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PERFORMANCE BASED SEISMIC ANALYSIS OF MULTISTORY BUILDING USING NONLINEAR RESPONSE HISTORY ANALYSIS

Kresna Dewangga Mukti[1*], Trias Rahardianto[1]
Department of Civil Engineering, Politeknik Negeri Malang[1]
Corespondent*, Email: *kresnaacademia@gmail.com*

ABSTRAK

Analisis berbasis kinerja mengacu pada peraturan ASCE 41-17 dengan metode analisis gempa berupa analisis riwayat waktu respons nonlinear. Pemodelan struktur dilakukan dengan aplikasi ETABS. Analisis ini mempertimbangkan berbagai tingkat performa dan sifat struktur dalam keadaan gempa yang beragam. Hasil dari analisis riwayat waktu respons nonlinear menunjukan bahwa struktur mengalami rasio simpangan antar lantai rata-rata terbesar adalah 1.5% untuk arah utara-selatan dan 1.75% untuk arah timur-barat, hasil dari kedua arah ini masih dibawah batas simpangan 4% yang tercantum di peraturan ASCE 7-16 untuk analisis riwayat waktu respons nonlinear. Elemen struktur yang dimodelkan secara nonlinear mencakup balok utama dan dinding geser, balok B1, B2B dan B3 masing-masing mengalami rotasi sendi plasti sebesar 0.0007 radians, 0.0004 radians, dan 0.0006 radians secara berurutan yang dimana masih dibawah nilai *immediate occupancy* sebesar 0.005 radians berdasarkan peraturan ASCE 41-17.

Kata kunci : analisi riwayat waktu respons nonlinear, analisis berbasis kinerja, analsis gempa, ASCE 7-16, ASCE 41-17

ABSTRACT

Performance based seismic design is largely based on ASCE 41-17 with nonlinear time history analysis used as the primary method of seismic analysis. Mathematical modelling of the structure is modelled in ETABS. This analysis measures different levels of performance and structural trait under different seismic loading. The results of nonlinear time history analysis indicate that the structure having the largest mean story drift rasio of 1.5% for north-south direction and 1.75% for east-west direction, results from both direction is still well below the limit of 4% that are imposed for in ASCE 7-16 for nonlinear time history analysis. Structural element that are modelled nonlinearly consist of primary beam and shear wall, beam B1, B2B, and B3 undergoes plastic hinge rotation of 0.0007 radians, 0.0004 radians, and 0.0006 radians respectively which all below the limit for immediate occupancy limit of 0.005 radians based on ASCE 41-17.

***Keywords** : nonlinear time history analysis, performance based seismic design, seismic analysis, ASCE 7-16, ASCE 41-17*

1. INTRODUCTION

Eartquake can cause devastating damage to life and livelihood of the people affected by it. Physical effect of earthquake can be observed in the form of surface rupture, settlement and uplift, liquefaction of soil and landslide. Damage from earthquake to building's structure can be observed from shear failure in reinforced concrete (RC) beam and flexural failure of RC column. [1]

Indonesia is an island nation that are sitting right on top of a series of active volcano called the Pacific Ring of Fire in which majority of earthquake worldwide occurs. The largest ever recorded earthquake that happens in this area, specifically in the Andaman Island that cause the 2004 Indian Ocean tsunami that results more than 200.000 deaths. Threats of earthquake always loom along Indonesia's chain of island especially with the threat of megathrust earthquake that can occur in the future that can impact life and society. [2] [3] [4]

Buidling codes specifically catters to the design of seismic resistant building was introduce as a national standard in mitigating the effect of seismic load to the building. SNI 1726-2019 is primarily used as standard in determining the minimum load subjected to the building by earthquake forces. SNI 1726-2019 gives both linear on nonlinear analysis as methods in determining the effects of earthquake loads. [5]

