The 2018 Structures Congress (Structures18)
Songdo Convensia, Incheon, Korea, August 27 - 31, 2018

Comparative Analysis of Fixed Base and Isolated Structure in "L" Shaped Plan with Time History Analysis Based on ASCE 7-16

*Hendro[1)], Josia Irwan Rastandi[2)], Sjahril A. Rahim[3)], and Yuskar Lase[4)]

[1),2),3),4)] *Department of Civil Engineering, Universitas Indonesia, Depok, 16424, Indonesia*
[1)] *hendro31@ui.ac.id*

ABSTRACT

An "L" shaped plane is being often chosen as a residential, office, or hospital plan, 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, an innovation emerges beyond conventional solution, in terms of base isolation. In this paper, the selected research object is lead rubber bearing (LRB) with damping ratio 27%. To complete the research of L-shaped, the variation of length of the wings are introduced. Six models are functioned as office buildings in 6-story tall; three models are designed with dual system and another three 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 motion, which are matched to MCER target spectra of Jakarta in soft soil condition. In the end, the dynamic main responses of isolated structure may provide better and optimal results. Besides, estimated cost for design phase of pre-construction can be done by the assesment of rebar density and equivalent thickness of concrete, known from the results of this study.

1. INTRODUCTION

Indonesia is one of countries with a larger population, majority based in the capital city of Jakarta. One the problems that comes up in this capital city was the imbalance between land demand and population, 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 assymetric floor plan 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)] Graduate Student
[2), 3), 4)] Senior Lecturer

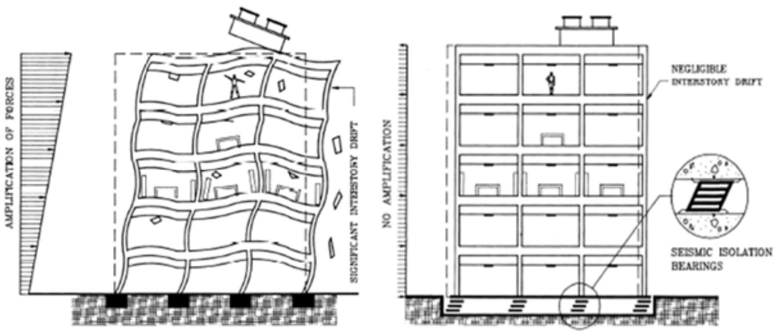
[5]. Therefore, it should be avoided since it does not meet the dynamic design principle of a structure, which states torsion response was not being expected to be occured in the fundamental mode when the building is given any earthquake excitation. Another problem caused by this shape is variations of rigidity, resulting in a local stress concentration at the “notch” of the reentrant corner [9]. Both problems, the stress concentration and torsion response are interrelated. To sustain of using the L-shaped plan, several solutions are provided; separating buildings into each other, stiffen the ends, and using collector beams or walls [9]. By using this conventional solutions, material costs and improvements at the notch will centainly 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 occured in conventional 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 [8]. 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 [6]. Besides reducing torsion, lateral forces occured in superstructure could be minimized by using base isolation [3]. Considering for these positive impacts, this paper is likely to be a reference in the real life for choosing fixed base or isolated structure, by giving the global response using time history analysis and the quantity of density rebar and equivalent thickness of concrete. The results of time history analysis will only be done on isolated model, due to the spend of computation time on fixed base that are not practical.

2. BASE ISOLATION – LEAD RUBBER BEARING

Base isolation is one of the most important device in the last decade for earthquake engineering which can be defined as decoupling the structure from accelerated foundation. In order to minimise damage to buildings, the superstructure is needed to be design stiff enough to provide rigid body motion. There are two main principle performance of base isolation; to extend the natural period of the whole structure and provide higher damping through its material components. Using base isolation system will not generate any amplification of shear forces on each floor above, resulting a significant reduction in floor accelerations and interstory drifts compared to conventional structure, as shown in **Fig. 1***.* 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.

The characteristic of LRB was actually in nonlinear condition when earthquake excitation was applied on it. Therefore, LRB is modeled by a biliniear model / histeresis curve, showing the force-displacement characteristic behavior. To determine the lateral stiffness and damping ratio, base isolation could be tested dynamically to plot hysteresis curve (**Fig. 2**).



