Comparison of structural performance of open frame structures based on SNI 03-1726-2002 and SNI 03-1726-2012

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Abstract. The performance analysis of a building structure under inelastic conditions consisted of static and dynamic methods, which each divided into linear and non-linear categories. The performance-based analysis was included in the non-linear static category and described in the Applied Technology Council (ATC)-40, Federal Emergency Management Agency (FEMA) 273, FEMA 356, and FEMA 440. In this study, some structural open frame models were assessed to determine the structural performance level. The aim of this study was to compare the performance of the open frame building structural models using pushover analysis based on SNI-1726-2002, SNI-1726-2012, and ATC-40 codes. The structural element properties were modeled based on SNI-1726-2002 to represent the buildings previously constructed before the application of SNI-1726-2012. The results showed that the open frame structural models analysed based on SNI-1726-2012 code, had a lower performance points and structural performance levels compared to their counterpart models which were analysed based on SNI-1726-2002 code. Other models showed the opposite behavior due to differences in the characteristics of seismic zones, represented by the response spectrum curves in the SNI-1726-2002 and SNI-1726-2012 codes.

1 Introduction

The building structure analysis comprises of static and dynamic methods, with each consists of linear and non-linear categories. The performance-based analysis was included in the non-linear static method and described in the Applied Technology Council (ATC)-40, Federal Emergency Management Agency (FEMA) 273, FEMA 274, FEMA 356 (the FEMA 273 language code), FEMA 440 (the enhancement of FEMA 356), National Earthquake Hazards Reduction Program (NEHRP) Guidelines for the Seismic Rehabilitation of Building, and Structural Engineers Association of California (SEAOC)'s Vision 2000: Performance-Based Seismic Engineering of Buildings (1995).

The performance level of a building structure is defined as a limitation associated with its degree of failure, which is determined by the physical damages of structural elements. In the pushover analysis, the building structure performance levels are categorized, as shown in Table 1 [1].

The aim of this study was to determine the performance points and structural performance levels of open frame structures designed using the previous Indonesian earthquake code [2] then compared the analysis and results by using the previous [2] and current [3] Indonesian earthquake codes.

| Non-structural performance levels | Structural performance levels |
|-----------------------------------|-------------------------------|
| SP-1 LA | SP-2 DC (range) | SP-3 LS | SP-4 limited safety (range) | SP-5 SS | SP-6 NC |
| NP-A O | 1-A | 2-A | NR | NR | NR |
| NP-B IO | 1-B | 2-B | 3-B | NR | NR |
| NP-C LS | 1-C | 2-C | 3-C | LS | 4-C | 5-C | 6-C |
| NP-D RH | NR | 2-D | 3-D | 4-D | 5-D | 6-D |
| NP-E NC | NR | NR | 3-E | 4-E | 5-E | SS | NA |

Notes:

O : Operational
IO : Immediate Occupancy
DC : Damage Control
A : unloaded condition
B : yield
C : nominal strength

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2 Nonlinear static procedures

In the performance-based theory, the pushover analysis is used to assess building structures in inelastic conditions through the formation of plastic hinges at the ends of beams and columns, to achieve specific structural performance levels under strong earthquakes. It generates a capacity curve, which correlates the base shear and roof displacement values (Fig. 1). Each point on the curve defines a specific damaged state. By correlating a capacity curve with a seismic demand curve that represents seismic characteristics of an earthquake zone, therefore the performance point on the capacity curve is obtained [1], from the responses of the structure under severe earthquakes [4].

![Building structure capacity curve](image1)

**Fig. 1.** Building structure capacity curve [1].

### 2.1. Pushover analysis

The pushover analysis is performed by applying increased lateral monotonic loads on the building structure that causes the structure achieves a specific boundary or failure. The structure reaction is based on the shear values that correlates with lateral load values. This reaction decreases after the structure achieves the maximum base shear due to failure.

The model of capacity curve shows structure condition since in unloaded condition (A), yield (B), nominal strength (C), reduced strength (D), and ultimate (E) on Fig. 2.

