Preliminary Seismic Performance-based Evaluation of Academic Reinforced Concrete Building in Yogyakarta based on Displacement Parameter

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***Abstract*— Periodical seismic safety evaluation for concrete buildings are necessary since they have been used for many years. Many approaches can be used to evaluate them, one of them is pushover analysis. This analysis is performed by applying incremental loads then reading the displacement that happen and comparing it to the response spectra demand to retrieve the performance point. Moreover, time history records can be used to determine the displacement appear in structure. This study aims to perform 3D evaluation of reinforced concrete buildings. The building sample was selected from academic building in Yogyakarta, Indonesia which has 7 storeys. The analysis was performed using STERA 3D software. Three time-history records namely El Centro, Kobe, and Parkfield earthquakes were used to determine the displacement. The result shows the performance level of the building and the displacement resulted from inputting time history, compared to the displacement limit from ATC-40 and FEMA 356. The result shows that the preliminary performance level indicated with spectral displacement is achieved at 13 cm on pushover analysis which complies the 0.01 height limitation from ATC-40 and FEMA 356. Since it is a preliminary study, it is hoped that further study could consider more aspects such as ductility, prediction of failure positions, and comprehensive pushover analysis based on FEMA 356.**

Keywords—preliminary evaluation, reinforced concrete building, displacement parameter, new Indonesian Seismic Hazard Map 2017

I. Introduction

Indonesia is a Southeast Asia country lays on 4 active Earth's plates, namely Eurasian Plate, Indian Ocean-Australian plate, Pacific plate, and Philippine Sea plate [1] and passed by Ring of Fire, which makes Indonesia has great potential risk of big earthquakes and other natural disasters. Indonesia is also the fourth biggest populated in the world with more that 264 million people [2] so that Indonesia has many constructed buildings with multipurpose, one of which is academic building. Based on Indonesian Ministry of Research and Higher Education in 2018, there are at least 228 institutions, 290 polytechnics, 1047 academies, and 601 universities in Indonesia [3]. With these number, many mid-rise and high-rise buildings in Indonesia are built up to support academic facilities. Some of these buildings were constructed since few decades ago and there might have been changes to its physical form or its use. These academic buildings safety must be guaranteed and controlled considering that many people supported by the building, as well as not causing any casualties if natural disasters such as earthquake occurs. Indonesia has many experiences many big earthquake events since 2004 in Aceh to 2018 in Lombok and Palu-Donggala. This makes earthquake is one of big threats as well as challenge to make sure that buildings are secure for its residents.

Buildings evaluation due to several hazards have been done by many researchers before, from linear to non-linear approach. One seismic performance evaluation that has been done on concrete frame is using endurance time approach [4]. This method is generating the acceleration function artificially then the response of nonlinear soil-foundation-reinforced concrete structures are evaluated. The Winkler's foundation are implemented in the finite element model. Other research related to seismic performance of building structure is the assessment based on risk which occur aftershock as well as mainshock-aftershock [5]. This method is considering any other hazard that effects on buildings in timeline closes to its earthquake event. Ground motion data are used to create fragility curves which reflect the seismic performance of buildings. As many seismic evaluation on buildings have been developed in the previous study before, one researcher tried to evaluate the consistency between performance-based seismic design approach and prescriptive for structural buildings, especially reinforced concrete [6]. Beside the consistency, the result of performance-based seismic design can be also improved by risk-targeted method using formulation of exceeding mean annual frequency (MAF) [7].

Apart from these mentioned studies, buildings are evaluated by other popular procedures, which are using pushover analysis [8] and time history analysis (THA). The pushover analysis is done by giving incremental lateral force to the building gradually then reading the displacement caused by this force. The graph between displacement and force can be generated and is called as pushover curve. This curve is overlapped with addressed earthquake demand curve, in this case is response spectrum curve which depends on scale of the damping. The intersection between these two graphs can be called as performance point. This point is compared to the displacement ratio stated on several code namely ATC-40 and FEMA 356, as it represents the building performance on many condition such as operational, immediate occupancy, life safety, or even collapse.

