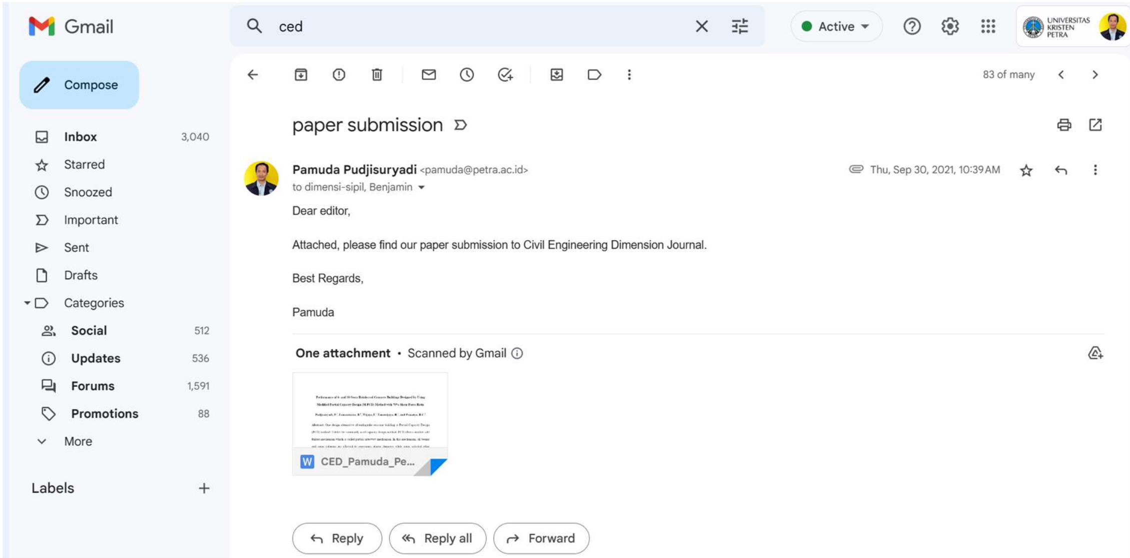
Daftar Korespondensi artikel:

Performance of Six- and Ten-story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio

Civil Engineering Dimension, Vol.23, No.2, September 2021

1. Submitted to the journal "Civil Engineering Dimension". (30-09-2021).
2. Submitted to the journal "Civil Engineering Dimension", abstract revision. (30-09-2021).
3. Revision, some suggested corrections need to be done, deadline before 02-10-2021. Comments include: wording suggestion, incomplete sentence (unclear information), a reference is still in Indonesian (01-10-2021).
4. Submitted to the journal "Civil Engineering Dimension", revised paper. (01-10-2021).
5. Paper is accepted, with minor redactional revision done by editor. (02-10-2021).

1. Submitted to the journal “Civil Engineering Dimension”. (30-09-2021).



Performance of 6- and 10-Story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio

Pudjisuryadi, P.[1], Lumantarna, B.[1], Wijaya,F.[1] Tanuwijaya, R.[2], and Prasetyo, B.C.[2]

Abstract: One design alternative of earthquake resistant building is Partial Capacity Design (PCD) method. Unlike the commonly used capacity design method, PCD allows another safe failure mechanism which is called partial sidesway mechanism. In this mechanism, all beams and some columns are allowed to experience plastic damages while some selected other columns (elastic columns) are designed to remain elastic. Recent development of PCD, which is called the Modified-PCD suggests the use of two structural models to predict required strengths needed to design each structural member. The first structural model is used to design elements which are allowed to yield during major earthquakes. This model is subjected to earthquake with seismic reduction factor R=8 (design earthquake). The second structural model is modified from the first one by reducing stiffness of members that may develop plastic hinges, and subjected to the difference between target earthquake (R=1.6) and design earthquake (R=8). The required strengths of the elastic columns are simply the sum of the two structural models. In this research 6- and 10-story reinforced concrete buildings were designed by using M-PCD, and their seismic performances were investigated. The base shear force resisted by the elastic columns was set to approximately 70% of the total base shear. The seismic load used was spectrum consistent ground accelerations generated from El Centro 18 May 1940 earthquake N-S and E-W components in accordance to Indonesian Seismic Code [1]. Both nonlinear static procedure (NSP) and nonlinear dynamic procedure (NDP) were used to analyze the structures. The results shows that the expected partial side sway mechanism is observed, and the drifts of the buildings meet the requirements of FEMA 273 [2].

Keywords: modified partial capacity design; partial side sway mechanism; reinforced concrete; seismic design.

Introduction

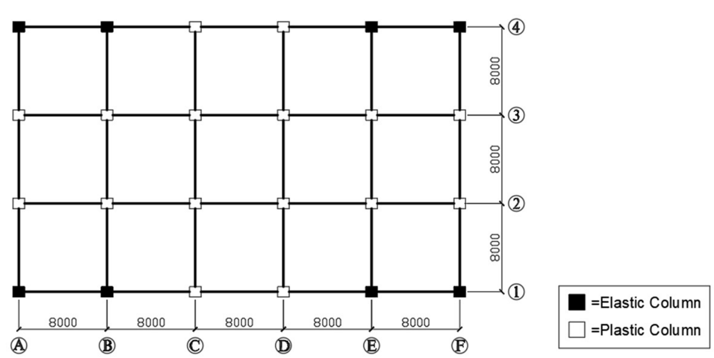
In the design of earthquake resistant structures, one alternative of the capacity design method is partial capacity design (PCD) method. The PCD method allows other safe failure mechanism proposed by Paulay and Priestley [3] which is called the partial sidesway mechanism. In this mechanism, some of columns are allowed to experience plastic damages while other columns (elastic columns) are intended to remain elastic during target earthquake. The challenge of this concept is how well the prediction of structural members' required strength. Early PCD method proposed that elastic columns need to be designed by using a single magnification factor which scales up their internal forces from a design earthquake. Seismic reduction factor of 8.0 was used to define the design earthquake with the assumption that the structure possesses good ductility. However, some studies showed that the performance of the method was somehow inconsistent. Based on the first study that used the single magnification factor to design the elastic columns, the test results showed that plastic hinges still occurred on the elastic column in the nonlinear time history analysis [4]. The other studies that used the single magnification factor with other variations of building that have vertical setback showed unsatisfied results because the partial side sway mechanism was not achieved effectively [5,6]. A more accurate approach in predicting the required strengths may be one of the answers to improve PCD method.

Recently, Tanaya [7] proposed a new approach in predicting the required strength to design the elastic columns. This new approach is called Modified-PCD (M-PCD). The M-PCD suggests the use of two structural models to predict required strengths needed to design each structural member. The first structural model was used to design elements which are allowed to yield during major earthquakes. This model was subjected to earthquake with seismic reduction factor R=8 (design earthquake). The second structural model was modified from the first one by reducing stiffness of members that may develop plastic hinges, and subjected to a target earthquake (R=1.6). This second model was used to design the elastic. Early test showed promising results, that most structure showed the expected partial sidesway mechanism and the drifts are well below the maximum values set by FEMA 273 [2]. However, more tests are needed to further develop and conform the effectiveness of this new approach.

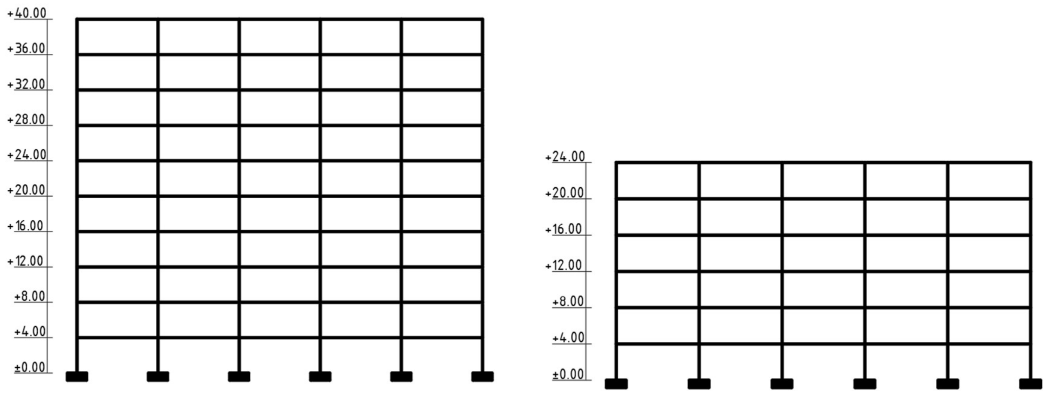
In this research, improvement of M-PCD proposed by Tanaya [7] is suggested. The second model is not subjected to full target earthquake, instead it is subjected by the difference between target earthquake and design earthquake used in the first model. This is logical, since after some members develop plastic damages, only the remaining earthquake load (beyond design earthquake) will be distributed according to structural responses of the second model. With this improvement, buildings similar to Tanaya's research are re-designed and investigated.

Model and Design of the Buildings

SAP2000 software [8] is used to model the buildings. The buildings are assumed to be located in Surabaya resting on soil with Site Class E, and intended as office building. The applied gravity loads were according to SNI 1727:2013 [9]. The building plans and elevation views can be seen in Figure 1.



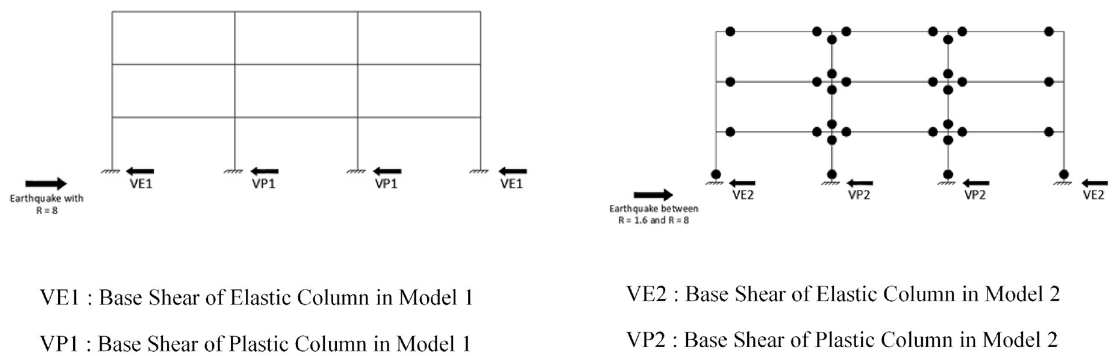
(a)



(b)

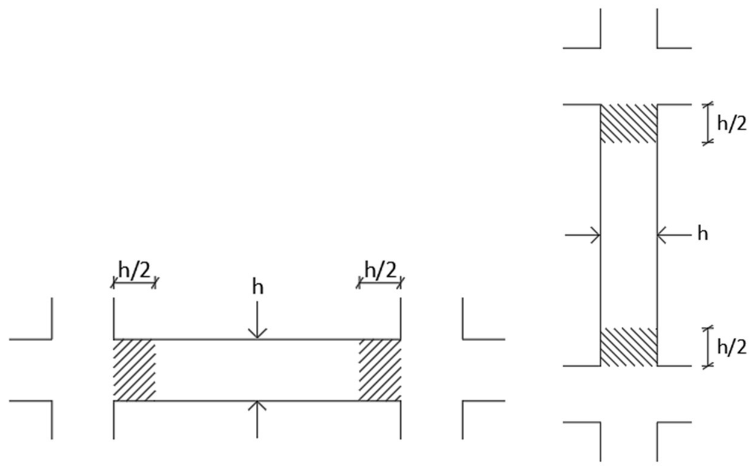
Figure 1. Observed structures: (a) Plan view; (b) Elevation view

In this study, the ratio of shear force resisted by elastic columns with respect to total base shear is approximately set as large as 70%, resulting in the use of eight elastic columns (Figure 1a). As mentioned in introduction, the two structural models are used in this approach. Illustration of these two structural models as well as seismic load (based on SNI 1726:2012 [1]) subjected to each model are shown in Figure 2. The modification factors (R) of 8.0 and 1.6 are chosen with the assumptions that the damaged frame members possess good ductility and elastic columns remain elastic, respectively. The stiffness reduction to simulate plastic damages is done by breaking the elements into three parts. Two of the parts are located close to element supports with the length of $0.5h_{element}$ (typical plastic hinge region), which flexural stiffnesses are reduced to model plastic hinges (see Figure 3). The flexural stiffness modification may be determined by looking at typical bilinear curve of moment-rotation curves of reinforced concrete section.



(a) (b)

Figure 2. Design assumption: (a) Model 1; (b) Model 2



(a) (b)

Figure 3. Stiffness reduction in Model 2 at: (a) Beam; (b) Column

Results from the first model are used to design the beams and plastic columns which may develop plastic damages. Since the columns may experience damages, the strong column weak beam requirement is neglected in this approach. However, the shear design of both beams and columns should still follow the capacity design concept since no shear failure is allowed. Required strengths used for designing the elastic columns are determined by combining the internal forces from both models. It should be noted that the effect of gravity load should only calculated once when combining results from both models. Again, only shear design of the elastic columns should follow standard capacity design approach. The base shear distribution ratio of the structure can be seen in Table 1. The design results of the beams and columns can be seen in Table 2, 3, and 4.

Table 1. Base Shear Distribution Ratio of Elastic Column for (a) 6-Story and (b) 10-Story Building

Design Earthquake X Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)	Design Earthquake Y Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)
Model 1	2055.09	1013.99	Model 1	1907.64	849.24
Model 2	3101.46	2791.54	Model 2	3096.14	2770.44
Total	5156.55	3805.53	Total	5003.78	3619.68
Shear Force Distribution Ratio		73.80%	**Shear Force Distribution Ratio**		72.34%

(a)

Design Earthquake X Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)	Design Earthquake Y Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)
Model 1	2452.52	1513.95	Model 1	2274.09	1441.90
Model 2	5611.75	3998.33	Model 2	5596.76	3880.43
Total	8064.27	5512.28	Total	7870.85	5322.33
Shear Force Distribution Ratio		68.35%	**Shear Force Distribution Ratio**		67.62%

(b)

Table 2. Reinforcement Details of 6-Story Building (a) Beam (b) Plastic Column

Type	Dimension	Position	Longitudinal			Transversal
			ρ	Reinforcement	Strength Ratio	s
BI-1	300x700	Top	1.04%	7D19	0.91	2D10-110
		Bottom	0.59%	4D19	0.76	
BI-2	300x700	Top	1.04%	7D19	0.98	2D10-110
		Bottom	0.59%	4D19	0.82	
BI-3	300x700	Top	0.89%	6D19	0.97	2D10-110
		Bottom	0.44%	3D19	0.93	
BI-4	300x700	Top	0.74%	5D19	0.92	2D10-110
		Bottom	0.44%	3D19	0.78	

(a)

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
6	350x350	4.51%	16D19	0.69	2D13-60
5	350x350	4.51%	16D19	0.78	2D13-60
4	400x400	3.36%	16D19	0.89	3D13-90
3	450x450	2.60%	16D19	0.94	3D13-100
2	450x450	3.90%	24D19	0.89	3D13-100
1	500x500	2.59%	20D19	0.79	3D13-100

(b)

Table 3. Reinforcement Details of 10-Story Building (a) Beam (b) Plastic Column

Type	Dimension	Position	Longitudinal			Transversal
			ρ	Reinforcement	Strength Ratio	s
BI-1	300x700	Top	0.89%	6D19	0.91	2D10-110
		Bottom	0.44%	3D19	0.88	
BI-2	300x700	Top	1.03%	7D19	0.94	2D10-110
		Bottom	0.59%	4D19	0.79	
BI-3	300x700	Top	1.18%	8D19	0.93	2D10-110
		Bottom	0.59%	4D19	0.89	
BI-4	300x700	Top	0.74%	5D19	0.92	2D10-110
		Bottom	0.44%	3D19	0.74	
BI-5	300x700	Top	1.33%	9D19	0.95	2D10-110
		Bottom	0.74%	5D19	0.81	
BI-6	300x700	Top	1.48%	10D19	0.95	2D10-110
		Bottom	0.74%	5D19	0.89	

(a)

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
10	350x350	4.96%	16D22	0.88	2D13-60
9	350x350	3.72%	12D22	0.96	2D13-60
8	400x400	3.80%	16D22	0.94	3D13-100
7	400x400	3.80%	16D22	0.93	3D13-100
6	450x450	3.00%	16D22	0.94	3D13-100
5	450x450	4.50%	24D22	0.95	3D13-100
4	500x500	3.65%	24D22	0.92	3D13-100
3	500x500	4.86%	32D22	0.92	3D13-100
2	600x600	2.11%	20D22	0.91	3D13-100
1	600x600	2.96%	28D22	0.93	3D13-100

(b)

Table 4. Reinforcement Details of Elastic Column (a) 6-Story Building (b) 10-Story Building

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
6	700x700	3.94%	24D32	0.98	3D13-100
5	700x700	5.25%	32D32	0.97	3D13-100
4	700x700	5.91%	36D32	0.94	3D13-100
3	700x700	4.59%	28D32	0.93	3D13-100
2	700x700	3.94%	24D32	0.96	3D13-90
1	700x700	2.62%	16D32	0.99	3D13-90

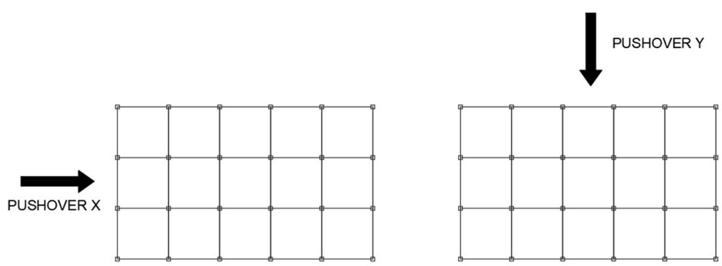
(a)

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
10	900x900	2.48%	16D40	0.90	4D13-100
9	900x900	3.10%	20D40	0.99	4D13-100
8	900x900	4.96%	32D40	0.87	4D13-100
7	900x900	4.96%	32D40	0.99	4D13-100
6	900x900	5.58%	36D40	0.96	4D13-100
5	900x900	5.58%	36D40	0.97	4D13-100
4	900x900	4.96%	32D40	0.95	4D13-100
3	900x900	4.34%	28D40	0.96	4D13-100
2	900x900	3.10%	20D40	0.86	4D13-100
1	900x900	3.72%	24D40	0.94	4D13-100

(b)

Buildings' Performances Analysis

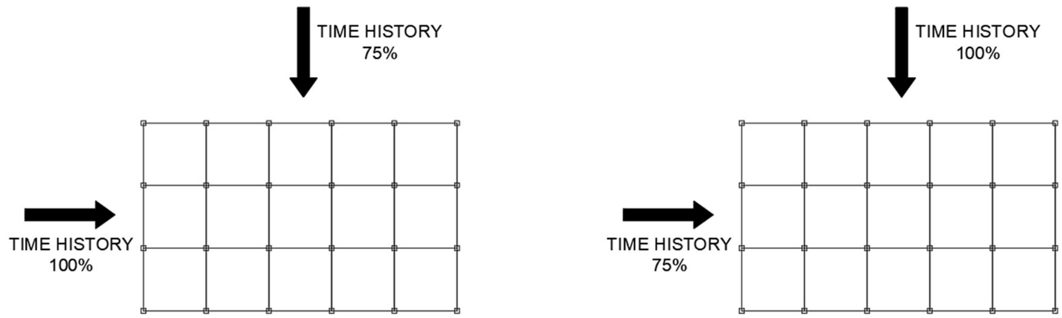
analysis is conducted twice for each building to model dominant earthquake in each orthogonal direction (see Figure 4). Performance of the buildings are reported at two levels of earthquakes which are the elThe buildings are analyzed with nonlinear static procedure (NSP) and nonlinear dynamic procedure (NDP) by using SAP 2000 software [8]. The NSP Plastic design response spectrum (EDRS) and maximum considered earthquakes (MCER) which is 1.5 times of EDRS. The load pattern used in NSP is the first translational mode of the corresponding directions.