![Typical curve of lateral load-deformation](image2)

**Fig. 2.** Typical curve of lateral load-deformation [5]

### 2.2 Converting the capacity curve

The next step converts the capacity curve into a capacity spectrum (Fig. 3), which is known as Acceleration-Displacement Response Spectrum (ADRS) method. Equations 1 - 4 are used for the conversion [1]:

\[
P_{F1} = \left[ \frac{\sum_{i=1}^{N} (w_i \phi_{1i}/g)}{\sum_{i=1}^{N} (w_i \phi_{1i}/g)} \right] (1)
\]

\[
\alpha_i = \left[ \frac{\sum_{i=1}^{N} (w_i \phi_{1i}/g)}{\sum_{i=1}^{N} (w_i \phi_{1i}/g)} \right] (2)
\]

\[
S_a = \frac{V/W}{a_1} (3)
\]

\[
S_d = \frac{S_{roof}}{P_{F1} \phi_{1,roof}} (4)
\]

where:

- \( P_{F1} \) is modal participation factor for the first natural mode
- \( \alpha_i \) is modal mass coefficient for the first mode
- \( w_i/g \) is mass assigned to story-i
- \( \phi_{1,i} \) is amplitude of mode-1 at story-i
- \( \phi_{1,roof} \) is amplitude of mode-1 at the roof
- \( N \) is number of building story
- \( V \) is base shear
- \( W \) is weight of the building (including self load and life load)
- \( \Delta_{roof} \) is roof displacement
- \( S_a \) is spectral acceleration
- \( S_d \) is spectral displacement

![Building structure capacity spectrum curves](image3)

**Fig. 3.** Building structure capacity spectrum curves [1].

### 2.3 Converting the response spectrum

The common response spectrum is expressed in spectral acceleration \( S_a \) and period \( T \) curve (Fig. 4). It needs to be converted into the ADRS format, also known as a demand spectrum (Fig. 5) using equations 5-7 [1].

![Response spectrum](image4)

**Fig. 4.** Response spectrum [1]
2.4 Performance point and equivalent viscous damping

The performance point is used to represent the performance level of a building structure under resisted earthquake loads. The performance point is located at the intersection of the demand spectrum and capacity curve. It correlates the maximum roof displacement (target displacement that occurs due to the earthquake) with the seismic acceleration.

The performance point location must satisfy the following two criteria: 1) it needs to be on the capacity spectrum curve to represent the structure condition on the certained displacement; and 2) it needs to be presented in the spectral demand curve reduced from the elastic, a 5%-damped design spectrum, to show a nonlinear demand at the same structural displacement [1]. In this method, the spectral reduction factors are defined to produce effective damping. This is calculated based on the capacity curve form, the estimated displacement demand, and the hysteretic curve. Some imperfections of a building’s hysteretic curve, as effects of degradation and duration, are calculated in the reduced equivalent viscous damping values. The formula for viscous damping value is expressed in equation (8) as follows:

\[ \beta_{eq} = \beta_\alpha + 0.05 \]  \hspace{1cm} (8)

where:
- \( \beta_{eq} \) is equivalent viscous damping of the structure
- \( \beta_\alpha \) is hysteretic damping that represents equivalent viscous damping
- 0.005 is initial damping of the structure (inherent damping)

The analysis of performance point is conducted through iteration to satisfy the criteria above using three procedures for locating performance points, namely [1]:

1. Procedure A
   This procedure is based on equations/formulas, and it is applied using spreadsheets.

2. Procedure B
   In this procedure, the capacity curve is simplified into a bilinear curve which produces a relatively direct solution.

3. Procedure C
   This procedure is purely graphical and is similar to the capacity spectrum method.

According to these three methods, procedure A is the most transparent and direct, with its iteration conducted as follows:

1. Create a 5% damped (elastic) response spectrum that represents the seismic zone.
2. Convert the response spectrum into a demand spectrum (sub. 2.3).
3. Plot the response spectrum curve of earthquake loads and the capacity curve of the building structure into the same area.
4. Select the initial point for the iteration of performance point \((a_p, d_p)\) on the capacity curve.
5. Plot the bilinear lines on the capacity curve using equations (1-4).
6. Determine the spectral reduction factors using equations (9 and 10).
7. Check if the demand spectrum intersects the capacity spectrum at the point \((a_p, d_p)\) or the displacement where the demand spectrum intersects the capacity spectrum is in the allowed value of \(d_p\).
8. If the demand spectrum fails to intersect the capacity spectrum within a range of allowed value limits, then it needs to choose another point of \((a_p, d_p)\) and start over from step 4.
9. If the demand spectrum intersects the capacity spectrum within a range of allowed value limits, then the point of \((a_p, d_p)\) is the performance point \((a_i, d_i)\) and the displacement \((d_i)\) represents the maximum expected displacement of the structure due to the demand spectrum of earthquake.

\[ SR_A = \frac{1}{B_s} \approx \frac{3.21 - 0.68 \ln(\beta_{eff})}{2.12} \]
\[ = \frac{3.21 - 0.68 \ln \left[ \frac{\delta_d p_i - \delta_d p_i}{\delta_d p_i} \right]}{2.12} \geq \text{value in Table 2.} \]  \hspace{1cm} (9)

\[ SR_V = \frac{1}{B_L} \approx \frac{2.31 - 0.41 \ln(\beta_{eff})}{1.65} \]
\[ = \frac{2.31 - 0.41 \ln \left[ \frac{\delta_d p_i - \delta_d p_i}{\delta_d p_i} \right]}{1.65} \geq \text{value in Table 2.} \]  \hspace{1cm} (10)

The value of \(SR_A, SR_V\), and the definition of structural behaviour types are described in Tables 2 and 3, respectively.
Table 2. Minimum allowable SR_A and SR_V values [1].

| Structural behavior type | SR_A | SR_V |
|--------------------------|------|------|
| A                        | 0.33 | 0.5  |
| B                        | 0.44 | 0.56 |
| C                        | 0.56 | 0.67 |

Table 3. Structural behavior types [1].

| Shaking duration | Essentially new building | Average existing building | Poor existing building |
|------------------|--------------------------|---------------------------|------------------------|
| Short            | A                        | B                         | C                      |
| Long             | B                        | C                         | C                      |

3 Building structural models

The 6-story open frame structural models were analysed. Each consisted of 3 bays on X-axis and Y-axis, with a span of 4 meters. One story height was 3 meters, with the structural models were designed as special moment resisting frames and operated as office buildings. The life and dead loads on the slabs were 300 kg/m² and 150 kg/m² respectively, while the dead load on the beams was 750 kg/m which represented the masonry walls.

The following material properties were used: concrete compression strength ($f'_c$) of 28 MPa; mild steel yield and ultimate strength ($f_y$ and $f_u$) of 240 MPa and 370 MPa; steel bar yield and ultimate strength ($f_y$ and $f_u$) of 400 MPa and 580 MPa, respectively.

All of the building structural models were designed based on the previous code [2] to represent that building structures were constructed before the application of the current code [3].

The beam and column properties are described in the Table 4. The dimension and reinforcement details of beams and columns were determined based on load combinations [6]. The column dimension and reinforcement details were the same for all structural models, while the required beam reinforcement details varied due to the load combinations, especially based on the specific earthquake loads on seismic zones. The thickness of all slabs was 120 mm. Figure 6 shows the location of columns on the plans of the structural models.

Table 4. Beam and column properties

| Element | $b$ | $h$ | $L$ | $A_g$ | $\rho$ |
|---------|-----|-----|-----|-------|-------|
| Beam    | 250 | 400 | 4000| 8 D19 | 2.52  |
| Column C1 | 300 | 300 | 3000| 8 D25 | 2.45  |
| Column C2 | 400 | 400 | 3000| 8 D25 | 2.45  |
| Column C3 | 325 | 325 | 3000| 8 D19 | 2.88  |

Notes: * depends on the load combinations; $b$: width; $h$: height; $L$: length; $A_g$: reinforcement; $\rho$: reinforcement percentage.

All capacity spectrum curves were compared to the demand spectrum curves of the previous [2] and current [3] Indonesian earthquake load codes to determine the performance points. The seismic properties of each structural model were based on the area where the cities were located along with the soil types as shown in Table 5. The period time ($T$) were calculated using equation (11) [2].

$$T = \zeta n$$

where

$\zeta$: the multiplier coefficient of the number of building structure floors that limits its fundamental natural period time; the values of coefficient depends on the seismic zone.

