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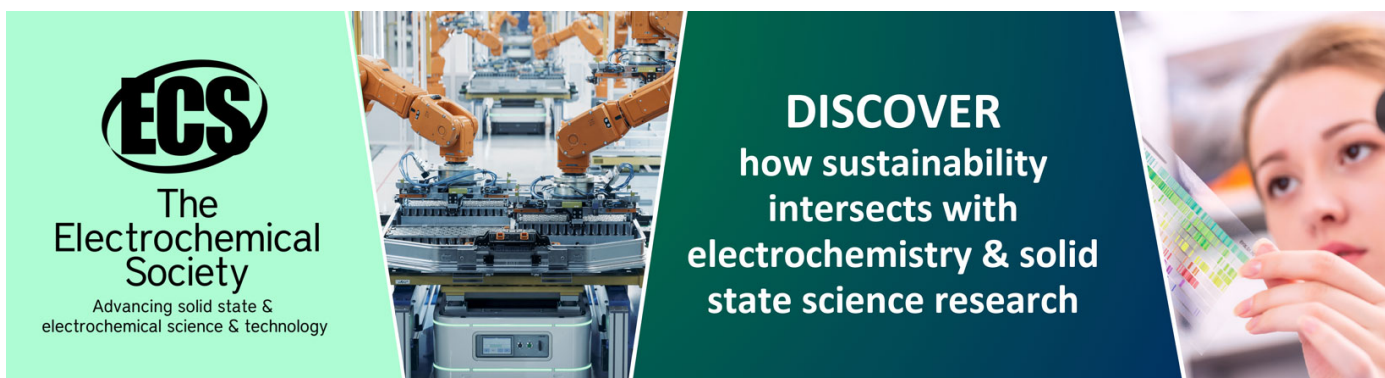
Comparative Analysis of Fixed base and Isolated Structure in “L” Shaped Plan with Time History Analysis based on ASCE 7-16

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Comparative Analysis of Fixed base and Isolated Structure in “L” Shaped Plan with Time History Analysis based on ASCE 7-16

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Abstract. An “L” shaped plan is often being chosen for residential, office, or hospital, whereas this configuration plan does not meet structural torsion requirement. This selection is done by the consideration of limited area and architectural needs, e.g. hospital needs for ventilation. Since the development of technology is very rapid this era, an innovation emerges beyond conventional solution, in terms of base isolation. In this paper, the selected research object is known as lead rubber bearing (LRB) with damping ratio 27%. To fulfill the research of L-shaped, the variation of length of the wings are proposed. Six models are functioned as office buildings in 6-story tall; three fixed base models are designed with dual system and another three isolated models are design using linear distribution lateral forces according to ASCE 7-16 code. Three-dimensional nonlinear time history analysis for isolated models is performed and will involve seven pairs of ground motions, which are matched to MCER target spectra of Jakarta in soft soil condition. In the end, the non-linear dynamic main responses of isolated structure may provide better and optimal results. In addition, estimated cost for design phase of pre-construction can be done by the assessment of rebar ratio and equivalent thickness of concrete, known from the results of this study.

1. Introduction

Indonesia is one of countries with a larger population growth, majority based in the capital city of Jakarta. One the major problems that comes up in Jakarta is the gap between land demand and the growth of local population or incoming migrants, causing land to be very expensive and the availability of symmetrical land to be scarce. Apart from these aspects, architectural design for natural ventilation in some building is also one of crucial reason of having L-shaped plan. L-shaped plan is one of the typical asymmetric floor plans surround besides T, H and + configuration. By several studies that have been conducted, L-shaped has strong torsion responses due to inconsistency between the center of mass and stiffness [1]. Therefore, it should be avoided since it does not meet the dynamic design principle of a structure, which states torsion response was not being expected to be occurred in the fundamental mode when the building is given any earthquake excitation energy [2]. Another problem caused by this shape is variations of rigidity, resulting in a local stress concentration at the “notch” of the reentrant corner. Both problems, the stress concentration and torsion response are interrelated. To sustain of using the L-shaped plan in design, several solutions are provided; separating buildings into each other, stiffen the ends, and using collector beams or walls [3]. By using these conventional solutions, material costs and improvements at the notch will certainly need to be considered.