Different with pushover analysis, the time history analysis (THA) is done by assessing the structure under earthquake load by inputting real or modified earthquake records. Many studies have also been done before related to THA, such as the correction of viscous damping in time history [9], comparation to the response spectrum analysis used on building [10], usage of the THA to assess base isolation system in irregular plan of reinforced concrete buildings [11], and even for analyzing the high-rise braced with frame-core buildings [12]. To evaluate seismic response of buildings, many research use software to conduct numerical analysis. Some previous studies use OpenSees to perform analysis on masonry infill walls participation `[13] and shear wall element analysis for super-tall buildings [14], other uses CSI software product such as ETABS for finding seismic performance of masonry shear walls [15] and SAP2000 for seismic performance on masonry towers [16].

Another popular software to conduct seismic response on building due to earthquake is STERA_3D, abbreviation for Structural Earthquake Response Analysis 3D [17]. It is a software that can evaluate building using pushover analysis and time history records data and has been developed by the co-author for many years. Many researchers also used this program to evaluate buildings, for example to evaluate school building in Malaysia against Ranau earthquake [18], to seek for the behavior of reinforced concrete structure by time history approach [19], and even to make a proposal for mid-rise existing building index of seismic evaluation [20].

Building in Indonesia is designed to based on earthquake building provision, SNI 1726:2012. This code has been upgraded since 2002 and the earthquake hazard map is updated in 2017. However, not many studies perform seismic evaluation on building based on this code [21], [22]. In this research, 7-storey academic building earthquake response in Yogyakarta is evaluated using STERA_3D. From this research, the preliminary result of assessment from displacement parameter can be known to be the input for the related stakeholders and for future research purposes.

II. Research Method

A. Numerical Analysis Software

Structural analysis was conducted using STERA_3D. This software has been developed by the co-author, Prof. Taiki Saito for many years until the present day. The software uses numerical analysis by implementing trilinear Takeda model for hysteresis loop on structural members, beams and columns. The preview of software graphical user interface can be seen in Fig. 1.

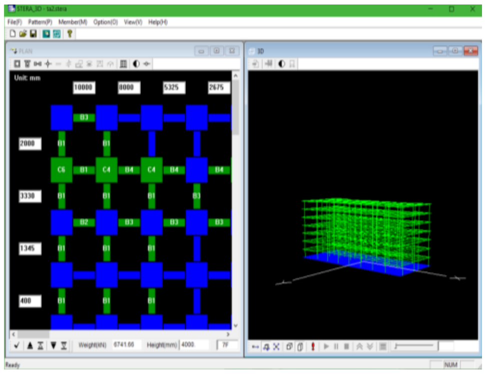

Fig. 1. Preview of structural modelling using STERA_3D

B. Time history data

In this study, three data records were retrieved from Pacific Earthquake Engineering Research Center (PEER Berkeley) and these three data records were chosen, namely Parkfield earthquake, El Centro 1940 earthquake, Kobe 1955 earthquake. These three data were chosen based on several earthquake characteristics which is similar with Yogyakarta previous earthquake events. These records can be seen in Fig. 2 to Fig. 4.

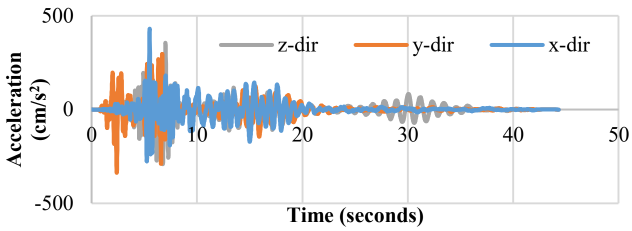

Fig. 2. Parkfield earthquake used in time history analysis [23]

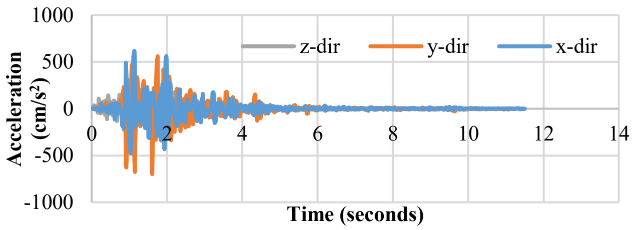

Fig. 3. Kobe earthquake used in time history analysis [23]

