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The Effectiveness of Performance Based Design to Establish Architectural Feature of Structural Design for Slender Building

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This research focuses on the building with reinforcement concrete and has 60,2 meter of height above the ground (14 stories). This system of the slender building has dual system which has shear wall and column to restraint lateral earthquake. The analysis method of this research is comparing behavior buildings designed based on code and alternative design due to earthquake. The building is also designed under MCE level due to strong earthquake risk in Jakarta. For preliminary design, the building is designed based on prescriptive code. The optimization is conducted based on performance based design guidelines (PBD guidelines). In this case, the value of SNI 1726-2012 is larger than MCE level because the code requires minimum strength 0.85CsW. Moreover, the acceptance criteria of code still requires strength concept for all element of the building. The research objectives are to assess the effectiveness of PBD in establishing architectural feature of structural design. The result of this research is the building performance which is designed under MCE level achieves Life Safety. In this case, the design based on PBD has reduced 30% column size with rebar 1% for all columns.

Keywords: ***Slender Building, 14 Stories, Performance Based Design, Maximum Considered Earthquake and Jakarta.***

I. Introduction

The location of Indonesia is in potential earthquake region, since Indonesia lies on the world's most active seismic zone, The Pacific Ring of Fire, and the world's second most active zone, The Alpide Belt. Moreover, Indonesia is surrounded by four major tectonic plates, such as Eurasian Plates, Pacific Plates, Australian Plates, and Philippine Plates.

Jakarta is the capital city of Indonesia which has a numbers of tall buildings. It is located near on many seismic source zones. Figure 1 shows the map of seismic source zone in Jakarta surrounding. According to historical earthquake in Jakarta surrounding (Java and Southern Sumatra interface), the maximum magnitude was 8,1 M on February, 27th 1905

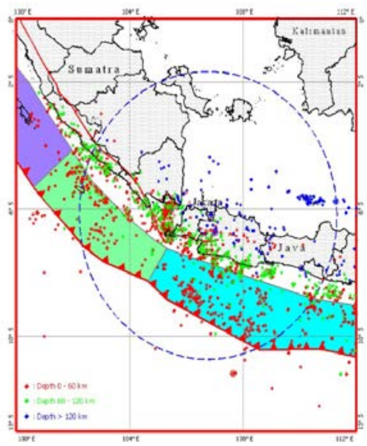


Figure1. Seismic Source Zone in Jakarta Surrounding (Singara, IW., 2012)

This condition is a challenge in designing building under Maximum Considered Earthquake (MCE) in Jakarta with earthquake motion. MCE analysis is required by Performance Based Design (PBD) guidelines. The concept of PBD uses capacity design which is different with the strength concept of code. The capacity design controls element of the building with force control for brittle element and deformation control for ductile element. The advantages of capacity design are to ensure the column strength is higher than the beam strength, to provide more reliable behavior, and to get ductility of structure.

The guidelines of performance design mostly used in United States are Tall Building Initiative 2010 (TBI 2010) and Los Angles Tall Building Structural Design Council 2014 (LATBSDC 2014). The application of LATBSDC 2014 is for buildings which have at least 160 feet (49 meter) of height, and on the other hand with TBI 2010, the application is for buildings which have fundamental period more than 1 second, significant mass participation and lateral response in higher modes vibration, and seismic force-resisting a slender aspect ratio.

To get the realistic behavior of the building, Ground motion of seismic is applied for analyzing the building. Ground motion of each earthquake has a unique set of acceleration that depends on the magnitude, the mechanism earthquake, distance, effect of attenuation, and local site condition. These characteristics are based on selecting recorded motion for Jakarta.

Previous study concerns the comparison design of 72 stories building with SNI 1726-2012 and LATBSDC 2014 in Jakarta by Arasy, S. Amir, et al [2015]. The result of the study provides behavior of tall building design with LATBSDC 2014 and code to get optimization.