As rapid technological development and science in the field of seismic engineering, an innovation was emerged to be solution of seismic problems occurred in fixed base structure, called base isolation. Several studies related to base isolation was mostly conducted; one of them is using FPS (friction pendulum system) as its research object under near-fault excitations [4]. By assigning an appropriate variation of rigidity of isolation system to produce a small eccentricity is a good strategy in rehabilitate low-rise asymmetric structures [5]. Besides reducing torsion, lateral forces occurred in superstructure could be minimized by using base isolation [6]. Considering for these positive impacts, this paper is likely to be a recommendation for choosing fixed base or isolated structure in the real case, by giving the global response using time history analysis and the quantity of rebar ratio and equivalent thickness of concrete. The results of time history analysis will only be done on isolated model due to the spend computation time on fixed base models.

2. Base isolation – lead rubber bearing

Base isolation is one of the most important devices in the last decade for earthquake engineering, which is used for decoupling the superstructure from accelerated foundation. To minimize damage to buildings, the superstructure is needed to be design stiffer enough to provide rigid body motion. There are two main principle performances of base isolation; to extend the natural period of the whole structure and provide higher damping through its lead component. Using base isolation system will not generate any amplification of shear forces on each floor above, resulting a significant reduction in floor accelerations and inter-story drifts compared to fixed base structure, as shown in figure 1 and figure 2. There are several types of base isolation; one of them is lead rubber bearing (LRB). Unlike the others, LRB has the ability of attenuation of large scale earthquake energy, because it equipped with lead material in the center inside.

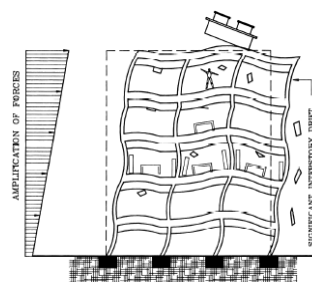


Figure 1. Fixed base (without base isolation).

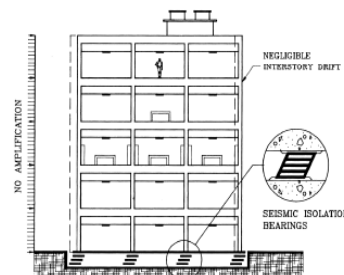


Figure 2. Base-isolated structure (using base isolation).

The characteristic of LRB was in nonlinear condition when earthquake excitation was applied on it. Therefore, the force-displacement behaviour of the LRB is modelled as bilinear model or hysteresis curve. To determine the lateral stiffness and damping ratio, base isolation could be tested dynamically to plot hysteresis curve. The isolator parameters that describe the bilinear law are initial elastic stiffness K_u , the post-yield stiffness K_d , characteristic strength Q_d , and force yield F_y . These all parameters are acquired from manufacturer of isolator, matching the criteria of the hysteresis loop of the analytical model and testing experimental [7].

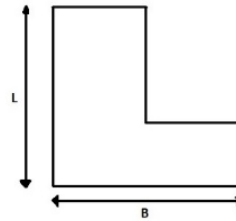
3. Description of study model

This all study models are office buildings using 6-story tall height, with typical floor height of 3.3 meters and 5 meters for the ground floor height. All the models are made asymmetrically L-shaped with variation of the wings length ratio (shown in table 1). The buildings fully used reinforced concrete with concrete quality f_c' 30 MPa (for beam, column, shear wall, and slab); for rebar “U40” is used, with specific quality as stated; f_y = 400 MPa, f_u = 570 MPa, f_{yE} = 468 MPa, and f_{uE} = 655 MPa. To make it into the real comparison, the L-shaped plan and code provisions are becoming the main reference for designing all models. The configuration and types of beams and columns in isolated models are made slightly different from the fixed base models, following the dimensional requirement.

