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State of Practice of Performance-Based Seismic Design in Indonesia

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Abstract

The current 2002 Indonesian Seismic Code consists of prescriptive criteria that are intended to result in buildings capable of providing certain levels of performance. However, the actual performance capability of buildings is not assessed as part of the code procedures. Several analysis procedures are allowed, and the state of practice is to use the RSA with six-zone seismic map developed for 475-year earthquake. This code is being revised and will adopt many of the ASCE7-10 provisions and 2475-year earthquake for MCE. The growth of tall buildings compels engineers to look for more optimal lateral system. The use of RC core wall as single system has been adopted by very few engineering firms, which is allowed in the current code but will no longer be the case if the new one is in effect. Other innovative structural system such as core wall and outrigger is not addressed in the proposed new code. Engineers must then resort to NLRHA. Currently, one 50-story building under construction using RC core wall and outrigger has been designed with RSA and employing capacity design principles, then evaluated using NLRHA per TBI Guidelines. Based on the evaluation, the performance of the 50-story building generally still meets the criteria of the TBI Guidelines. The result of the case study is presented in this paper.

Keywords: Performance based seismic design, Nonlinear response history analysis, Core wall and outriggers

1. Current Seismic Code

The current 2002 Indonesian Seismic Code, which adopted many of the UBC-1997 provisions, consists of prescriptive criteria that are intended to result in buildings capable of providing certain levels of performance. Three performance levels are stipulated, in which buildings are expected to withstand minor earthquake without damage, withstand moderate earthquake without major structural damage, and to withstand major earthquake without collapse. However, acceptance criteria to show conformance to the expected performance levels have never been formally established using engineering parameters, nor required to be demonstrated in the calculation report. Therefore, the actual performance capability of buildings is not assessed as part of the current code procedures. Consequently, structural evaluation under a different hazard level, such as Service Level Earthquake (SLE) for performance verification is not part of the current code design requirement.

Several analysis procedures are allowed by the current code: Equivalent Lateral Force, Response Spectrum Analysis (RSA), Linear and Nonlinear Response History Analysis (NLRHA). While static equivalent lateral force procedure was widely adopted in 1980s, the current state of practice is to use the RSA. For hazard, the Indonesian Seismic Code divides the seismic map into six zones, based on 475-year earthquake as the design level earthquake. An important thing to note is that peer review process and approval is required for all buildings 8-stories or taller, located in Jakarta.

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2. New Code

The code is currently under revision and will adopt many of the ASCE 7-10 provisions. Similar to ASCE 7-10, the new code will consist of prescriptive criteria to achieve the goal of providing safety to life and will not require direct performance assessment of buildings, as does the current 2002 code. The highlight of the new code revision is an updated seismic map based on 2475-year earthquake as the Maximum Considered Earthquake (MCE) level. Design using the new code will then be based on two-thirds of the MCE level load. Another key revision is the inclusion of list of permitted structural system based on height limit and structural design category if the prescriptive procedure is used. The new code will have alternative (non-prescriptive) provisions that allow direct application of performance-based procedures, however no further specific guidelines are given. Service level EQ is not defined as well. Because of this, the engineers will need to refer to available document that provides guidelines and criteria on how to apply such procedures using nonlinear response history analysis (NLRHA), which is the Tall Building Initiative (TBI)

Guidelines issued by Pacific Earthquake Engineering Research Center (PEER). Peer review approval will be required in the municipality of Jakarta as being currently practiced for all buildings taller than 8 stories. It is expected the TBI guidelines will be the reference for NLRHA in Indonesia.

3. Effects of the New Code

Based on the new code, most buildings in Jakarta will fall into seismic design category D, per ASCE 7-10 classification. Therefore, once the new code and hence the structural system limitation is in effect, prescriptive design of tall single core wall systems that is currently allowed will be prohibited. Engineers must then resort to dual systems for prescriptive design of tall buildings. Despite the popularity of dual systems in the past decades, the ongoing height-increase of tall buildings compels the use of other more innovative systems. In addition, in comparison to other systems, dual systems have some disadvantages in terms of cost, construction time, and net ceiling height.

Hence, the alternative non-prescriptive design method, namely Performance-Based Seismic Design (PBSD), will be the only option for design of tall structures with special systems, such as single systems or mega frame structures. TBI Guidelines is one of the documents that can be used for PBSD implementation using NLRHA.

4. PBSD Utilizing NLRHA in Indonesia

At present, the use of PBSD utilizing NLRHA is not a common practice. In the past thirty years there were only two buildings that have been designed using NLRHA, both were done just recently: the Gudang Garam Office Tower, a 25-story seismically isolated structure using high damping rubber bearings, designed and reviewed to meet ASCE 7-10 provisions, and the 50-story Pakubuwono Signature apartment building, a 250-meter tall RC core wall and outrigger structure which was designed with RSA and then revisited with NLRHA per PEER Tall Building Initiative (TBI) Guidelines.