To continue the application of PBD in Jakarta, this research analysis the behavior of 14 stories building which includes tall building categorized by alternative design. This aims of the research are to get the realistic behavior of building based on ground motion and get the appropriate design.

II. THEORETICAL BACKGROUND

II.1 Physic Theories of Building Motion

Earthquake can affect building structures under performance in undamaged, minor damaged, and collapse. The damage of the building depends on duration, displacement, and velocity of ground motion. Those have great correlation to the frequency of the wave motion.

The seismic creates inertial force within building to resist a change in velocity. Inertial force is described by Newton's second law. Newton's second law states that the inertial force acting is equal to the mass times the acceleration showed Eq. (1). The inertial force is calculated as follows;

$$F = m\,a \qquad (1)$$

In which F reflects force, which is defined with seismic load, m is mass which can be represented as equivalent to the weight of the building, and a is for acceleration which effects the building motion.

The vulnerability damage also depends on period and frequency of earthquake wave and building motion. Period is time in a cycle of wave and depends on mass and stiffness of structures. Frequency is number of complete the cycles of vibration per second. The inverse of frequency is period. The definitions of period are given by

$$T = \frac{1}{f} \qquad (2)$$

All buildings have their own natural frequency and natural period. The greatest damage occurs if the natural frequency of buildings is close to frequency of ground motion. This case is named the buildings suffer resonance.

Eq. (2) shows the correlation frequency and period. Natural period is an inverse of frequency. The interaction between the natural periods of structure, T_s, the period of ground, T_g, have high priority for designing building to prevent collapse due to resonance.

II.2 Prescriptive Code and Performance Based Design

Prescriptive Code which is used in Indonesia to design is SNI 1726-2012. This code is based on ASCE 7-10 which requires 0.85CsW as minimum strength of building. In contrast, PBD guidelines requires the minimum strength as service level. In PBD guidelines, the expected material properties are used for noncritical element and specified material for critical element. There are many different concepts between prescriptive code and alternative design. The comparisons of them are showed in Table 1.

Table 1. Comparison of SNI 1726-2012 and Performance Base Design

Topic	SNI 1726-2012	PBD	
		LATBSDC 2014	TBI 2010
Minimum Strength	85% Cs W	43-year, 2,5% damped serviceability spectrum	43-year, 2,5% damped serviceability spectrum
Material Properties	Specified Material Properties	Expected Material Properties (non-critical element) Specified Material Properties (critical element)	Expected Material Properties (non-critical element) Specified Material Properties (critical element)
Stiffness Assumptions	Assume Cracking at DBE Level	Assume Cracking at Service Level	Assume Cracking at Service Level
MCE-Level hazard	MCE Level checks were not required	Seven earthquake records	Seven earthquake records

II.3 Structure Parameter

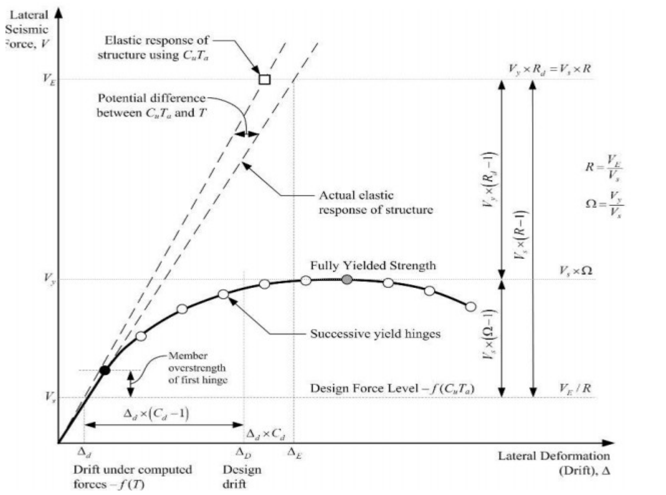


Figure 2. Structure Parameter in Building Code ASCE 7-10

Structure parameter consists of response modification factor R, over strength factor Ω_0, and deflection amplification C_d.