$n$: number of story (was 6 in this study)

5. The period time ($T$) were calculated using equation (11) [2].

The value of earthquake reduction factor ($R$) was 8.5 for reinforced concrete special moment resisting frames and the importance factor ($I$) was 1. In this study, seismic zones 1 and 2 were excluded due to their low seismic impact on building structures [2,3]. However, the specific design, such as structure element dimensions and reinforcement details were unique and dependent on each designer [7]. The cities of Jakarta, Bandung, Padang, and Bengkulu were chosen to represent the seismic zones of 3, 4, 5, and 6 [2].

The structural behavior type was B for reinforced concrete special moment resisting frames with values of coefficient of response modification ($R$), system overstrength factor ($\Omega_\alpha$), and deflection amplification factor ($C_d$) were 8, 3, and 5.5, respectively [2] to determine the performance points.
The plastic hinges were set on each beam and column ends. Furthermore, the hinge properties of all columns were arranged as a default of the program [5] and the hinge types were interacting P-M2-M3. The hinge types of all beams were moment M3. Each beam hinge properties were calculated based on the section dimension, longitudinal and transversal reinforcements [8], which consisted of values of moment/safety factor, rotation/safety factor, and yield moment. The values of rotation/safety factor (acceptance criteria) of IO, LS, and CP also were determined [1].

Each floor was set as a diaphragm to ensure it moved as a structural unity in lateral directions. Due to symmetrical behaviour of the structural models on X and Y-axis, the pushover analysis was only determined on X-axis.

### 4 Results and analysis

The structural models were deformed into inelastic condition due to earthquake loads by developing plastic hinges on the beam and column ends. The plastic hinges provide ductility and earthquake energy dissipation to ensure structure deformation and minimize severe damage [9]. In every step of pushover analysis, some new structural performance levels of plastic hinges were formed. It continued until the structural models achieved the displacement target on the building roof [10].

The beam reinforcements of all models are shown in Tables 6 and 7. The differences of the reinforcement depended on the load combinations, mostly through specific earthquake loads in the seismic zones.

The results and analysis of all load combinations were the minimum required reinforcements of beams and columns. All columns showed capacity ratios were less than 1.0, which indicated that the dimension and reinforcement details satisfied the requirements [11].

All pushover curves of structural models are shown in Figures 7 to 10. Each curve was unique due to specific beam reinforcement and hinge properties of the structural models, which were referred to the earthquake loads on the seismic zones. The X and Y-axis values provide information of roof lateral displacement ($d$) and shear force ($V$), respectively.

### Table 5. Seismic properties

| Cities | Soil type | Seismic zone | $C_a$ (g) | $C_v$ (g) | $T$ (sec.) |
|--------|-----------|--------------|----------|----------|------------|
| Jakarta | Soft      | 3            | 0.30     | 0.75     | 0.18       | 1.08       |
|         | Medium    | 3            | 0.23     | 0.33     | 0.18       | 2.32       |
|         | Hard      | 4            | 0.34     | 0.85     | 0.17       | 1.02       |
| Bandung | Soft      | 4            | 0.28     | 0.42     | 0.15       | 0.96       |
|         | Medium    | 5            | 0.36     | 0.90     | 0.16       | 0.90       |
|         | Hard      | 6            | 0.38     | 0.95     | 0.15       | 0.90       |
| Padang  | Soft      | 5            | 0.32     | 0.50     | 0.16       | 0.90       |
|         | Medium    | 6            | 0.28     | 0.35     | 0.16       | 0.90       |
|         | Hard      | 7            | 0.36     | 0.42     | 0.15       | 0.90       |
| Bengkulu| Soft      | 8            | 0.36     | 0.54     | 0.15       | 0.90       |
|         | Medium    | 9            | 0.33     | 0.42     | 0.15       | 0.90       |
|         | Hard      | 10           | 0.32     | 0.48     | 0.15       | 0.90       |

