Pushover Analysis of 10-Floors Reinforced Concrete Building
(Case study: Mahkota Majolelo Sati Bautique Hotel)

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Abstract. Analysis of nonlinear pushover (push load) is one component of performance based design that can be used as a means of determining the capacity of a structure. The analysis is carried out by giving a static lateral load pattern to the structure whose value is increased gradually until a displacement target is reached or until the structure collapses. The purpose of this study is to determine the performance level of the building structure of the Mahkota Majolelo Sati Bautique Hotel according to the ATC-40 document. The capacity curve can estimate the basic shear force and maximum deformation that occurs in the structure. The results of the pushover analysis can show the pattern of collapse and the scheme of the occurrence of plastic hinges in the structure when given loading. By looking at the scheme of the occurrence of plastic hinges, then it can be seen the critical parts of the structure of the Majolelo Sati Bautique Hotel Mahkota Building. Pushover analysis is carried out by referring to the new regulations in effect in Indonesia, namely SNI 1726-2019, SNI 1727-2013 and SNI 2847-2019. The performance point is obtained by using the FEMA 440 Equivalent Linearization method, which is a simplification of the capacity spectrum method. The determination of the performance level of the structure follows the ATC-40 document.

1. Introduction

Indonesia is located in the Pacific Earthquake Belt and the Asian earthquake route (Trans Asiatic Earthquake Belt), so the chance of an earthquake occurring is very high. Given the high potential for earthquakes, a strong but also economical structure is required. Currently, a new concept has been developed in the analysis and planning of reinforced concrete building structures, namely the concept of performance-based design. This concept can help designers and practitioners alike in estimating the level of damage to building structures when subjected to earthquake loads. By knowing in advance the effect of earthquake loads on the structure, it is hoped that a strong but also economical building is created.

In this study, a nonlinear analysis of the push load was carried out on the structure of the Mahkota Majolelo Sati Bautique Hotel Building. The nonlinear pushover analysis is one component from the performance based design which can show the effect of the earthquake on the building structure and then can be determined the performance level of the structure. In the analysis process pushover, the building structure is pushed with a static lateral loading pattern whose value is gradually increased until the base shear and deformation are maximum structure is achieved. The results of this study can be used as a reference in planning the repair, strengthening and rehabilitation of structures.
In addition, this research is expected to provide new insights in assessing the performance of structures in resisting lateral loads, especially earthquake loads.

The concept of performance-based earthquake resistant building planning known as Performance Based Earthquake Engineering (PBEE) is a combination of durability and service aspects. This concept can be used to design new buildings (Performance Based Seismic Design) or evaluation of existing buildings (Performance Based Seismic Evaluation). The methodology which is based on performance based seismic design is a design and evaluation criterion which is expressed as the objectivity of the structure's usability. It can be used to define different levels of structural performance. The main objective of performance based seismic design is to create earthquake resistant buildings whose structural capacity can be estimated. Performance based seismic design has two main elements in its planning, namely structural capacity (capacity) and load (demand). The load in question is a representation of the ground motion due to an earthquake, which will be described as a spectrum response curve. The response spectrum curve will be converted into a demand spectrum curve. The capacity of the structure will be described as a capacity curve that shows the structure's ability to withstand earthquake forces without experiencing damage. The process of planning for a performance-based earthquake resistant building begins by modeling the structure in accordance with the prevailing regulations. Furthermore, the performance simulation is carried out on various earthquake events. Each stage of the simulation provides information on the level of damage and the resistance of the structure so that it can be estimated how much safety (life), readiness to use (occupancy) and loss of property (economic loss) that will occur\[1,2\]. The planner can then rearrange the acceptable risk of damage accordingly with the risk of costs incurred.

2. Methodology of Research

2.1. Description of building

Building structure modeling is done in 2D and 3D using structural analysis software. The structural data in the form of dimensions and quality of materials used for this modeling are in accordance with the building plan drawings.

The type of loading given to the structure of the MahkotaMajolelo Sati Bautique Hotel is in the form of gravity loads and lateral loads. The gravity load used is dead load, namely the load from the structure's own weight and also live loads. While the lateral loads used are static and dynamic earthquake loads.