Performance based seismic design (PBSD) is a building seismic design methodology that facilitates the execption of code provisions by certain evaluation of performance target. PBSD is more commonly used for high rise building in urban centers near seismic active zone such as Indonesia, China, Japan, Turkey, etc. The use of PBSD allows structural engineers to shift the focus from prescriptice check list of code provision to requiring the designer to more fully understand building performance and the code's intent. Performance objective of PBSD have not yet introduce by Indonesia's authorithy, therefore the use of ASCE 41-17 can provide valuable parameters in determining the building performance objective. [6, pp. 9, 12-13] [7] [8]

Target performance of a building is identified in ASCE 41 that can be specific to levels of seimic intensities. Details on anticipated levels of structural damage under each performance objectives can be seen in ASCE 41-17 (see **Table 1**)

Table 1. Excerpt from ASCE 41-17 for Building Structural Performance

Risk Category	BSE-1E	BSE-2E
I and II	Life Safety (LS) Structural Performance	Collapse Prevention (CP) Structural Performance
III	Damage Control Structural Performance	Limited Safety (LS) Structural Performance
IV	Immediate Occupancy (IO) Structural Performance	Life Safety Structural Performance

Source: ASCE 41-17 Table 2-3

Inelastic structural element can be differentiated by how the plasticity is distributed along the element length. From **Figure 1**, it can be seen the different types of idealized model types for simulating the inelastic response of beam-columns.

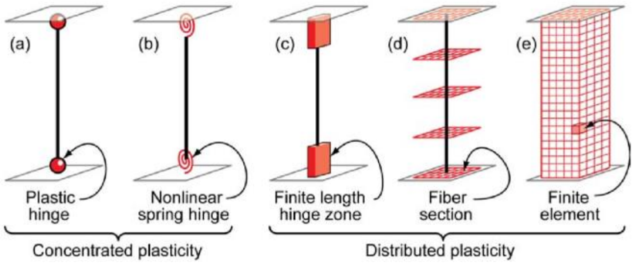

Figure 1. Idealized Models of Beam-Column Element (Source: NIST, 2010)

To accurately asses the performance of the building, nonlinear time history analysis (NTHA) is used. NTHA overcomes the limitation of pushover analysis as it can provide multi mode behaviour, and a realistic modelling of ground motion charasteristics. [9, pp. 5-1]

NTHA relies on the selection and modification of ground motion so as to accurately represent the specific hazard that the building's site imposed. The selection of ground motion will be based on magnitude, distance, site soil condition, and spectral shape. ASCE 7-16 Section 16.2.2 requires for the selection of not less than 11 ground motions with each shall consist of pairs of orthogonal horizontal ground motion components. For modification of ground motion, ASCE 7-16 Section 16.2.3 gives the option to do amplitude scaling or spectral matching The modification of ground motion will employ SeismoMatch 2025, as it is capable to do spectrum matching of multiple ground motion within the specified tolerance. [9, pp. 5-2] [7, p. 164] [10] [11, p. 165]

The building that will be the subject of analysis is 11 storey building functioning as hotel with the building height of 42.5 meters and building area of 26,271 m^2. The structure consists entirely of reinforce concrete with shear wall as it's seismic resisting system working alongside with moment frames. The building has the uniquely shape Y as can be seen from **Figure 2**.

Extended Three-Dimensional Analysis of Building System (ETABS) is an application that are capable to run nonlinear analysis of building with complex geometry. ETABS is equipped with Fast Nonlinear Analysis (FNA) that are efficient in formulation, making it suitable for time-history analysis. [12]