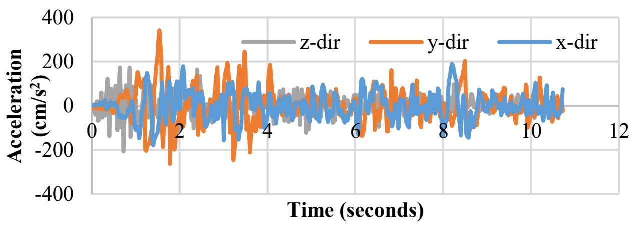

Fig. 4. El Centro earthquake used in time history analysis [23]

C. Non-linear analysis and damping

Non-linear behavior applied in this research is based on Takeda Model, especially for the hysteresis model for bending springs of the beam and column. This represents the consideration of crack and yield factor on the non-linear analysis. The illustration of this application can be seen in Fig. 5. This adaptation is following the degrading tri-linear slip model.

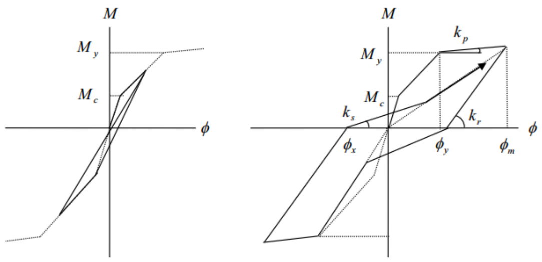

Fig. 5. El Centro earthquake used in time history analysis [23]

The value of k_p, k_r, and k_s (stiffness parameters) in the depicted figure above is calculated using equations shown in Equation 1, 2, and 3, with the value of inputted in the model is using the default parameter, which α = 0.5, β = 0, and η = 0.001.

$$k_p = \eta \left(\frac{M_y}{\phi_y}\right) \tag{1}$$

$$k_r = \left(\frac{M_y}{\phi_y}\right)\left|\frac{\phi_y}{\phi_m}\right|^{\alpha} \tag{2}$$

$$k_s = \left(\frac{M_m}{\phi_m - \phi_x}\right)\left|\frac{\phi_y}{\phi_m}\right|^{\beta} \tag{3}$$

The α indicates *R1* parameter in the program, which is the stiffness degrading ration in the trilinear hysteresis where if the value is 0, it means no degradation. The β indicates *R2* parameter, which is slip stiffness ratio in the trilinear hysteresis. To create capacity curve, top roof displacement is converted to the spectral displacement using participation factor parameter. To calculate this, several steps were taken through eigen value analysis using Equation 4 to 7 as figured below.

$$PF_1 = \left[\frac{\sum_{i=1}^{n}(w_i\phi_{i1})/g}{\sum_{i=1}^{n}(w_i\phi_{i1})^2/g}\right] \tag{4}$$

$$\alpha_1 = \frac{[\sum_{i=1}^{n}(w_i\phi_{i1})/g]^2}{[\sum_{i=1}^{n} w_i/g].[\sum_{i=1}^{n}(w_i\phi_{i1})^2/g]} \tag{5}$$

$$S_a = \frac{V/W}{\alpha_1} \tag{6}$$

$$S_d = \frac{\Delta_{roof}}{\mathrm{PF}_1.\phi_{roof.1}} \tag{7}$$

Where PF_1 is modal participation on the first mode, α1 is modal mass coefficient on the first mode, w_i/g is the mass in the floor number i, ϕ_{i1} is first mode amplitude in the floor number i, N is the number of floor, V is the base shear force, W is the total building weight, and Δ_{roof} is top roof displacement. The building damping is considered for both analyses, which is illustrated in the potential energy equations shown in Equation 8 below where the damping force, [C] and restoring force [K] equal to inertia force [M]. The damping factor used in this study is 0.05 with the type of stiffness proportional damping is using initial stiffness matrix, which refers to the default value in the program. Fig. 6 and Equation 9 illustrate the applied damping.