Dead loads are loads that are caused by the structure's own weight and other loads that are permanently attached to the structure. The dead load used when modeling is the structure's own weight and the additional dead load. The structure's weight has been calculated automatically by software so that manual calculations are not performed. Additional dead load is calculated manually. The calculation of additional dead load can be seen in Table1 below.

| Material          | Density Width  | Total     |
|-------------------|----------------|-----------|
| Ceramics          | 22 kN/m³ 0,01  | 0,22 kN/m²|
| Spesi             | 22 kN/m³ 0,03 | 0,66 kN/m²|
| Sand              | 16 kN/m³ 0,01 | 0,16 kN/m²|
| Plafond and hanger| 0,20kN/m² -    | 0,20kN/m² |
| Utility           | 0,25 kN/m² -   | 0,25 kN/m²|
| Masonry Wall      | 250 kg/m -     | 250 kg/m  |
Modeling is done by describing all structural elements, namely columns, beams, floor plates and shear walls. The building has ten floor and is aimed to be a hotel. The model of the building can be seen from the Figure 1.

![Figure 1. Building modelling](image)

### 2.2. Dynamic Analysis

Based on SNI 1726-2019 (seismic resistance planning procedures for building and non-building structures), the calculation of dynamic earthquake loads with a spectrum response is carried out in the following stages[3]:

- **a. Determining Risk Categories and Priority Factors of the Earthquake (Iₑ)**
  
  Based on Table 3 (Risk categories for buildings and non-buildings for earthquake loads) and Table 4 (earthquake priority factors) from SNI 1726-2019, the analyzed building structure is a hotel, so it is included in the building with risk category II and earthquake priority factor (Iₑ) of 1,0.

- **b. Determining the Sₛ and S₁ Mapped Acceleration Parameters**
  
  The Sₛ parameter (bedrock acceleration in a short period of 0.2 seconds) and the S₁ parameter (bedrock acceleration in a 1 second period) are determined according to the Indonesian earthquake zoning map presented in SNI 1726-2019.

- **c. Determining Site Class and Site Coefficient Fₐ and Fᵥ**
  
  Soil type is assumed to be a medium soil type so based on Table 5 (Site Classification) SNI 1726-2019, the analyzed buildings are included in the SD site class. Based on Table 6 (site coefficient, Fₐ) and Table 7 (site coefficient, Fᵥ) from SNI 1726-2019, the values of the Fₐ and Fᵥ site coefficients are as follows:
  
  \[ Fₐ = 1,000 \]
  
  \[ Fᵥ = 1,700 \]

- **d. Determining the Sₛ Value (Acceleration spectral response parameter in a short period) and Sₛ Value (Acceleration spectral response parameter in a long period)**
  
  Based on Article 6.2 (Site coefficients and spectral response parameters of maximum earthquake acceleration which are considered as targeted risks) from SNI 1726-2019, the parameter values of Sₛ and Sₛ₁ are calculated according to the following equation:

  \[ Sₛ = Fₐ \times Sₛ = 1,000 \times 1,500 = 1,500 \text{ g} \]
e. Determining the Design Spectral Acceleration Parameters of $S_{DS}$ (Short-period Design Spectral Acceleration Parameters) and $S_{D1}$ (Long-Period Design Spectral Acceleration Parameters)

f. Defining the Design Response Spectrum $S_a$

After doing those procedures, the response spectrum of Padang City is obtained as can be seen in Figure 2.

![Figure 2. Response spectrum Padang City.](image)

2.3. Pushover Analysis

Pushover analysis is a static procedure that uses a simplified nonlinear technique to estimate seismic structural deformations\cite{4,5}. Structures redesign themselves during earthquakes. As individual components of a structure yield or fail, the dynamic forces on the building are shifted to other components\cite{6,7}. The initial stage in conducting a nonlinear analysis of thrust loads is to determine the amount of load applied to the structure. There are two types of loading given, namely gravity loading and lateral loading.

3. Results and Discussion

3.1. Capacity Curve

After modeling and checking the capacity of the structure is done, it is followed by running static nonlinear pushover for the x and y directions. From the results of the running, a capacity curve will be obtained and then the performance level of the structure being analyzed can be determined.

