance point of the structure. In the pushover analysis, it is necessary to pay attention that each step in the pushover analysis for all directions of the axis of the occurrence of plastic joints must occur on the beam of the bottom floor which then propagates to the top floor of the structure which is then closed by the occurrence of plastic joints on the ground floor columns which indicates that the structure has undergone complete destruction.

Conclusion

After conducting the analysis, it was found that all displacement ratios were below the target performance level for existing structures classified as Risk Category 2. Before confirming that the structure meets the expected performance target, a verification process was carried out based on the requirements outlined in ASCE 41-17. The strength values obtained were 1.8943 and 2.9624 for the x-axis and y-axis, respectively, which are lower than the maximum values of 1.9820 and 3.5155. This indicates that the performed pushover analysis is satisfactory and meets the specified requirements. The analysis results showed that plastic hinges first formed in the beams and then progressively spread upward to the top floor of the structure, with the final steps indicating plastic hinge formation in the ground floor columns. This confirms that the structure fully complies with the Strong Column–Weak Beam principle.

Moving forward, the Pushover method can be applied to structures with more complex conditions and a greater number of stories. In addition to commonly used software, SeismoStruct can be utilized alongside other programs for nonlinear static pushover analysis, optimizing time efficiency and reducing memory usage. Beyond the software employed, the ATC-40 and ASCE 41-17 codes can be adopted in the future, considering that Indonesia's current regulations still evaluate structural performance based on applied forces rather than actual displacements. These codes can also be applied to different structural forms or other civil engineering structures to assess worst-case scenarios in the event of an earthquake.

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Conflicts of Interest
The authors declare no conflict of interest

References

ACI 374.1-05. (2005). Acceptance criteria for moment frames based on structural testing and commentary. *ACI*, *374*, 1–5. Retrieved from https://www.concrete.org/store/productdetail.aspx?ItemID=374105&Format=DOWNLOAD&Language=English&Units=US_Units

ACI 374.2R-13. (2013). *Guide for testing reinforced concrete structural elements under slowly applied simulated seismic loads*. American Concrete Institute.

Aksoylu, C., Mobark, A., Hakan Arslan, M., & Hakkı Erkan, İ. (2020). A comparative study on ASCE 7-16, TBEC-2018 and TEC-2007 for reinforced concrete buildings. *Revista de La Construcción*, *19*(2), 282–305. http://dx.doi.org/10.7764/rdlc.19.2.282

ASCE. (2017). *Seismic Evaluation and Retrofit of Existing Buildings*. Reston, VA: American Society of Civil Engineers. https://doi.org/10.1061/9780784414859

Asmara, K. B., Isneini, M., & DWSBU, C. N. (2021). Evaluasi Kinerja Struktur Bangunan Tinggi dengan Analisis Pushover Menggunakan Aplikasi Pemodelan Struktur (Studi Kasus: The Venetian Tower). *Jurnal Rekayasa Sipil Dan Desain*, *9*(1), 486868. Retrieved from https://journal.eng.unila.ac.id/index.php/jrsdd/article/view/1721

Astarini, S. D., & Utomo, C. (2020). *The Factors of Implementation Performance-Based Building Design on High Rise Residential Building in Indonesia*. http://dx.doi.org/10.20944/preprints202007.0121.v1

Choudhury, S. (2024). *Performance Based Seismic Design of Structures*.

Dalal Sejal, P., Vasanwala, S. A., & Desai, A. K. (2011). Performance based seismic design of structure: A review. *International Journal of Civil and Structural Engineering*, *1*(4), 795–803. http://dx.doi.org/10.6088/ijcser.0020201006

Dewi, D. I. R. (2020). Evaluasi Kinerja Struktur Gedung Dengan Metode Pushover Analysis Sesuai Pedoman ATC-40 (Studi Kasus: SMP 3 Muhammadiyah Yogyakarta). *Inersia: Jurnal Teknik Sipil*, *12*(1), 1–11. http://dx.doi.org/10.33369/ijts.12.1.1-11

Dewobroto, W. (2005). Evaluasi Kinerja Struktur Baja Tahan Gempa dengan Analisa Pushover. *Universitas Pelita Harapan*.

Golesorkhi, R., Joseph, L., Klemencic, R., Shook, D., & Viise, J. (2017). Performance-based seismic design for tall buildings. *CTBUH Performance-Based Seismic Design Working Group Technical Guides, USA*.