Figure 1. Artist's Impression.

5. Case Study

The Pakubuwono Signature is a 50-story luxury apartment building located in prime residential area of Jakarta. The building has been designed using RSA in 2009 and revisited using PBSD approach. Figure 1 shows the artist impression of the 250-meter building, currently under construction. The single frame system adopted in this building consists of RC core wall and 3-story deep outrigger located on level 22 to level 24, and flat slab as floor system. A net ceiling height of 3.0 meter is achievable with 3.65 meter floor to floor height.

The concrete grade used is 55 MPa, the highest one can get without a batching plant nearby and considering the traffic condition of Jakarta. Considering the wind effect and occupant's comfort, the core wall has a thickness of 650 mm at the base and becomes 300 mm at the top. For this tower, the dimension of the core must be adequate to provide stability to the building. Core layout and its content were developed with close cooperation with architect and interior designer from the very early phase, where the input from the structural engineer strongly influenced the design. Figure 2 shows the cross section and plan of the structure. The detailing of the core wall follows the Indonesian Reinforced Concrete Code which has adopted many of ACI 318-2002 provisions, including the requirement for confinement in boundary elements. With this structural configuration, the building has a very good performance for wind effect as demonstrated by wind tunnel test, showing top floor acceleration value of 8.5 milli-g at 1.0 percent damping for 1-year wind, and 11.5 milli-g at 1.0 percent damping for 10-year wind respectively.

Probabilistic seismic hazard analysis has been conduc-

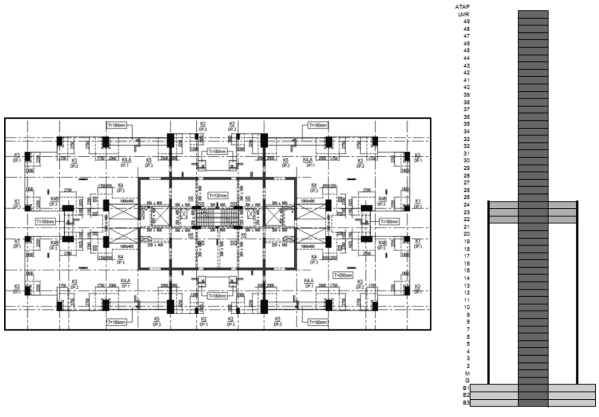


Figure 2. Structural plan and cross section.

Table 1. Modal Response Analysis Result

Mode	Periods (s)	Mass participation Factor (%)		
		X-trans	Y-trans	Rz-rotn
1	6.46	-	60.69	-
2	5.42	61.32	-	-
3	2.99	-	-	74.23

ted for this site, and a site specific response spectrum has been established and used in the design. RSA was conducted with ETABS program. The fixity level is taken at ground floor. Torsional effect including accidental one has been included as well. Table 1 gives the result of modal analysis.

Capacity design principles have been employed when designing the structure with RSA. Plasticity is expected at the composite shear plate coupling beams of the outriggers, then at coupling beams of the core wall and lastly at the core wall near the fixity level. Outrigger columns are designed to take the seismic effect multiplied by overstrength factor. The 3-level outrigger beam has openings and connected by composite steel plate coupling beams which serve as fuses to protect the outrigger columns. The building is now under construction. Figure 3 shows the work in progress.

6. Nonlinear Response History Analysis

The building has been revisited using NLRHA following the TBI Guidelines. The following discussions describe the analysis process and present the evaluation results.

7. Seismic Input

Service level earthquake evaluation was not performed for this study. The seismic hazard level used for NLRHA evaluation is 2500-year MCE level. The site-specific target spectrum was developed starting with Probabilistic Seismic Hazard Analysis method to produce uniform hazard spectrum at bedrock. The process was then followed by de-aggregation, ground motion selection and scaling to match the spectrum at bedrock. The scaled

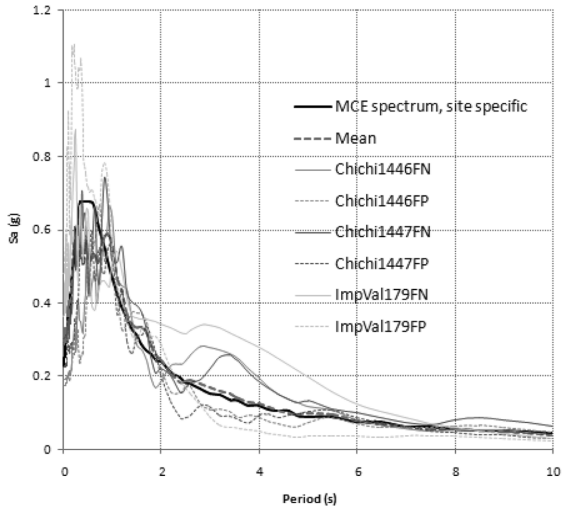


Figure 4. NLRHA target spectrum.

ground motions were then used to perform one-dimensional dynamic response analyses including effect of shear wave propagation to compute the elastic spectral acceleration at the base of the mat foundation, where seismic input was applied.