Response modification factor R is the structure parameter to dissipate energy through inelastic behavior. In design process, R factor is used to estimate strength demand of structure. R is calculated as follow;

$$R = \frac{Ve}{Vd} \qquad (3)$$

III. METHODOLOGY

The preliminary design in this research is based on code design SNI 1726-2012 with Linear Procedure (Response Spectrum) and the optimization is based on PBD guidelines, such as TBI 2010 and LATBSDC 2014. The research analyzes the structure with 7 records motion of earthquake under MCE level. The research focuses on optimization to establish architecture feature and optimization. The methodology of this research is showed in figure 3.

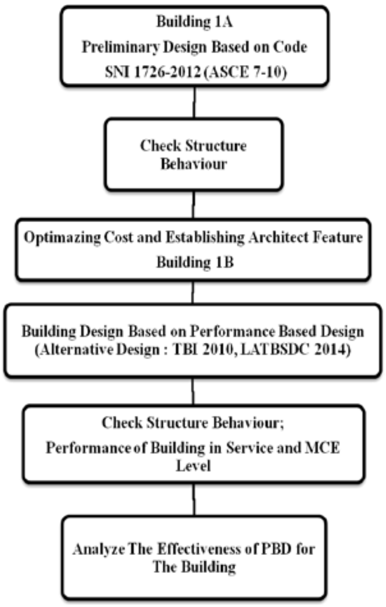


Figure 3. Research Methodology

IV. MODEL DESCRIPTION

IV.1 Ground Motion

Ground motions have been selected to PBD analysis. The selection of ground motion is based on de-aggregation of the Probabilistic Seismic Hazard Analysis (PSHA) and Site Specific Response Analysis (SSRA). Singara, IW (2015) was conducted PSHA and SSRA to find 7 pairs of ground motion which appropriate with potential earthquake near Jakarta. The ground motions which are used in this research are Chi-chi earthquake 1999, Tohoku earthquake 2011, Sitka earthquake 1972, and Landers earthquake 1992.

Figure 4 shows the spectra response in site of Jakarta, Service level and MCE level have 2.5% damping, while Design Level has 5%. Figure 5 shows the ground motions have been scaled for periods ranging from 0.2T to 1.5T.

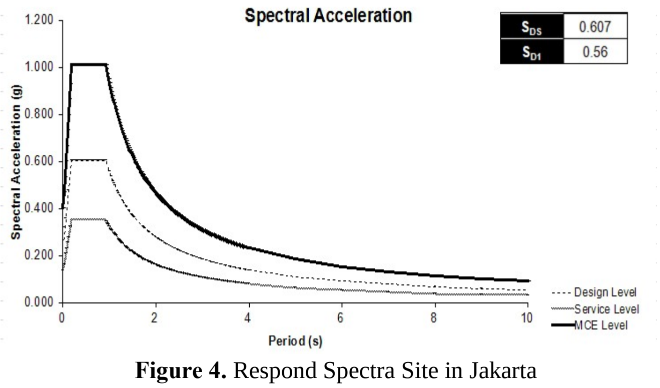


Figure 4. Respond Spectra Site in Jakarta

The research uses 2 dimension analyses for scaling. The strongest components of pairs are selected ground motion. Graphic 2 shows the averaged ground motion is scaled in 0.2T to 1.5T, where T is fundamental period. In period ranging from 0.2T to 1.5T, the average is not less than the MCE response spectrum for the site.