### Table 6. Required beam reinforcement

| No. | City     | Seismic zone | Soil type | Beam | $A_x$ required at support |
|-----|----------|--------------|-----------|------|--------------------------|
|     |          |              |           |      | Top | Bottom |
|     |          |              |           |      | (mm²) | (mm²) |
| 1   | Jakarta  | 3            | Soft      | 1    | 586  | 344 |
| 2   | Jakarta  | 3            | Medium    | 2    | 333  | 218 |
| 4   | Bandung  | 4            | Soft      | 4    | 680  | 404 |
| 5   | Bandung  | 4            | Medium    | 4    | 401  | 262 |
| 6   | Bandung  | 4            | Hard      | 5    | 325  | 213 |
| 7   | Padang   | 5            | Soft      | 5    | 725  | 477 |
| 8   | Padang   | 5            | Medium    | 6    | 471  | 302 |
| 9   | Padang   | 5            | Hard      | 7    | 370  | 242 |
| 10  | Bengkulu | 6            | Soft      | 8    | 760  | 510 |
| 11  | Bengkulu | 6            | Medium    | 9    | 523  | 302 |
| 12  | Bengkulu | 6            | Hard      | 10   | 436  | 284 |

### Table 7. Applied beam reinforcement

| No. | Beam | As applied at support | As applied at support |
|-----|------|------------------------|------------------------|
|     |      | Top | Bottom | Top | Bottom |
|     |      | (mm²) | (mm²) | (mm²) | (mm²) |
| 1   | 3    | 16  | 13     | 603.19 | 398.20  |
| 2   | 3    | 13  | 12     | 398.20 | 265.46  |
| 3   | 3    | 13  | 12     | 398.20 | 265.46  |
| 4   | 2    | 22  | 2      | 760.27 | 567.06  |
| 5   | 2    | 16  | 2      | 402.12 | 265.46  |
| 6   | 3    | 13  | 2      | 398.20 | 265.46  |
| 7   | 2    | 22  | 2      | 760.27 | 567.06  |
| 8   | 2    | 19  | 3      | 567.06 | 398.20  |
| 9   | 3    | 13  | 2      | 398.20 | 265.46  |
| 10  | 2    | 22  | 2      | 760.27 | 567.06  |
| 11  | 2    | 19  | 2      | 567.06 | 402.12  |
| 12  | 2    | 19  | 3      | 567.06 | 398.20  |

The roof target displacement i.e. 200 mm were achieved by all structural models, while the maximum lateral force was different as shown in Table 8.

All structural models used seismic design category B which represented a moderate reduction of hysteretic loop areas of structural responses with $\kappa$ of 2/3. The $\kappa$-factor is a measure of the extent to which the actual building hysteretic behaviour [1]. The response spectrum curves of all cities and soil types were provided through an official Indonesian seismic map [12].

![Fig. 7. Pushover curves of structural models in Jakarta city](https://example.com/pushover_curves.png)
Figures 11 and 12 showed that the performance point properties \( (S_a, S_d) \) are not the same due to different response spectrum curves of the previous [2] and current [3] Indonesian earthquake load codes. The current [3] maximum spectral response acceleration parameters \( (C_o \) or \( S_a) \) of Jakarta city on soft soil was less than the previous one [2]. Therefore, it influenced the structural model performance in resisting earthquake. The same behaviour occurred on other models of Jakarta on medium and hard soil; Bandung on soft soil; Padang on soft and medium soil; also Bengkulu on hard, medium, and soft soil. The opposite behaviour showed by the structural models under earthquake of Bandung on medium and hard soil; and Padang on hard soil (Fig. 13 and 14). In simplifying this study, only four figures of the spectral acceleration-spectral displacement curves are shown. The performance points and structural performance levels of all 12 open frame structural models were determined, each by using response spectrum curves of the previous [2] and current [3] Indonesian earthquake load codes as shown in Tables 9 to 11.

