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

Siti Aisyah Nurjannah^{1*}, Yoga Megantara², Erwin Lim³, Iswandi Imran³

¹Civil and Planning Engineering Department, Faculty of Engineering, Universitas Sriwijaya, Jl. Raya Palembang-Prabumulih Km. 32, Indralaya, Indonesia

²Center of Research and Development of People Residence, Ministry of Public Work and People Residence, Jl. Panyawungan, Cileunyi, Bandung, Indonesia

³Structure Research Group, Civil Engineering Department, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Jalan Ganesha No. 10, Bandung 40132, Indonesia

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 is 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.

Table 1. Buildings performance levels.

Non-structural performance levels	Structural performance levels					
	SP-1 IO	SP-2 DC (range)	SP-3 LS	SP-4 li- mit- ed safe- ty (range)	SP-5 SS	SP-6 NC
NP-A O	1-A O	2-A	NR	NR	NR	NR
NP-B IO	1-B IO	2-B	3-B	NR	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

* Corresponding author: sitiaisahn@ft.unsri.ac.id

LS : Life Safety D: reduced strength
RH : Reduced Hazards E : ultimate
SS : Structural Stability NA : Not Applicable
NC : Not Considered

Legend

Commonly ref. building performance levels (SP-NP)
 Other possible combination of SP-NP
 Not recommended combinations of SP-NP

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].

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.

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]:

$$PF_1 = \frac{\left[\sum_{i=1}^N (w_i \phi_{i1}) / g \right]}{\left[\sum_{i=1}^N (w_i \phi_{i1}^2) / g \right]} \quad (1)$$

$$\alpha_1 = \frac{\left[\sum_{i=1}^N (w_i \phi_{i1}) / g \right]}{\left[\sum_{i=1}^N (w_i / g) \right] \left[(w_i \phi_{i1}^2) / g \right]} \quad (2)$$

$$S_a = \frac{V/W}{\alpha_1} \quad (3)$$

$$S_d = \frac{\Delta_{roof}}{PF_1 \phi_{1,roof}} \quad (4)$$

where:

PF_1 is modal participation factor for the first natural mode
 α_1 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)
 Δ_{roof} is roof displacement
 S_a is spectral acceleration
 S_d is spectral displacement

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].

Fig. 4. Response spectrum [1]

$$S_{di} = \frac{T_i^2}{4\pi^2} S_{ai} g \quad (5)$$

$$S_{ai} g = \frac{2\pi}{T_i} S_v \quad (6)$$

$$S_{di} = \frac{T_i}{2\pi} S_v \quad (7)$$

Fig. 5. Demand 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 certain 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 :

$$\beta_{eq} = \beta_o + 0.05 \quad (8)$$

where:

- β_{eq} is equivalent viscous damping of the structure
- β_o 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_{pi}, d_{pi}) 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_{pi}, d_{pi}) or the displacement where the demand spectrum intersects the capacity spectrum is in the allowed value of d_{pi} .
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_{pi}, d_{pi}) 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_{pi}, d_{pi}) is the performance point (a_p, d_p) and the displacement (d_p) represents the maximum expected displacement of the structure due to the demand spectrum of earthquake.

$$SR_A = \frac{1}{B_s} \approx \frac{3.21 - 0.68 \ln(\beta_{eff})}{2.12} \quad (9)$$

$$= \frac{3.21 - 0.68 \ln \left[\frac{63.7\kappa (a_y d_{pi} - d_y a_{pi})}{a_{pi} d_{pi}} + 5 \right]}{2.12}$$

$\geq$ value in Table 2.

$$SR_V = \frac{1}{B_L} \approx \frac{2.31 - 0.41 \ln(\beta_{eff})}{1.65} \quad (10)$$

$$= \frac{2.31 - 0.41 \ln \left[\frac{63.7\kappa (a_y d_{pi} - d_y a_{pi})}{a_{pi} d_{pi}} + 5 \right]}{1.65}$$

$\geq$ value in Table 2.

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_{ys} and f_{us}) 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	ρ
	(mm)	(mm)	(mm)	(mm ²)	(%)
Beam	250	400	4000	*	*
Column C1	300	300	3000	8 D19	2.52
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; ρ : 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].

$$T = \zeta n \quad (11)$$

where

ζ : 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)

Fig. 6. Plans of the structural models

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 (Ω_o), and deflection amplification factor (C_d) were 8, 3, and 5.5, respectively [2] to determine the performance points.

