Pushover analysis of reinforced concrete building seismically designed based on SNI 1726-2019

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Abstract. Indonesia has experienced many earthquakes due to its geographic location. Therefore, the Indonesian National Standard (SNI) for seismic design has recently been released for immediate application. In this study, nonlinear static analysis procedure is adopted to evaluate the seismic performance of reinforced concrete frame structures seismically designed using SNI. The main purpose of this study is to assess the safety level of the building under an earthquake. Three typical building with different height have been evaluated. The analysis is conducted using the commercial finite element ETABS. The performance level is determined according to ASCE41-17 acceptance criteria. The results revealed that the SNI designed building generally comply with to the acceptance criteria.

Keywords: earthquake, nonlinear, concrete, performance-based, finite element.

1. Introduction

Indonesia has moderate to high seismicity prone zones since its location lies on the pacific ring of fire. Thus, it is no surprise that many major earthquakes occurred in Indonesia region [1–3]. It is believed that the earthquake event cause building failure that may endanger the safety of people. Therefore, the National Standardization Body of Indonesia issued a seismic design guideline for building structures called as SNI 1726:2019[4].

Many engineers practically adopt the SNI guideline owing to its simplicity. The approach used in SNI is basically based on the linear analysis so that the behaviour of the building is assumed in the elastic condition. It is noted that linear analysis does not represent the actual response of the structure under an earthquake. The most accurate approach to simulate the behaviour of structure under an earthquake is nonlinear time history analysis. However, it is very complex and time consuming since it needs cyclic inelastic response and earthquake ground motion [5,6].

On the other hand, pushover analysis provides simpler method that can predict the nonlinear behaviour of the building against an earthquake[7–9]. According to ASCE 41-17[10], it is recommended to adopt nonlinear analysis to evaluate the existing design. Therefore, the main objective of this study is to investigate the level of safety of the existing building design based on the current SNI 1726:2019 [4] using nonlinear analysis.
2. Pushover analysis

Generally, the response of the building under an earthquake can be evaluated using linear analysis and nonlinear analysis. Linear analysis is the most common and simplest method in which the application of a factor to consider the nonlinear behaviour as well as the dynamic effect of the building during an earthquake. The actual response of the building cannot be accurately evaluated using the linear approach since during an earthquake the building may behave beyond the elastic limit.

On the other hand, nonlinear time history analysis has been used to analyse the seismic behaviour of the building since it is theoretically the most accurate analyse which considers all type of nonlinearity and dynamic effects. However, the nonlinear dynamic approach is extremely time-consuming and need high level of expertise. Nonlinear static analysis known as pushover analysis has been recently developed as a new approach to solve the drawbacks. Figure 1 shows the fundamental differences between nonlinear time history analysis and nonlinear static analysis.

The application of pushover analysis has drawn wide attention particularly in the seismic performance evaluation of the building[5,8,9]. This approach adopts a specific lateral load subjected to the building. This load is gradually increased until the building collapse. This analysis results a pushover curve or capacity curve which is the relationship between the base shear and the top lateral displacement of the building. In pushover analysis, it is assumed that the response of the building is dominantly controlled by a single mode. It is noted that this assumption is not theoretically accurate. However, a number of studies[7,11,12] have found that this assumption led to a decent prediction of the seismic response of multi degree of freedom structure.

In pushover analysis, it is essential to specify the target displacement which represent the expected lateral displacement of the building under certain earthquake. There are several approaches available to specify the target displacement such as capacity spectrum [13], displacement coefficient [14] and displacement modifications [15]. In general, all these approaches adopt the relationship between pushover curve and response spectrum. In this study, the displacement modifications approach is adopted since the previous study showed that this method results more conservative compared with other approaches.

There are four main performance level of the building that can be determined based on the target displacement as follows.

a. Immediate Occupancy Level (IO), lateral displacement less than 1%
The structure does not have any structural and non-structural damage. The condition of the building is almost the same as the condition before the earthquake happens.

b. Damage Control Level (DC), lateral displacement between 1% and 2%
Non-structural damage can be noticed when an earthquake occurs, however the structure still can be used.

c. Life Safety Level (LS), lateral displacement between 2% and 3%
Although the building has minor structural damage, the structure is able to withstand an earthquake. The occupants who are in the building are kept safe from the earthquake that occurred.

d. Collapse Prevention Level (CP), lateral displacement between 3% and 4%
At the time of the earthquake, the structure suffered severe structural damage, but not to the structure of total collapse.