Figure 4 shows the site-specific target spectrum that was developed using the described procedure. The ground motion selection and scaling were performed utilizing the latest PEER ground motion database to match the target spectrum at the period range between $0.2T_1$ to $2T_1$. Three suites of scaled ground motion pairs were used as permitted by ASCE7-10.

Table 2 gives the list of the selected accelerograms that are consistent with a number of de-aggregation analyses for sites in Jakarta (see Figs. 6 & 7). Since the database of strong motion records that can represent seismic hazard in Jakarta is limited - especially one that characterize shallow crustal event, the search for the suitable accelerograms has been a challenging task. The records were carefully selected such that the spectral shape of the records can generally represent the shape of the target spectrum and such that the scaling factor used for each record is not too large.



Figure 3. Construction photos showing work in progress.

Table 2. Selected ground motion records

Event	Characteristic	Magnitude, M_w	Distance (km)	Scale Factor	PGA (g)	Source
Chi Chi (1999)	Megathrust zone	7.62	117	5.3	0.18	PEER
Chi Chi (1999)	Benioff zone	7.62	118	5.7	0.26	PEER
Imperial Valley (1994)	Shallow crustal	6.5	25	1.0	0.42	PEER

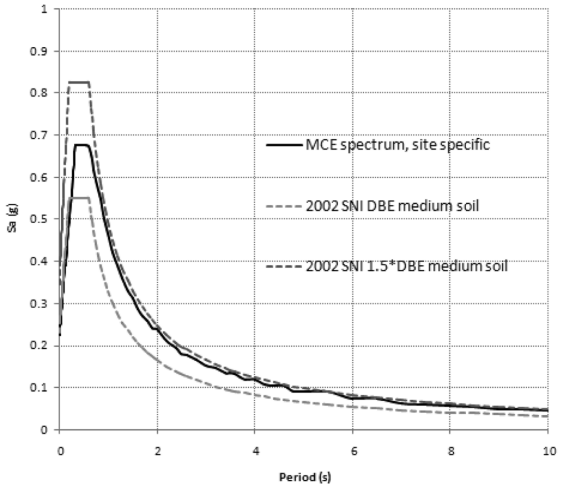


Figure 5. Comparison between NLRHA and RSA target spectrum.

Figure 5 shows comparison between the NLRHA target spectrum and the 2002 Indonesian Seismic Code spectrum. The NLRHA target spectrum is generally close to the code spectrum for medium soil case, with the exception of the lower spectral acceleration values within the short period range. This can be explained since the NLRHA target spectrum includes the effects of site-specific soil condition and embedment from surface (Golesorkhi & Gouchon, 2000).

8. Nonlinear Model

A 3-dimensional model was developed using CSI PERFORM3D v5.0 software. Core wall, outrigger walls and columns were modeled from the mat foundation level up to the roof level. Ground and subterranean level diaphragms, including the basement walls were also included in the model. The model is fixed at the mat foundation level where ground motion input is applied. Soil structure interaction was not included and the effect of the soil surrounding the subterranean levels was neglected.

The core wall, outrigger wall, and outrigger column flexural behavior were modeled with inelastic properties at levels where plasticity is anticipated (see Fig. 8). All coupling beams were also modeled with inelastic properties. Elastic properties were assigned to other part of core wall, outrigger wall, and outrigger column shear behavior, basement diaphragms and walls.

Inelastic flexural behavior of the walls and columns were modeled using fiber elements that consist of rein-

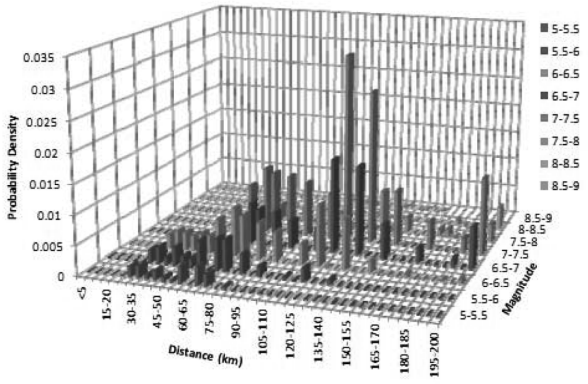


Figure 6. De-aggregation hazard result of 2500 year return period for Jakarta, T = 0.2 sec (Hendriawan & Azis, 2010).