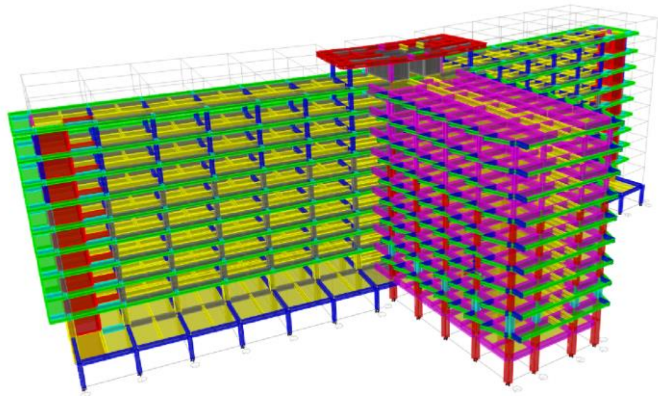

Figure 2. 3D Model of the Building

2. METHOD

This research attemps to evaluate the performance of the building under seismic load using NTHA. Performance targets will be using ASCE 7-16 drift limit for NTHA as prescribed in Section 16.4.1.2 that is twice the limit in linear analysis, and the acceptance criteria for reinforced concrete element adhere to ASCE 41-17 Chapter 10. Structural analysis application ETABS will be used to run the analysis.

Nonlinear modelling of structural element only limited at primarily beams and shear walls, this is due to conserve computational resources. Beam and shear wall shall be modelled as finite length hinge and fiber section respectively as illustrated in **Figure 1**.

Table 2. Ground Motion Set

Index	Event	Mw	Station	Distance (km)	PGA (g)
1	Iwate, Japan	7.4	AOMH13	107	0.376
2	Iwate, Japan	7.4	IWT020	96.5	0.438
3	Tokachi-oki, Japan	8.29	IBUH03	121.7	1.280
4	Tokachi-oki, Japan	8.29	HKD066	138.5	1.370
5	Tokachi-oki, Japan	8.29	HKD070	125	1.340
6	Tokachi-oki, Japan	8.29	HKD128	130.8	0.789
7	Ibaraki, Japan	7.92	IBRH10	88.9	0.434
8	Ibaraki, Japan	7.92	TKY020	92.74	0.229
9	El Mayor, Mexico	7.2	El Centro	40.96	0.940
10	Darfield, New Zeland	7.0	Christchurch	19.48	1.250
11	Kocaeli, Turkey	7.51	Ambarli	68.09	1.020

Source: PEER Ground Motion Database

Ground motion that has been selected can be seen from **Table 2**. The selected ground motion shall be modified by spectrum matching using SeismoMatch as seen from **Figure 3** and **Figure 4**.

The matched ground motion shall be used as load case for running NTHA with ETABS. **Figure 3** Shows the matched ground motions, while **Figure 4** is the target response spectrum used for spectral matching.

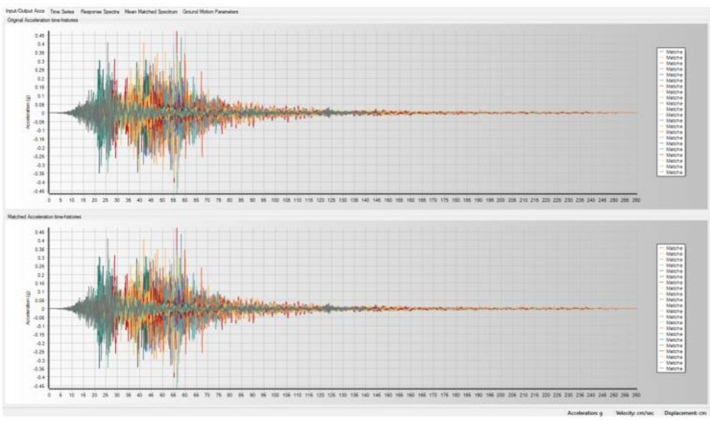

Figure 3. Matched Ground Motion

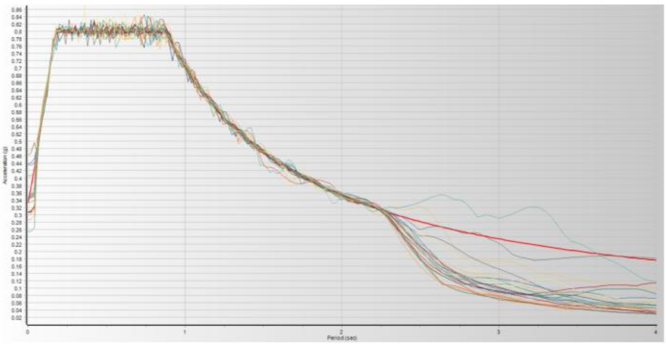

Figure 4. Matched Response Spectrum vs Target Response Spectrum

3. ANALYSIS AND RESULTS

After running NTHA, we have acquired the story response of the building from each ground motion. **Figure 5** and **Figure 6** shows the combined shear from each ground motions.