(a) (b)

Figure 4. Nonlinear Static Procedure (NSP) in: (a) X-direction (b) Y-direction

In NDP analysis, the seismic load used is spectrum consistent ground accelerations generated from El Centro 18 May 1940 earthquake N-S and E-W components in accordance to Indonesian Seismic Code (SNI 1726:2012 [1]). Two level of acceleration response spectrums to match are the elastic design response spectrum (EDRS) and spectrum corresponding to maximum considered earthquake (MCER). The buildings are subjected to two-directional ground motion which peak ground accelerations ratio (4:3) is taken the same as the original earthquake motion. Illustration of the ground motions used for analysis are presented in Figure 5.

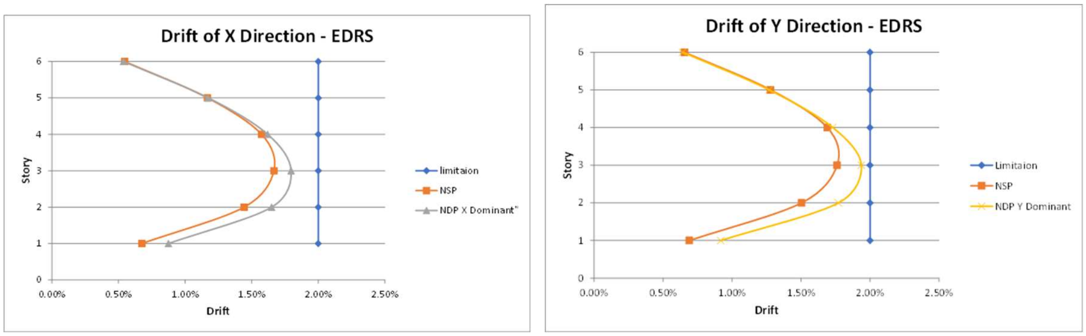


(a) (b)

Figure 5. Nonlinear Dynamic Procedure (NDP) with dominant ground motion in: (a) X-Dominant (b) Y-Dominant

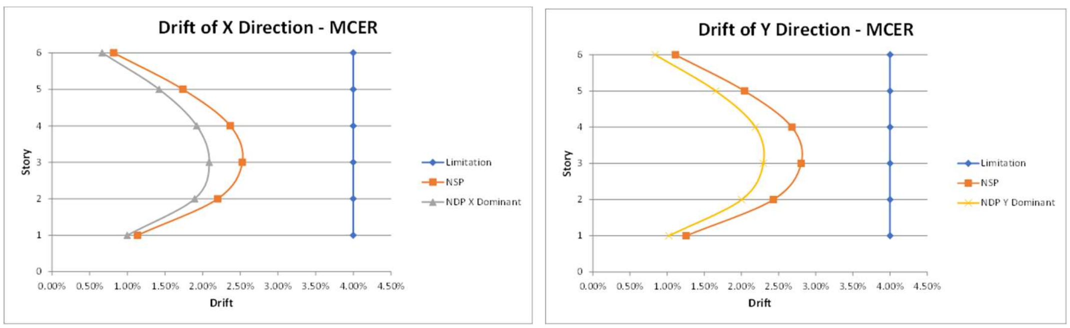
Analysis results

The drifts of the buildings are presented in Figures 6 to 9. The drifts are plotted against limitation according to FEMA 273 [2], which are 2% for design earthquake (EDRS) and and 4% for maximum considered (MCER) earthquake. It can be seen in Figures 6 and 7, that the 6-story building performs very well as all drifts satisfy the allowable drift in both directions and both earthquake levels. In X-direction, it is recorded that the maximum drifts are 1.80% and 2.53% for EDRS and MCER earthquakes, respectively. While in Y-direction, the drifts are 1.94% and 2.80% for EDRS and MCER earthquakes, respectively.



(a) (b)

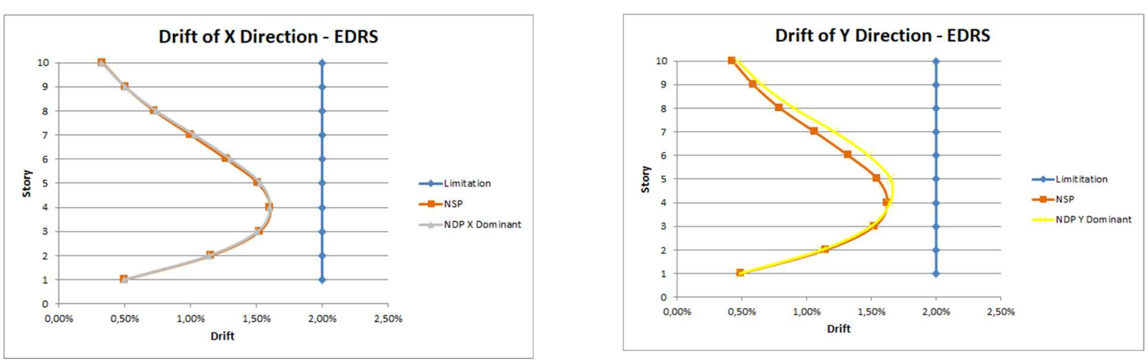
Figure 6. Drifts of 6-Story building for EDRS in: (a) X-direction; (b) Y-direction



(a) (b)

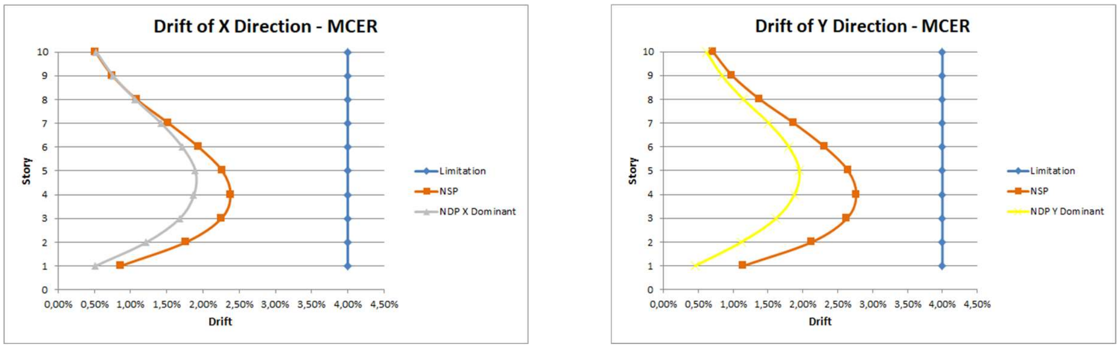
Figure 7. Drifts of 6-Story building for MCER in: (a) X-direction; (b) Y-direction

Similar performances are seen at 10-story buildings that all the drifts meet the requirement by FEMA 273. In Figures 8 and 9, it can be observed that the drifts of the buildings at EDRS and MCER earthquakes are 1.60% and 2.38% in X-direction, and 1.65% and 2.76% in Y-direction.



(a) (b)

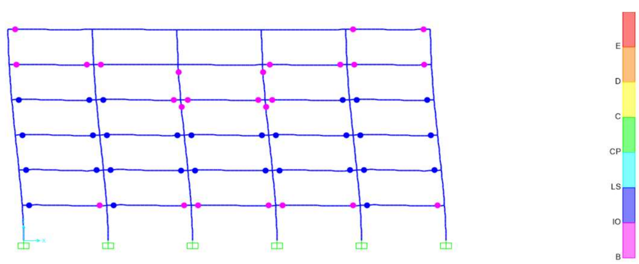
Figure 8. Drift of 10-Story Building for EDRS in: (a) X Direction (b) Y Direction



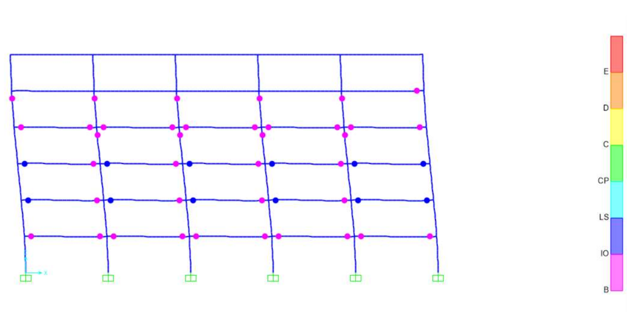
(a) (b)

Figure 9. Drift of 10-Story Building for MCER in: (a) X Direction (b) Y Direction

In order to make sure if the buildings have good performance, safe failure mechanism should be investigated. From all variations of the analysis (the number of story, the level of earthquake used for analysis, the analysis procedures, and direction of dominant earthquake), it is observed that there are no plastic damages in the elastic columns which means the structures can resist the earthquakes with safe partial sidesway mechanism. Figures 10 to 13 show typical plastic damages of the frames.

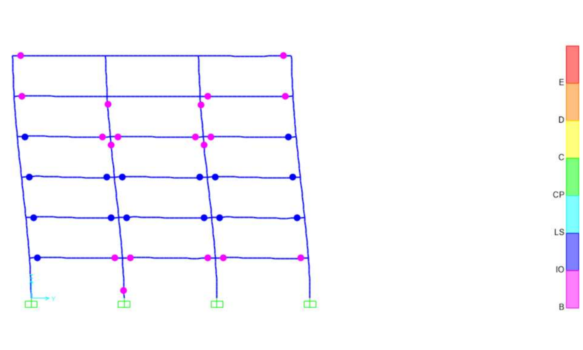


(a)

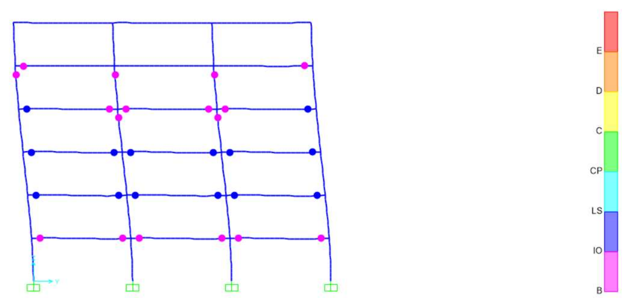


(b)

Figure 10. Plastic Damages of 6-story building from NSP analysis with EDRS earthquake level in X-direction: (a) Frame 1; and (b) Frame 2

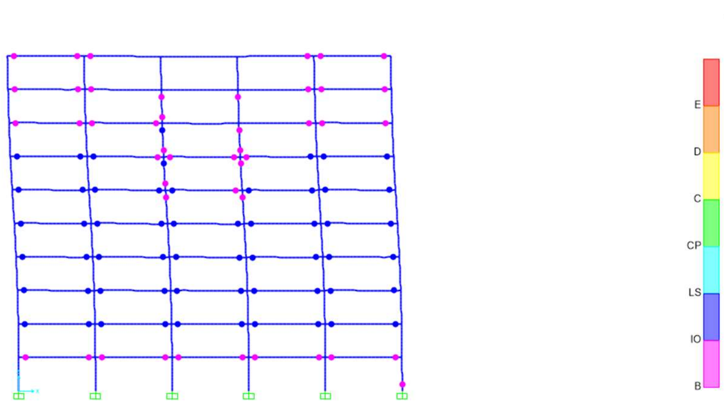


(a)

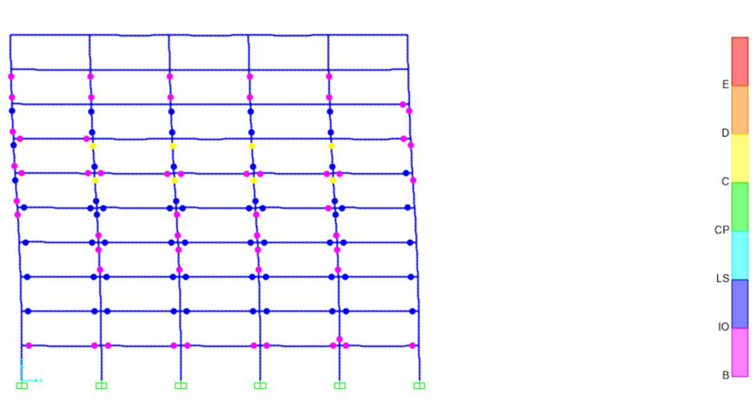


(b)

Figure 11. Plastic Damages of 6-story building from NSP analysis with EDRS earthquake level in Y-direction (a) Frame A; and (b) Frame C

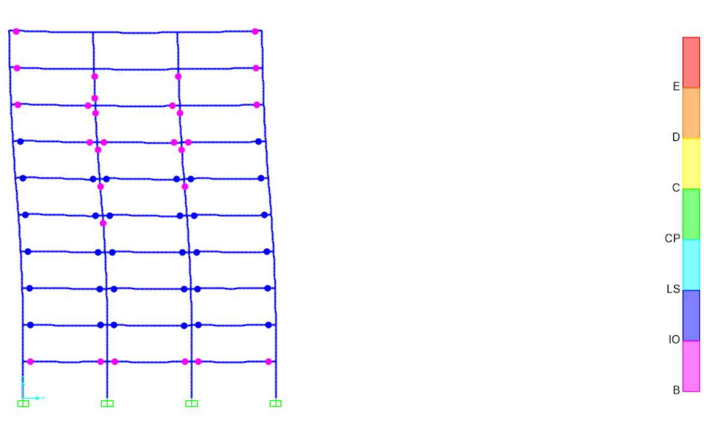


(a)

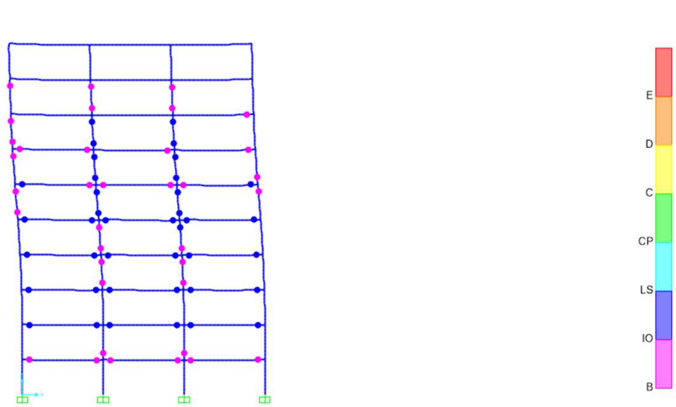


(b)

Figure 12. Plastic Damages of 10-story building from NDP analysis with MCER earthquake level in X-direction (a) Frame 1; and (b) Frame 2



(a)



(b)

Figure 13. Plastic Damages of 10-story building from NDP analysis with MCER earthquake level in Y-direction (a) Frame A; and (b) Frame C

Moreover, from the analysis results, it can be observed how far the deviation of shear force ratio resisted by the elastic columns. The shear force distribution ratio are presented in Table 5. In the design stage, this ratio is set approximately 70% with the assumption that all members experience plastic damages except the elastic columns. Since the actual performance seen in Figures 11 to 22 show less damages, it is logical if the shear force resisted by the elastic columns are less than 70%.

Table 5. Actual Base Shear Distribution Ratio of (a) 6-Story Building and (b) 10-Story Building

	X Direction	Y Direction
Design	73.80%	72.34%
Pushover EDRS	44.77%	42.05%
Pushover MCER	39.92%	42.56%
Time History X Dominant EDRS	50.63%	41.97%
Time History Y Dominant EDRS	49.78%	48.46%
Time History X Dominant MCER	49.54%	44.55%
Time History Y Dominant MCER	45.29%	47.82%

	X Direction	Y Direction
Design	68.35%	67.62%
Pushover EDRS	59.79%	58.72%
Pushover MCER	51.31%	49.93%
Time History Dominan X EDRS	59.91%	56.50%
Time History Dominan Y EDRS	58.17%	58.80%
Time History Dominan X MCER	59.50%	59.35%
Time History Dominan Y MCER	59.67%	58.95%

(a)

(b)

Conclusion

Based on the seismic performance of 6- and 10-story reinforced concrete building designed by using modified partial capacity design method (M-PCD) with 70% of base shear distribution ratio, some conclusion may be drawn:

1. The drifts of the observed buildings meet the criteria set by FEMA 273 [2]. The drifts are below 2% and 4% limit for design earthquake (EDRS) and maximum considered earthquake (MCER) levels. The drifts of 6-story building are 1.94% and 2.80% for EDRS

and MCER earthquake levels. The drifts of 10-story building are 1.65% and 2.76% for EDRS and MCER earthquake levels.

2. Both observed buildings can resist up to earthquake with MCER level with partial sidesway mechanism, since no elastic columns experience plastic damages.
3. The actual base shear distribution ratio in the elastic column with respect to total base shear is less than that on the design stage. This is logical since the frames (excluding the elastic columns) experience less damage compared to assumption in the design stage. This means that the stiffer frame may resist more force and the elastic columns may resist less force.

References

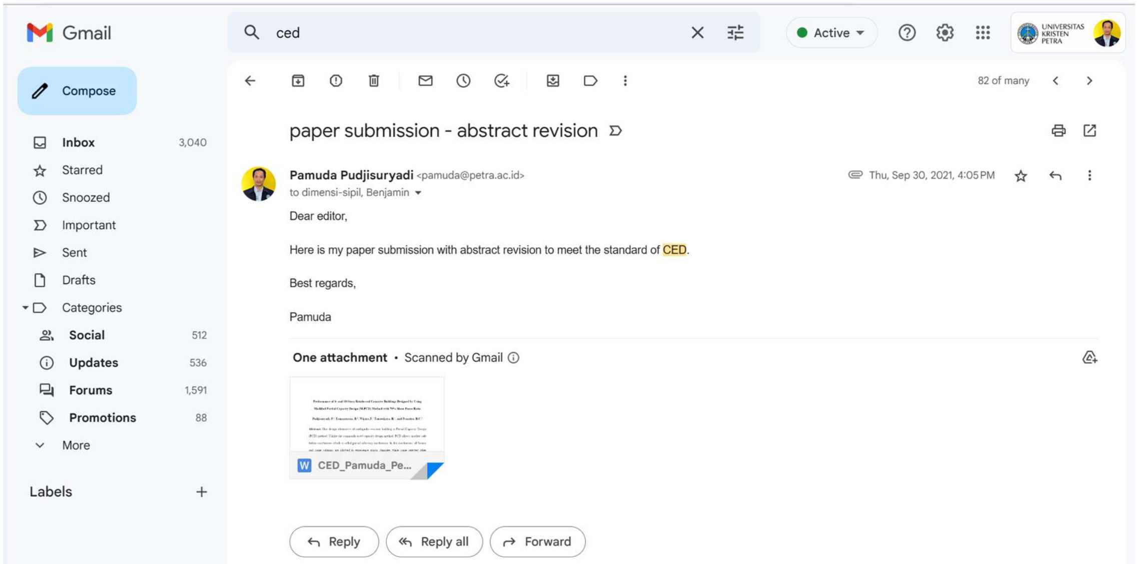
1. Badan Standarisasi Nasional. (2012). SNI-03-1726-2012. *Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung*. Jakarta.
2. Federal Emergency Management Agency 273 (1997). *NEHRP Guidelines For the Seismic Rehabilitation of Buildings*. Washington, D.C., USA.
3. Paulay, T. and Priestly, M.J.N. (1992). *Seismic Design of Reinforced Concrete and Masonry Buildings*. John Wiley & Sons, Inc., New York.
4. Lumantarna, B. and Fransisca, C. (1994), *Perencanaan Kapasitas Alternatif, Suatu Studi Pendahuluan*, Proc. of the International Conference on Modern Design and Construction for Safety, Economy, and Durability, Petra Christian University, Surabaya, Indonesia.
5. Muljati, I. and Lumantarna, B. (2007), *Partial Capacity Design, an Alternative to the Capacity Design Method*, Proceedings of the 19th Australasian Conference on the Mechanics of Structures and Materials; ACMSM19, Christchurch, New Zealand, pp. 409-414.
6. Muljati, I. and Lumantarna, B. (2008). *Performance of Partial Capacity Design on Fully Ductile Moment Resisting Frame in Highly Seismic Area in Indonesia*. The Eleventh

East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-11). Taipei, November, 2008.