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = -[M][U]\begin{Bmatrix}\ddot{X}_0\\ \ddot{Y}_0\\ \ddot{Z}_0\end{Bmatrix} \tag{8}$$

$$[C] = \frac{2h}{\omega_1}\,[\mathrm{K}_0] \tag{9}$$

Where h is damping factor, ω_1 is circular frequency of the first natural mode, and $[\mathrm{K}_0]$ is initial stiffness matrix.

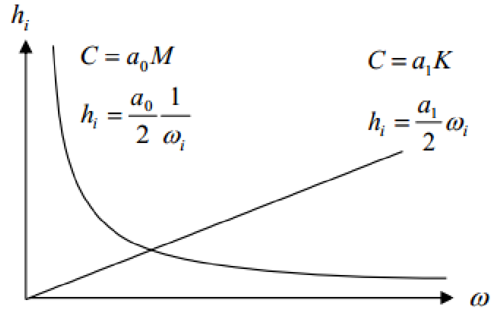

Fig. 6. Damping factor in STERA_3D [24]

D. Limitation of the study

Non-linear performance-based analysis of building using pushover analysis and time history analysis can give good result for the assessment if it is done comprehensively by checking all parameters. In this study, displacement is the only parameter key to preliminary assess the building so that other parameters such as structural ductility, failure position, failure behavior and so on are not inspected yet. Top roof and spectral displacement as the result of this study are compared with the performance-based analysis provisions, which are FEMA 356 and ATC-40, which the limit value is given in Table I and Table II below.

TABLE I. LIMIT OF DEFORMATION IN OF VARIOUS LEVELS [25]

limit of Interstorey drift	Performance levels			
	Immediate Occupancy	Damage Control	Life Safety	Structural Stability
Max total drift	0.01	0.01-0.02	0.02	$0.33\frac{V_i}{P_i}$
Max inelastic drift	0.005	0.005-0.015	No limit	No limit

TABLE II. DRIFT LIMIT FOR CONCRETE FRAMES [26]

Performance level of structure	Drift (%)	
Immediate Occupancy	1.0	Transient
Life Safety	2.0	Transient
	1.0	Permanent
Collapse Prevention	4.0	Transient or permanent

III. RESEARCH SUBJECT

The academic reinforced concrete building subjected to this research has seven storey and has risk category IV based on SNI 1726:2012. The concrete properties of the column has f'_c of 30 MPa, while the beam has f'_c of 25 MPa. The reinforcement steel has yield strength (f_y) of 400 MPa with Young's modulus (E_s) is 200,000 MPa. Moreover, the Young's modulus of concrete in this model is using 4,700 $\sqrt{f'_c}$. The detail of the site plan can be seen in Fig. 7 and the view from the side is illustrated in Fig. 8. The detailed dimension of the beam and column with the number of reinforcing can be seen in Table III and Table IV. The stairs and elevators are separated structure, so that these elements are not modelled in this evaluation. The original building has the shearwall and the STERA_3D is also capable to include the shearwall as a structural component, however in this modelling example, the shearwall is not modelled. The model also excludes the masonry walls, depicting the building is in the initial condition after structural construction. The weight for each floor is provided in Table V.

The structure has its own mass for each storey that had to be inputted in STERA_3D. This structure mass is calculated manually based on Indonesian building provision SNI 1727:2013, which includes the dead load and life load. The dead load is the concrete itself, which has 2.4 kN/m^3 of density, while the life load is given based on the usage of the room, and the magnitude is between 2.9 to 5.0 kN/m^2, depends on the room function.