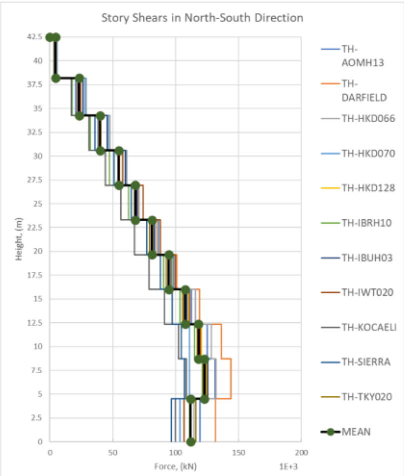

Figure 5. Story Shears in North-South Direction

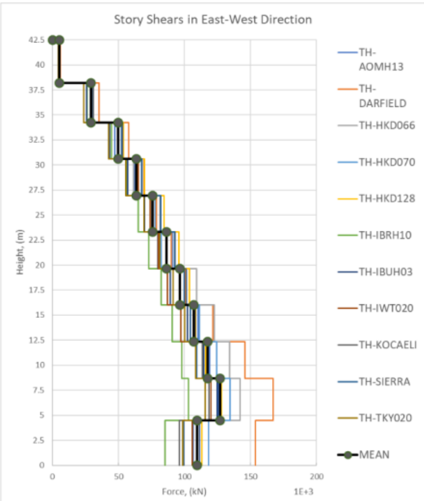

Figure 6. Story Shears in East-West Direction

From **Figure 5** it is indicated that the ground motion contributing the largest story shear in the north-south is the TH-Darfield ground motion. The ground motion contriburing to the largest story shear in the east-west direction is the TH-Darfield as shown in **Figure 6**, similar with the result in **Figure 5**.

Overturning moment that resulted from ground motions can be seen from **Figure 7** and **Figure 8**.

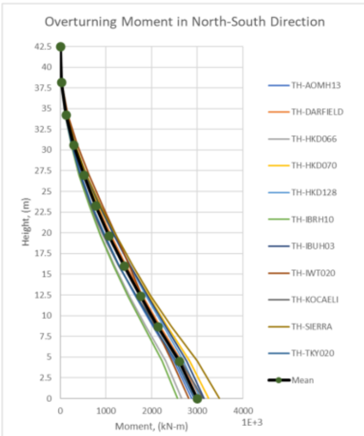

Figure 7. Overturning Moment in North-South Direction

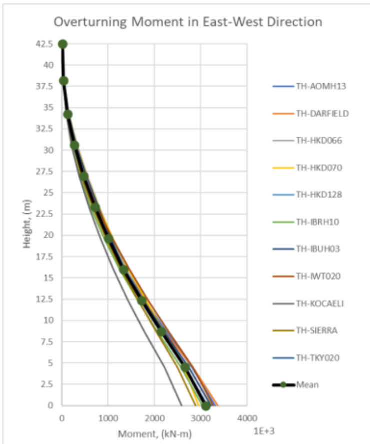

Figure 8. Overturning Moment in East-West Direction

From **Figure 7**, largest contributing ground motion for overturning moment in the north-south direction is the TH-Sierra ground motion. The largest contributing ground motion for overturning moment in the east-west direction is the TH-Darfield ground motion as shown in **Figure 8**.

Story drift ratio resulted from each ground motion can be seen in **Figure 9** and **Figure 10**. The largest mean drift ratio in the north-south direction is 1.50% and the largest mean drift ratio in the east-west direction 1.75%.