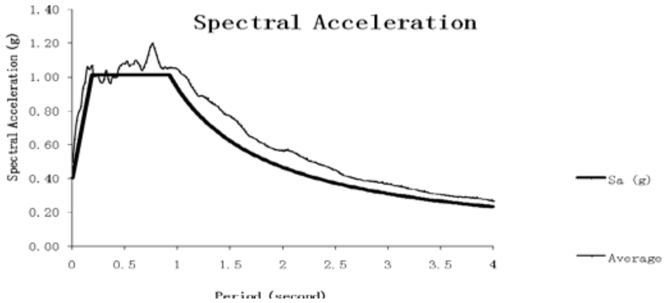


Figure 5. Response Spectra and Averaged Suite Motion

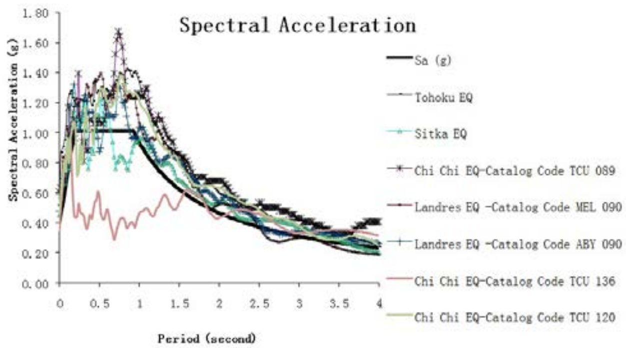
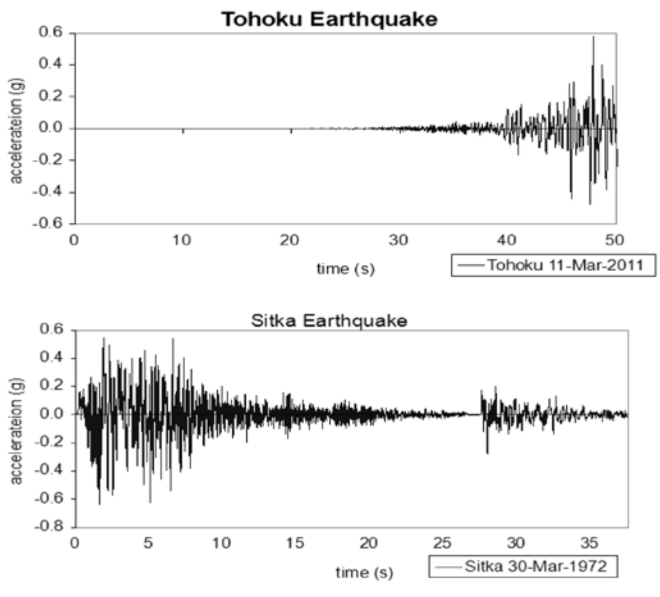


Figure 6. Response Spectra of Suite Motion Scaled

Figure 6 shows the scaled ground motions which suite for Jakarta site. The ground motions have been already above spectral design in range 0.2T to 1.5T. With T 2.66 s, the range is 0.53 s to 4 s.

Figure 7 shows the ground motions have been scaled for periods ranging from 0.2T to 1.5T.