The most types of beams using in both models are B36 (300x600 mm) as primary beams and B5A25 (250x500 mm) as secondary beams, but there is also additional collector beams B58 (500x800 mm) only in fixed models around the “notch” area. For columns, in isolated models are using C66 (600x600 mm) whereas in fixed base models are using bigger dimension; C88 (800x800 mm) and C75 (750x750 mm). To modelling the damping on the superstructure of isolated models, the stiffness-proportional damping is being applied, as recommended by [8].

Table 1. List of model variations.

Model	Ratio of bays (L/B)	Note
L1-FB	9:5	Fixed base
L1-BI		Base-isolated
L2-FB	9:7	Fixed base
L2-BI		Base-isolated
L3-FB	9:9	Fixed base
L3-BI		Base-isolated



Fixed base models are then modified by inserting link elements on the base of the structure to generate isolated models (details can be seen in figure 3). To avoid torsion effect, the specifications in the layout of base isolation used in each column are designed to be proportional to the gravity load resisted in each supports. In order to determine nonlinear parameters of isolators, an approach for the global and each of effective stiffness could be calculated by using equation (1) and equation (2). The specification of each base isolation based on the previous equations can be improved by the empirical formula and gave values as shown in table 2.

$$(K_{eff})_{total} = \frac{4\pi^2 W_{eff}}{T_M^2 g} \quad (1)$$

$$K_{effective-i} = \frac{W_i}{\sum W_i} * (K_{eff})_{total} \quad (2)$$

In which,

$(K_{eff})_{total}$ = total effective stiffness of the isolation system at the maximum displacement [kN/m]

$K_{effective-i}$ = effective stiffness of i-isolation system at the maximum displacement [kN/m]

W_{eff} = effective seismic weight [kN]

T_M = effective period of seismically isolated structure at the maximum displacement [s]

g = acceleration caused by gravity [m/s²]

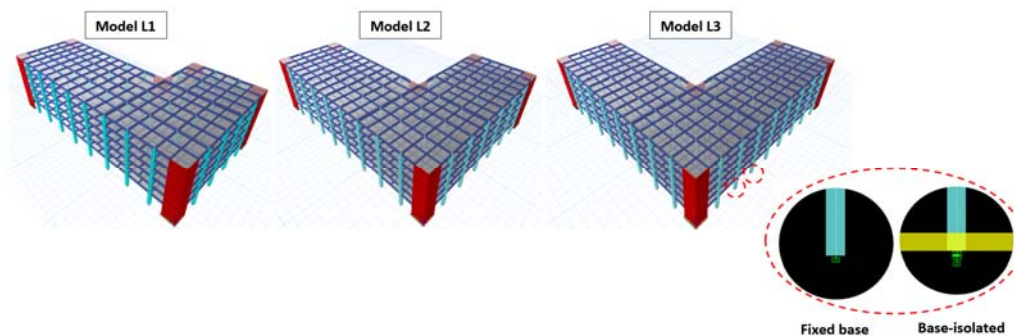
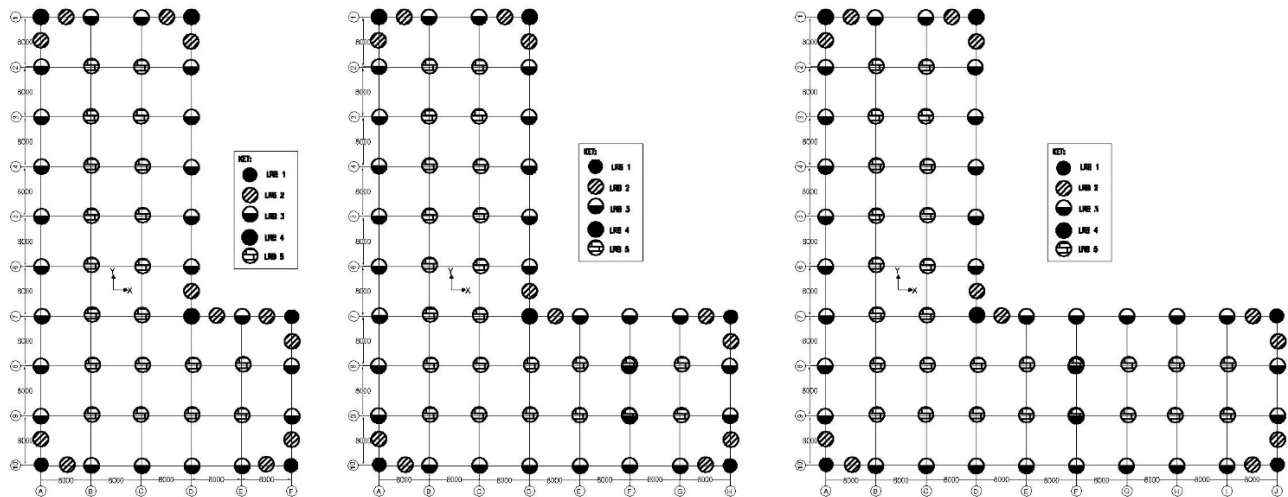