7. Tanaya, L.S. (2021). *Metode Modified Partial Capacity Design (M-PCD)*. (Unpublished Thesis). Universitas Kristen Petra, Surabaya, Indonesia.
8. *CSI Analysis Reference Manual For SAP2000, ETABS, SAFE and CSIBridge*. (2017). Computer & Structure, Inc.
9. ATC 40. (1996), *Seismic Evaluation and Retrofit of Concrete Buildings Volume 1*. Applied Technology Council, California, USA.
10. Badan Standarisasi Nasional. (2013). SNI-03-2847-2013. *Persyaratan Beton Struktural untuk Bangunan Gedung*. Jakarta.
11. *CSICOL For Analysis and Design of Reinforced and Composite Column*, (2005). Computer & Structure, Inc.
12. Muljati, I. and Lumantarna, B. (2011). *The Use of Magnification Factor Formula in Partial Capacity Design Method on Fully Ductile Moment Resisting Frame*. The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-12). Hongkong, Januari, 2011.
13. Muljati, I. and Lumantarna, B. (2011), *Seismic Performance of Structure with Vertical Geometric Irregularity Designed Using Partial Capacity Design*, 2nd International Conference on Earthquake Engineering and Disaster Mitigation (ICEEDM), 19 July 2011 , Surabaya, Indonesia.
14. Pacific Earthquake Engineering Research Center. (2021). *PEER Ground Motion Database El Centro 1940.* https://ngawest2.berkeley.edu/spectras/438744/searches/406857/edit
15. Paulay, T. (1995), "Special Issues in Seismic Design", Structural Engineering International, Volume 5, Issue 3: 160-165.

16. Pudjisuryadi, P., Lumantarna, B., Teddy, S., Wijoyo, H. (2011). *Seismic Performance of Structure with Vertical Set-Back Designed Using Partial Capacity Design*, The 3rd International Conference of EACEF (European Asian Civil Engineering Forum), 20-22 September 2011, Universitas Atma Jaya, Yogyakarta, Indonesia.

17. Wijaya, F. and Widjojo, L. (2012). *Kritisi Desain Pseudo Elastis pada Bangunan Beraturan 6- dan 10- Lantai dengan Denah Persegi Panjang di Wilayah 2 Peta Gempa Indonesia*. Universitas Kristen Petra, Surabaya, Indonesia



paper submission - abstract revision

Pamuda Pudjisuryadi <pamuda@petra.ac.id>
to dimensi-sipil, Benjamin

Thu, Sep 30, 2021, 4:05 PM

Dear editor,

Here is my paper submission with abstract revision to meet the standard of CED.

Best regards,

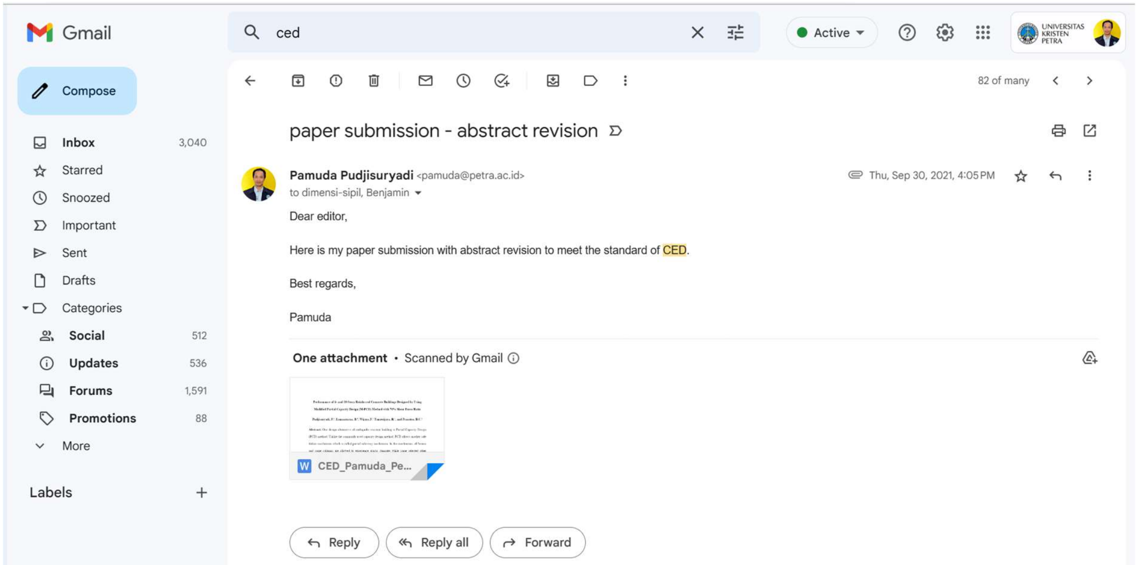
Pamuda

One attachment • Scanned by Gmail

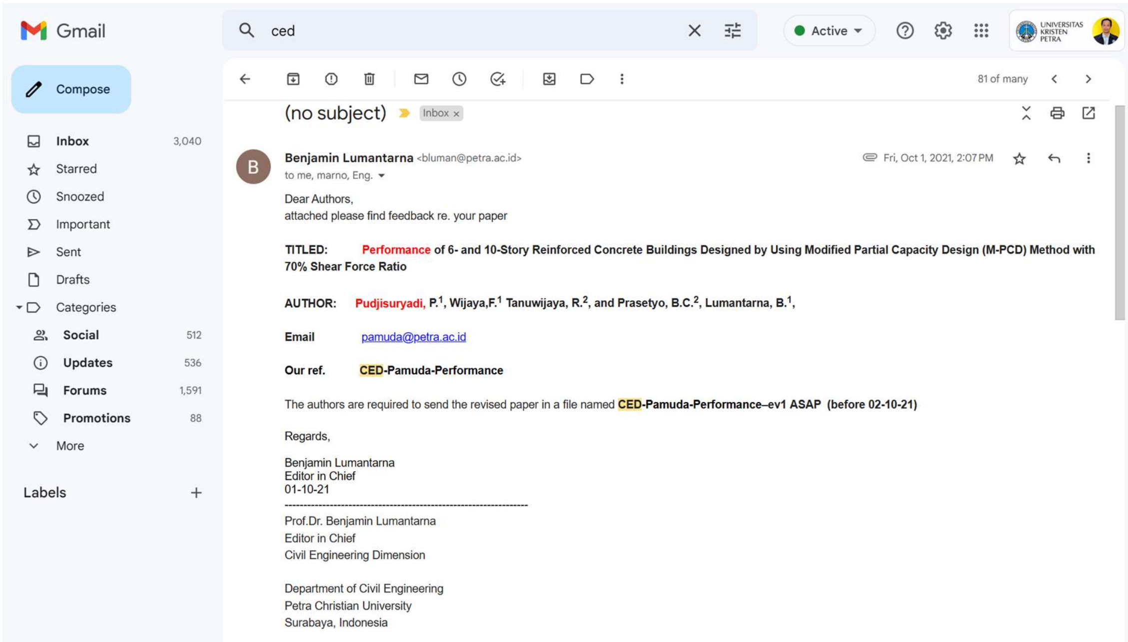
CED_Pamuda_Pe...

Reply | Reply all | Forward

2. Submitted to the journal "Civil Engineering Dimension", abstract revision. (30-09-2021).



3. Revisions, some suggested corrections need to be done, deadline before 02-10-2021. Comments include: wording suggestion, incomplete sentence (unclear information), a reference is still in Indonesian (01-10-2021).



Dear Authors,
attached please find feedback re. your paper

TITLED: **Performance of 6- and 10-Story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio**

AUTHOR: **Pudjisuryadi, P.[1], Wijaya,F.[1] Tanuwijaya, R.[2], and Prasetyo, B.C.[2], Lumantarna, B.[1],**

Email pamuda@petra.ac.id

Our ref. **CED-Pamuda-Performance**

The authors are required to send the revised paper in a file named **CED-Pamuda-Performance–ev1 ASAP (before 02-10-21)**

Regards,

Benjamin Lumantarna
Editor in Chief
01-10-21

Prof.Dr. Benjamin Lumantarna
Editor in Chief
Civil Engineering Dimension

Department of Civil Engineering
Petra Christian University
Surabaya, Indonesia

CIVIL ENGINEERING DIMENSION
Journal of Civil Engineering Science and Application

Dimensi Teknik Sipil
Jurnal Keilmuan dan Penerapan Teknik Sipil

Jl. Siwalankerto, 121-131, Surabaya 60236, Indonesia. Phone: (031) 8494830-31 ext. 3139, 3148, Fax. (031) 8436418,
Email: dimensi-sipil@petra.ac.id

REVIEW on
SUBMITTED PAPER

TITLE: **Performance of 6- and 10-Story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio**

AUTHOR: **Pudjisuryadi, P.[1], Wijaya,F.[1] Tanuwijaya, R.[2], and Prasetyo, B.C.[2], Lumantarna, B.[1],**

Email pamuda@petra.ac.id

Our ref. **CED-Pamuda-Performance**

This paper can be accepted and published in the September edition of the Civil Engineering Dimension, however, some corrections need to be done as noted in the manuscript

The authors are required to send the revised paper in a file named **CED-Pamuda-Performance–ev1 ASAP (before 02-10-21)**

Regards,

Benjamin Lumantarna
Editor in Chief
01-10-21

Performance of 6- and 10-Story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio

Pudjisuryadi, P.[1], Wijaya,F.[1] Tanuwijaya, R.[2], and Prasetyo, B.C.[2] , Lumantarna, B.[1]

Abstract: One design alternative of earthquake resistant building is Partial Capacity Design (PCD) method. Unlike the commonly used capacity design method, PCD allows a~~another~~ safe failure mechanism which is called partial sidesway mechanism. In this mechanism, all beams and some columns are allowed to experience plastic damages while some selected ~~other~~ columns ~~(elastic columns)~~ are designed to remain elastic (called elastic columns). A new approach ~~is proposed~~ to predict the required strengths needed to design each structural member, called modified-PCD (M-PCD) is proposed ~~(modified PCD)~~. In this research six~~6~~- and ~~10~~ten-story reinforced concrete buildings were designed ~~by~~ using M-PCD, and their seismic performances are investigated. The base shear force resisted by the elastic columns was set to approximately 70% of the total base shear. Both nonlinear static procedure (NSP) and nonlinear dynamic procedure (NDP) are used to analyze the structures. The results show that the expected partial side sway mechanism is observed, and the drifts of the buildings are acceptable.

Keywords: modified partial capacity design; partial side sway mechanism; reinforced concrete; seismic design.

Introduction

In the design of earthquake resistant structures, one alternative of the capacity design method [1] is partial capacity design (PCD) method. The PCD method allows ~~other~~ a safe failure mechanism proposed by Paulay and Priestley [2] which is called the partial sidesway mechanism. In this mechanism, some of columns are allowed to experience plastic damages while other columns (elastic columns) are intended to remain elastic during target earthquake.

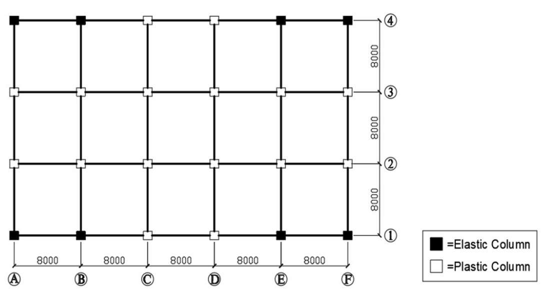
The challenge of this concept is how well the prediction of structural members' required strength. Early PCD method proposed that elastic columns ~~need~~ could~~to~~ be designed by using a single magnification factor which scales up their internal forces from a design earthquake. Seismic reduction factor of 8.0 was used to define the design earthquake with the assumption that the structure possesses good ductility. However, some studies showed that the performance of the method was somehow inconsistent. Based on the early~~first~~ study that used the single magnification factor to design the elastic columns, the test results showed that plastic hinges still occurred on the elastic column in the nonlinear time history analysis [3]. O~~The o~~ther studies that used the single magnification factor with other variations of building that have vertical setback showed ~~unsatisfied~~ unsatisfactory results because the partial side sway mechanism was not achieved effectively [4,5]. A more accurate approach in predicting the required strengths may be one of the answers to improve PCD method.

Recently, Tanaya [6] proposed a new approach in predicting the required strength to design the elastic columns. This new approach is called Modified-PCD (M-PCD). The M-PCD suggests the use of two structural models to predict the required strengths needed to design ~~each~~ the structural members. The first structural model was used to design elements which are allowed to yield during major earthquakes. This model was subjected to earthquake with seismic reduction factor R=8 (design earthquake). The second structural model was modified from the first one by reducing stiffness of members that may develop plastic hinges, and subjected to a target earthquake (R=1.6). This second model was used to design the elastic columns. Early test showed promising results, ~~that~~ most structure showed the expected partial sidesway mechanism and the drifts are well below the maximum values set by FEMA 273 [7]. However, more tests are needed to further develop and conform the effectiveness of this new approach.

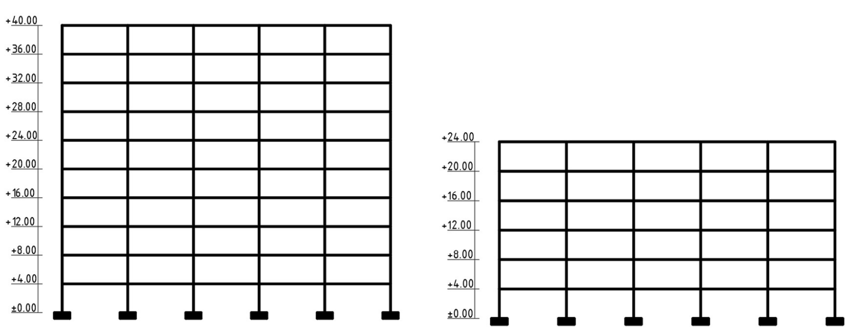
In this research, improvement of M-PCD proposed by Tanaya [7] is suggested. The second model is not subjected to full target earthquake, instead it is subjected by the difference between target earthquake and design earthquake used in the first model. This is logical, since after some members develop plastic damages, only the remaining earthquake load (beyond design earthquake) will be distributed according to structural responses of the second model. With this improvement, buildings similar to Tanaya's research are re-designed and investigated.

Model and Design of the Buildings

SAP2000 software [8] is used to model the buildings. The buildings are assumed to be located in Surabaya resting on soil with Site Class E, and intended as office buildings. The applied gravity loads were according to SNI 1727:2013 [9]. The building plans and elevation views can be seen in Figure 1.



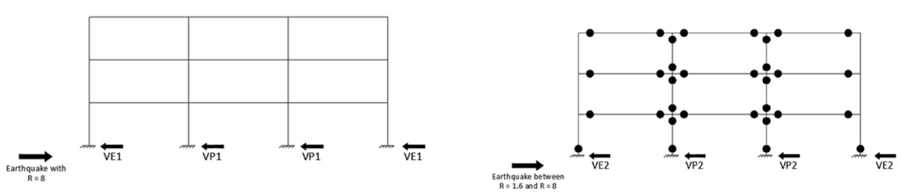
(a)



(b)

Figure 1. Observed structures: (a) Plan view; (b) Elevation view

In this study, the ratio of shear force resisted by elastic columns with respect to the total base shear is approximately set as large as 70%, resulting in the use of eight elastic columns (Figure 1a). As mentioned in the introduction, ~~the~~ two structural models are used in this approach. Illustration of these two structural models as well as seismic load (based on SNI 1726:2012 [1]) subjected to each model are shown in Figure 2. The modification factors (R) of 8.0 and 1.6 are chosen with the assumptions that the damaged frame members possess good ductility and elastic columns remain elastic, respectively. The stiffness reduction to simulate plastic damages is done by breaking the elements into three parts. Two of the parts are located close to element supports with the length of $0.5h_{element}$ (typical plastic hinge region), which flexural stiffnesses are reduced to model plastic hinges (see Figure 3). The flexural stiffness modification may be determined by looking at typical bilinear curve of moment-rotation curves of reinforced concrete section.



VE1 : Base Shear of Elastic Column in Model 1

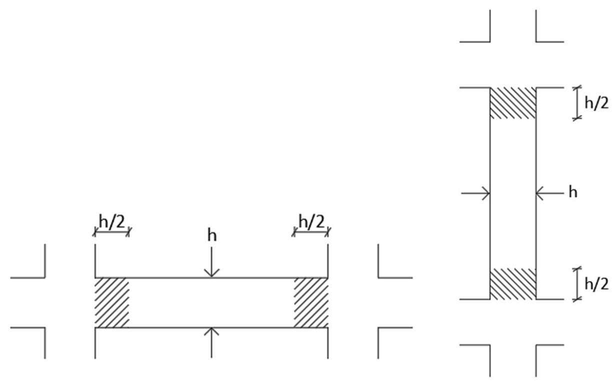
VP1 : Base Shear of Plastic Column in Model 1

VE2 : Base Shear of Elastic Column in Model 2

VP2 : Base Shear of Plastic Column in Model 2

(a) (b)

Figure 2. Design assumption: (a) Model 1; (b) Model 2



(a) (b)

Figure 3. Stiffness reduction in Model 2 at: (a) Beam; (b) Column

Results from the first model are used to design the beams and plastic columns which may develop plastic damages. Since the columns may experience damages, the strong column weak beam requirement is neglected in this approach. However, the shear design of both beams and columns should still follow the capacity design concept since no shear failure is allowed. Required strengths used for designing the elastic columns are determined by combining the internal forces from both models. It should be noted that the effect of gravity load should only calculated once when combining results from both models. Again, only shear design of the elastic columns should follow standard capacity design approach. The base shear distribution ratio of the structure can be seen in Table 1. The design results of the beams and columns can be seen in Table 2, 3, and 4.