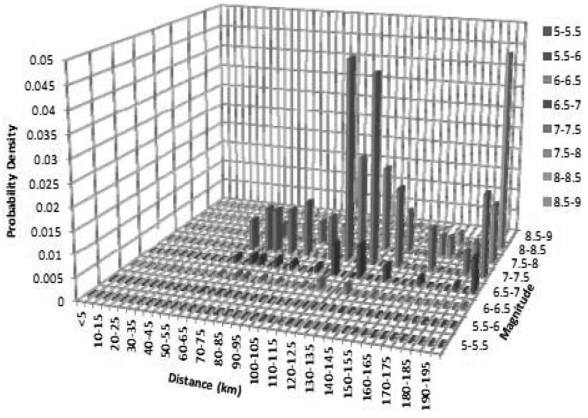


Figure 7. De-aggregation hazard result of 2500 year return period for Jakarta, T = 4.0 sec (Hendriawan & Azis, 2010).

forcing steel and confined or unconfined concrete materials. The force-deformation relationship for the reinforcement material was based on ASTM material specifications. The force-deformation relationship for the confined and unconfined concrete materials was based on the models proposed by Razvi and Saatcioglu (1992).

Inelastic shear behavior of the coupling beams were modeled using rigid shear links. Since the building consists of three types of coupling beams - conventionally-reinforced, diagonally-reinforced, and steel plate-reinforced, separate link models were developed for each type. The backbone curve and explicit cyclic deterioration characteristics for the first two types were generated per the ATC-72-1 recommendations while one for the latter type was established per ASCE SEI recommen-

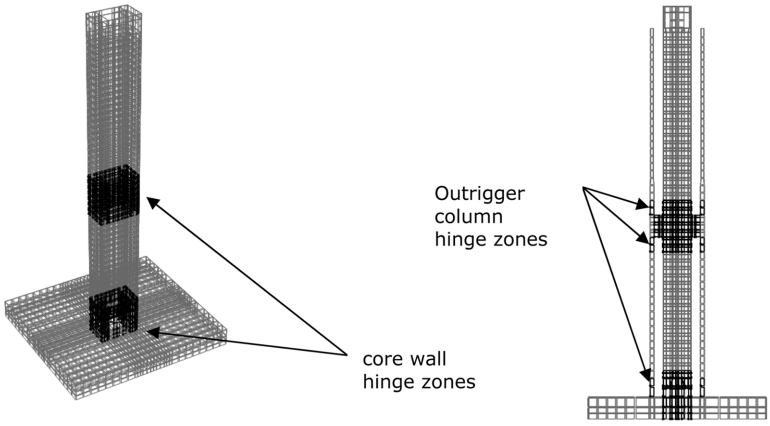


Figure 8. PERFORM-3D model.

dations for hybrid coupling beams and per the proposed model by Lam, Su, and Pam (2004). The coupling beams were modeled with flexural stiffness of $0.15E_cI_g$ and shear modulus, G of $0.1E_c$.

In order to account for effects of damping not explicitly modeled in the analysis, modal damping of 2.5% was used as permitted by PEER TBI guidelines and as considered appropriate by ATC-72 report. P-Delta effects were considered in the analysis as required by the PEER TBI guidelines. Gravity load combination used is DL + 0.25LL.

9. Acceptance Criteria

Acceptance criteria selected for collapse prevention performance under the MCE level is in accordance with PEER TBI guidelines and ATC-72-1 recommendations. The summary is shown in Table 3. Note that the demand is taken as the maximum of 3 records instead of the mean of seven for this case study.

10. NLRHA Results

Table 4 summarizes the results of the NLRHA. Figs. 9 to 16 show plots of the NLRHA result. Each result is labeled to indicate recording station number per PEER database that represent selected ground motions as shown on Table 2. Additional sub label A or B is tagged on each result, indicating two different direction of each ground motion pair with respect to the building orientation. Based on the plots, it can be observed that the Imperial Valley case dictates most of the maximum demand values, which is expected from the shape of the response spectrum on Fig. 4. A hump that exceeds the target spectrum can be observed in the response spectrum for the Imperial Valley record within the period range at 2 to 6 seconds. It is worth noting that the use of the maximum demand as

Table 4. Summary of NLRHA results

Parameter	NLRHA
Mode 1, Y dir period	7.1 sec
Mode 2, X dir period	6.0 sec
Mode 3, torsional period	5.1 sec
Seismic base shear at grade level (Y dir)	9,500 ton
Seismic base shear at grade level (X dir)	8,500 ton
Seismic overturning moment at grade level (about X dir)	390,000 ton-m
Seismic overturning moment at grade level (about Y dir)	480,000 ton-m