Table 8. Maximum displacement \( (d_{max}) \) and lateral force \( (V_{max}) \)

| City    | Soil type | \( d_{max} \) | \( V_{max} \) |
|---------|-----------|----------------|---------------|
|         |           | (mm)           | (kN)          |
| Jakarta | Soft      | 200.001        | 2283.767      |
|         | Medium    | 200.001        | 2222.701      |
|         | Hard      | 200.001        | 2222.701      |
| Bandung | Soft      | 200.001        | 2334.539      |
|         | Medium    | 200.001        | 2228.283      |
|         | Hard      | 200.001        | 2222.701      |
| Padang  | Soft      | 200.001        | 2334.539      |
|         | Medium    | 200.001        | 2258.895      |
|         | Hard      | 200.001        | 2222.701      |
| Bengkulu| Soft      | 200.001        | 2334.539      |
|         | Medium    | 200.001        | 2266.678      |
|         | Hard      | 200.001        | 2258.895      |

FIGURES

Fig. 8. Pushover curves of structural models in Bandung city

Fig. 9. Pushover curves of structural models in Padang city

Fig. 10. Pushover curves of structural models in Bengkulu city

Fig. 11. Pushover curves of a structural model and response spectrum curves of Jakarta city based on the previous earthquake code [2] of soft soil
Fig. 12. Pushover curves of a structural model and response spectrum curves of Jakarta city based on the recent earthquake code [3] of soft soil

Fig. 13. Pushover curves of a structural model and response spectrum curves of Padang city based on the previous earthquake code [2] of hard soil

Fig. 14. Pushover curves of a structural model and response spectrum curves of Padang city based on the recent earthquake code [3] of hard soil

Table 9. Performance points ($V - d$)

| No. | City   | Soil type | Code version | Performance points |
|-----|--------|-----------|--------------|--------------------|
|     |        |           |              | Deformation (d)    | Shear (V)         |
|     |        |           |              | (mm)               | (kN)              |
| 1   | Jakarta| S         | 2002         | 151.966            | 2058.573          |
|     |        |           | 2012         | 108.334            | 1733.843          |
| 2   | Jakarta| M         | 2002         | 72.577             | 1233.548          |
|     |        |           | 2012         | 68.727             | 1183.022          |
| 3   | Jakarta| H         | 2002         | 49.639             | 926.965           |
|     |        |           | 2012         | 55.805             | 1013.455          |
| 4   | Bandung| S         | 2002         | 167.336            | 2199.403          |
|     |        |           | 2012         | 145.743            | 2095.862          |
| 5   | Bandung| M         | 2002         | 93.806             | 1479.055          |
|     |        |           | 2012         | 97.772             | 1521.233          |
| 6   | Bandung| H         | 2002         | 65.739             | 1143.815          |
|     |        |           | 2012         | 97.772             | 1521.233          |
| 7   | Padang | S         | 2002         | 182.572            | 2268.175          |
|     |        |           | 2012         | 145.743            | 2095.862          |
| 8   | Padang | M         | 2002         | 103.071            | 1687.402          |
|     |        |           | 2012         | 110.503            | 1750.212          |
| 9   | Padang | H         | 2002         | 77.956             | 1304.140          |
|     |        |           | 2012         | 103.405            | 1574.946          |
| 10  | Bengkulu| S        | 2002         | 196.123            | 2319.773          |
|     |        |           | 2012         | 114.366            | 1901.894          |
| 11  | Bengkulu| M        | 2002         | 111.704            | 1764.962          |
|     |        |           | 2012         | 93.475             | 1602.170          |
| 12  | Bengkulu| H        | 2002         | 87.791             | 1545.995          |
|     |        |           | 2012         | 84.420             | 1487.391          |

Notes: S = soft; M = medium; H = hard

Table 10. Performance points ($S_d - S_a$)