Table 5. Seismic properties

Cities	Soil type	Seismic zone	C_a	C_v		T
			(g)	(g)		(sec.)
Jakarta	Soft	3	0.30	0.75	0.18	1.08
	Medium		0.23	0.33		
	Hard		0.18	0.23		
Bandung	Soft	4	0.34	0.85	0.17	1.02
	Medium		0.28	0.42		
	Hard		0.24	0.30		
Padang	Soft	5	0.36	0.90	0.16	0.96
	Medium		0.32	0.50		
	Hard		0.28	0.35		
Bengkulu	Soft	6	0.38	0.95	0.15	0.90
	Medium		0.36	0.54		
	Hard		0.33	0.42		

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 6. Required beam reinforcement

No.	City	Seismic zone	Soil type	Beam A_s required at support	
				Top	Bottom
				(mm ²)	(mm ²)
1	Jakarta	3	Soft	586	344
2	Jakarta	3	Medium	333	218
3	Jakarta	3	Hard	302	180
4	Bandung	4	Soft	680	404
5	Bandung	4	Medium	401	262
6	Bandung	4	Hard	325	213
7	Padang	5	Soft	725	477
8	Padang	5	Medium	471	302
9	Padang	5	Hard	370	242
10	Bengkulu	6	Soft	760	510
11	Bengkulu	6	Medium	523	302
12	Bengkulu	6	Hard	436	284

Table 7. Applied beam reinforcement

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

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

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 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_v 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.

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) (mm)	Shear (V) (kN)
1	Jakarta	S	2002 2012	151.966 108.334	2058.573 1733.843
2	Jakarta	M	2002 2012	72.577 68.727	1233.548 1183.022
3	Jakarta	H	2002 2012	49.639 55.805	926.965 1013.455
4	Bandung	S	2002 2012	167.336 145.743	2199.403 2095.862
5	Bandung	M	2002 2012	93.806 97.772	1479.055 1521.233
6	Bandung	H	2002 2012	65.739 84.420	1143.815 1379.287
7	Padang	S	2002 2012	182.572 165.782	2268.175 2192.255
8	Padang	M	2002 2012	103.071 110.503	1687.402 1750.212
9	Padang	H	2002 2012	77.956 103.405	1304.140 1574.946
10	Bengkulu	S	2002 2012	196.123 114.366	2319.773 1901.894
11	Bengkulu	M	2002 2012	111.704 93.475	1764.962 1602.170
12	Bengkulu	H	2002 2012	87.791 81.481	1545.995 1487.391

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

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

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

Table 11. Performance points ($T_{eff} - \beta_{eff}$)

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

Table 12. Structural performance level on performance point

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

No./ city/ soil type	Code vers- ion	Performance points	
		Maximum Level	Structure elements
7/ Pdg/ S	2002	LS	Columns (floor 1; edge and middle frames)
	2012	IO	Columns (floor 1; edge and middle frames)
8/ Pdg/ M	2002	B	Beams (floor 2-6); columns (floor 1; edge and middle frames)
	2012	IO	Columns (floor 1; edge & middle frames)
9/ Pdg/ H	2002	B	Beams (floor 2-6); columns (floor 1)
	2012	B	Beams (floor 2-6); columns (floor 1)
10/ Bgl/ S	2002	C	Columns (floor 1, edge frames)
	2012	IO	Columns (floor 1; edge & middle frames)
11/ Bgl/ M	2002	IO	Columns (floor 1; edge & middle frames)
	2012	B	Beams (floor 2-6); columns (floor 1; middle and edge edge frames)
12/ Bgl/ H	2002	B	Beams (floor 2-6); columns (floor 1; middle and edge edge frames)
	2012	B	Beams (floor 2-5); columns (floor 1; middle and edge edge frames)

Notes:

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

Table 13. Structural performance level on ultimate condition

No.	Code vers- ion	Ultimate condition	
		Maximum Level	Structure elements
1/ Jkt/ S	2002	LS	Columns (floor 1, edge and middle frames)
	2012	LS	Columns (floor 1, edge and middle frames)
2/ Jkt/ M	2002	LS	Columns (floor 1, edge and middle frames)
	2012	LS	Columns (floor 1, edge and middle frames)
3/ Jkt/ H	2002	LS	Columns (floor 1, edge and middle frames)
	2012	LS	Columns (floor 1, edge and middle frames)
4/ Bdg/ S	2002	C	Columns (floor 1; edge frames)
	2012	C	Columns (floor 1; edge frames)
5/ Bdg/ M	2002	LS	Columns (floor 1, edge and middle frames)
	2012	LS	Columns (floor 1, edge and middle frames)
6/ Bdg/ H	2002	LS	Columns (floor 1, edge and middle frames)
	2012	LS	Columns (floor 1, edge and middle frames)