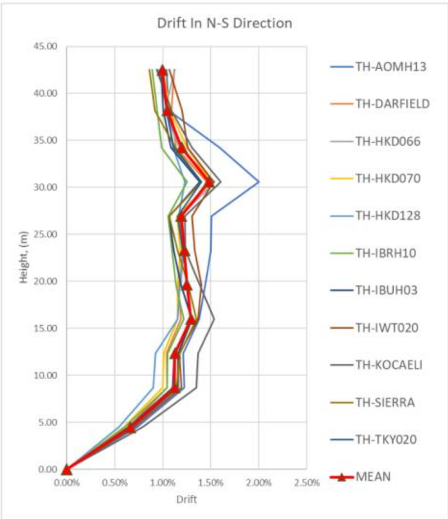

Figure 9. Story Drift Ratio in the North-South Direction

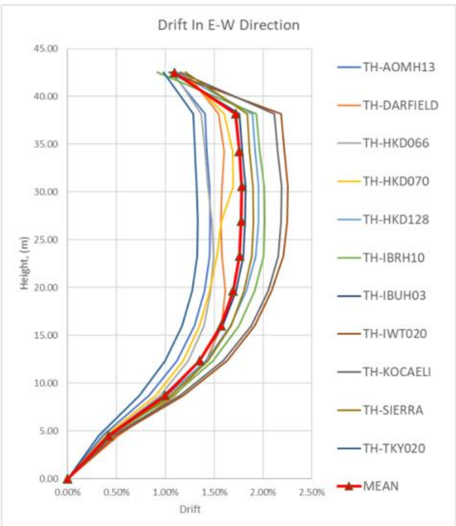

Figure 10. Story Drift Ratio in the East-West Direction

The limit imposed by ASCE 7-16 is the drift limit for nonlinear analysis is twice that of linear analysis. For building with risk category II with structure considered as dual system, the allowable story drift ratio is 2% for linear analysis from Table 12.12-1 and 4% for nonlinear analysis as in accordance to Section 16.4.1.2. The mean story drift ratio for both direction shows to be below 4% which indicates the building is still within the acceptable criteria as prescribed in ASCE 7-16.

Acceptance criteria for structural element that are modeled as nonlinear element is observed from the plastic rotation hinge measured in radians.

Table 3. Beam Plastic Rotation

Beam Section	Hinge Rotation (radians)	Acceptance Criteria (radians)		
		IO	LS	CP
B1	0.0007	0.005	0.02	0.05
B2B	0.0004	0.005	0.02	0.05
B3	0.0006	0.005	0.02	0.05

From **Table 3,** all of the beam has the hinge rotation to be below the IO limit, concluding that the beam observed from the table to be within the acceptable criteria.

4. CONCLUSION

Based on the research conducted above, these are the conclusion of the study are as follow:

1. Performance based seismic design has different approach and methodologies when evaluating a building's seismic capabalities. ASCE 7-16 Chapter 16 and ASCE 41-17 specifically gives acceptance criteria for nonlinear analysis.
2. Story shear peaks around 130000 kN in the north-south direction and 155000 kN in the east-west direction.
3. Story overturning moment peaks around 3450000 kN-m in the north-south direction and 3200000 kN-m in the east-west direction.
4. The largest mean story drift ratio in the north-south direction is 1.50% and the largest mean drift ratio in the east-west direction 1.75% are all below the maximum allowable story drift ratio of 4%.
5. Plastic hinge rotation for beam B1, B2B, and B3 is 0.0007, 0.0004, and 0.0006 respectively are all below the IO limit of 0.005.

Recommendation

Based on the study conducted, these are recommendation to be made for future study similar in topics.

1. Nonlinear modelling should encompass column to accurately captures the element respond to NTHA.
2. Using fiber section as nonlinear modelling should be considered to accurately account inelastic behaviour of columns, and beam.
3. The effect of soil-structure interaction can be considered as it will affect the overall building's respond towards NTHA.

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