Table 3. Summary of NLRHA acceptance criteria

Item	Demand	Limit
Global level		
Story drift	Max of 3 NLRHA results	3%
Component level – deformation-controlled actions		
Coupling beam rotation	Max of 3 NLRHA results	0.06
Core wall reinforcement axial tensile strain	Max of 3 NLRHA results	0.05
Core wall reinforcement axial compression strain	Max of 3 NLRHA results	0.02
Core wall confined concrete axial strain	Max of 3 NLRHA results	0.015
Component level – force-controlled actions		
Core wall and outrigger column shear	1.5* Max of 3 NLRHA results	Expected capacity
Outrigger column axial	1.5* Max of 3 NLRHA results	Expected capacity

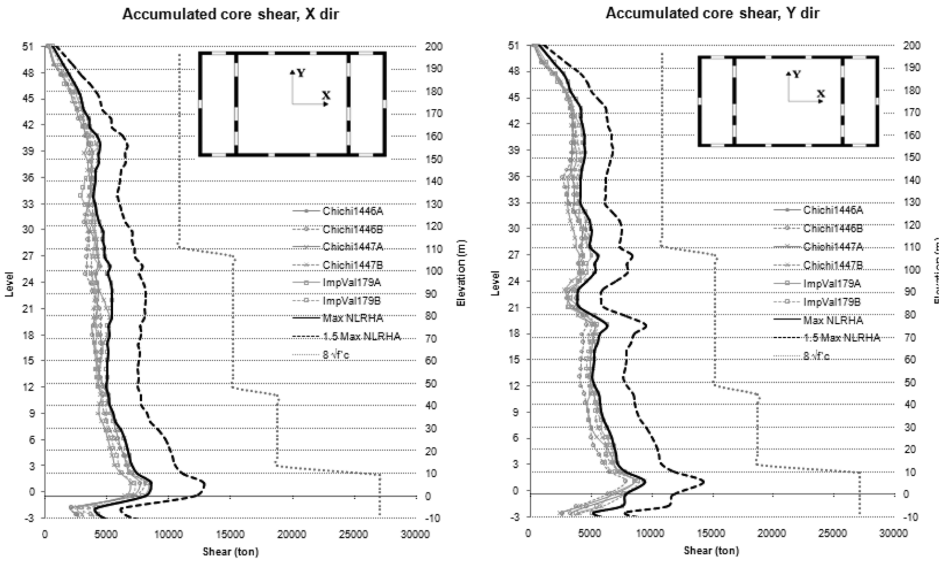


Figure 9. Core wall accumulated shear.

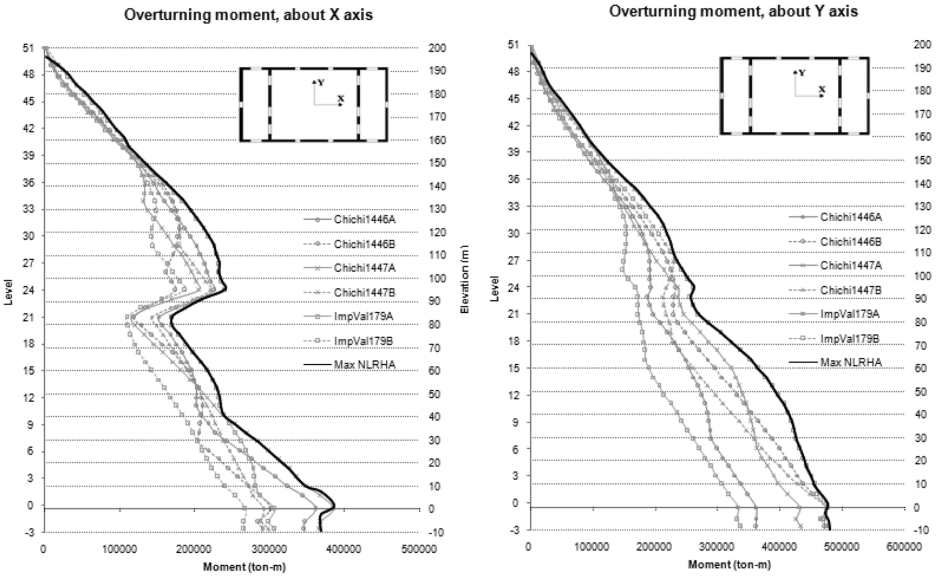


Figure 10. Overturning moment.

oppose to the mean demand can overestimate higher mode contribution to the response parameter due to one single record.

11. Interstory Drift & Overall Building Drift

The interstory drift ratios fall well below the maximum accepted limit of 3%. The maximum overall building drifts are also very minimal for all ground motion records.

12. Coupling Beam Rotation

The coupling beam rotations in general are within the acceptable limit of 0.06 radian. The distribution of the coupling beam rotations over the height of the structure varies considerably from one earthquake record to another.

13. Core Wall Overturning Moment

The core wall overturning moment values are larger for the Imperial Valley record compared to the Chi Chi records.