3. Generic building
In this study, three generic buildings, 3-storey, 6-storey and 9-storey are analysed. The storey height is taken as 3 m. All buildings have similar symmetric plan with span of 8 m as shown in Figure 2. All dimension of beams and columns are presented in Table 1. Furthermore, the building is evaluated based on the drift limit as shown in Figure 3.

![Figure 2. The generic building plan](image)

| Table 1. Beams and columns dimensions |
|---------------------------------------|
| Column (mm)       | 600 x 600 | 700 x 700 | 700 x 700 |
| Beam (mm)         | 500 x 600 | 650 x 500 | 650 x 550 |
4. Results and discussions

As previously mentioned, pushover analysis produces pushover curves or capacity curves as presented in Figure 4. These pushover curves represent the resistance of the building against lateral loads such as earthquake. For the case of 3-storey building, the performance point can be determined when the lateral displacement is 106.14 mm, and the lateral load is 10348 kN. It is worth noting that the performance point is automatically determined in ETABS. Table 2 shows the performance point for all buildings.

From the target displacement, the performance level can be determined based on ACI 437 [16]. It can be seen that the performance level of all building is damage control since the target displacement for all building is between 1% and 2%.
Figure 4. Capacity/pushover curves
Table 2. Target displacement

| Building | Height of building (m) | Target Displacement (mm) | Performance level |
|----------|------------------------|--------------------------|-------------------|
| 3-storey | 9.0                    | 106,14                   | Damage control    |
| 6-storey | 18.0                   | 227,591                  | Damage control    |
| 9-storey | 27.0                   | 358,756                  | Damage control    |

5. Conclusions
In this investigation, the main goal is to assess the safety level of the multiple storeys reinforced concrete building designed according to SNI 1726-2019[4]. Nonlinear static pushover analysis was performed to study actual behaviour of the building under an earthquake. Three different buildings have been selected. The performance of the building is evaluated based on the target displacement[10]. The findings reported here shed new light on how the seismically designed buildings perform during an earthquake. The most obvious finding to emerge from this analysis is that all generic buildings have similar performance level of damage control. Thus, it can be concluded that the design of the buildings complies with the seismic requirements design.

Further studies could be carried out by varying the number of floors, the height of the structure, and the structural rigidity system since they may affect the dynamic characteristic of the structure. Hence, the results of the study become more varied with different data so that the conclusions obtained are broader in scope.

References
[1] BBC News 2018 Indonesia earthquake: Hundreds dead in Palu quake and tsunami BBC
[2] BBC News 2018 Lombok earthquake
[3] Ashar F, Amaratunga D, Sridarren P and Haigh R 2019 Practices of Tsunami Evacuation Planning in Padang, Indonesia (Elsevier Inc.)
[4] BSN 2019 SNI 1726-2019: Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan non gedung Badan Stand. Nas. Indones.
[5] Bhandari M, Bharti S D, Shrimali M K and Datta T K 2018 Assessment of proposed lateral load patterns in pushover analysis for base-isolated frames Eng. Struct. 175 531–48
[6] Krawinkler H 2006 Importance of good nonlinear analysis Struct. Des. Tall Spec. Build. 15 515–31
[7] Fajfar P 2000 Structural analysis in earthquake engineering—a breakthrough of simplified non-linear methods 12th Eur. Conf. Earthq. Eng. 1–20
[8] Salihovic A and Ademovic N 2017 Nonlinear analysis of reinforced concrete frame under lateral load Coupled Syst. Mech. 6 523–37
[9] Suwondo R, Mangindaan D, Cunningham L and Alama S 2021 Non-linear analysis of seismic performance of low-rise concrete buildings in Indonesia IOP Conf. Ser. Earth Environ. Sci. 794
[10] ASCE 2017 ASCE 41-17: Seismic Evaluation and Retrofit of Existing Buildings
[11] Dya A F C and Oretaa A W C 2015 Seismic Vulnerability Assessment of Soft Story Irregular Buildings Using Pushover Analysis Procedia Eng. 125 925–32
[12] Li S, Zuo Z, Zhai C and Xie L 2017 Comparison of static pushover and dynamic analyses using RC building shaking table experiment Eng. Struct. 136 430–40
[13] ATC 1996 ATC-40: Seismic evaluation and retrofit of concrete buildings Appl. Technol.
[14] FEMA 2000 FEMA-356: Prestandard and Commentary for the Seismic Rehabilitation of Buildings *Rehabil. Requir.* 1–518

[15] FEMA 2005 FEMA-440: Improvement of Nonlinear Static Seismic Analysis Procedures - Dep. Homel. Secur. Fed. Emerg. Manag. Agency

[16] ACI 2019 437R-19: *Strength Evaluation of Existing Concrete Buildings*