TABLE III. DETAIL OF DIMENSION AND REINFORCEMENT FOR BEAMS

Code name	Dimension (mm)	Main Reinforcement Bar	
		Top	Bottom
B1	400 x 800	12-D25	6-D25
B2	350 x 650	7-D19	5-D19
B3	300 x 550	7-D22	4-D22
B4	350 x 700	6-D25	4-D25

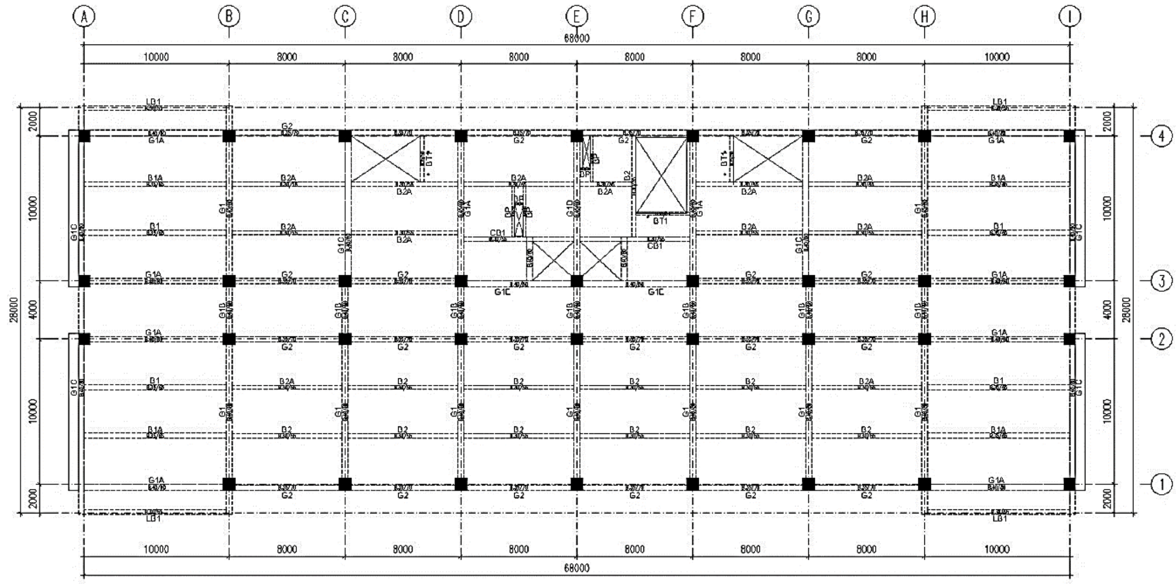

Fig. 7. Plan view of academic building subjected to the research

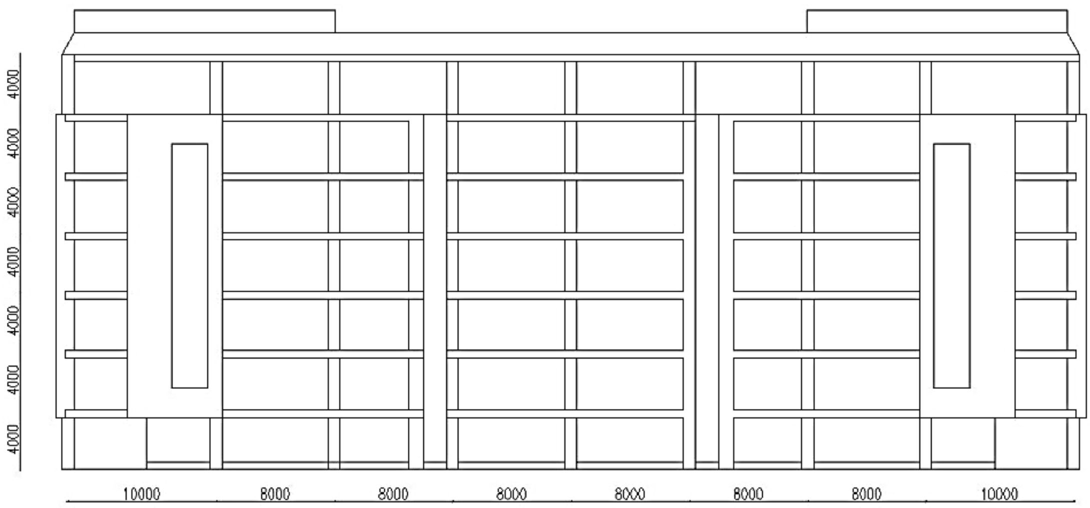

Fig. 8. Side view of academic building subjected to the research

TABLE IV. DETAIL OF DIMENSION AND REINFORCEMENT FOR COLUMN

Code name	Dimension (mm)	Main Reinforcement Bar	
		X Side	Y Side
C1	800 x 800	6-D25	10-D25
C2	800 x 800	10-D22	10-D22
C3	800 x 800	10-D25	10-D25
C4	800 x 800	10-D19	10-D19
C5	800 x 800	10-D22	10-D22
C6	800 x 800	10-D19	10-D19