Figure 3. 3-Dimensional model on each variation and the difference between fixed base and base-isolated.

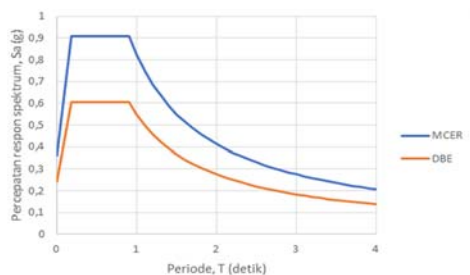
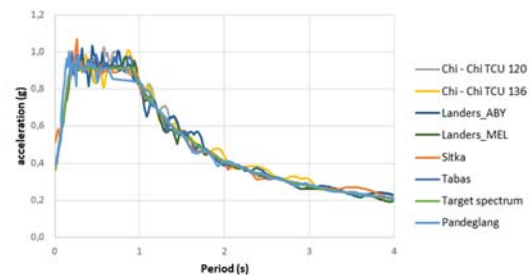
Table 2. The specifications of each base isolation are used in each L plans.

Model	L1-BI					L2-BI					L3-BI				
Parameter	Tipe isolator					Tipe isolator					Tipe isolator				
	LRB 1	LRB 2	LRB 3	LRB 4	LRB 5	LRB 1	LRB 2	LRB 3	LRB 4	LRB 5	LRB 1	LRB 2	LRB 3	LRB 4	LRB 5
Initial stiffness (kN/m)	2881	2842	5265	4802	9166	2907	2894	5298	4848	9125	3011	2973	5385	4909	9135
Stiffness post-yield (kN/m)	288	284	526	480	917	291	289	530	485	912	301	297	538	491	913
Characteristic strength, Qd (kN)	77	76	141	129	245	80	77	142	130	244	81	80	144	131	244
Force yield (kN)	86	84	157	143	273	88	86	158	144	271	90	88	160	146	272
Effective stiffness (kN/m)	492	486	900	821	1567	501	495	906	829	1560	515	508	920	839	1561
Effective damping ratio (%)	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27

**Figure 4.** Layout of base isolation on L1, L2, and L3 models.

4. Loading assumption for design

In general, there are two types of loading to be included: gravity load and lateral load (limited to earthquake load). Gravitational loads are consisted of self-weight load, superimposed dead load, and live load. Superimposed dead load will be assigned 250 kg/m² on typical floor and 600 kg/m² on the roof. Live load will fulfill the SNI 1727:2013 (equivalent as [9]) code provision used for office: 240 kg/m² on typical floor (not including ground floor), 500 kg/m² on the ground floor, and 100 kg/m² on the rooftop. Meanwhile, earthquake load is using DBE spectrum response of Jakarta type SE site (soft soil) for the design of structural elements and using MCER spectrum of Jakarta for the time history analysis to determine the real responses. The comparison of both spectra are shown in figure 5.