| No. | City   | Seismic zone | Soil type | Code version | Performance points |
|-----|--------|--------------|-----------|--------------|--------------------|
|     |        |              |           |              | $S_a$ (g)          | $S_d$ (mm)         |
| 1   | Jakarta| 3           | S         | 2002         | 0.528             | 122.935           |
|     |        |              |           | 2012         | 0.455             | 87.079            |
| 2   | Jakarta| 3           | M         | 2002         | 0.333             | 57.973            |
|     |        |              |           | 2012         | 0.319             | 54.899            |
| 3   | Jakarta| 3           | H         | 2002         | 0.249             | 39.624            |
|     |        |              |           | 2012         | 0.272             | 44.580            |
| 4   | Bandung| 4           | S         | 2002         | 0.553             | 136.847           |
|     |        |              |           | 2012         | 0.532             | 118.561           |
| 5   | Bandung| 4           | M         | 2002         | 0.397             | 74.954            |
|     |        |              |           | 2012         | 0.408             | 78.130            |
| 6   | Bandung| 4           | H         | 2002         | 0.308             | 52.513            |
|     |        |              |           | 2012         | 0.372             | 67.439            |
| 7   | Padang | 5           | S         | 2002         | 0.568             | 149.765           |
|     |        |              |           | 2012         | 0.552             | 135.531           |
| 8   | Padang | 5           | M         | 2002         | 0.444             | 82.782            |
|     |        |              |           | 2012         | 0.458             | 88.857            |
| 9   | Padang | 5           | H         | 2002         | 0.352             | 62.269            |
|     |        |              |           | 2012         | 0.420             | 82.667            |
| 10  | Bengkulu| 6          | S         | 2002         | 0.579             | 161.349           |
|     |        |              |           | 2012         | 0.491             | 92.198            |
| 11  | Bengkulu| 6          | M         | 2002         | 0.462             | 89.840            |
|     |        |              |           | 2012         | 0.425             | 74.966            |
| 12  | Bengkulu| 6          | H         | 2002         | 0.412             | 70.338            |
|     |        |              |           | 2012         | 0.399             | 65.200            |
### Table 11. Performance points ($T_{eff} - \beta_{eff}$)

| No. | City  | Seismic zone | Soil type | Code version | $T_{eff}$ (sec.) | $\beta_{eff}$ | Performance points |
|-----|-------|--------------|-----------|--------------|-----------------|--------------|-------------------|
| 1   | Jakarta | 3           | S         | 2002         | 0.968           | 0.174        | 7/ Pdg/ H        |
|     |        | 2012        |           | 0.877        | 0.142           |              |                   |
| 2   | Jakarta | 3           | M         | 2002         | 0.835           | 0.101        | 8/ Pdg/ M        |
|     |        | 2012        |           | 0.829        | 0.101           |              |                   |
| 3   | Jakarta | 3           | H         | 2002         | 0.797           | 0.096        | 9/ Pdg/ H        |
|     |        | 2012        |           | 0.810        | 0.100           |              |                   |
| 4   | Bandung | 4           | S         | 2002         | 0.997           | 0.209        | 10/ Bgkl/ S      |
|     |        | 2012        |           | 0.946        | 0.191           |              |                   |
| 5   | Bandung | 4           | M         | 2002         | 0.871           | 0.112        | 11/ Bgkl/ M      |
|     |        | 2012        |           | 0.878        | 0.115           |              |                   |
| 6   | Bandung | 4           | H         | 2002         | 0.825           | 0.101        | 12/ Bgkl/ H      |
|     |        | 2012        |           | 0.853        | 0.105           |              |                   |
| 7   | Padang  | 5           | S         | 2002         | 1.030           | 0.217        | 1/ Jkt/ S        |
|     |        | 2012        |           | 0.994        | 0.208           |              |                   |
| 8   | Padang  | 5           | M         | 2002         | 0.866           | 0.139        | 2/ Jkt/ M        |
|     |        | 2012        |           | 0.882        | 0.144           |              |                   |
| 9   | Padang  | 5           | H         | 2002         | 0.843           | 0.102        | 3/ Jkt/ H        |
|     |        | 2012        |           | 0.889        | 0.119           |              |                   |
| 10  | Bengkulu| 6           | S         | 2002         | 1.059           | 0.223        | 4/ Bdg/ S        |
|     |        | 2012        |           | 0.869        | 0.160           |              |                   |
| 11  | Bengkulu| 6           | M         | 2002         | 0.883           | 0.145        | 5/ Bdg/ M        |
|     |        | 2012        |           | 0.841        | 0.125           |              |                   |
| 12  | Bengkulu| 6           | H         | 2002         | 0.827           | 0.118        | 6/ Bdg/ H        |
|     |        | 2012        |           | 0.811        | 0.109           |              |                   |