The capacity curve is a curve that shows the relationship between the displacement of the control point and the base shear force of the structure. The control point in question is a point on the top floor of the building which is used as a reference to see the behavior of the structure when given a thrust load. In this study, the control point is set on the top floor of the lift. The capacity curves for both directions can be seen in the graphic image below:

$$S_{M1} = F_Y \times S_1 = 1,700 \times 0,600 = 1,020 \, g$$
It can be described in Figure 3 that the curve is nonlinear, this is due to the addition of the load given to the structure so that the strength and stiffness of the structural elements decrease and there is a change in the properties of the structural elements from elastic to plastic.

The displacement values and basic shear forces for pushover direction x can be seen in Table 2 below:

Table 2. Displacement and shear forced for pushover – x.

| Step | Monitored Displacement (mm) | Base Force (kN) | A-B | B-C | C-D | D-E | >E | A-IO | I0-LS | LS-CP | >CP | Total |
|------|-----------------------------|-----------------|-----|-----|-----|-----|----|------|-------|-------|-----|-------|
| 0    | 0                           | 0               | 0   | 0   | 0   | 0   | 0  | 1634 | 0     | 0     | 0   | 1634  |
| 1    | 16,206                      | 1144,656        | 1634| 0   | 0   | 0   | 0  | 1634 | 0     | 0     | 0   | 1634  |
| 2    | 116,262                     | 7428,614        | 1606| 28  | 0   | 0   | 0  | 1634 | 0     | 0     | 0   | 1634  |
| 3    | 216,646                     | 11937,49        | 1485| 149 | 0   | 0   | 0  | 1633 | 0     | 0     | 1   | 1634  |
| 4    | 318,638                     | 15147,667       | 1360| 274 | 0   | 0   | 0  | 1618 | 15    | 0     | 1   | 1634  |
| 5    | 330,518                     | 15420,453       | 1349| 285 | 0   | 0   | 0  | 1614 | 19    | 0     | 1   | 1634  |
| 6    | 330,528                     | 15411,087       | 1349| 285 | 0   | 0   | 0  | 1614 | 19    | 0     | 1   | 1634  |
| 7    | 400,01                      | 16892,698       | 1305| 327 | 1   | 0   | 1  | 1603 | 25    | 4     | 2   | 1634  |
| 8    | 391,821                     | 16397,743       | 1305| 326 | 2   | 0   | 1  | 1603 | 25    | 3     | 3   | 1634  |

It can be seen in Table 2 above that the structure collapses at step 8 which is marked by a reversal of the capacity curve. In the 8th step, the displacement value at the control point is 391,821 mm with the base shear applied to the structure of 16397,743 kN. The maximum displacement at the control point occurs at step 7 which is 400,01 mm with a basic shear force of 16892,698 kN.

On the other hand, the capacity curve for Y direction is can be observed from the Figure 4 below:
The displacement values and basic shear forces for pushover direction Y can be seen in Table 3.