**Figure 5.** The comparison of DBE and MCER spectrum.**Figure 6.** Seven selected ground motions are matching to target spectrum MCER.

5. Nonlinear time history analysis (NLTHA)

In base-isolated models, nonlinear modelling is only applied to the LRB isolator element (for U2 and U3 direction). Since the inner forces generated in superstructure are insignificant, all the structural elements are not necessary for nonlinear modelling. According to [9], nonlinear time history analysis (NLTHA) will involve not less than seven pairs of horizontal scaling ground motion records, either by scaling or spectral matching to the target spectrum MCER Jakarta of soft soil. The scaling process will

not change the frequency content from the original earthquake but only changes in the amplitude in each period with different scale factor, the scaling result is shown in figure 6.

6. Results

6.1. Base shear

To acquire the result of response spectrum analysis (RSA) to be compared, this analysis will consider 100% in critical direction and 30% in the perpendicular, to include any additional torsion. While the results of time history analysis are the average responses of seven selected ground motion records. In figure 7, the base shear obtained by nonlinear time history analysis (NLTHA) is consistent to be higher than RSA method in inelastic response of isolated modes by the concept of equal displacement rule. The base shear of NLTHA in isolated models was not clearly define a significant reduction, since it is slightly larger than fixed base models using modification factor (R) of 7. The common value of R for designing dual system structure is 7, however, when nonlinear time history analysis is performed, the obtained R value may not exactly the same as initial design assumption. It depends on the number of hinge yielding occurs during earthquake; when the number is increasing, the reduction factor becomes greater. The difference of both values can be noted 34.23%, 33.31%, and 36.75%, respectively for L1, L2, L3 models.

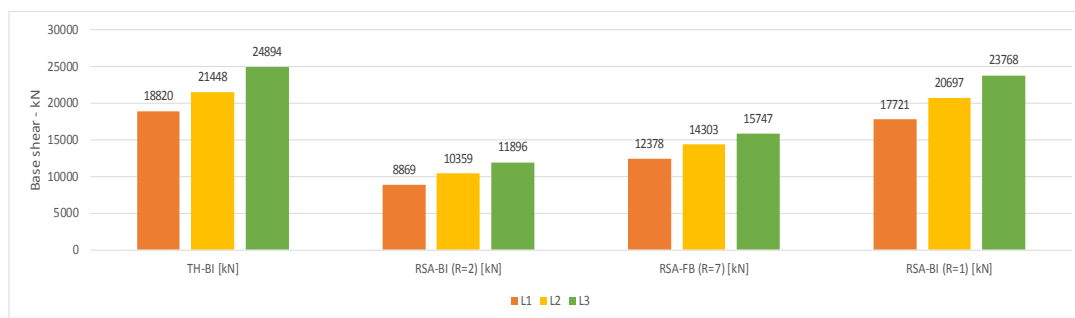


Figure 7. The comparison base shear of fixed base and base-isolated.

Furthermore, the results of time history analysis are giving closely to the unreduced response spectra analysis, with percentage difference of less than 6%. It does happen because the mass participation over 90% had occurred in the first mode. Therefore, by using RSA method to analyze isolated structure can be a reasonable alternative to acquire dynamics response.

6.2. Drift story



Figure 8. The comparison drift story of fixed base and base-isolated on each model.

According to the results in figure 8, it shows that the isolated structure can significantly reduce the rate of drift story at the MCER condition. By comparing the performance of base isolation in NLTHA to fixed base in RSA, will be obtained a reduction range of 72.15 – 86.57% in all variation models.

6.3. Rebar ratio and equivalent thickness of concrete

Before comparing to each other, it is important to note that all the isolated models are designed using reduction factor of 2 and following the linear vertical distribution of lateral forces approach on the superstructure based on MCE parameter; while the other models of fixed base are designed using dual system in accordance with the current earthquake design requirement. In this study, RSA is chosen as the basic of design process for all models since RSA method was often used in mid-rise building. The results obtained is an estimation on several structural elements, including beams, columns, slabs, and shear walls on the superstructure, but the detail of rebar calculation is not including the length of anchorage at the end and lap splicing. In order to determine the spacing of shear rebar in each element, ACI code was used for guidance. Overall the results will be acquired and calculated ideally by program, so that the value might be smaller than the reality.