14. Core Wall Axial Strain

In general, the compression strain at the corners of the core wall is uniformly distributed over the height of the

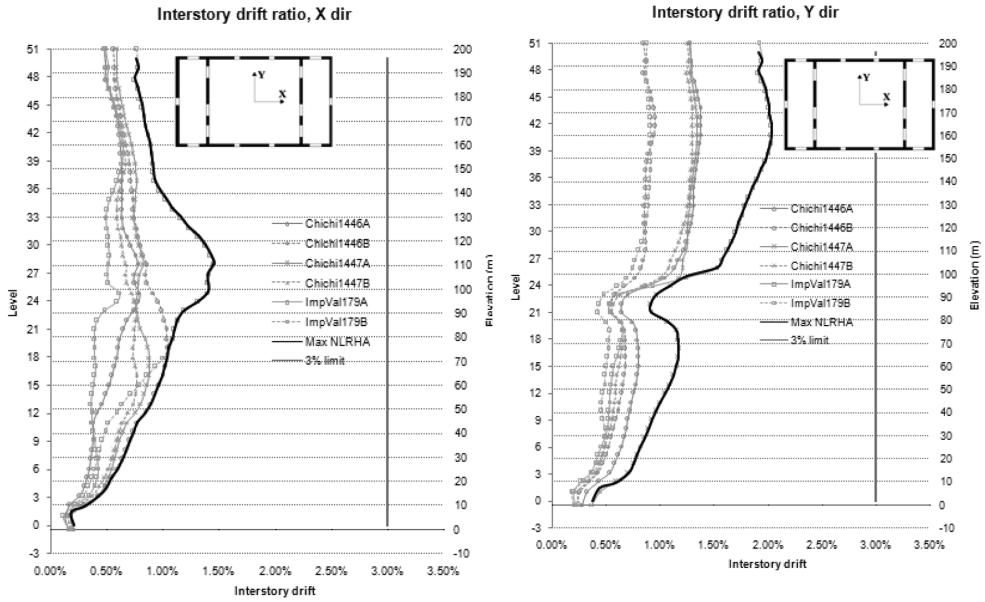


Figure 11. Maximum interstory drift.

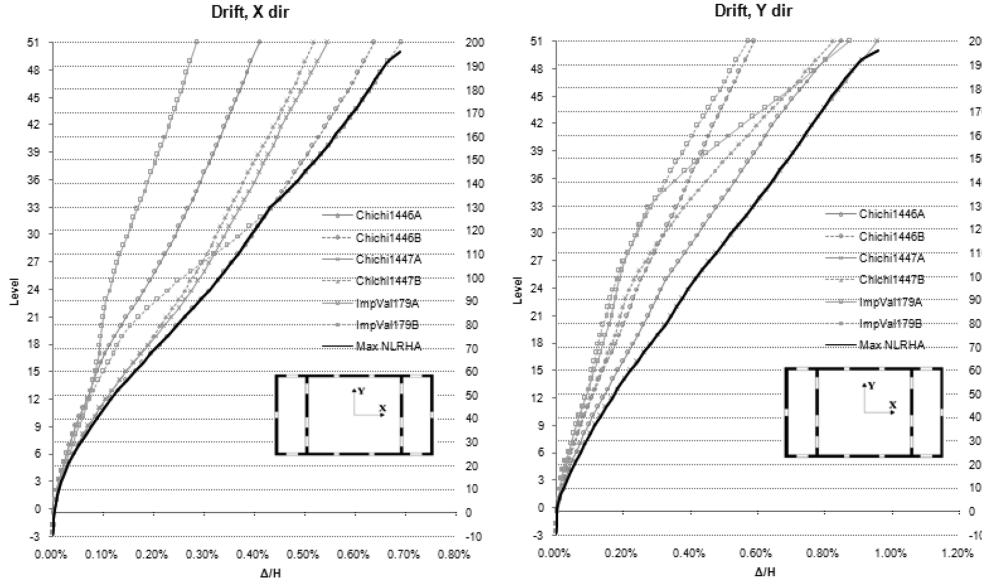


Figure 12. Maximum drift.

structure and still fall well below the 0.015 limit.

Concentration of higher tensile strain at the base and the outrigger level indicates that those areas are experiencing inelasticity as anticipated (Fig. 13).

15. Core Wall Shear

Figs. 9 and 15 shows accumulated shear plots of the core wall and individual piers, respectively. The maximum demands are still less than the 8f`c*Av for the overall core wall. For individual piers the values are generally less than 10f`c*Av.

16. Outrigger Column Axial

The outrigger columns axial behavior was checked as a force-controlled element and demonstrated to be adequate.