Table 1. Base Shear Distribution Ratio of Elastic Column for (a) 6-Story and (b) 10-Story Building

Design Earthquake X Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)	Design Earthquake Y Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)
Model 1	2055.09	1013.99	Model 1	1907.64	849.24
Model 2	3101.46	2791.54	Model 2	3096.14	2770.44
Total	5156.55	3805.53	Total	5003.78	3619.68
Shear Force Distribution Ratio		73.80%	Shear Force Distribution Ratio		72.34%

(a)

Design Earthquake X Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)	Design Earthquake Y Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)
Model 1	2452.52	1513.95	Model 1	2274.09	1441.90
Model 2	5611.75	3998.33	Model 2	5596.76	3880.43
Total	8064.27	5512.28	Total	7870.85	5322.33
Shear Force Distribution Ratio		68.35%	Shear Force Distribution Ratio		67.62%

(b)

Table 2. Reinforcement Details of 6-Story Building (a) Beam (b) Plastic Column

Type	Dimension	Position	Longitudinal			Transversal
			ρ	Reinforcement	Strength Ratio	s
BI-1	300x700	Top	1.04%	7D19	0.91	2D10-110
		Bottom	0.59%	4D19	0.76	
BI-2	300x700	Top	1.04%	7D19	0.98	2D10-110
		Bottom	0.59%	4D19	0.82	
BI-3	300x700	Top	0.89%	6D19	0.97	2D10-110
		Bottom	0.44%	3D19	0.93	
BI-4	300x700	Top	0.74%	5D19	0.92	2D10-110
		Bottom	0.44%	3D19	0.78	

(a)

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
6	350x350	4.51%	16D19	0.69	2D13-60
5	350x350	4.51%	16D19	0.78	2D13-60
4	400x400	3.36%	16D19	0.89	3D13-90
3	450x450	2.60%	16D19	0.94	3D13-100
2	450x450	3.90%	24D19	0.89	3D13-100
1	500x500	2.59%	20D19	0.79	3D13-100

(b)

Table 3. Reinforcement Details of 10-Story Building (a) Beam (b) Plastic Column

Type	Dimension	Position	Longitudinal			Transversal
			ρ	Reinforcement	Strength Ratio	s
BI-1	300x700	Top	0.89%	6D19	0.91	2D10-110
		Bottom	0.44%	3D19	0.88	
BI-2	300x700	Top	1.03%	7D19	0.94	2D10-110
		Bottom	0.59%	4D19	0.79	
BI-3	300x700	Top	1.18%	8D19	0.93	2D10-110
		Bottom	0.59%	4D19	0.89	
BI-4	300x700	Top	0.74%	5D19	0.92	2D10-110
		Bottom	0.44%	3D19	0.74	
BI-5	300x700	Top	1.33%	9D19	0.95	2D10-110
		Bottom	0.74%	5D19	0.81	
BI-6	300x700	Top	1.48%	10D19	0.95	2D10-110
		Bottom	0.74%	5D19	0.89	

(a)

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
10	350x350	4.96%	16D22	0.88	2D13-60
9	350x350	3.72%	12D22	0.96	2D13-60
8	400x400	3.80%	16D22	0.94	3D13-100
7	400x400	3.80%	16D22	0.93	3D13-100
6	450x450	3.00%	16D22	0.94	3D13-100
5	450x450	4.50%	24D22	0.95	3D13-100
4	500x500	3.65%	24D22	0.92	3D13-100
3	500x500	4.86%	32D22	0.92	3D13-100
2	600x600	2.11%	20D22	0.91	3D13-100
1	600x600	2.96%	28D22	0.93	3D13-100

(b)

Table 4. Reinforcement Details of Elastic Column (a) 6-Story Building (b) 10-Story Building

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
6	700x700	3.94%	24D32	0.98	3D13-100
5	700x700	5.25%	32D32	0.97	3D13-100
4	700x700	5.91%	36D32	0.94	3D13-100
3	700x700	4.59%	28D32	0.93	3D13-100
2	700x700	3.94%	24D32	0.96	3D13-90
1	700x700	2.62%	16D32	0.99	3D13-90

(a)

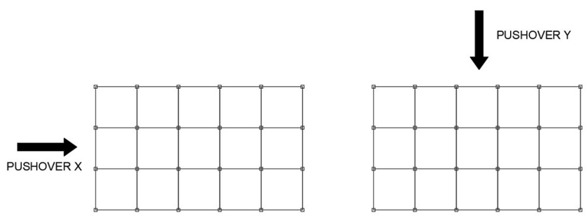
Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
10	900x900	2.48%	16D40	0.90	4D13-100
9	900x900	3.10%	20D40	0.99	4D13-100
8	900x900	4.96%	32D40	0.87	4D13-100
7	900x900	4.96%	32D40	0.99	4D13-100
6	900x900	5.58%	36D40	0.96	4D13-100
5	900x900	5.58%	36D40	0.97	4D13-100
4	900x900	4.96%	32D40	0.95	4D13-100
3	900x900	4.34%	28D40	0.96	4D13-100
2	900x900	3.10%	20D40	0.86	4D13-100
1	900x900	3.72%	24D40	0.94	4D13-100

(b)

Buildings' Performances Analysis

~~analysis~~ Analysis is conducted twice for each building to model dominant earthquake in each orthogonal direction (see Figure 4). Performance of the buildings are reported at two levels of earthquakes which are the elThe buildings are analyzed with nonlinear static procedure (NSP) and nonlinear dynamic procedure (NDP) ~~by~~ using SAP 2000 software [8]. The NSP Plastic design response spectrum (EDRS) and maximum considered earthquakes (MCER) which is 1.5 times of EDRS. The load pattern used in NSP is the first translational mode of the corresponding directions.

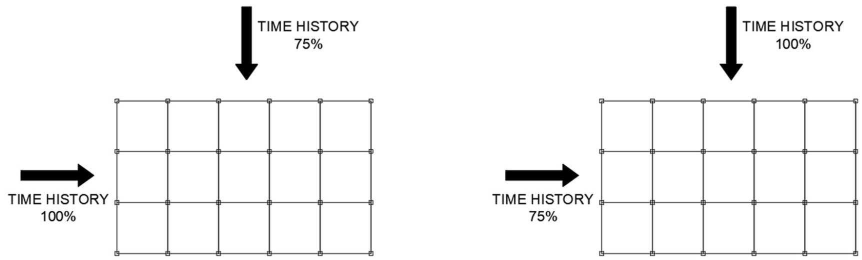
Commented [B1]: Something is missing here



(a) (b)

Figure 4. Nonlinear Static Procedure (NSP) in: (a) X-direction (b) Y-direction

In NDP analysis, the seismic load used is spectrum consistent ground accelerations generated from El Centro 18 May 1940 earthquake N-S and E-W components in accordance to Indonesian Seismic Code (SNI 1726:2012 [1]). Two level of acceleration response spectrums to match are the elastic design response spectrum (EDRS) and spectrum corresponding to maximum considered earthquake (MCER). The buildings are subjected to two-directional ground motion which peak ground accelerations ratio (4:3) is taken the same as the original earthquake motion. Illustration of the ground motions used for analysis are presented in Figure 5.

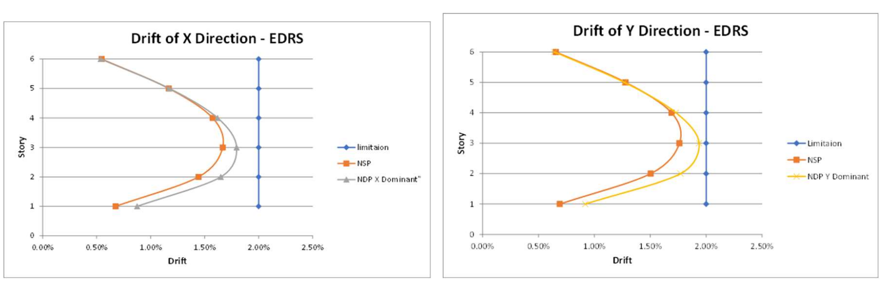


(a) (b)

Figure 5. Nonlinear Dynamic Procedure (NDP) with dominant ground motion in: (a) X-Dominant (b) Y-Dominant

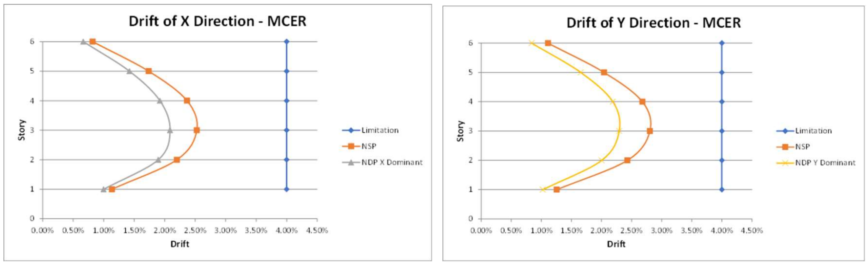
Analysis results

The drifts of the buildings are presented in Figures 6 to 9. The drifts are plotted against limitation according to FEMA 273 [2], which are 2% for design earthquake (EDRS) and and 4% for maximum considered (MCER) earthquake. It can be seen in Figures 6 and 7, that the 6-story building performs very well as all drifts satisfy the allowable drift in both directions and both earthquake levels. In X-direction, it is recorded that the maximum drifts are 1.80% and 2.53% for EDRS and MCER earthquakes, respectively. While in Y-direction, the drifts are 1.94% and 2.80% for EDRS and MCER earthquakes, respectively.



(a) (b)

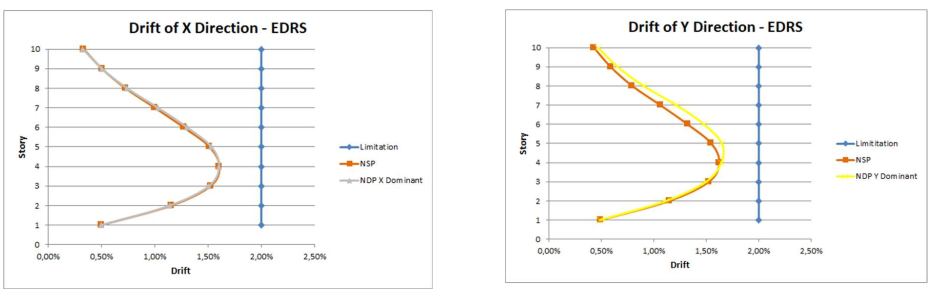
Figure 6. Drifts of 6-Story building for EDRS in: (a) X-direction; (b) Y-direction



(a) (b)

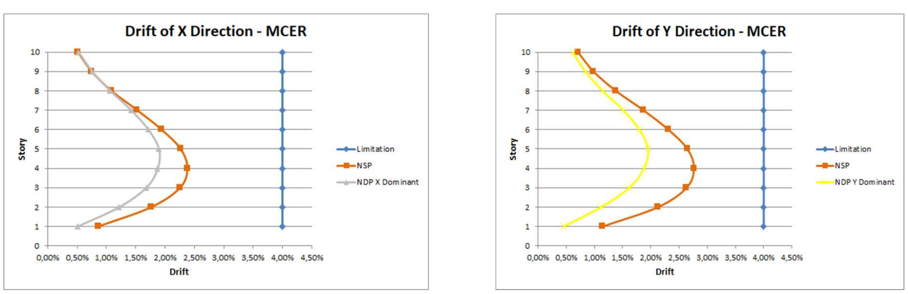
Figure 7. Drifts of 6-Story building for MCER in: (a) X-direction; (b) Y-direction

Similar performances are seen at 10-story buildings that all the drifts meet the requirement by FEMA 273. In Figures 8 and 9, it can be observed that the drifts of the buildings at EDRS and MCER earthquakes are 1.60% and 2.38% in X-direction, and 1.65% and 2.76% in Y-direction.



(a) (b)

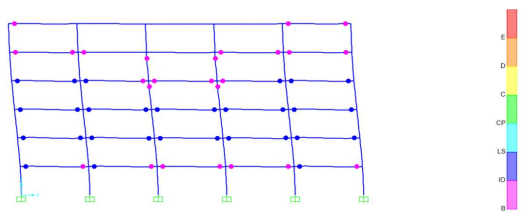
Figure 8. Drift of 10-Story Building for EDRS in: (a) X Direction (b) Y Direction



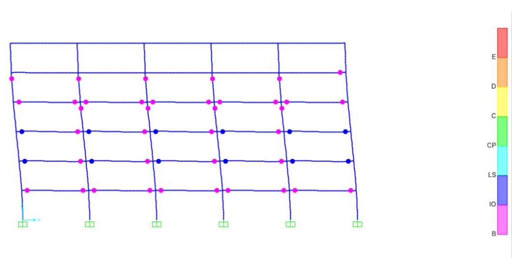
(a) (b)

Figure 9. Drift of 10-Story Building for MCER in: (a) X Direction (b) Y Direction

In order to make sure if the buildings have good performance, safe failure mechanism should be investigated. From all variations of the analysis (the number of story, the level of earthquake used for analysis, the analysis procedures, and direction of dominant earthquake), it is observed that there are no plastic damages in the elastic columns which means the structures can resist the earthquakes with safe partial sidesway mechanism. Figures 10 to 13 show typical plastic damages of the frames.

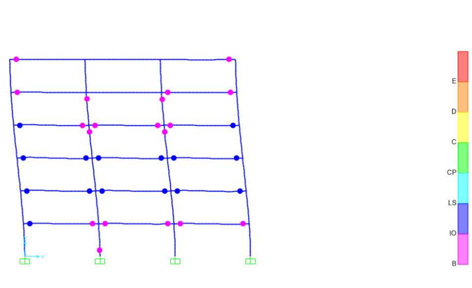


(a)

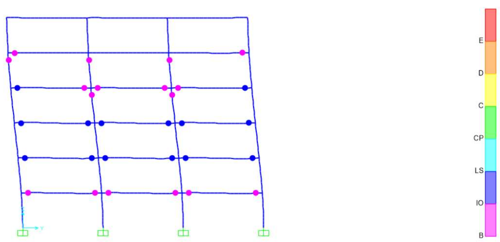


(b)

Figure 10. Plastic Damages of 6-story building from NSP analysis with EDRS earthquake level in X-direction: (a) Frame 1; and (b) Frame 2

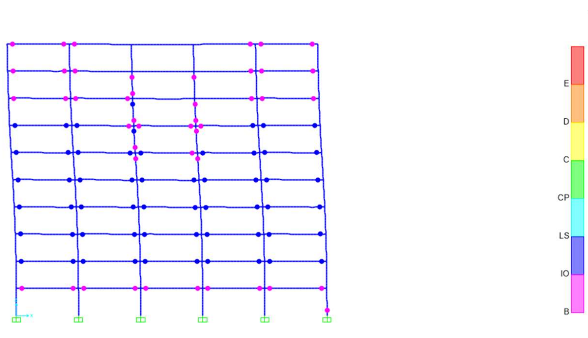


(a)

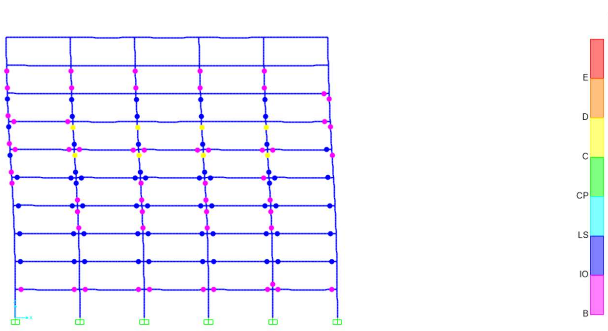


(b)

Figure 11. Plastic Damages of 6-story building from NSP analysis with EDRS earthquake level in Y-direction (a) Frame A; and (b) Frame C

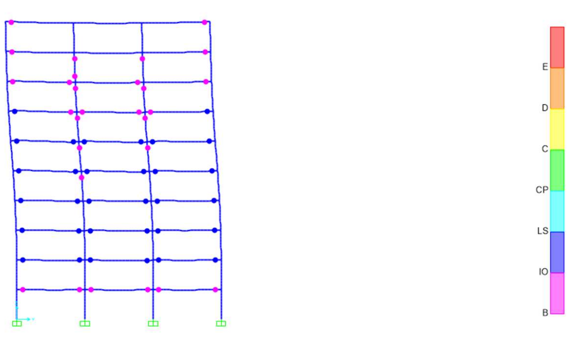


(a)

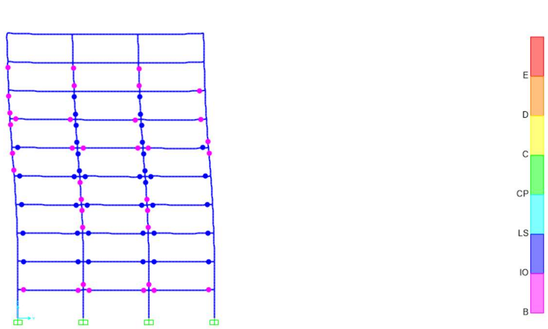


(b)

Figure 12. Plastic Damages of 10-story building from NDP analysis with MCER earthquake level in X-direction (a) Frame 1; and (b) Frame 2



(a)



(b)

Figure 13. Plastic Damages of 10-story building from NDP analysis with MCER earthquake level in Y-direction (a) Frame A; and (b) Frame C

Moreover, from the analysis results, it can be observed how far the deviation of shear force ratio resisted by the elastic columns. The shear force distribution ratio are presented in Table 5. In the design stage, this ratio is set approximately 70% with the assumption that all members experience plastic damages except the elastic columns. Since the actual performance seen in Figures 11 to 22 show less damages, it is logical if the shear force resisted by the elastic columns are less than 70%.

Commented [B2]: What is this/

Table 5. Actual Base Shear Distribution Ratio of (a) 6-Story Building and (b) 10-Story Building

	X Direction	Y Direction
Design	73.80%	72.34%
Pushover EDRS	44.77%	42.05%
Pushover MCER	39.92%	42.56%
Time History X Dominant EDRS	50.63%	41.97%
Time History Y Dominant EDRS	49.78%	48.46%
Time History X Dominant MCER	49.54%	44.55%
Time History Y Dominant MCER	45.29%	47.82%

	X Direction	Y Direction
Design	68.35%	67.62%
Pushover EDRS	59.79%	58.72%
Pushover MCER	51.31%	49.93%
Time History Dominan X EDRS	59.91%	56.50%
Time History Dominan Y EDRS	58.17%	58.80%
Time History Dominan X MCER	59.50%	59.35%
Time History Dominan Y MCER	59.67%	58.95%

(a)

(b)

Conclusion

Based on the seismic performance of 6- and 10-story reinforced concrete building designed by using modified partial capacity design method (M-PCD) with 70% of base shear distribution ratio, some conclusion may be drawn:

1. The drifts of the observed buildings meet the criteria set by FEMA 273 [2]. The drifts are below 2% and 4% limit for design earthquake (EDRS) and maximum considered earthquake (MCER) levels. The drifts of 6-story building are 1.94% and 2.80% for EDRS and MCER earthquake levels. The drifts of 10-story building are 1.65% and 2.76% for EDRS and MCER earthquake levels.
2. Both observed buildings can resist up to earthquake with MCER level with partial sidesway mechanism, since no elastic columns experience plastic damages.
3. The actual base shear distribution ratio in the elastic column with respect to total base shear is less than that on the design stage. This is logical since the frames (excluding the elastic columns) experience less damage compared to assumption in the design stage. This

means that the stiffer frame may resist more force and the elastic columns may resist less force.