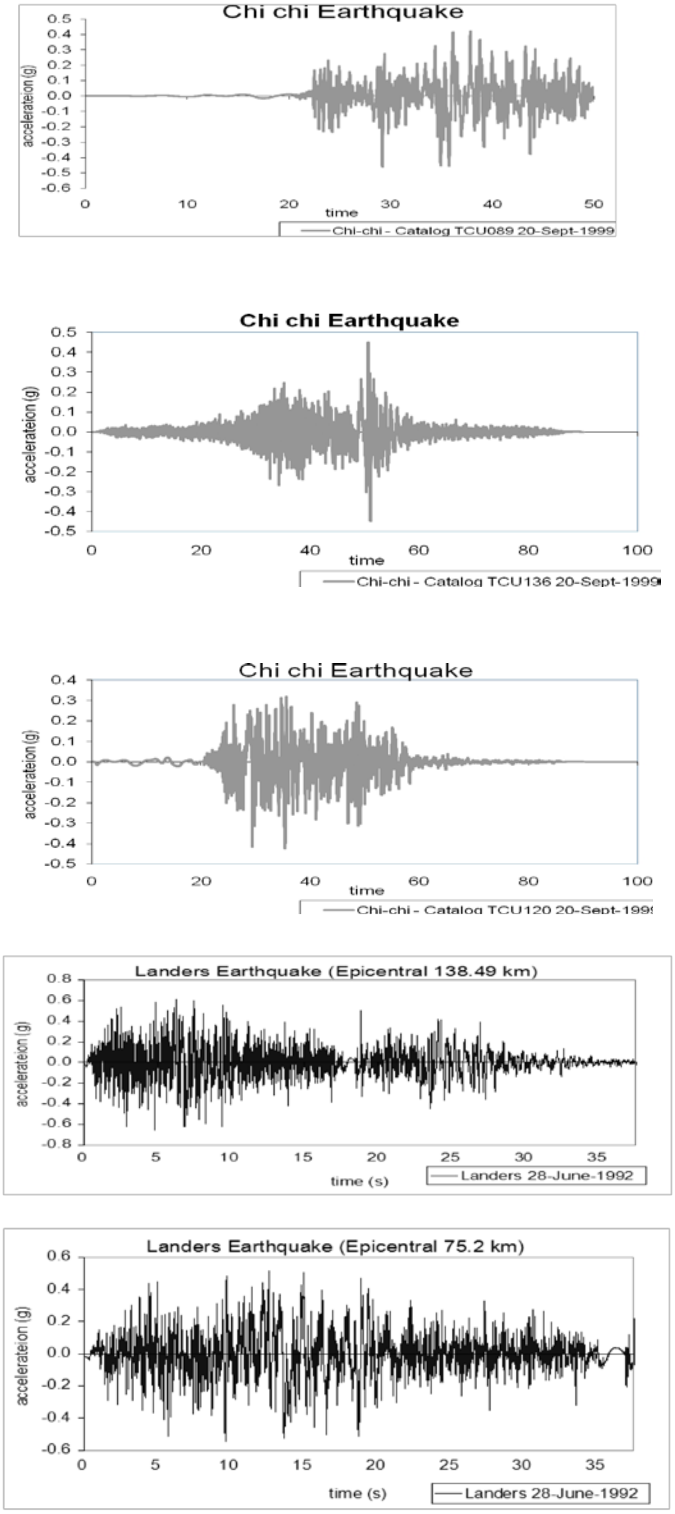


Figure 7. Ground Motions have been Scaled for Period 0.2T to 1.5T

IV.2 Building Structure

The building is an apartment that consists of 14 stories, 60,2 meter. The building which is located in Jakarta is constructed with reinforcement concrete and has resistance lateral load, such as shear wall and column. Table 2 shows the concrete grade. The concrete grade of shear wall and column is 45 MPa, for slab and beam is 35 MPa, and the steel grade is Fy 400 MPa. Area of the building is ± 840.38 m2 in each level. The preliminary is designed based on SNI 1726- 2012 by program Etabs 2013. Figure 8 and 9 show the building design in Etabs.