**Table 3. Displacement and shear forced for pushover – y.**

| Step | Monitored Displacement (mm) | Base Force (kN) | A-B | B-C | C-D | D-E | >E | A-IO | IO-LS | LS-C | >CP | Total |
|------|-----------------------------|-----------------|-----|-----|-----|-----|----|------|-------|------|-----|-------|
| 0    | 0                           | 0               | 1634| 0   | 0   | 0   | 0  | 1634 | 0     | 0    | 0    | 1634  |
| 1    | 24,478                      | 2365,685        | 1634| 0   | 0   | 0   | 0  | 1634 | 0     | 0    | 0    | 1634  |
| 2    | 124,746                     | 9865,413        | 1567| 67  | 0   | 0   | 0  | 1634 | 0     | 0    | 0    | 1634  |
| 3    | 227,887                     | 14432,265       | 1376| 256 | 0   | 0   | 0  | 1634 | 0     | 0    | 0    | 1634  |
| 4    | 335,61                      | 17559,202       | 1281| 353 | 0   | 0   | 0  | 1618 | 15    | 0    | 1    | 1634  |
| 5    | 439,407                     | 20074,28        | 1206| 428 | 0   | 0   | 0  | 1589 | 44    | 0    | 1    | 1634  |
| 6    | 540,479                     | 22083,753       | 1124| 510 | 0   | 0   | 0  | 1509 | 123   | 1    | 1    | 1634  |
| 7    | 540,489                     | 22061712        | 1124| 510 | 0   | 0   | 0  | 1509 | 123   | 1    | 1    | 1634  |
| 8    | 600,769                     | 23114,937       | 1073| 556 | 5   | 0   | 0  | 1460 | 159   | 10   | 5    | 1634  |
| 9    | 600,769                     | 23114,948       | 1072| 557 | 5   | 0   | 0  | 1460 | 159   | 10   | 5    | 1634  |
| 10   | 600,779                     | 23071694        | 983 | 626 | 17  | 0   | 8  | 1406 | 187   | 22   | 19   | 1634  |
| 11   | 596,781                     | 22564,94        | 983 | 625 | 15  | 3   | 8  | 1406 | 187   | 22   | 19   | 1634  |

Based on Table 3, it can be concluded that the structure collapsed at the 11th step with a displacement value at the control point of 596,781 mm with a basic shear force of 22564,940 kN. The maximum displacement occurs in the 10th step, which is 600,779 mm with a base shear force of 23071,694 kN.

3.2. Performance Point

The value of performance points in x and y direction can be seen from the Figure 5. The orange line is the capacity spectrum curve, while the blue line is the demand spectrum curve. The point of intersection between the capacity spectrum curve and the demand spectrum curve is the performance point of the structure for the given direction.
The performance points of the structure are calculated through an iteration process which is carried out automatically by the program. It can be concluded from Figure 5 that for both the x and y directions the structure has a sufficiently good capacity to bear the defined earthquake load plan. The method used to get the performance point is the FEMA 440 Equivalent Linearization method. This method is an improvement over the capacity spectrum method (ATC-40) [8]. The way this method works is by converting the capacity curve into a capacity spectrum curve to form a relationship curve between spectral acceleration (Sa) and spectral demand (Sd). Then the spectrum response curve is converted into MADRS (Modified Acceleration Displacement Response Spectrum) format so that a demand spectrum curve is formed.

3.3. Performance Level
The determination of the performance level of the structure follows the ATC-40. The calculation and determination of the structural performance levels for the x and y directions are shown in Table 4 below. It can be seen in Table 4 that for the x and y direction pushover, the structure performance level is obtained including the Immediate Occupancy (IO) performance level. This means that when an
earthquake with the strength of the planned earthquake occurs, the structure does not experience structural or non-structural damage so that it can be immediately reused.

Table 4. Performance level of pushover X and Y.

| Case     | Dt (mm)  | D1 (mm)  | Ht (mm) | Maximum Total Drift | Maximum Inelastic Drift |
|----------|----------|----------|---------|---------------------|-------------------------|
| Pushover X | 183,254  | 116,262  | 45000   | Immediate Occupancy | Immediate Occupancy     |
| Pushover Y | 155,43   | 124,746  | 45000   | Immediate Occupancy | Immediate Occupancy     |

4. Conclusions
After analysing the push load on the structure of the Majolelo Sati Bautique Hotel Mahkota Building, the following conclusions can be drawn:

1. Based on the ATC-40 document, the performance level of the structure for pushover in the x direction and y direction is included in the Immediate Occupancy (IO) performance level, which means the Majolelo Sati Bautique Hotel Mahkota Building does not experience structural and non-structural damage when an earthquake occurs as large as the planned earthquake so that immediately reusable.

2. The performance point of the structure based on the FEMA 440 Equivalent Linearization method is obtained for pushover direction x point (V; D) is (10437,643; 183,254) and direction y is at point (11223,943; 155,428).

3. Based on the capacity curve, the x-direction pushover results in a maximum displacement of 400.01 mm with a total base shear of 16892,698 kN while the y-direction pushover produces a maximum displacement of the structure of 600,779 mm with a total basic shear force of 23071,694 kN.

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