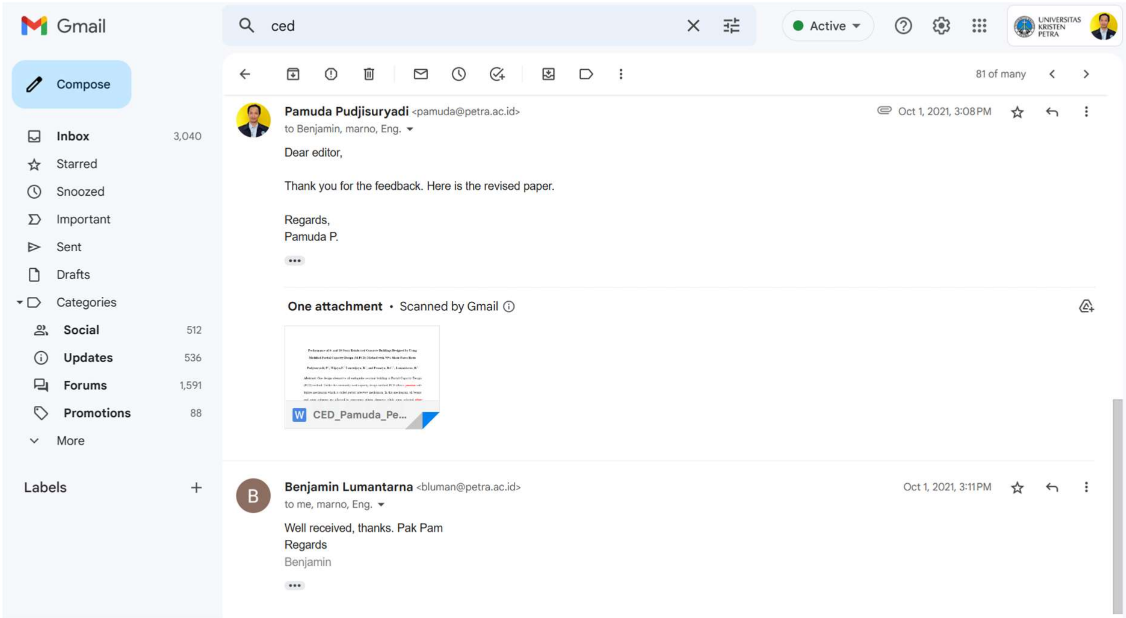
References

1. Badan Standarisasi Nasional. (2012). SNI-03-1726-2012. *Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung*. Jakarta.
2. Paulay, T. and Priestly, M.J.N. (1992). *Seismic Design of Reinforced Concrete and Masonry Buildings*. John Wiley & Sons, Inc., New York.
3. Lumantarna, B. and Fransisca, C. (1994), *Perencanaan Kapasitas Alternatif, Suatu Studi Pendahuluan*, Proc. of the International Conference on Modern Design and Construction for Safety, Economy, and Durability, Petra Christian University, Surabaya, Indonesia.
4. Muljati, I. and Lumantarna, B. (2007), *Partial Capacity Design, an Alternative to the Capacity Design Method*, Proceedings of the 19th Australasian Conference on the Mechanics of Structures and Materials; ACMSM19, Christchurch, New Zealand, pp. 409-414.
5. Muljati, I. and Lumantarna, B. (2008). *Performance of Partial Capacity Design on Fully Ductile Moment Resisting Frame in Highly Seismic Area in Indonesia*. The Eleventh East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-11). Taipei, November, 2008.
6. Tanaya, L.S. (2021). *Metode Modified Partial Capacity Design (M-PCD)*. (Unpublished Thesis). Universitas Kristen Petra, Surabaya, Indonesia.
7. Federal Emergency Management Agency 273 (1997). *NEHRP Guidelines For the Seismic Rehabilitation of Buildings*. Washington, D.C., USA.
8. *CSI Analysis Reference Manual For SAP2000, ETABS, SAFE and CSIBridge*. (2017). Computer & Structure, Inc.

Commented [B3]: How come a paper presented in international conf is presented in Bahasa Indonesia. Could you please check.

9. ATC 40. (1996), *Seismic Evaluation and Retrofit of Concrete Buildings Volume 1*. Applied Technology Council, California, USA.
10. Badan Standarisasi Nasional. (2013). SNI-03-2847-2013. *Persyaratan Beton Struktural untuk Bangunan Gedung*. Jakarta.
11. *CSICOL For Analysis and Design of Reinforced and Composite Column*, (2005). Computer & Structure, Inc.
12. Muljati, I. and Lumantarna, B. (2011). *The Use of Magnification Factor Formula in Partial Capacity Design Method on Fully Ductile Moment Resisting Frame*. The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-12). Hongkong, Januari, 2011.
13. Muljati, I. and Lumantarna, B. (2011), *Seismic Performance of Structure with Vertical Geometric Irregularity Designed Using Partial Capacity Design*, 2nd International Conference on Earthquake Engineering and Disaster Mitigation (ICEEDM), 19 July 2011 , Surabaya, Indonesia.
14. Pacific Earthquake Engineering Research Center. (2021). *PEER Ground Motion Database El Centro 1940.* https://ngawest2.berkeley.edu/spectras/438744/searches/406857/edit
15. Paulay, T. (1995), "Special Issues in Seismic Design", Structural Engineering International, Volume 5, Issue 3: 160-165.
16. Pudjisuryadi, P., Lumantarna, B., Teddy, S., Wijoyo, H. (2011). *Seismic Performance of Structure with Vertical Set-Back Designed Using Partial Capacity Design*, The 3rd International Conference of EACEF (European Asian Civil Engineering Forum), 20-22 September 2011, Universitas Atma Jaya, Yogyakarta, Indonesia.
17. Wijaya, F. and Widjojo, L. (2012). *Kritisi Desain Pseudo Elastis pada Bangunan Beraturan 6- dan 10- Lantai dengan Denah Persegi Panjang di Wilayah 2 Peta Gempa Indonesia*. Universitas Kristen Petra, Surabaya, Indonesia

4. Submitted to the journal "Civil Engineering Dimension", revised paper. (01-10-2021).



Performance of 6- and 10-Story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio

Pudjisuryadi, P.[1], Wijaya,F.[1] Tanuwijaya, R.[2], and Prasetyo, B.C.[2] , Lumantarna, B.[1]

Abstract: One design alternative of earthquake resistant building is Partial Capacity Design (PCD) method. Unlike the commonly used capacity design method, PCD allows a~~another~~ safe failure mechanism which is called partial sidesway mechanism. In this mechanism, all beams and some columns are allowed to experience plastic damages while some selected ~~other~~ columns ~~(elastic columns)~~ are designed to remain elastic (called elastic columns). A new approach ~~is proposed~~ to predict the required strengths needed to design each structural member, called modified-PCD (M-PCD) is proposed ~~(modified PCD)~~. In this research six~~6~~- and ~~10~~ten-story reinforced concrete buildings were designed ~~by~~ using M-PCD, and their seismic performances are investigated. The base shear force resisted by the elastic columns was set to approximately 70% of the total base shear. Both nonlinear static procedure (NSP) and nonlinear dynamic procedure (NDP) are used to analyze the structures. The results show that the expected partial side sway mechanism is observed, and the drifts of the buildings are acceptable.

Keywords: modified partial capacity design; partial side sway mechanism; reinforced concrete; seismic design.

Introduction

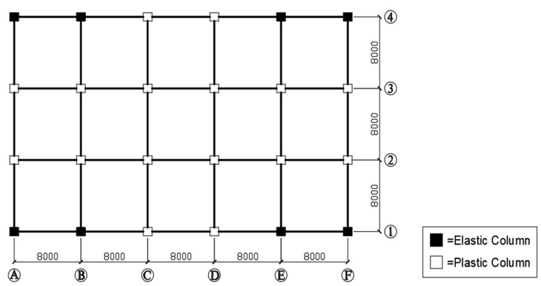
In the design of earthquake resistant structures, one alternative of the capacity design method [1] is partial capacity design (PCD) method. The PCD method allows ~~other~~ a safe failure mechanism proposed by Paulay and Priestley [2] which is called the partial sidesway mechanism. In this mechanism, some of columns are allowed to experience plastic damages while other columns (elastic columns) are intended to remain elastic during target earthquake. The challenge of this concept is how well the prediction of structural members' required strength. Early PCD method proposed that elastic columns ~~need~~ could~~to~~ be designed by using a single magnification factor which scales up their internal forces from a design earthquake. Seismic reduction factor of 8.0 was used to define the design earthquake with the assumption that the structure possesses good ductility. However, some studies showed that the performance of the method was somehow inconsistent. Based on the early~~first~~ study that used the single magnification factor to design the elastic columns, the test results showed that plastic hinges still occurred on the elastic column in the nonlinear time history analysis [3]. O~~The o~~ther studies that used the single magnification factor with other variations of building that have vertical setback showed ~~unsatisfied~~ unsatisfactory results because the partial side sway mechanism was not achieved effectively [4,5]. A more accurate approach in predicting the required strengths may be one of the answers to improve PCD method.

Recently, Tanaya [6] proposed a new approach in predicting the required strength to design the elastic columns. This new approach is called Modified-PCD (M-PCD). The M-PCD suggests the use of two structural models to predict the required strengths needed to design ~~each~~ the structural members. The first structural model was used to design elements which are allowed to yield during major earthquakes. This model was subjected to earthquake with seismic reduction factor R=8 (design earthquake). The second structural model was modified from the first one by reducing stiffness of members that may develop plastic hinges, and subjected to a target earthquake (R=1.6). This second model was used to design the elastic columns. Early test showed promising results, ~~that~~ most structure showed the expected partial sidesway mechanism and the drifts are well below the maximum values set by FEMA 273 [7]. However, more tests are needed to further develop and conform the effectiveness of this new approach.

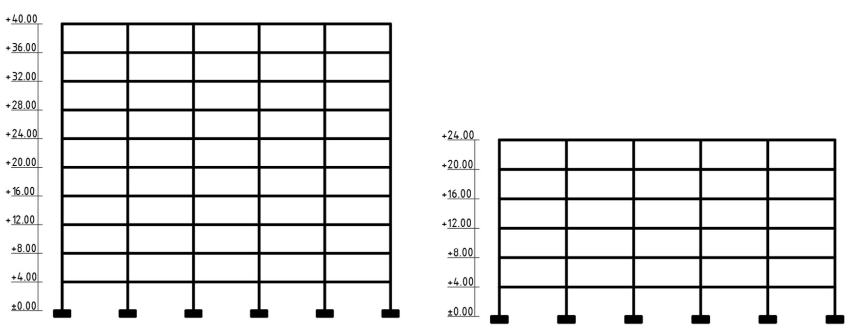
In this research, improvement of M-PCD proposed by Tanaya [~~7~~6] is suggested. The second model is not subjected to full target earthquake, instead it is subjected by the difference between target earthquake and design earthquake used in the first model. This is logical, since after some members develop plastic damages, only the remaining earthquake load (beyond design earthquake) will be distributed according to structural responses of the second model. With this improvement, buildings similar to Tanaya's research are re-designed and investigated.

Model and Design of the Buildings

SAP2000 software [8] is used to model the buildings. The buildings are assumed to be located in Surabaya resting on soil with Site Class E, and intended as office buildings. The applied gravity loads were according to SNI 1727:2013 [9]. The building plans and elevation views can be seen in Figure 1.



(a)

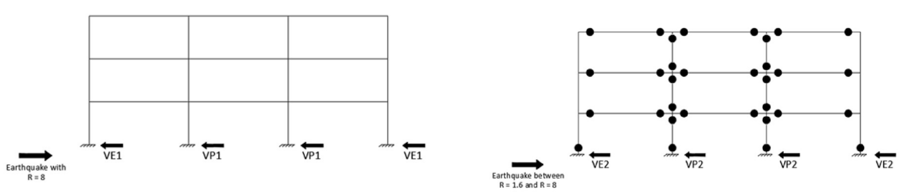


(b)

Figure 1. Observed structures: (a) Plan view; (b) Elevation view

In this study, the ratio of shear force resisted by elastic columns with respect to the total base shear is approximately set as large as 70%, resulting in the use of eight elastic columns (Figure

1a). As mentioned in the introduction, ~~the~~ two structural models are used in this approach. Illustration of these two structural models as well as seismic load (based on SNI 1726:2012 [1]) subjected to each model are shown in Figure 2. The modification factors (R) of 8.0 and 1.6 are chosen with the assumptions that the damaged frame members possess good ductility and elastic columns remain elastic, respectively. The stiffness reduction to simulate plastic damages is done by breaking the elements into three parts. Two of the parts are located close to element supports with the length of $0.5h_{element}$ (typical plastic hinge region), which flexural stiffnesses are reduced to model plastic hinges (see Figure 3). The flexural stiffness modification may be determined by looking at typical bilinear curve of moment-rotation curves of reinforced concrete section.



VE1 : Base Shear of Elastic Column in Model 1

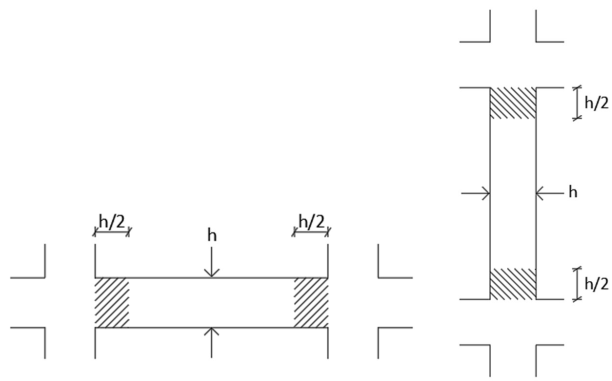
VP1 : Base Shear of Plastic Column in Model 1

VE2 : Base Shear of Elastic Column in Model 2

VP2 : Base Shear of Plastic Column in Model 2

(a) (b)

Figure 2. Design assumption: (a) Model 1; (b) Model 2



(a) (b)

Figure 3. Stiffness reduction in Model 2 at: (a) Beam; (b) Column

Results from the first model are used to design the beams and plastic columns which may develop plastic damages. Since the columns may experience damages, the strong column weak beam requirement is neglected in this approach. However, the shear design of both beams and columns should still follow the capacity design concept since no shear failure is allowed. Required strengths used for designing the elastic columns are determined by combining the internal forces from both models. It should be noted that the effect of gravity load should only calculated once when combining results from both models. Again, only shear design of the elastic columns should follow standard capacity design approach. The base shear distribution ratio of the structure can be seen in Table 1. The design results of the beams and columns can be seen in Table 2, 3, and 4.

Table 1. Base Shear Distribution Ratio of Elastic Column for (a) 6-Story and (b) 10-Story Building

Design Earthquake X Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)	Design Earthquake Y Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)
Model 1	2055.09	1013.99	Model 1	1907.64	849.24
Model 2	3101.46	2791.54	Model 2	3096.14	2770.44
Total	5156.55	3805.53	Total	5003.78	3619.68
Shear Force Distribution Ratio		73.80%	Shear Force Distribution Ratio		72.34%

(a)

Design Earthquake X Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)	Design Earthquake Y Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)
Model 1	2452.52	1513.95	Model 1	2274.09	1441.90
Model 2	5611.75	3998.33	Model 2	5596.76	3880.43
Total	8064.27	5512.28	Total	7870.85	5322.33
Shear Force Distribution Ratio		68.35%	Shear Force Distribution Ratio		67.62%

(b)

Table 2. Reinforcement Details of 6-Story Building (a) Beam (b) Plastic Column

Type	Dimension	Position	Longitudinal			Transversal
			ρ	Reinforcement	Strength Ratio	s
BI-1	300x700	Top	1.04%	7D19	0.91	2D10-110
		Bottom	0.59%	4D19	0.76	
BI-2	300x700	Top	1.04%	7D19	0.98	2D10-110
		Bottom	0.59%	4D19	0.82	
BI-3	300x700	Top	0.89%	6D19	0.97	2D10-110
		Bottom	0.44%	3D19	0.93	
BI-4	300x700	Top	0.74%	5D19	0.92	2D10-110
		Bottom	0.44%	3D19	0.78	

(a)

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
6	350x350	4.51%	16D19	0.69	2D13-60
5	350x350	4.51%	16D19	0.78	2D13-60
4	400x400	3.36%	16D19	0.89	3D13-90
3	450x450	2.60%	16D19	0.94	3D13-100
2	450x450	3.90%	24D19	0.89	3D13-100
1	500x500	2.59%	20D19	0.79	3D13-100

(b)

Table 3. Reinforcement Details of 10-Story Building (a) Beam (b) Plastic Column

Type	Dimension	Position	Longitudinal			Transversal
			ρ	Reinforcement	Strength Ratio	s
BI-1	300x700	Top	0.89%	6D19	0.91	2D10-110
		Bottom	0.44%	3D19	0.88	
BI-2	300x700	Top	1.03%	7D19	0.94	2D10-110
		Bottom	0.59%	4D19	0.79	
BI-3	300x700	Top	1.18%	8D19	0.93	2D10-110
		Bottom	0.59%	4D19	0.89	
BI-4	300x700	Top	0.74%	5D19	0.92	2D10-110
		Bottom	0.44%	3D19	0.74	
BI-5	300x700	Top	1.33%	9D19	0.95	2D10-110
		Bottom	0.74%	5D19	0.81	
BI-6	300x700	Top	1.48%	10D19	0.95	2D10-110
		Bottom	0.74%	5D19	0.89	

(a)

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
10	350x350	4.96%	16D22	0.88	2D13-60
9	350x350	3.72%	12D22	0.96	2D13-60
8	400x400	3.80%	16D22	0.94	3D13-100
7	400x400	3.80%	16D22	0.93	3D13-100
6	450x450	3.00%	16D22	0.94	3D13-100
5	450x450	4.50%	24D22	0.95	3D13-100
4	500x500	3.65%	24D22	0.92	3D13-100
3	500x500	4.86%	32D22	0.92	3D13-100
2	600x600	2.11%	20D22	0.91	3D13-100
1	600x600	2.96%	28D22	0.93	3D13-100

(b)

Table 4. Reinforcement Details of Elastic Column (a) 6-Story Building (b) 10-Story Building

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
6	700x700	3.94%	24D32	0.98	3D13-100
5	700x700	5.25%	32D32	0.97	3D13-100
4	700x700	5.91%	36D32	0.94	3D13-100
3	700x700	4.59%	28D32	0.93	3D13-100
2	700x700	3.94%	24D32	0.96	3D13-90
1	700x700	2.62%	16D32	0.99	3D13-90

(a)

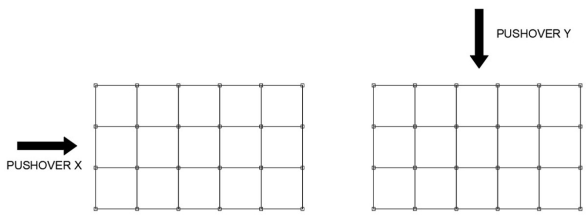
Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
10	900x900	2.48%	16D40	0.90	4D13-100
9	900x900	3.10%	20D40	0.99	4D13-100
8	900x900	4.96%	32D40	0.87	4D13-100
7	900x900	4.96%	32D40	0.99	4D13-100
6	900x900	5.58%	36D40	0.96	4D13-100
5	900x900	5.58%	36D40	0.97	4D13-100
4	900x900	4.96%	32D40	0.95	4D13-100
3	900x900	4.34%	28D40	0.96	4D13-100
2	900x900	3.10%	20D40	0.86	4D13-100
1	900x900	3.72%	24D40	0.94	4D13-100

(b)

Buildings' Performances Analysis

~~analysis~~ Analysis is conducted twice for each building to model dominant earthquake in each orthogonal direction (see Figure 4). Performance of the buildings are reported at two levels of earthquakes which are the elastic design response spectrum (EDRS) and maximum considered earthquakes (MCER) which is 1.5 times of EDRS. ~~el~~The buildings are analyzed with nonlinear static procedure (NSP) and nonlinear dynamic procedure (NDP) ~~by~~ using SAP 2000 software [8]. ~~The NSP Plastic design response spectrum (EDRS) and maximum considered earthquakes (MCER) which is 1.5 times of EDRS.~~ The load pattern used in NSP is the first translational mode of the corresponding directions.