Table 2. Concrete Grade of Element

Strength, f'c (Mpa)	Element
35	Beam and Slab
45	Column and Shear Wall

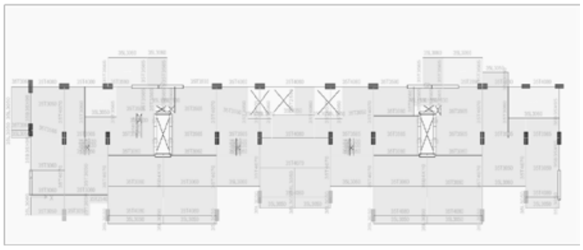


Figure 8. Floor Plan Typical in Etabs 2013

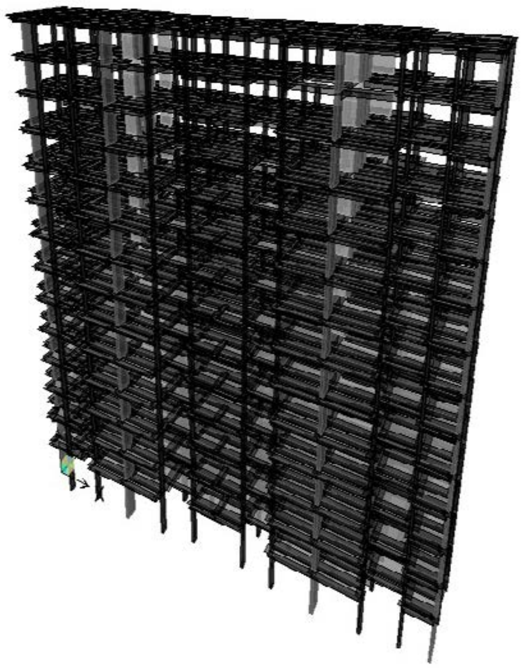


Figure 9. Design of Building in Etabs 2013

Figure 9 shows three dimension of structures in Etabs. The element size of preliminary building design is described in Table 3 and 4. Table 5 shows the optimization of Column Size in building 1B.

Table 3. Beam Size of Building

Element Structure	Building 1A Based on Prescriptive Code	Building 1B Based on PBD
Beam	B150x300	B 150x300
	B300x600	B 300x600
	B250x400	B 250x400
	B300x500	B 300x500
	B300x700	B 300x700
	B350x650	B 350x650
	B350x950	B 350x950
	B400x800	B 400x800

Table 4. Column Size of Building 1A

Column Type	Column Size (mm) and Height (m) LGF~L6 Column Size (mm)	L6~L10 Column Size (mm)	L10~ROOF Column Size (mm)	Total (n)	Volume (m3)
K1	500X1200	400X1000	400X800	10	269.92
K2	400X1100	400X1000	400X800	1	23.34
K3	400X1100	400X1000	400X800	3	70.03
K4	500X1300	500X1200	500X1100	6	217.38
K5	500X1300	500X1200	500X1100	2	72.46
K6	500X1300	500X1200	500X1100	6	217.38
				Total	870.52

Table 5. Optimization of Column Size

Column Type	Column Size (mm) and Height (m) LGF~L8 Column Size (mm)	L8~L10 Column Size (mm)	L10~ROOF Column Size (mm)	Total (n)	Volume (m3)
K1	400X1000	400X800	400X800	10	217.60
K2	400X1000	400X800	400X800	1	21.76
K3	400X1000	400X800	400X800	3	65.28
K4	400X1000	400X800	400X800	6	130.56
K5	400X1000	400X800	400X800	2	43.52
K6	400X1000	400X800	400X800	6	130.56
				Total	609.28

V. Analysis and Result

V.1 Frequency and Natural Period of Ground Motion

The frequency value is used to analysis the probability of resonance for the building. Frequency can be observed from each suite ground motion. Table 6 describes velocity maximum, acceleration maximum, frequency and period of ground motion. Table 6 describes range period of ground motion T_g is 0.12-0.76 s.

Table 6. Frequency and Period of Ground Motion

Earthquake	Velocity Max (cm/s)	Acceleration Max (cm/s2)	Frequency	T_g (s)
Tohoku	89.82	0.58	1.77	0.56
Sitka	123.54	0.53	1.92	0.52
Chi-Chi TCU089	120.22	0.58	1.81	0.55
Chi-Chi TCU136	98.80	0.52	8.33	0.12
Chi-Chi TCU120	59.80	0.42	1.32	0.76
Landres MEL 090	127.52	0.54	1.94	0.51
Landres ABY 090	86.22	0.53	1.95	0.51

V.2 Modal Analysis

The natural period of building 1A is 2.66 s and 2.48 s in principal direction x-axis 0.72 and y-axis 0.74 modal participating mass ratios. In MCE level, the natural period of the building 1B is 2.46 s and 2.35 s in principal direction x-axis 0.50 and y-axis 0.66 modal participating mass ratios. Table 7 shows modal analysis.