No.	Code version	Ultimate condition	
		Maximum Level	Structure elements
7/ Pdg/ S	2002	C	Columns (floor 1; edge frames)
	2012	C	Columns (floor 1; edge frames)
8/ Pdg/ M	2002	LS	Columns (floor 1, edge and middle frames)
	2012	LS	Columns (floor 1, edge and middle frames)
9/ Pdg/ H	2002	LS	Columns (floor 1, edge and middle frames)
	2012	LS	Columns (floor 1, edge and middle frames)
10/ Bgkl/ S	2002	C	Columns (floor 1; edge frames)
	2012	C	Columns (floor 1; edge frames)
11/ Bgkl/ M	2002	C	Columns (floor 1; edge frames)
	2012	C	Columns (floor 1; edge frames)
12/ Bgkl/ H	2002	LS	Columns (floor 1, edge and middle frames)
	2012	LS	Columns (floor 1, edge and middle frames)

The structural levels of performance points became more severe from yield (B) to Immediate Occupancy (IO) and yield (B) to yield (B) with more damaged plastic hinges, respectively, on the structural models in Padang city of medium and hard soil. This was caused by the higher of maximum spectral response acceleration parameters (C_v or S_a) in the current earthquake code [3] than the previous one [2], where the values changed from 0.83 to 0.931 on medium soil and 0.70 to 0.931 on hard soil. The higher spectral response acceleration parameters caused a more severe earthquake load to the structural models and lowered the structural performance.

The opposite behaviour was showed by the structural models in Padang on soft soil and Bengkulu on soft and medium soil, where the structural performance levels of performance point were better from Life Safety (LS) to IO, Collapse (C) to IO, and IO to yield (B). This was because the maximum spectral response acceleration parameters in the current code [3] was less than in the previous code [2] for Padang on soft soil and Bengkulu cities on soft and medium soil, i.e. 0.838 [3] and 0.900 [2]; 0.678 [3] and 0.950 [2], 0.790 [3] and 0.950 [2], respectively.

Other structural models showed the same performance levels according to the previous [2] and current codes [3], such as in Jakarta and Bandung cities on soft soil, in accordance with the IO levels, as well as the medium and hard soils in (B) levels. In the ultimate condition, the structural performance levels of all models were the same which were analysed by the previous [2] and current codes [3]. All structural performance levels on performance point and ultimate condition are presented in Tables 12 and 13, respectively.

5 Conclusions

From the modelling results, the following conclusions were derived:

1. The pushover analysis provides structural models performance in resisting earthquake loads by showing performance levels.
2. The current Indonesian earthquake code (SNI 1726-2012) provides different response spectrum curves compared to the previous (SNI 1726-2002). It implicates more or less severe earthquake loads depending on the areas. The pushover analysis on 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.

References

1. California Seismic Safety Commission, *Applied Technology Council 40 Volume 1: Seismic Evaluation and Retrofit of Concrete Buildings*, (1996).
2. National Standardization Board, *SNI 1726-2002 Procedure for Earthquake Resistant Design of Building Structures* (in Indonesian; 2002).
3. National Standardization Board, *SNI 1726-2012 Procedure for Earthquake Resistant Design of Building and Non-Building Structures* (in Indonesian; 2012).
4. J.R. Qian, W.J. Zhang, and X.D. Ji, *The 14th World Conference on Earthquake Engineering*, Beijing (2008).
5. Computers & Structures, Inc., *SAP2000: Integrated Software for Structural Analysis and Design v.14.1.0*, Berkley, CA, USA.
6. National Standardization Board, *SNI 03-2847-2013 Code of Structural Concrete Requirements of Building Structures*, (in Indonesian; 2013).
7. R.A. Hakim, M.S. Alama, S.A. Ashour, *Arab Journal Science Engineering* **39**:7691–7699 (2014).
8. E.C. Bentz and M.P. Collins, *Response 2000 v. 1.0.5*, University of Toronto.
9. T. Paulay and M.J.N. Priestly, *Seismic Design of Reinforced Concrete and Masonry Buildings*, John Willey & Sons (1992).
10. R.A. Hakim, *Seismic Assessment of RC Building Using Pushover Analysis*, *International Journal of Engineering and Technology Development* **1** (3) ISSN 2337-3180 (2013).
11. Computers & Structures, Inc., *Bridge: Integrated 3-D Bridge Analysis, Design, and Rating*, CA (2017)
12. http://puskim.pu.go.id/Aplikasi/desain_spektra_indonesia_2011/. Accessed on 17th May 2019.