TABLE V. WEIGHT FOR EACH FLOOR

Floor	Weight (kN)
7F	6739
6F	6644
5F	6644
4F	6644
3F	6594
2F	6265
1F	7460

IV. Result and Discussion

STERA_3D software developed by the co-author is capable to generate the pushover curve. In this study, the pushover curve is presented simultaneously with Yogyakarta's response spectrum demand with 5% of damping ratio stated in the Hazard Map 2017 as can be seen in Fig. 9. The performance point is the meeting point between these two graphs. The spectral displacement at meeting point is measured as 13 cm. This number is still below the immediate occupancy limit level regulated in ATC-40, which is 0.01 of total height. In this case, the total height is 2,800 cm, while the immediate occupancy level is 28 cm. It can be known that the model of building in STERA_3D gives operational result based on the displacement parameter.

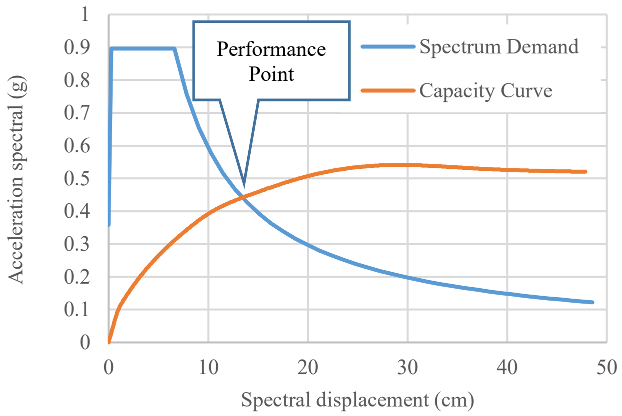

Fig. 9. Result of Capacity curve from STERA_3D overlapped with Spectrum Demand

From the time history analysis, total displacement for each storey can be generated, and this value is processed to get the inter-storey drift. The inter-storey drift then is compared with the limit from ATC-40 and FEMA 356, which is 0.01 of the inter level height. In this case, the inter level height is 400 cm, so that the limit is 4 cm. All the inter-storey drift due to three time-history data records can be seen in Fig. 10 to Fig. 12. It also can be known that all displacements are still below the limit.