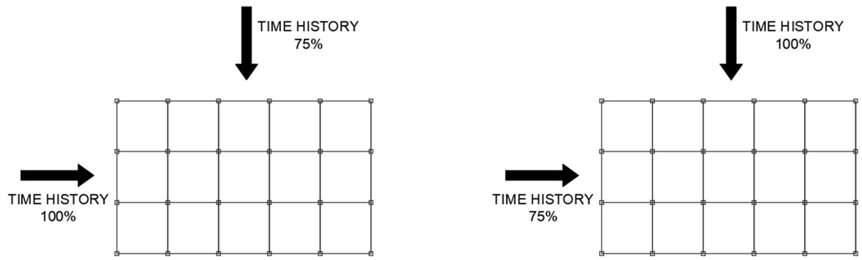
Commented [B1]: Something is missing here



(a) (b)

Figure 4. Nonlinear Static Procedure (NSP) in: (a) X-direction (b) Y-direction

In NDP analysis, the seismic load used is spectrum consistent ground accelerations generated from El Centro 18 May 1940 earthquake N-S and E-W components in accordance to Indonesian Seismic Code (SNI 1726:2012 [1]). Two level of acceleration response spectrums to match are the elastic design response spectrum (EDRS) and spectrum corresponding to maximum considered earthquake (MCER). The buildings are subjected to two-directional ground motion which peak ground accelerations ratio (4:3) is taken the same as the original earthquake motion. Illustration of the ground motions used for analysis are presented in Figure 5.

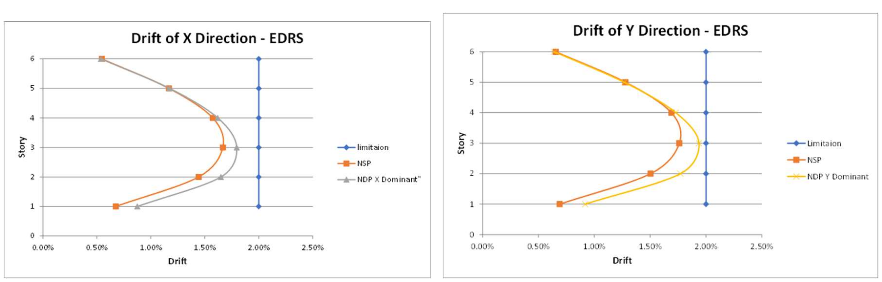


(a) (b)

Figure 5. Nonlinear Dynamic Procedure (NDP) with dominant ground motion in: (a) X-Dominant (b) Y-Dominant

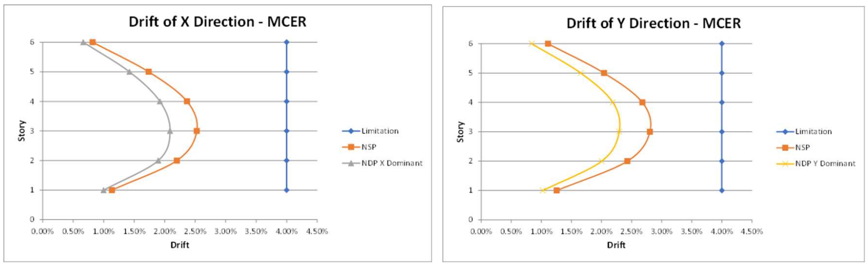
Analysis results

The drifts of the buildings are presented in Figures 6 to 9. The drifts are plotted against limitation according to FEMA 273 [~~2~~7], which are 2% for design earthquake (EDRS) and and 4% for maximum considered (MCER) earthquake. It can be seen in Figures 6 and 7, that the 6-story building performs very well as all drifts satisfy the allowable drift in both directions and both earthquake levels. In X-direction, it is recorded that the maximum drifts are 1.80% and 2.53% for EDRS and MCER earthquakes, respectively. While in Y-direction, the drifts are 1.94% and 2.80% for EDRS and MCER earthquakes, respectively.



(a) (b)

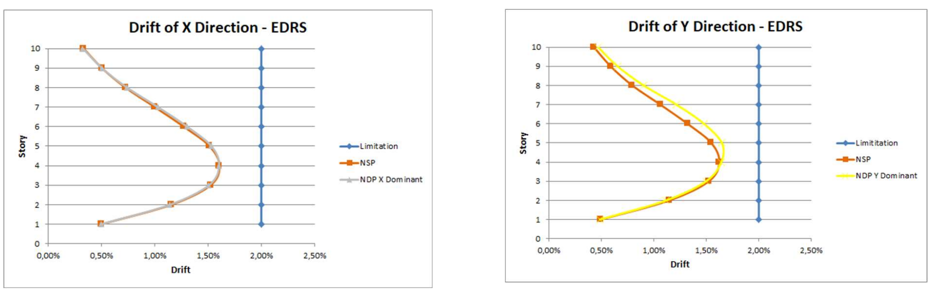
Figure 6. Drifts of 6-Story building for EDRS in: (a) X-direction; (b) Y-direction



(a) (b)

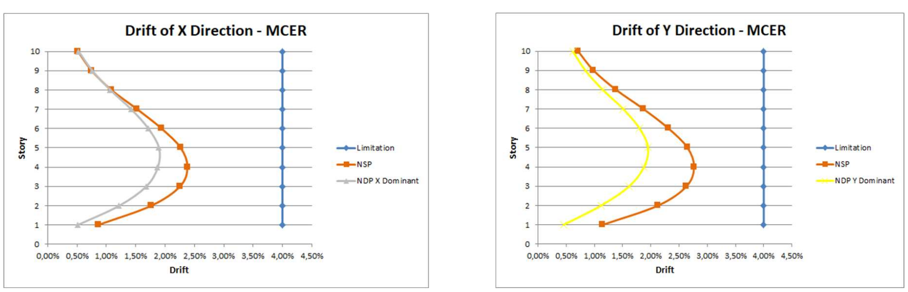
Figure 7. Drifts of 6-Story building for MCER in: (a) X-direction; (b) Y-direction

Similar performances are seen at 10-story buildings that all the drifts meet the requirement by FEMA 273. In Figures 8 and 9, it can be observed that the drifts of the buildings at EDRS and MCER earthquakes are 1.60% and 2.38% in X-direction, and 1.65% and 2.76% in Y-direction.



(a) (b)

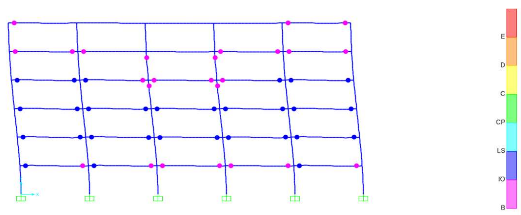
Figure 8. Drift of 10-Story Building for EDRS in: (a) X Direction (b) Y Direction



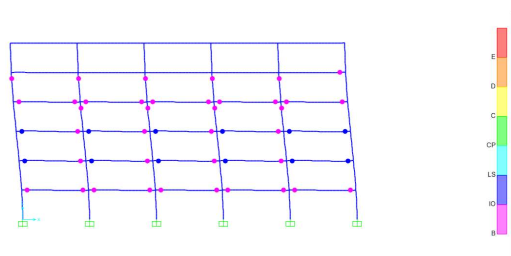
(a) (b)

Figure 9. Drift of 10-Story Building for MCER in: (a) X Direction (b) Y Direction

In order to make sure if the buildings have good performance, safe failure mechanism should be investigated. From all variations of the analysis (the number of story, the level of earthquake used for analysis, the analysis procedures, and direction of dominant earthquake), it is observed that there are no plastic damages in the elastic columns which means the structures can resist the earthquakes with safe partial sidesway mechanism. Figures 10 to 13 show typical plastic damages of the frames.

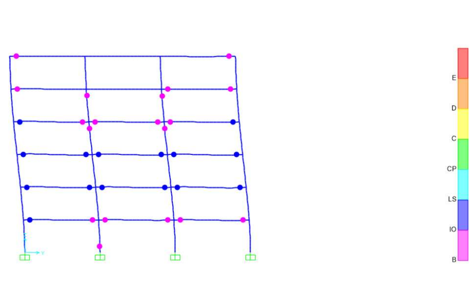


(a)

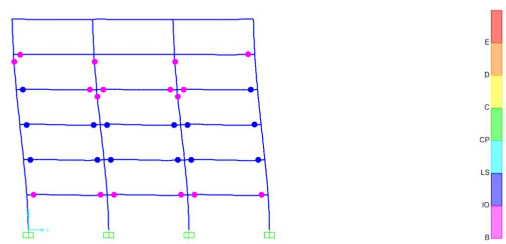


(b)

Figure 10. Plastic Damages of 6-story building from NSP analysis with EDRS earthquake level in X-direction: (a) Frame 1; and (b) Frame 2

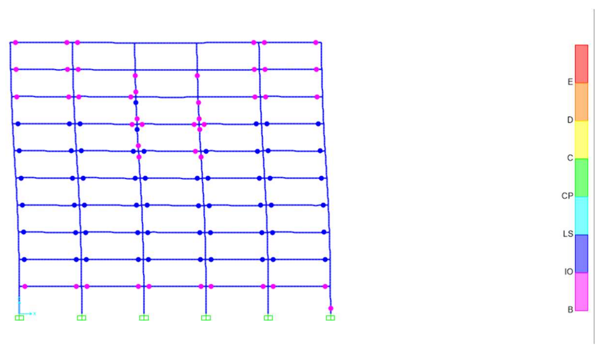


(a)

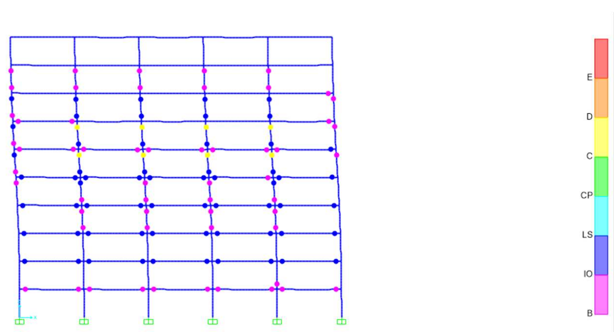


(b)

Figure 11. Plastic Damages of 6-story building from NSP analysis with EDRS earthquake level in Y-direction (a) Frame A; and (b) Frame C

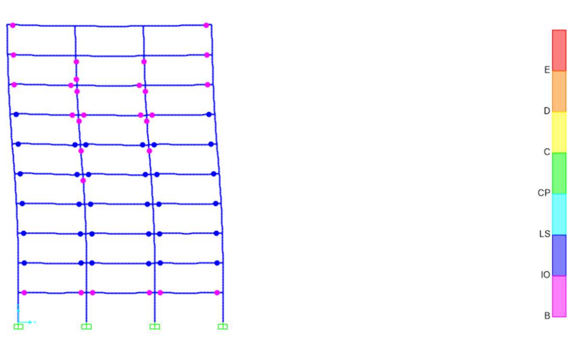


(a)

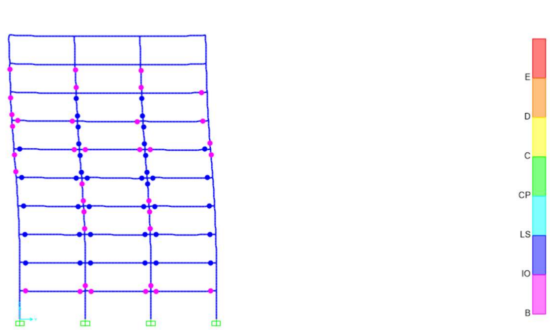


(b)

Figure 12. Plastic Damages of 10-story building from NDP analysis with MCER earthquake level in X-direction (a) Frame 1; and (b) Frame 2



(a)



(b)

Figure 13. Plastic Damages of 10-story building from NDP analysis with MCER earthquake level in Y-direction (a) Frame A; and (b) Frame C

Moreover, from the analysis results, it can be observed how far the deviation of shear force ratio resisted by the elastic columns. The shear force distribution ratio are presented in Table 5. In the design stage, this ratio is set approximately 70% with the assumption that all members experience plastic damages except the elastic columns. Since the actual performance seen in Figures ~~11~~ 10 to ~~22~~ 13 show less damages, it is logical if the shear force resisted by the elastic columns are less than 70%.

Commented [B2]: What is this/

Table 5. Actual Base Shear Distribution Ratio of (a) 6-Story Building and (b) 10-Story Building

	X Direction	Y Direction
Design	73.80%	72.34%
Pushover EDRS	44.77%	42.05%
Pushover MCER	39.92%	42.56%
Time History X Dominant EDRS	50.63%	41.97%
Time History Y Dominant EDRS	49.78%	48.46%
Time History X Dominant MCER	49.54%	44.55%
Time History Y Dominant MCER	45.29%	47.82%

(b)

	X Direction	Y Direction
Design	68.35%	67.62%
Pushover EDRS	59.79%	58.72%
Pushover MCER	51.31%	49.93%
Time History Dominan X EDRS	59.91%	56.50%
Time History Dominan Y EDRS	58.17%	58.80%
Time History Dominan X MCER	59.50%	59.35%
Time History Dominan Y MCER	59.67%	58.95%

(a)

Conclusion

Based on the seismic performance of 6- and 10-story reinforced concrete building designed by using modified partial capacity design method (M-PCD) with 70% of base shear distribution ratio, some conclusion may be drawn:

1. The drifts of the observed buildings meet the criteria set by FEMA 273 [~~2~~7]. The drifts are below 2% and 4% limit for design earthquake (EDRS) and maximum considered earthquake (MCER) levels. The drifts of 6-story building are 1.94% and 2.80% for EDRS and MCER earthquake levels. The drifts of 10-story building are 1.65% and 2.76% for EDRS and MCER earthquake levels.
2. Both observed buildings can resist up to earthquake with MCER level with partial sidesway mechanism, since no elastic columns experience plastic damages.
3. The actual base shear distribution ratio in the elastic column with respect to total base shear is less than that on the design stage. This is logical since the frames (excluding the elastic columns) experience less damage compared to assumption in the design stage. This means that the stiffer frame may resist more force and the elastic columns may resist less force.

References

1. Badan Standarisasi Nasional. (2012). SNI-03-1726-2012. *Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung*. Jakarta.
2. Paulay, T. and Priestly, M.J.N. (1992). *Seismic Design of Reinforced Concrete and Masonry Buildings*. John Wiley & Sons, Inc., New York.
3. Lumantarna, B. ~~and Fransisca, C.~~ (1994), *Perencanaan Kapasitas Alternatif, Suatu Studi Pendahuluan*, Proc. of the ~~the International~~ Conference on Modern Design and Construction for Safety, Economy, and Durability, Petra Christian University, Surabaya, Indonesia.
4. Muljati, I. and Lumantarna, B. (2007), *Partial Capacity Design, an Alternative to the Capacity Design Method*, Proceedings of the 19th Australasian Conference on the Mechanics of Structures and Materials; ACMSM19, Christchurch, New Zealand, pp. 409-414.
5. Muljati, I. and Lumantarna, B. (2008). *Performance of Partial Capacity Design on Fully Ductile Moment Resisting Frame in Highly Seismic Area in Indonesia*. The Eleventh East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-11). Taipei, November, 2008.
6. Tanaya, L.S. (2021). *Metode Modified Partial Capacity Design (M-PCD)*. (Unpublished Thesis). Universitas Kristen Petra, Surabaya, Indonesia.
7. Federal Emergency Management Agency 273 (1997). *NEHRP Guidelines For the Seismic Rehabilitation of Buildings*. Washington, D.C., USA.
8. *CSI Analysis Reference Manual For SAP2000, ETABS, SAFE and CSIBridge*. (2017). Computer & Structure, Inc.
9. Badan Standarisasi Nasional. (2013). SNI-03-2847-2013. *Persyaratan Beton Struktural untuk Bangunan Gedung*. Jakarta.
10. ~~ATC 40. (1996), *Seismic Evaluation and Retrofit of Concrete Buildings Volume 1*. Applied Technology Council, California, USA.~~

Commented [B3]: How come a paper presented in international conf is presented in Bahasa Indonesia. Could you please check.

~~11. *CSICOL For Analysis and Design of Reinforced and Composite Column*, (2005). Computer & Structure, Inc.~~

~~12. Muljati, I. and Lumantarna, B. (2011). *The Use of Magnification Factor Formula in Partial Capacity Design Method on Fully Ductile Moment Resisting Frame*. The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-12). Hongkong, Januari, 2011.~~

~~13. Muljati, I. and Lumantarna, B. (2011), *Seismic Performance of Structure with Vertical Geometric Irregularity Designed Using Partial Capacity Design*, 2nd International Conference on Earthquake Engineering and Disaster Mitigation (ICEEDM), 19 July 2011 , Surabaya, Indonesia.~~

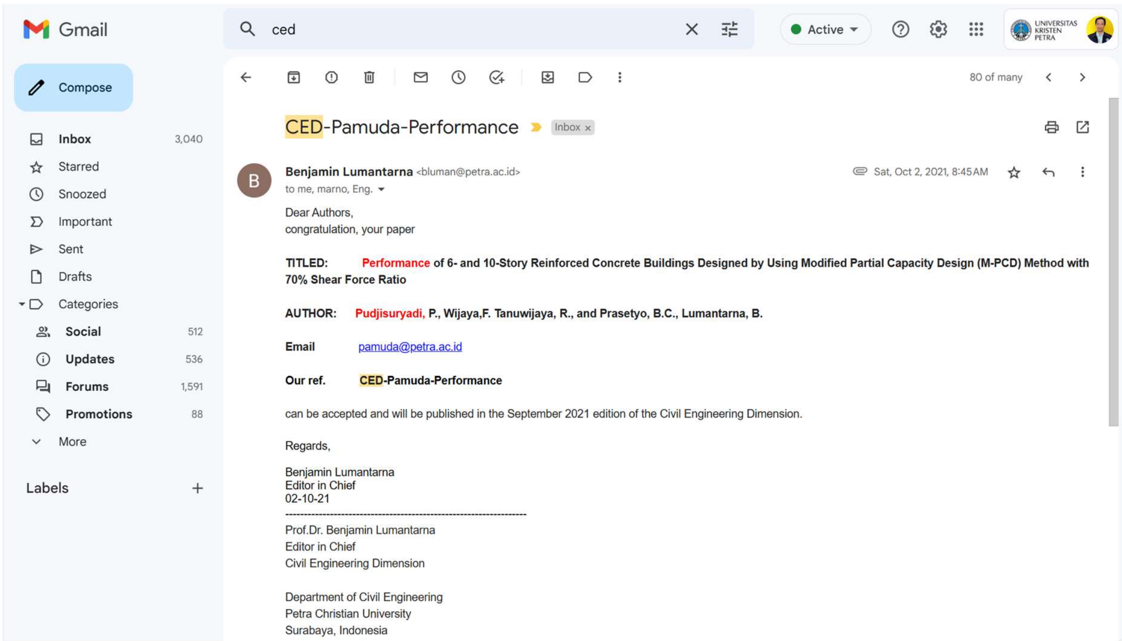
~~14. Pacific Earthquake Engineering Research Center. (2021). *PEER Ground Motion Database El Centro 1940.* https://ngawest2.berkeley.edu/spectras/438744/searches/406857/edit~~

~~15. Paulay, T. (1995), "Special Issues in Seismic Design", Structural Engineering International, Volume 5, Issue 3: 160-165.~~

~~16. Pudjisuryadi, P., Lumantarna, B., Teddy, S., Wijoyo, H. (2011). *Seismic Performance of Structure with Vertical Set-Back Designed Using Partial Capacity Design*, The 3rd International Conference of EACEF (European Asian Civil Engineering Forum), 20-22 September 2011, Universitas Atma Jaya, Yogyakarta, Indonesia.~~

~~17.~~10. ~~Wijaya, F. and Widjojo, L. (2012). *Kritisi Desain Pseudo Elastis pada Bangunan Beraturan 6- dan 10- Lantai dengan Denah Persegi Panjang di Wilayah 2 Peta Gempa Indonesia*.~~ Universitas Kristen Petra, Surabaya, Indonesia

5. Paper is accepted, with minor redactional revision done by editor. (02-10-2021).



CED-Pamuda-Performance

Benjamin Lumantarna <bluman@petra.ac.id>
to me, marno, Eng.