In figure 9, the rebar ratio of fixed base obtained consistently in the range of 136 – 140 kg/m³. While in isolated model, the rebar ratio is increasing along the various asymmetric L-shaped plan – generating 15%, 7%, 7% differences on model L1, L2, L3, respectively. Besides rebar, the total quantity of concrete known, as equivalent thickness will have slightly differenced i.e. the 239-242 mm range for model fixed base and the 229-234 mm range for isolated models (shown in figure 10). The usage of base isolation is more likely to save steel rebar more than concrete, since the reduction in concrete is not significant. This is following to the rules of condition that allow the design of superstructure over base isolated models with low ductility, in this way, the details of reinforcement between joints and larger local stress element in “notch” area can be designed in simple way.

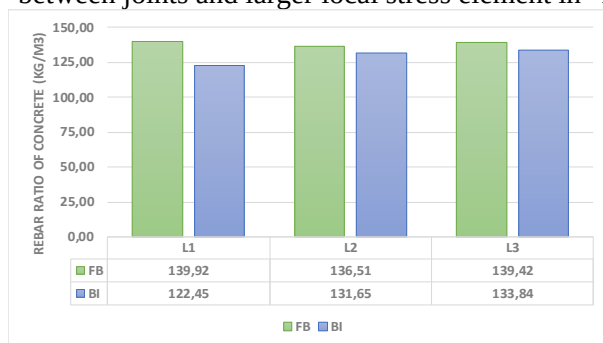


Figure 9. The comparison of rebar ratio in a cubic concrete (kg/m³) of fixed base and isolated base.

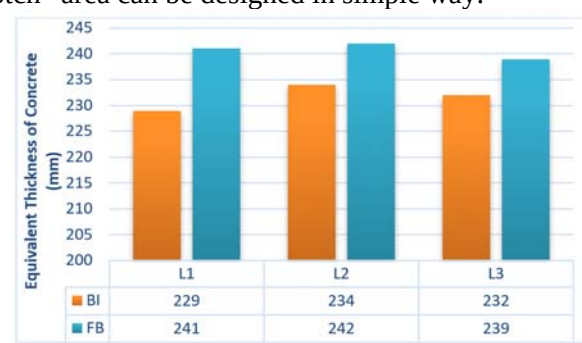


Figure 10. The comparison of equivalent thickness concrete of fixed base and isolated base.

Table 3. Detail of material saving of concrete and rebar on each variation.

Variation	Component	Model		
		FB	BI	% Saving
L1	Rebar (ton)	506,24	428,38	15%
	Concrete (m3)	3617,96	3498,46	3%
L2	Rebar (ton)	576,30	538,47	7%
	Concrete (m3)	4221,65	4090,28	3%
L3	Rebar (ton)	672,51	626,06	7%
	Concrete (m3)	4823,46	4677,85	3%

7. Conclusion

From the study, the base isolation is proven to be effective in dissipate seismic energy and more efficient in rebar usage. Here are the details of some conclusion remarks:

1. The torsion effect could be avoided in fundamental modes with the proper types and isolator layout
2. By using base isolation, mass participation factor in translation and torsion over 90 percent will be more easily achieved, so the analysis is enough to represent the real vibrated mass
3. The base shear calculated from the NLTHA is consistent higher than RSA on fixed base. The difference of both values is 34.23%% for L1 model; 33.31% for L2 model; and 36.75% for L3 model
4. The isolated structure is giving the smallest drift story rate of not more than 0.2% for each story, avoiding any damages to nonstructural elements inside the building
5. Using base isolation can lead to the saving effort; i.e. rebar by 7-15% and concrete by 3%.

Acknowledgements

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