17. Conclusion

For this case study, RSA accompanied by seismic capacity design principles is capable to produce a design that generally meets the NLRHA MCE criteria per TBI guidelines. NLRHA facilitates detailed evaluation of high-rise structures within the nonlinear range including expli-

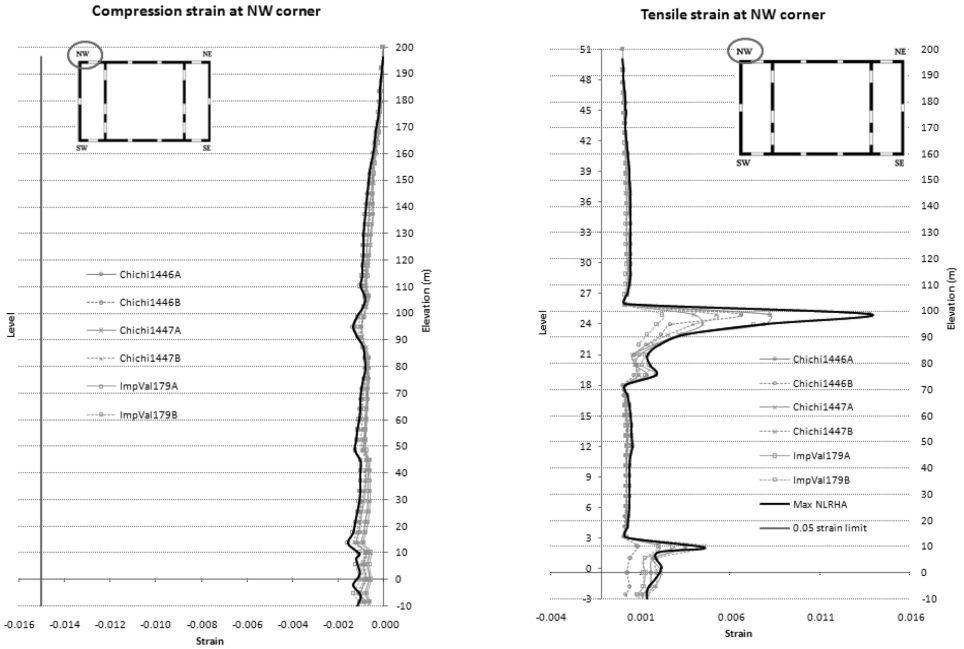


Figure 13. Core wall strains at Northwest corner.

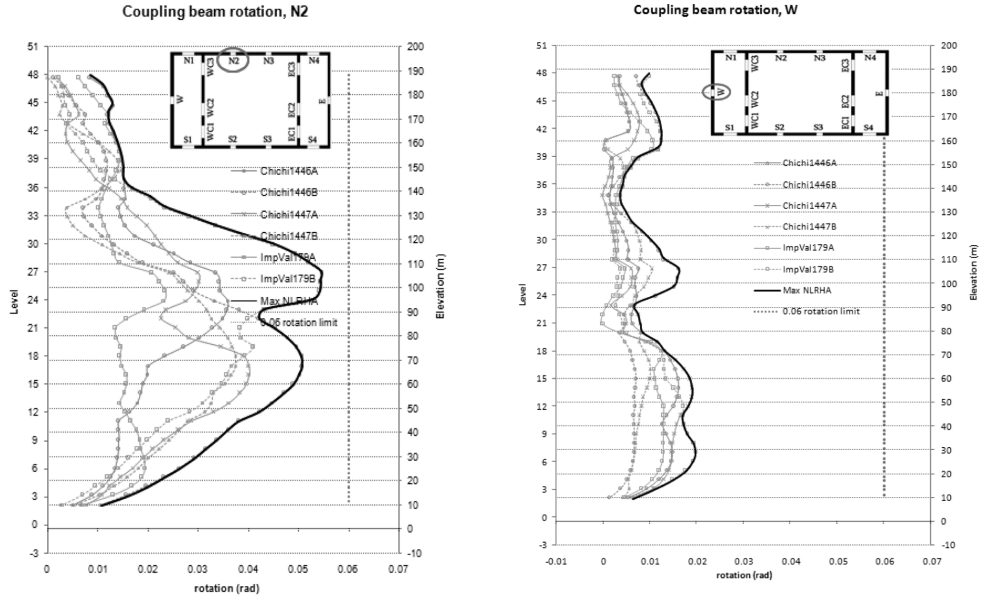


Figure 14. Coupling beam rotations.

cit simulation of the hysteretic energy dissipation, which is not possible to obtain using RSA method. This evaluation is therefore important for seismic application, where structures are expected to yield beyond their linear range.

Proper implementation of the procedure requires appropriate selection of the ground motion input since it can significantly affect the response of the building under evaluation and hence the design of the building. Appropriate spectral shape and scaling factors are important factors to consider for proper ground motion selection. With such high uncertainty and the potential conservatism that can be resulted, it is recognized that mean result from seven ground motions will likely yield more reasonable and realistic results in comparison with maximum result from three ground motions.