Sat, Oct 2, 2021, 8:45 AM

Dear Authors,
congratulation, your paper

TITLED: Performance of 6- and 10-Story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio

AUTHOR: Pudjisuryadi, P., Wijaya,F. Tanuwijaya, R., and Prasetyo, B.C., Lumantarna, B.

Email pamuda@petra.ac.id

Our ref. CED-Pamuda-Performance

can be accepted and will be published in the September 2021 edition of the Civil Engineering Dimension.

Regards,

Benjamin Lumantarna
Editor in Chief
02-10-21

Prof.Dr. Benjamin Lumantarna
Editor in Chief
Civil Engineering Dimension

Department of Civil Engineering
Petra Christian University
Surabaya, Indonesia

Performance of Six- and Ten-story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio

Pudjisuryadi, P.[1], Wijaya,F.[1] Tanuwijaya, R.[2], and Prasetyo, B.C.[2] , Lumantarna, B.[1]

Abstract: One design alternative of earthquake resistant building is Partial Capacity Design (PCD) method. Unlike the commonly used capacity design method, PCD allows a safe failure mechanism which is called partial sidesway mechanism. In this mechanism, all beams and some columns are allowed to experience plastic damages while some selected columns are designed to remain elastic (called elastic columns). A new approach to predict the required strengths needed to design each structural member, called modified-PCD (M-PCD) is proposed. In this research six- and ten-story reinforced concrete buildings were designed using M-PCD, and their seismic performances are investigated. The base shear force resisted by the elastic columns was set to approximately 70% of the total base shear. Both nonlinear static procedure (NSP) and nonlinear dynamic procedure (NDP) are used to analyze the structures. The results show that the expected partial side sway mechanism is observed, and the drifts of the buildings are acceptable.

Keywords: modified partial capacity design; partial side sway mechanism; reinforced concrete; seismic design.

Introduction

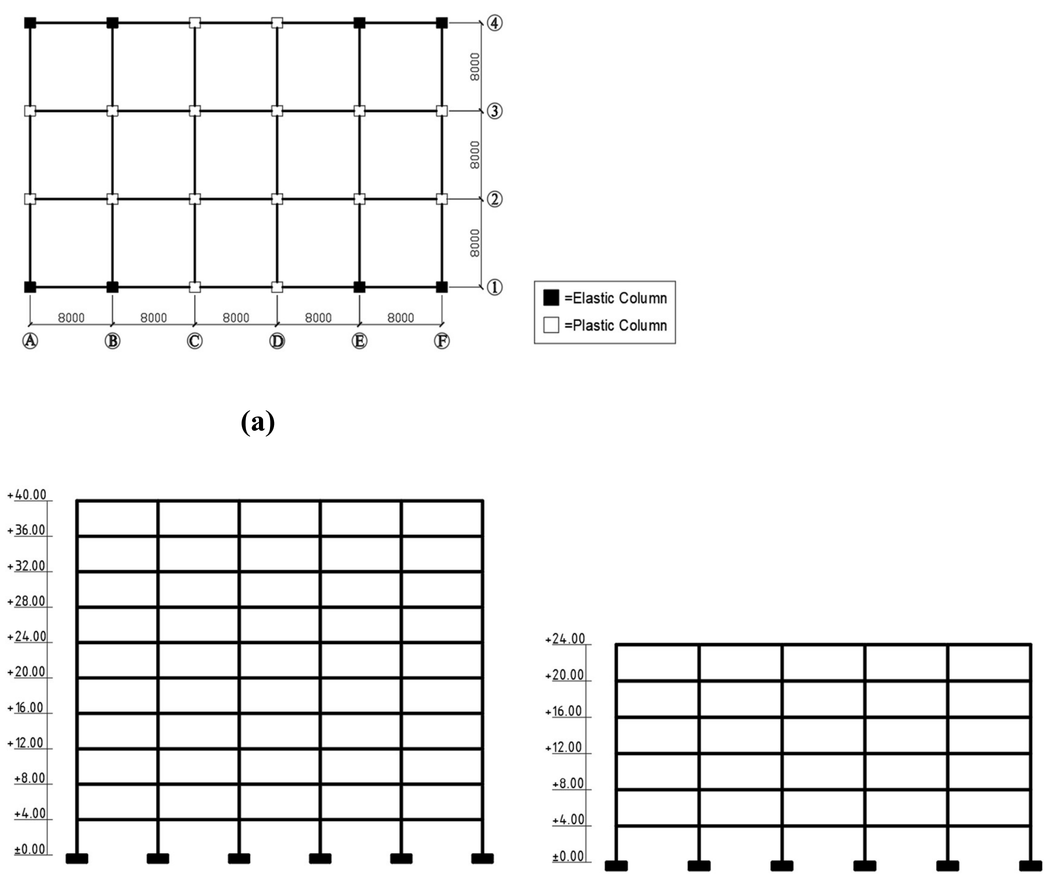
In the design of earthquake resistant structures, one alternative of the capacity design method [1] is partial capacity design (PCD) method. The PCD method allows a safe failure mechanism proposed by Paulay and Priestley [2] which is called the partial sidesway mechanism. In this mechanism, some of columns are allowed to experience plastic damages while other columns (elastic columns) are intended to remain elastic during target earthquake. The challenge of this concept is how well the prediction of structural members' required strength. Early PCD method proposed that elastic columns could be designed by using a single magnification factor which scales up their internal forces from a design earthquake. Seismic reduction factor of 8.0 was used to define the design earthquake with the assumption that the structure possesses good ductility. However, some studies showed that the performance of the method was somehow inconsistent. Based on the early study that used the single magnification factor to design the elastic columns, the test results showed that plastic hinges still occurred on the elastic column in the nonlinear time history analysis [3]. Other studies that used the single magnification factor with other variations of building that have vertical setback showed unsatisfactory results because the partial side sway mechanism was not achieved effectively [4,5]. A more accurate approach in predicting the required strengths may be one of the answers to improve PCD method.

Recently, Tanaya [6] proposed a new approach in predicting the required strength to design the elastic columns. This new approach is called Modified-PCD (M-PCD). The M-PCD suggests the use of two structural models to predict the required strengths needed to design the structural members. The first structural model was used to design elements which are allowed to yield during major earthquakes. This model was subjected to earthquake with seismic reduction factor R=8 (design earthquake). The second structural model was modified from the first one by reducing stiffness of members that may develop plastic hinges, and subjected to a target earthquake (R=1.6). This second model was used to design the elastic columns. Early test showed promising results, most structure showed the expected partial sidesway mechanism and the drifts are well below the maximum values set by FEMA 273 [7]. However, more tests are needed to further develop and conform the effectiveness of this new approach.

In this research, improvement of M-PCD proposed by Tanaya [6] is suggested. The second model is not subjected to full target earthquake, instead it is subjected by the difference between target earthquake and design earthquake used in the first model. This is logical, since after some members develop plastic damages, only the remaining earthquake load (beyond design earthquake) will be distributed according to structural responses of the second model. With this improvement, buildings similar to Tanaya's research are re-designed and investigated.

Model and Design of the Buildings

SAP2000 software [8] is used to model the buildings. The buildings are assumed to be located in Surabaya resting on soil with Site Class E, and intended as office buildings. The applied gravity loads were according to SNI 1727:2013 [9]. The building plans and elevation views can be seen in Figure 1.

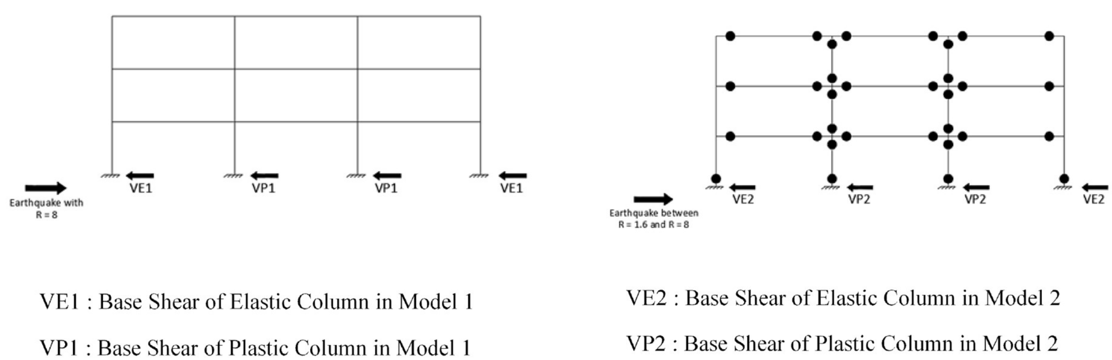


(a)

(b)

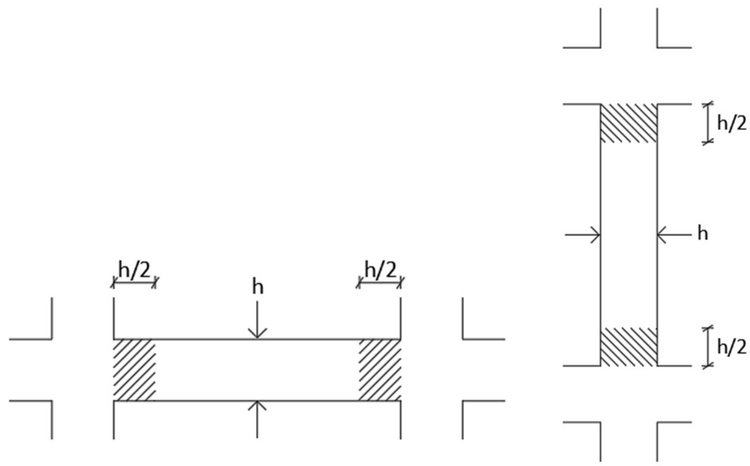
Figure 1. Observed structures: (a) Plan view; (b) Elevation view

In this study, the ratio of shear force resisted by elastic columns with respect to the total base shear is approximately set as large as 70%, resulting in the use of eight elastic columns (Figure 1a). As mentioned in the introduction, two structural models are used in this approach. Illustration of these two structural models as well as seismic load (based on SNI 1726:2012 [1]) subjected to each model are shown in Figure 2. The modification factors (R) of 8.0 and 1.6 are chosen with the assumptions that the damaged frame members possess good ductility and elastic columns remain elastic, respectively. The stiffness reduction to simulate plastic damages is done by breaking the elements into three parts. Two of the parts are located close to element supports with the length of $0.5h_{element}$ (typical plastic hinge region), which flexural stiffnesses are reduced to model plastic hinges (see Figure 3). The flexural stiffness modification may be determined by looking at typical bilinear curve of moment-rotation curves of reinforced concrete section.



(a) (b)

Figure 2. Design assumption: (a) Model 1; (b) Model 2



(a) (b)

Figure 3. Stiffness reduction in Model 2 at: (a) Beam; (b) Column

Results from the first model are used to design the beams and plastic columns which may develop plastic damages. Since the columns may experience damages, the strong column weak beam requirement is neglected in this approach. However, the shear design of both beams and columns should still follow the capacity design concept since no shear failure is allowed. Required strengths used for designing the elastic columns are determined by combining the internal forces from both models. It should be noted that the effect of gravity load should only calculated once when combining results from both models. Again, only shear design of the elastic columns should follow standard capacity design approach. The base shear distribution ratio of the structure can be seen in Table 1. The design results of the beams and columns can be seen in Table 2, 3, and 4.

Table 1. Base Shear Distribution Ratio of Elastic Column for (a) 6-Story and (b) 10-Story Building

Design Earthquake X Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)	Design Earthquake Y Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)
Model 1	2055.09	1013.99	Model 1	1907.64	849.24
Model 2	3101.46	2791.54	Model 2	3096.14	2770.44
Total	5156.55	3805.53	Total	5003.78	3619.68
Shear Force Distribution Ratio		73.80%	**Shear Force Distribution Ratio**		72.34%

(a)

Design Earthquake X Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)	Design Earthquake Y Direction	Total Base Shear (kN)	Total Base Shear Elastic Column (kN)
Model 1	2452.52	1513.95	Model 1	2274.09	1441.90
Model 2	5611.75	3998.33	Model 2	5596.76	3880.43
Total	8064.27	5512.28	Total	7870.85	5322.33
Shear Force Distribution Ratio		68.35%	**Shear Force Distribution Ratio**		67.62%

(b)

Table 2. Reinforcement Details of 6-Story Building (a) Beam (b) Plastic Column

Type	Dimension	Position	Longitudinal			Transversal
			ρ	Reinforcement	Strength Ratio	s
BI-1	300x700	Top	1.04%	7D19	0.91	2D10-110
		Bottom	0.59%	4D19	0.76	
BI-2	300x700	Top	1.04%	7D19	0.98	2D10-110
		Bottom	0.59%	4D19	0.82	
BI-3	300x700	Top	0.89%	6D19	0.97	2D10-110
		Bottom	0.44%	3D19	0.93	
BI-4	300x700	Top	0.74%	5D19	0.92	2D10-110
		Bottom	0.44%	3D19	0.78	

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
6	350x350	4.51%	16D19	0.69	2D13-60
5	350x350	4.51%	16D19	0.78	2D13-60
4	400x400	3.36%	16D19	0.89	3D13-90
3	450x450	2.60%	16D19	0.94	3D13-100
2	450x450	3.90%	24D19	0.89	3D13-100
1	500x500	2.59%	20D19	0.79	3D13-100

(a) (b)

Table 3. Reinforcement Details of 10-Story Building (a) Beam (b) Plastic Column

Type	Dimension	Position	Longitudinal			Transversal
			ρ	Reinforcement	Strength Ratio	s
BI-1	300x700	Top	0.89%	6D19	0.91	2D10-110
		Bottom	0.44%	3D19	0.88	
BI-2	300x700	Top	1.03%	7D19	0.94	2D10-110
		Bottom	0.59%	4D19	0.79	
BI-3	300x700	Top	1.18%	8D19	0.93	2D10-110
		Bottom	0.59%	4D19	0.89	
BI-4	300x700	Top	0.74%	5D19	0.92	2D10-110
		Bottom	0.44%	3D19	0.74	
BI-5	300x700	Top	1.33%	9D19	0.95	2D10-110
		Bottom	0.74%	5D19	0.81	
BI-6	300x700	Top	1.48%	10D19	0.95	2D10-110
		Bottom	0.74%	5D19	0.89	

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
10	350x350	4.96%	16D22	0.88	2D13-60
9	350x350	3.72%	12D22	0.96	2D13-60
8	400x400	3.80%	16D22	0.94	3D13-100
7	400x400	3.80%	16D22	0.93	3D13-100
6	450x450	3.00%	16D22	0.94	3D13-100
5	450x450	4.50%	24D22	0.95	3D13-100
4	500x500	3.65%	24D22	0.92	3D13-100
3	500x500	4.86%	32D22	0.92	3D13-100
2	600x600	2.11%	20D22	0.91	3D13-100
1	600x600	2.96%	28D22	0.93	3D13-100

(a) (b)

Table 4. Reinforcement Details of Elastic Column (a) 6-Story Building (b) 10-Story Building

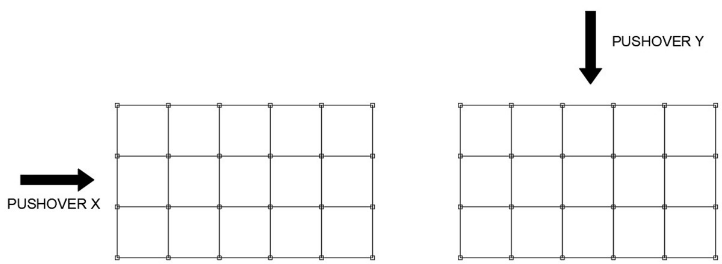
Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
6	700x700	3.94%	24D32	0.98	3D13-100
5	700x700	5.25%	32D32	0.97	3D13-100
4	700x700	5.91%	36D32	0.94	3D13-100
3	700x700	4.59%	28D32	0.93	3D13-100
2	700x700	3.94%	24D32	0.96	3D13-90
1	700x700	2.62%	16D32	0.99	3D13-90

Story	Dimension	Longitudinal			Transversal
		ρ	Reinforcement	Strength Ratio	s
10	900x900	2.48%	16D40	0.90	4D13-100
9	900x900	3.10%	20D40	0.99	4D13-100
8	900x900	4.96%	32D40	0.87	4D13-100
7	900x900	4.96%	32D40	0.99	4D13-100
6	900x900	5.58%	36D40	0.96	4D13-100
5	900x900	5.58%	36D40	0.97	4D13-100
4	900x900	4.96%	32D40	0.95	4D13-100
3	900x900	4.34%	28D40	0.96	4D13-100
2	900x900	3.10%	20D40	0.86	4D13-100
1	900x900	3.72%	24D40	0.94	4D13-100

(a) (b)

Buildings' Performances Analysis

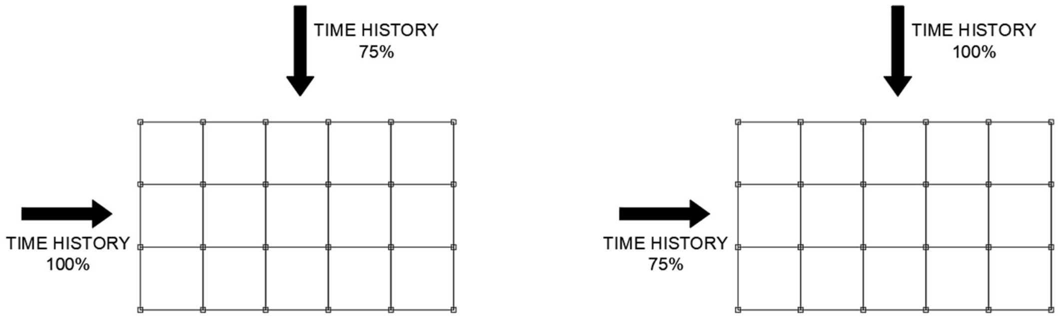
Analysis is conducted twice for each building to model dominant earthquake in each orthogonal direction (see Figure 4). Performance of the buildings are reported at two levels of earthquakes which are the elastic design response spectrum (EDRS) and maximum considered earthquakes (MCER) which is 1.5 times of EDRS. The buildings are analyzed with nonlinear static procedure (NSP) and nonlinear dynamic procedure (NDP) using SAP 2000 software [8]. The load pattern used in NSP is the first translational mode of the corresponding directions.