Table 7. Modal Analysis

Model	Earthquake Level	Fundamental	Mass
Building 1A-Code	2/3 MCE Level	T_1 = 2.66 s	Ux 0.72
		T_2 = 2.48 s	Uy 0.74
Building 1B-PBD	Service Level	T_1 = 2.32 s	Ux 0.50
		T_2 = 2.08 s	Uy 0.66
	MCE Level	T_1 = 2.46 s	Ux 0.50
		T_2 = 2.35 s	Uy 0.66

V.3 Base Shear

The weight of building 1A is 25422 ton and 1B 25275 ton. Table 8 shows the base shear of code based design in level design and PBD in MCE level. CBD considers minimum strength requirement 85% Cs W.

Table 8. Comparison Story Shear of CBD and PBD

Code SNI 1726-2012- Building 1A		
V_{design}	11695	KN
PBD – MCE Level Time History Method- Buidling 1B		
V_{yield}	16000	KN
$V_{ultimate}$	37897	KN
$V_{elastic}$	95060	KN

V.4 Structure Parameter

Structure parameters (R, Ω_0, and C_d) are important parameter that accounts structural capacity. Structure parameters are calculated with ASCE 7-10. Table 9 describes R factor of building 1B is accepted due to $V_{yield} > V_{design}$, C_d value is 2.75 and Ω_0 1.90.

Table 9. Structure Parameter Optimization (Building 1B-PBD)

PBD – 2/3 MCE Level Time History Method - Building 1B		
U_{design}	0.24	meter
U_{yield}	0.30	meter
$U_{ultimate}$	0.66	meter
V_{design}	11708	KN
V_{yield}	14537	KN
$V_{ultimate}$	21980	KN
Cd Factor	2.75	
Ω_0	1.90	
R Factor	vyield > vdesign; R factor ok	

V.5 Building Performance

The PBD is conducted to show building 1B performance. The performance can show the level damage of building. The performance are immediate occupancy (no damage in structure), life safety (minor damage in structure), and collapse prevention.

The PBD guidelines require Non Linear Dynamic analysis for MCE level (strong earthquake) to get reliable behavior structure and service level with Pushover or Nonlinear Dynamic Analysis. The research finds the different result between Linear Dynamic Analysis and Nonlinear Dynamic Analysis in building 1B performance under MCE level. Table 10 describes building 1B performance with pushover method. Figure 10 shows performance in Life safety under MCE level.

Table 10. Performance Level for Element Structure (Pushover)

Load Case	Performance Buiding 1B			
	Elastic	IO	LS	CP
Gravity Load	100%	-	-	-
Service Level	100%	-	-	-
MCE Level	77%	15%	8%	-
(yellow)	Acceptance Limit			

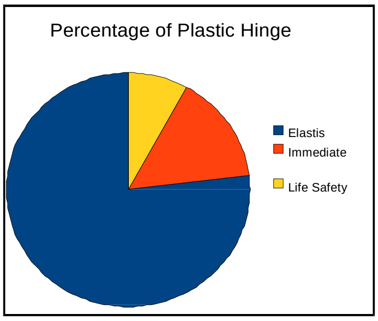


Figure 10. Graphic Building Performance

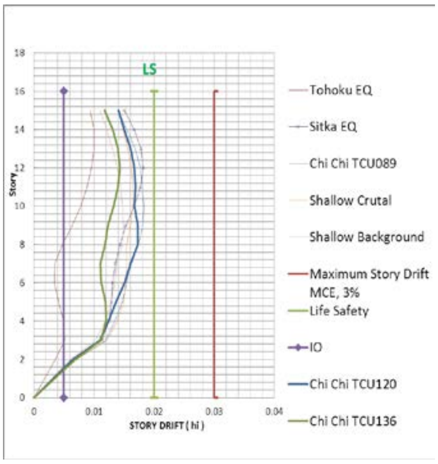


Figure 11. Story Drift Building 1B under MCE Level in Life Safety

Table 10 show building 1B remains elastic in service level. In MCE level, plastic hinges are found 8% in Life Safety and 15% in Immediate Occupancy. Figure 11 describes building 1B achieves Life Safety with time history analysis.