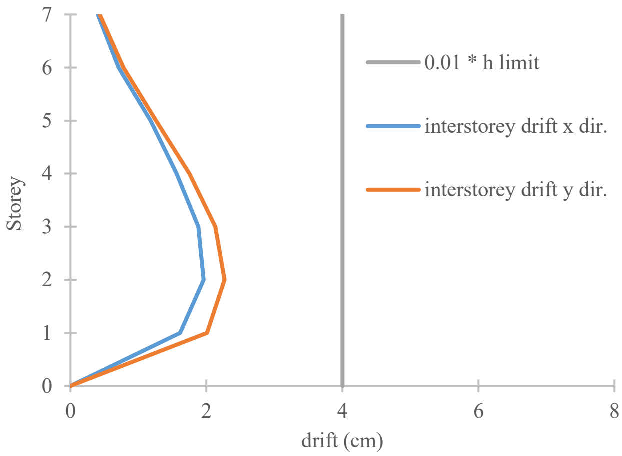

Fig. 10. Inter-storey drift due to El Centro earthquake

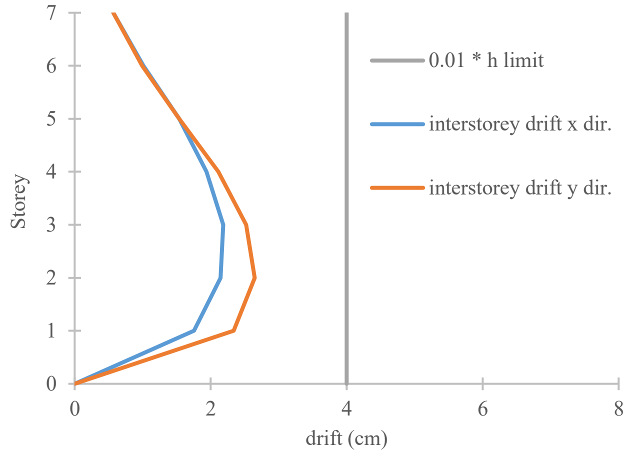

Fig. 11. Inter-storey drift due to Kobe earthquake

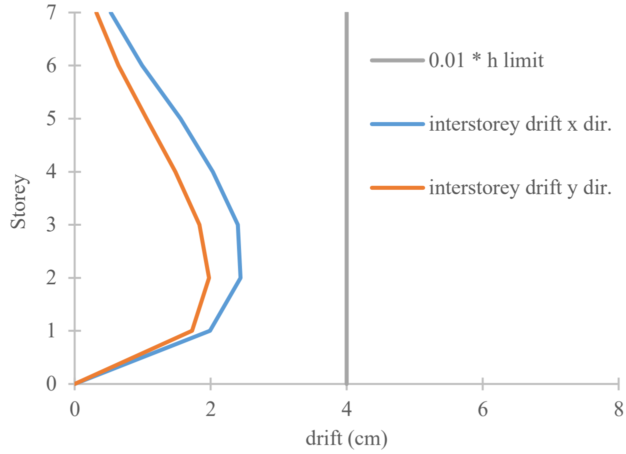

Fig. 12. Inter-storey drift due to Parkfield earthquake

V. Conclusion

The modelling is an approach to preliminary evaluate a structural performance of building due to earthquake. The methods used in this study are non-linear pushover analysis and non-linear time history analysis using STERA_3D software. From the pushover analysis, it can be known that the performance point has spectral displacement of 13 cm, which is still below the limit of immediate occupancy stated in ATC-40 and FEMA 356 so that the preliminary result complies with the limit. Furthermore, the time history analysis shows the similar result with the pushover analysis. The three time-history records inputted to perform time history analysis produces inter-storey drift that is still below the limit. This study result can be a preliminary information for the related stakeholders especially the owner and user of the academic building. However, the further study is still needed to sharpen the exact result since the modelling in this study is only from the given shop drawing. The more data inputted according to the actual building in its original state, the modeling results will be closer to the actual results. The future research is suggested to conduct evaluation comprehensively with all parameters, including ductility at the performance point, irregularities effects, and many more based on FEMA 356.

References

[1] J. A. Katili, "volcanism and plate tectonics in the indonesian island arcs," *Tectonophysics*, vol. 26, no. 3–4, pp. 165–188, 1975.

[2] U. S. Census Bureau Current Population, "World Population,"