Handana, M. A. P., & Karolina, R. (2018). Performance evaluation of existing building structure with pushover analysis. *IOP Conference Series: Materials Science and Engineering*, *309*(1), 012039. IOP Publishing. http://dx.doi.org/10.1088/1757-899X/309/1/012039

Hassanzadeh, A., Moradi, S., & Burton, H. V. (2024). Performance-Based Design Optimization of Structures: State-of-the-Art Review. *Journal of Structural Engineering*, *150*(8), 03124001. http://dx.doi.org/10.1061/JSENDH.STENG-13542

Huang, Y. (2020). Static Pushover Analysis of Beam-Column Joints in Frame Structures. *Journal of Physics: Conference Series*, *1648*(3), 032154. IOP Publishing. http://dx.doi.org/10.1088/1742-6596/1648/3/032154

Ing, T. L., Simatupang, R., & Setiawan, D. (2016). Pengaruh Penggunaan PS Ball terhadap Balok Beton Bertulang dengan Pembebanan Monotonik dan Pembebanan Siklik. *Jurnal Teknik Sipil*, *12*(2), 160–180. https://doi.org/10.28932/jts.v12i2.1422

Ismail, A. (2014). Non linear static analysis of a retrofitted reinforced concrete building. *HBRC Journal*, *10*(1), 100–107. http://dx.doi.org/10.1016/j.hbrcj.2013.07.002

Kam, W. Y., & Jury, R. (2015). Performance-based seismic assessment: myths and fallacies. *2015 New Zealand Society for Earthquake Engineering Annual Technical Conference*.

Kuria, K. K., & Kegyes-Brassai, O. K. (2023). Pushover analysis in seismic engineering: A detailed chronology and review of techniques for structural assessment. *Applied Sciences*, *14*(1), 151. http://dx.doi.org/10.3390/app14010151

Mamesah, H. Y., Wallah, S. E., & Windah, R. S. (2014). Analisis Pushover Pada Bangunan Dengan Soft First Story. *Jurnal Sipil Statik*, *2*(4), 214–224.

Nie, X., Zhang, S., Jiang, T., & Yu, T. (2020). The strong column–weak beam design philosophy in reinforced concrete frame structures: A literature review. *Advances in Structural Engineering*, *23*(16), 3566–3591. http://dx.doi.org/10.1177/1369433220933463

O'Reilly, G. J., & Calvi, G. M. (2019). Conceptual seismic design in performance-based earthquake engineering. *Earthquake Engineering & Structural Dynamics*, *48*(4), 389–411. http://dx.doi.org/10.1002/eqe.3141

Purwanto, E., & Yanto, D. (2010). Menentukan level kinerja struktur beton bertulang pasca gempa. *Media Teknik Sipil*, *10*(1), 49–54.

Setiawan, B., Suryanita, R., & Djauhari, Z. (2017). Prediksi Tingkat Kinerja Struktur Gedung Kantor Berdasarkan Mutu Beton Dengan Metode Jaringan Saraf Tiruan. *Siklus : Jurnal Teknik Sipil*, *3*(2), 107–116. https://doi.org/10.31849/siklus.v3i2.393

SNI 1726:2019. (2019). *Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung*. Retrieved from www.bsn.go.id

SNI 1727:2020. (2020). " *Beban desain minimum dan kriteria terkait untuk bangunan gedung dan struktur lain*. Retrieved from www.bsn.go.id

SNI 2847:2019. (2019). *Persyaratan beton struktural untuk bangunan gedung dan penjelasan*. Retrieved from www.bsn.go.id

Sucipto, W., Tanijaya, J., & Kalangi, H. T. (2023). Analisis Kinerja Seismik Struktur Beton Bertulang (Studi Kasus: Tower "A" Gedung Ciputra School Of Business Makassar). *Jurnal Media Teknik Sipil*, *1*(1), 16–26. http://dx.doi.org/10.56963/judiateks.v1i1.11

Sullivan, T. J., Saborio-Romano, D., O'Reilly, G. J., Welch, D. P., & Landi, L. (2021). Simplified pushover analysis of moment resisting frame structures. *Journal of Earthquake Engineering*, *25*(4), 621–648. http://dx.doi.org/10.1080/13632469.2018.1528911

Suwandi, H. P. (2019). Analisis Gempa Non-Linear Static Pushover Dengan Metode Atc-40 Untuk Evaluasi Kinerja Struktur Bangunan Gedung. *Media Komunikasi Dunia Ilmu Sipil (MoDuluS)*, *1*(1), 35–45. http://dx.doi.org/10.32585/modulus.v1i1.379

Wibawa, I. M. S., Tubuh, I. K. D. K., & Prawira, P. P. L. A. (2021). Analisis Kinerja Struktur Gedung Dengan Analisis Pushover Pada Proyek Gedung Rektorat Universitas Mahasaraswati Denpasar. *Jurnal Ilmiah Kurva Teknik*, *10*(2), 53–61. https://doi.org/10.36733/jikt.v10i2.3001