### Table 12. Structural performance level on performance point

| No./ city/ soil type | Code version | Performance points |
|----------------------|--------------|--------------------|
| Maximum Level Structure elements | 1/ Jkt/ S | Columns (floor 1-4) |
|                      | 2002        | IO                 |
|                      | 2012        | Columns (floor 1)  |
|                      | 2/ Jkt/ M  | Beams (floor 2-6); columns (floor 1; edge and middle frames) |
|                      | 2002        | B                 |
|                      | 2012        | Beams (floor 2-6); columns (floor 1; edge and middle frames) |
|                      | 3/ Jkt/ H  | Beams (floor 2-6) |
|                      | 2002        | B                 |
|                      | 2012        | Beams (floor 2-6); columns (floor 1; edge and middle frames) |
|                      | 4/ Bdg/ S  | Columns (floor 1-2; edge & middle frames) |
|                      | 2002        | IO                |
|                      | 2012        | Columns (floor 1; edge frames) |
|                      | 5/ Bdg/ M  | Beams (floor 2-6); columns (floor 1-4; middle and edge frames) |
|                      | 2002        | B                 |
|                      | 2012        | Beams (floor 2-6); columns (floor 1-4; middle and edge frames) |
|                      | 6/ Bdg/ H  | Beams (floor 2-6); columns (floor 1; edge and middle frames) |
|                      | 2002        | B                 |
|                      | 2012        | Beams (floor 2-6); columns (floor 1; edge and middle frames) |

Notes:
- Jkt: Jakarta; Bdg: Bandung; Pdg: Padang; Bgkl: Bengkulu; S: Soft soil; M: Medium soil; H: Hard soil.

### Table 13. Structural performance level on ultimate condition

| No. | Code version | Ultimate condition |
|-----|--------------|--------------------|
| Maximum Level Structure elements | 1/ Jkt/ S | Columns (floor 1, edge and middle frames) |
|     | 2002        | LS                 |
|     | 2012        | LS                 |
|     | 2/ Jkt/ M  | Columns (floor 1, edge and middle frames) |
|     | 2002        | LS                 |
|     | 2012        | LS                 |
|     | 3/ Jkt/ H  | Columns (floor 1, edge and middle frames) |
|     | 2002        | LS                 |
|     | 2012        | LS                 |
|     | 4/ Bdg/ S  | Columns (floor 1, edge and middle frames) |
|     | 2002        | LS                 |
|     | 2012        | LS                 |
|     | 5/ Bdg/ M  | Columns (floor 1, edge and middle frames) |
|     | 2002        | LS                 |
|     | 2012        | LS                 |
|     | 6/ Bdg/ H  | Columns (floor 1, edge and middle frames) |
|     | 2002        | LS                 |
|     | 2012        | LS                 |
Tables 12 and 13, respectively. The pushover analysis of structural models showed that the different structural performance levels on performance points depended on the various maximum spectral response acceleration values in the codes.

3. The pushover analysis of structural models in Padang city on the medium and hard soil showed that the structural levels of performance points were more severe from yield (B) to Immediate Occupancy (IO) and yield (B) to yield (B) with more damaged plastic hinges, respectively, due to higher spectral response acceleration parameters in the current code. This condition needs to be considered by engineers in designing proper new structures or evaluating existing structures to resist earthquake loads.

4. The pushover analysis of structural models in Padang on soft soil and Bengkulu cities on soft and medium soil showed that the structural levels of performance points improved from Life Safety (LS) to IO, Collapse (C) to IO, and IO to yield (B) due to the decreased maximum spectral response acceleration parameters in the current code.

5. The pushover analysis of structural models in Jakarta and Bandung on soft, medium, and hard soil, and Bengkulu on hard soil showed the same performance levels according to the SNI 1726-2002 and SNI 1726-2012 codes.

6 Recommendations

These following recommendations are necessary for further studies:

1. The details of structural reinforcement constructed based on SNI 1726-2002 in some areas that resisted more severe earthquake loads due to higher maximum earthquake response factor in SNI 1726-2012 need to be further analyzed.

2. Other buildings were constructed in various shapes, even in asymmetric and rounded shapes. They had various hinge properties and provided different structural performance levels.

3. The structural design process needs to analyze other types of building, such as open frames strengthened by shear walls to provide better performance in resisting earthquake loads.
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