United States Census Bureau, 2019. [Online]. Available: https://www.census.gov/popclock/print.php?component=counter. [Accessed: 31-May-2019].
[3] PDDIKTI, “Number of Institution and University in Indonesia (Grafik Jumlah Perguruan Tinggi),” 2019. [Online]. Available: https://forlap.ristekdikti.go.id/perguruantinggi/homegraphpt. [Accessed: 31-May-2019].
[4] J. Bai, S. Jin, J. Zhao, and B. Sun, “Seismic performance evaluation of soil-foundation-reinforced concrete frame systems by endurance time method,” *Soil Dyn. Earthq. Eng.*, vol. 118, no. December 2018, pp. 47–51, 2019.
[5] M. Shokrabadi and H. V. Burton, “Risk-based assessment of aftershock and mainshock-aftershock seismic performance of reinforced concrete frames,” *Struct. Saf.*, vol. 73, no. September 2017, pp. 64–74, 2018.
[6] S. Sattar, “Evaluating the consistency between prescriptive and performance-based seismic design approaches for reinforced concrete moment frame buildings,” *Eng. Struct.*, vol. 174, no. August 2017, pp. 919–931, 2018.
[7] P. Franchin, F. Petrini, and F. Mollaioli, “Improved risk-targeted performance-based seismic design of reinforced concrete frame structures,” *Earthq. Eng. Struct. Dyn.*, vol. 47, no. 1, pp. 49–67, 2018.
[8] M. A. P. Handana, R. Karolina, and Steven, “Performance evaluation of existing building structure with pushover analysis,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 309, no. 1, 2018.
[9] A. . Chopra and F. McKenna, “Modeling viscous damping in nonlinear response history analysis of buildings for earthquake excitation,” *Earthq. Eng. Struct. Dyn.*, vol. 45, no. 17 Sept 2015, pp. 193–211, 2016.
[10] S. Dadawala and N. R. Chandak, “Response spectrum analysis of multi storied buildings: A review,” *2018 Adv. Sci. Eng. Technol. Int. Conf. ASET 2018*, pp. 1–5, 2018.
[11] D. Cancellara and F. De Angelis, “Assessment and dynamic nonlinear analysis of different base isolation systems for a multi-storey RC building irregular in plan,” *Comput. Struct.*, vol. 180, pp. 74–88, 2017.
[12] E. Brunesi, R. Nascimbene, and L. Casagrande, “Seismic analysis of high-rise mega-braced frame-core buildings,” *Eng. Struct.*, vol. 115, pp. 1–17, 2016.
[13] A. Furtado, H. Rodrigues, and A. Arêde, “Modelling of masonry infill walls participation in the seismic behaviour of RC buildings using OpenSees,” *Int. J. Adv. Struct. Eng.*, vol. 7, no. 2, pp. 117–127, 2015.
[14] X. Lu, L. Xie, H. Guan, Y. Huang, and X. Lu, “A shear wall element for nonlinear seismic analysis of super-tall buildings using OpenSees,” *Finite Elem. Anal. Des.*, vol. 98, pp. 14–25, 2015.
[15] N. Aly and K. Galal, *Seismic performance and height limits of ductile reinforced masonry shear wall buildings with boundary elements*, vol. 190, no. March. Elsevier, 2019.
[16] A. C. Altunışık, B. Alemdar, and A. F. Genç, “a Study on Seismic Behaviour of Masonry Towers,” *Earthquakes Struct.*, vol. 10 (6), pp. 1331–1346, 2016.
[17] T. Saito, *Stera_3D Manual*. 2008.
[18] S. Takano and T. Saito, “Analysis of a school building damaged by the 2015 Ranau earthquake Malaysia,” *AIP Conf. Proc.*, vol. 1892, 2017.
[19] M. Afifuddin, M. A. R. Panjaitan, and D. Ayuna, “The behaviour of reinforced concrete structure due to earthquake load using Time History analysis Method,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 56, no. 1, 2017.
[20] A. Naqi and T. Saito, “A proposal for seismic evaluation index of mid-rise existing RC buildings in Afghanistan,” *AIP Conf. Proc.*, vol. 1892, 2017.
[21] E. Wahyuni, “Vulnerability Assessment of Reinforced Concrete Building Post-Earthquake,” *Procedia Earth Planet. Sci.*, vol. 14, pp. 76–82, 2015.
[22] H. D. Shrestha, R. Yatabe, N. P. Bhandary, and J. Subedi, “Vulnerability assessment and retrofitting of existing school buildings: A case study of Aceh,” *Int. J. Disaster Resil. Built Environ.*, vol. 3, no. 1, pp. 52–65, 2012.
[23] Pacific Earthquake Engineering Research Center, “Ground Motion Database,” 2019. [Online]. Available: https://peer.berkeley.edu/.
[24] T. Saito, *STERA_3D Technical Manual*. Toyohashi: Toyohashi University of Technology, 2019.
[25] Applied Technology Council, *Seismic Evaluation and Retrofit of Concrete Buildings*. Redwood City, California, 1996.
[26] FEMA, “FEMA 356 Prestandard November 2000,” no. November, pp. 40–70, 2000.