(a) (b)

Figure 4. Nonlinear Static Procedure (NSP) in: (a) X-direction (b) Y-direction

In NDP analysis, the seismic load used is spectrum consistent ground accelerations generated from El Centro 18 May 1940 earthquake N-S and E-W components in accordance to Indonesian Seismic Code (SNI 1726:2012 [1]). Two level of acceleration response spectrums to match are the elastic design response spectrum (EDRS) and spectrum corresponding to maximum considered earthquake (MCER). The buildings are subjected to two-directional ground motion which peak ground accelerations ratio (4:3) is taken the same as the original earthquake motion. Illustration of the ground motions used for analysis are presented in Figure 5.

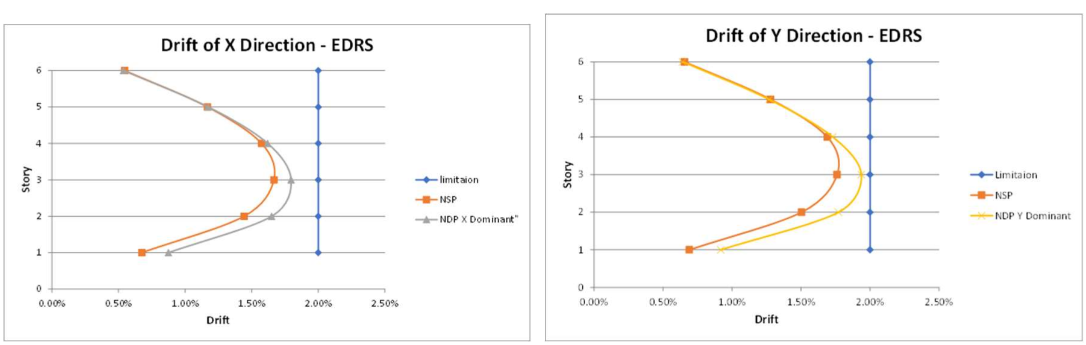


(a) (b)

Figure 5. Nonlinear Dynamic Procedure (NDP) with dominant ground motion in: (a) X-Dominant (b) Y-Dominant

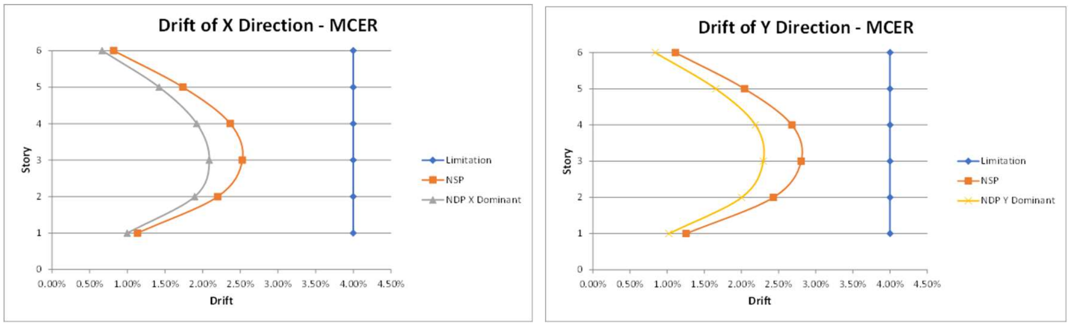
Analysis results

The drifts of the buildings are presented in Figures 6 to 9. The drifts are plotted against limitation according to FEMA 273 [7], which are 2% for design earthquake (EDRS) and and 4% for maximum considered (MCER) earthquake. It can be seen in Figures 6 and 7, that the 6-story building performs very well as all drifts satisfy the allowable drift in both directions and both earthquake levels. In X-direction, it is recorded that the maximum drifts are 1.80% and 2.53% for EDRS and MCER earthquakes, respectively. While in Y-direction, the drifts are 1.94% and 2.80% for EDRS and MCER earthquakes, respectively.



(a) (b)

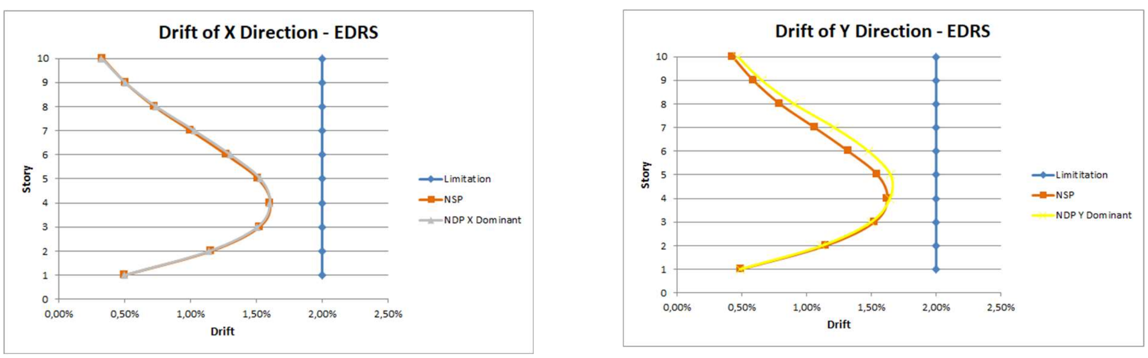
Figure 6. Drifts of 6-Story building for EDRS in: (a) X-direction; (b) Y-direction



(a) (b)

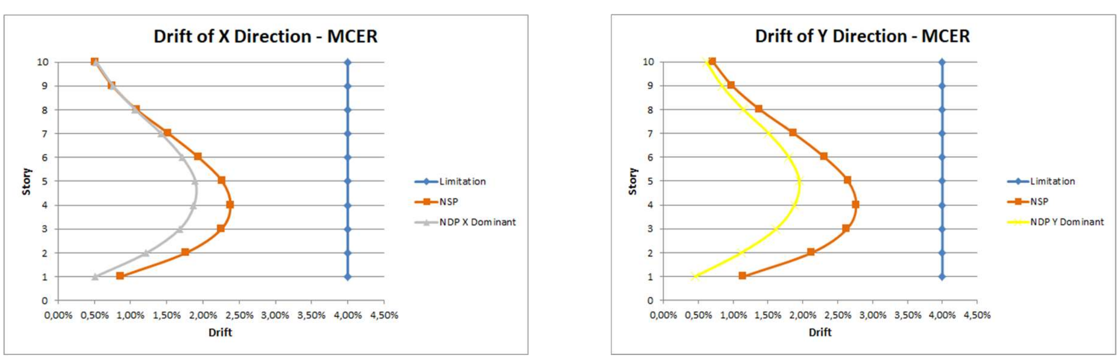
Figure 7. Drifts of 6-Story building for MCER in: (a) X-direction; (b) Y-direction

Similar performances are seen at 10-story buildings that all the drifts meet the requirement by FEMA 273. In Figures 8 and 9, it can be observed that the drifts of the buildings at EDRS and MCER earthquakes are 1.60% and 2.38% in X-direction, and 1.65% and 2.76% in Y-direction.



(a) (b)

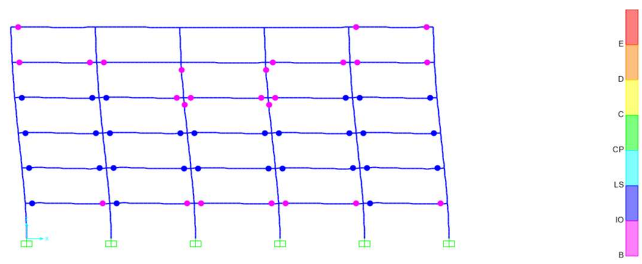
Figure 8. Drift of 10-Story Building for EDRS in: (a) X Direction (b) Y Direction



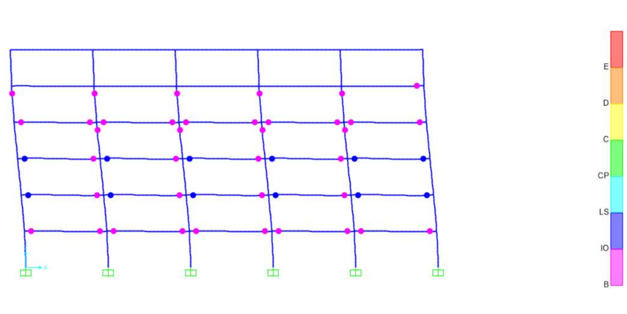
(a) (b)

Figure 9. Drift of 10-Story Building for MCER in: (a) X Direction (b) Y Direction

In order to make sure if the buildings have good performance, safe failure mechanism should be investigated. From all variations of the analysis (the number of story, the level of earthquake used for analysis, the analysis procedures, and direction of dominant earthquake), it is observed that there are no plastic damages in the elastic columns which means the structures can resist the earthquakes with safe partial sidesway mechanism. Figures 10 to 13 show typical plastic damages of the frames.

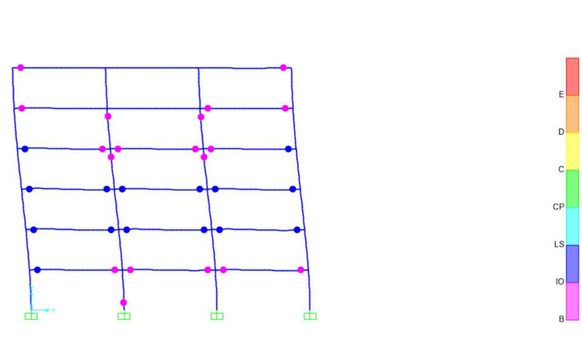


(a)

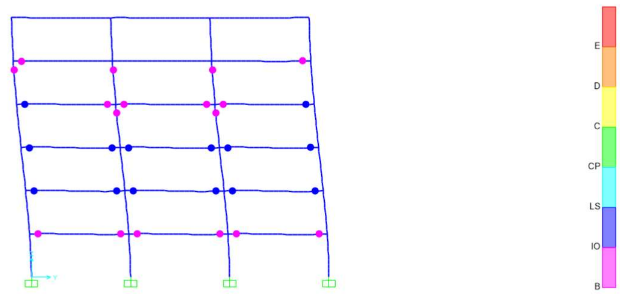


(b)

Figure 10. Plastic Damages of 6-story building from NSP analysis with EDRS earthquake level in X-direction: (a) Frame 1; and (b) Frame 2

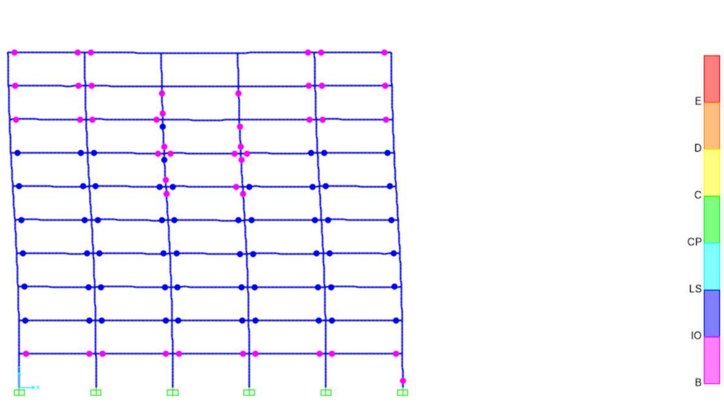


(a)

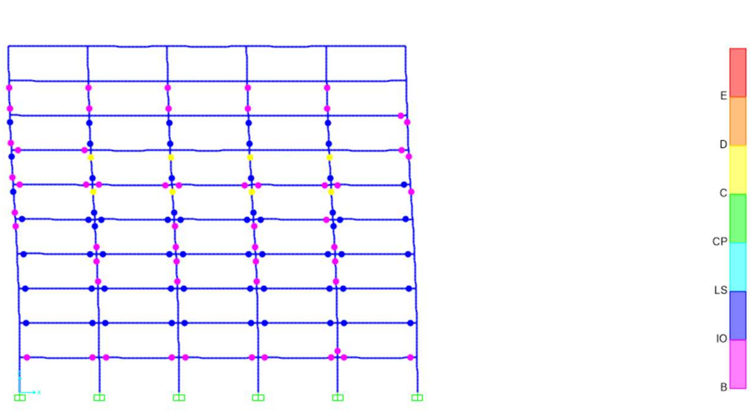


(b)

Figure 11. Plastic Damages of 6-story building from NSP analysis with EDRS earthquake level in Y-direction (a) Frame A; and (b) Frame C

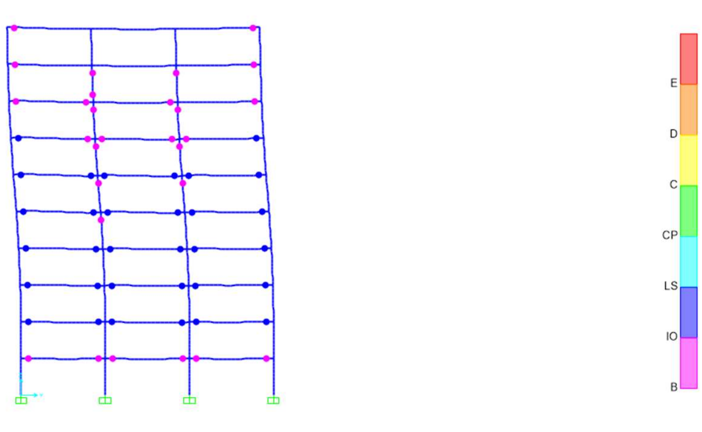


(a)

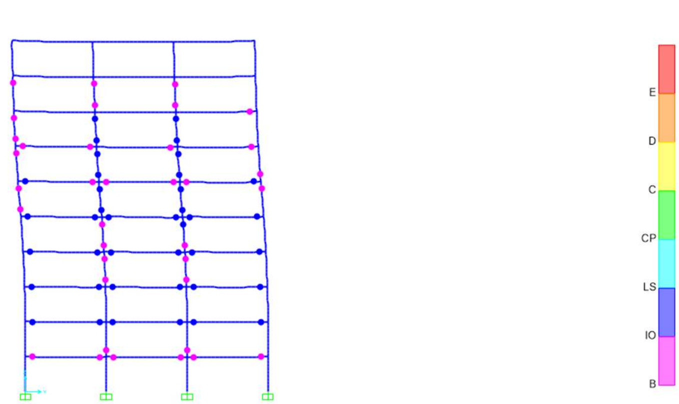


(b)

Figure 12. Plastic Damages of 10-story building from NDP analysis with MCER earthquake level in X-direction (a) Frame 1; and (b) Frame 2



(a)



(b)

Figure 13. Plastic Damages of 10-story building from NDP analysis with MCER earthquake level in Y-direction (a) Frame A; and (b) Frame C

Moreover, from the analysis results, it can be observed how far the deviation of shear force ratio resisted by the elastic columns. The shear force distribution ratio are presented in Table 5. In the design stage, this ratio is set approximately 70% with the assumption that all members experience plastic damages except the elastic columns. Since the actual performance seen in Figures 10 to 13 show less damages, it is logical if the shear force resisted by the elastic columns are less than 70%.

Table 5. Actual Base Shear Distribution Ratio of (a) 6-Story Building and (b) 10-Story Building

	X Direction	Y Direction
Design	73.80%	72.34%
Pushover EDRS	44.77%	42.05%
Pushover MCER	39.92%	42.56%
Time History X Dominant EDRS	50.63%	41.97%
Time History Y Dominant EDRS	49.78%	48.46%
Time History X Dominant MCER	49.54%	44.55%
Time History Y Dominant MCER	45.29%	47.82%

	X Direction	Y Direction
Design	68.35%	67.62%
Pushover EDRS	59.79%	58.72%
Pushover MCER	51.31%	49.93%
Time History Dominan X EDRS	59.91%	56.50%
Time History Dominan Y EDRS	58.17%	58.80%
Time History Dominan X MCER	59.50%	59.35%
Time History Dominan Y MCER	59.67%	58.95%

(a)

(b)

Conclusion

Based on the seismic performance of 6- and 10-story reinforced concrete building designed by using modified partial capacity design method (M-PCD) with 70% of base shear distribution ratio, some conclusion may be drawn:

1. The drifts of the observed buildings meet the criteria set by FEMA 273 [7]. The drifts are below 2% and 4% limit for design earthquake (EDRS) and maximum considered earthquake (MCER) levels. The drifts of 6-story building are 1.94% and 2.80% for EDRS and MCER earthquake levels. The drifts of 10-story building are 1.65% and 2.76% for EDRS and MCER earthquake levels.
2. Both observed buildings can resist up to earthquake with MCER level with partial sidesway mechanism, since no elastic columns experience plastic damages.
3. The actual base shear distribution ratio in the elastic column with respect to total base shear is less than that on the design stage. This is logical since the frames (excluding the elastic columns) experience less damage compared to assumption in the design stage. This

means that the stiffer frame may resist more force and the elastic columns may resist less force.

References

1. Badan Standarisasi Nasional. (2012). SNI-03-1726-2012. *Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung*. Jakarta.
2. Paulay, T. and Priestly, M.J.N. (1992). *Seismic Design of Reinforced Concrete and Masonry Buildings*. John Wiley & Sons, Inc., New York.
3. Lumantarna, B. (1994), *Perencanaan Kapasitas Alternatif, Suatu Studi Pendahuluan*, Proc. of the Conference on Modern Design and Construction for Safety, Economy, and Durability, Petra Christian University, Surabaya, Indonesia.
4. Muljati, I. and Lumantarna, B. (2007), *Partial Capacity Design, an Alternative to the Capacity Design Method*, Proceedings of the 19th Australasian Conference on the Mechanics of Structures and Materials; ACMSM19, Christchurch, New Zealand, pp. 409-414.
5. Muljati, I. and Lumantarna, B. (2008). *Performance of Partial Capacity Design on Fully Ductile Moment Resisting Frame in Highly Seismic Area in Indonesia*. The Eleventh East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-11). Taipei, November, 2008.
6. Tanaya, L.S. (2021). *Metode Modified Partial Capacity Design (M-PCD)*. (Unpublished Thesis). Universitas Kristen Petra, Surabaya, Indonesia.
7. Federal Emergency Management Agency 273 (1997). *NEHRP Guidelines For the Seismic Rehabilitation of Buildings*. Washington, D.C., USA.
8. *CSI Analysis Reference Manual For SAP2000, ETABS, SAFE and CSIBridge*. (2017). Computer & Structure, Inc.

9. Badan Standarisasi Nasional. (2013). SNI-03-2847-2013. *Persyaratan Beton Struktural untuk Bangunan Gedung*. Jakarta.

CIVIL ENGINEERING DIMENSION
Journal of Civil Engineering Science and Application
Dimensi Teknik Sipil
Jurnal Keilmuan dan Penerapan Teknik Sipil

Jl. Siwalankerto, 121-131, Surabaya 60236, Indonesia. Phone: (031) 8494830-31 ext. 3139, 3148, Fax. (031) 8436418,
Email: dimensi-sipil@petra.ac.id

REVIEW on
SUBMITTED PAPER

TITLE: **Performance of 6- and 10-Story Reinforced Concrete Buildings Designed by Using Modified Partial Capacity Design (M-PCD) Method with 70% Shear Force Ratio**

AUTHOR: **Pudjisuryadi, P., Wijaya,F. Tanuwijaya, R., and Prasetyo, B.C., Lumantarna, B.**

Email pamuda@petra.ac.id

Our ref. **CED-Pamuda-Performance**

Congratulation, the above-captioned paper can be accepted and will be published in the September 2021 edition of the Civil Engineering Dimension.

Regards,

Benjamin Lumantarna
Editor in Chief
02-10-21