Employed carefully as a design tool, NLRHA will certainly lead to design of structures with better seismic performance. With the adoption of the upcoming seismic code in Indonesia, widespread application of PBSD with NLRHA for high-rise structures with single system such

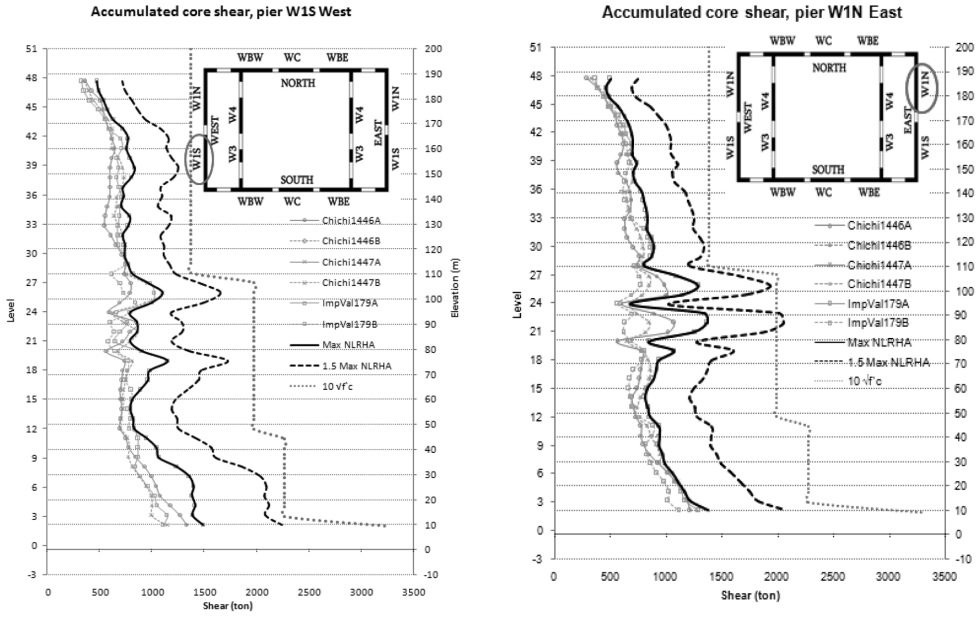


Figure 15. Individual core wall pier accumulated shear.

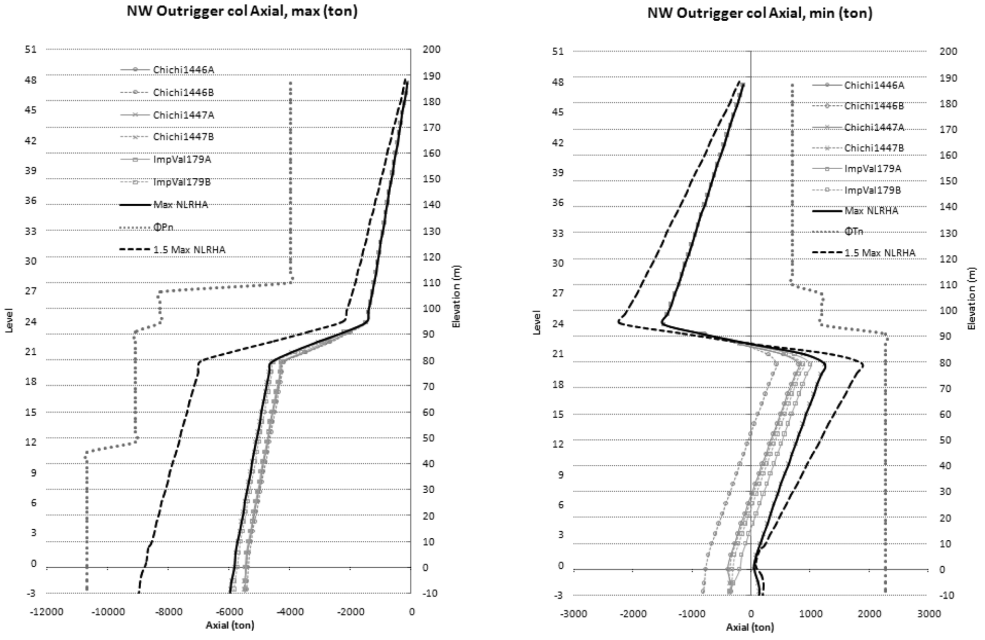


Figure 16. Outrigger column axial.

as RC core wall and other innovative systems will take place in the near future. Inevitably, procedures for ground motion selection and scaling as NLRHA seismic input will become routine and a good guidance on this issue is needed.

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