Figure 12 and 13 show the plastic hinge in Immediate Occupancy of elements in design level. The analysis of design level is conducted to shows the performance. The building which is analyzed under service level and MCE level has safety level in design level. The reason is considered of PBD to not require analysis in design level.

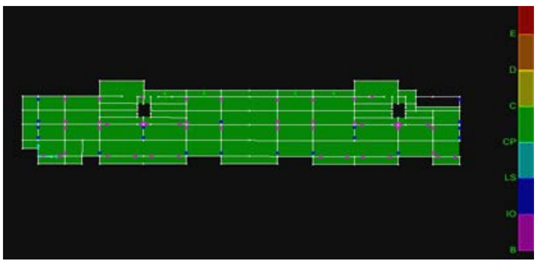


Figure 12. Plastic Hinges Achieve IO of Building 1B Floor Plan With Chi-chi Time History in Design Level

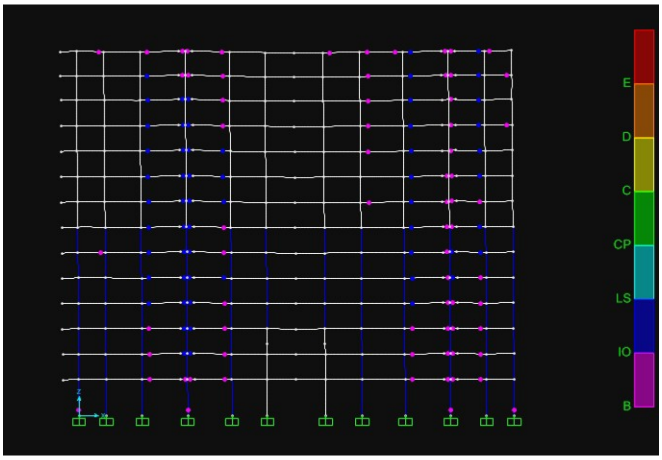


Figure 13. Plastic Hinges Achieve IO of Building 1B Elevation with Chi-chi Time History in Design Level

V.6 Efficiency of Using PBD

PBD optimizes column size which establish architectural feature. Table 11 describes the result of the optimization column size with rebar 1% for all columns. The PBD reduces 30% column volume CBD (870.52 – 609.28 = 261.24m^3).

Table 11. Reinforcement Comparison in Ground Floor –L6

Building 1A-CBD		Building 1B-PBD	
Column Size	Rebar Reinforcement (%)	Column Size	Rebar Reinforcement (%)
K1 500X1200	2.0%	K1 400x1000	1%
K2 400x1100	1.6%	K2 400x1000	1%
K3 400x1100	3.1%	K3 400x1000	1%
K4 500X1300	4.0%	K4 400x1000	1%
K5 500X1300	1.4%	K5 400x1000	1%
K6 500X1300	2.7%	K6 400x1000	1%

VI. CONCLUSION

In conclusion, CBD and PBD have different concept to design structure. CBD (SNI 1726-2012) uses strength based concept and PBD guidelines use capacity based design concept. PBD requires design process to approach reality, so the PBD concept reduces the implementation of the structure parameters, such as R, Ω_0, and C_d.

In this case, slender building 14 stories uses preliminary design in building 1A with SNI 1726-2012 which is design regulation in Indonesia. To establish the architectural feature in space, the performance of building 1b is conducted with PBD. The building 1B performance is life safety under MCE level. The result, PBD have reduced 30% column size with longitudinal reinforcement 1% for all columns. The column size is important factor to establish architectural feature. These result show the PBD for building slender 14 stories in this case is effective to establish space for architectural feature.

VII. ACKNOWLEDGEMENTS

The research was supported by PT Wiratman. The author is grateful to PT Wiratman.

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