(a) (b)

Fig. 1 Conventional structure / fixed base (a), Base-isolated structure (b)

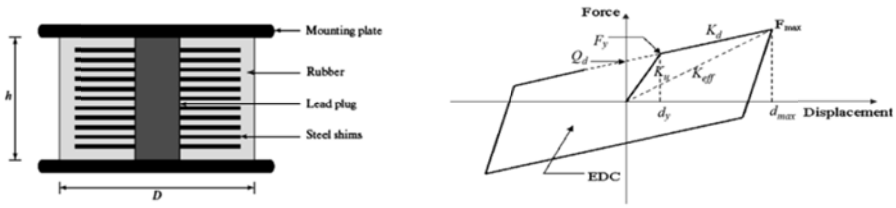


Fig. 2 LRB system and bilinear model of LRB

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.

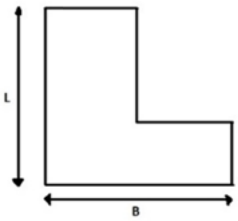
3. DESCRIPTION OF STUDY MODEL

This all study models are office buildings using 6-story tall height, with typical floor height of 3,3 meters and 5 meter for the ground floor height. All the models are made asymmetrically L-shaped with variation of the wings length ratio (**Table 1**). The main building material used reinforced concrete with concrete quality fc' 30 MPa (for beam, column, shearwall, and slab); for rebar, U40 is used with quality fy= 400 MPa, fu= 570 MPa, fye = 468 MPa, and fue = 655 MPa. To make the real comparison, the L-shaped plan dan code provisions are becoming reference for designing all models. Therefore, the configuration and types of beams and columns in isolated models are made slightly different from the fixed base models due to the dimentional 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 are also additional collector beams B58 (500x800 mm) only in fixed models . For columns, in isolated models are using C66 (600x600 mm) whereas in fixed base models are using 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 [10].

To develop isolated models, fixed base models are modified by inserting link elements on the base of the structure (**Fig. 3**). Since the layout of base isolation is very crucial to prevent the torsion effect, then the isolator parameters are proportioned against the distribution of gravity load under each columns. The total and each of effective stiffness could be calculated using **Eq. (1)** and **Eq. (2)**

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



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

$$K_{eff-i} = \frac{w_i}{\sum w_i} * \left(K_{eff}\right)_{total} \tag{2}$$

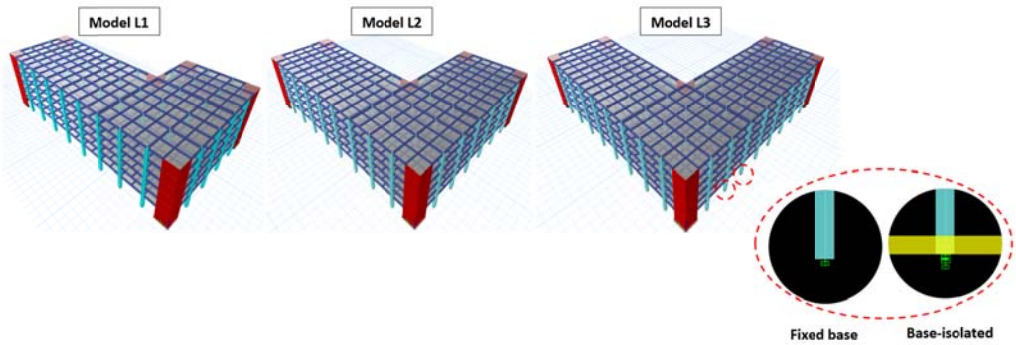


Fig. 3 3D model on each variations and the difference between fixed base and base-isolated

4. LOADING FOR DESIGN

In general, the load is divided into two types, gravity load and lateral load (focusing on earthquake). Gravitational loads consist of self-weight load, superimposed dead load, and live load. Superimposed dead load will be assigned 250 kg/m^2 on typical floor and 600kg/m^2 on the roof. While for the live load will follow the SNI 1727:2013 (equivalent as [1]) regarding as an office: 240 kg/m^2 on typical floor (not including ground floor), 500 kg/m^2 on the ground floor, and 100 kg/m^2 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.

Table 2. Specification of each base isolation used

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

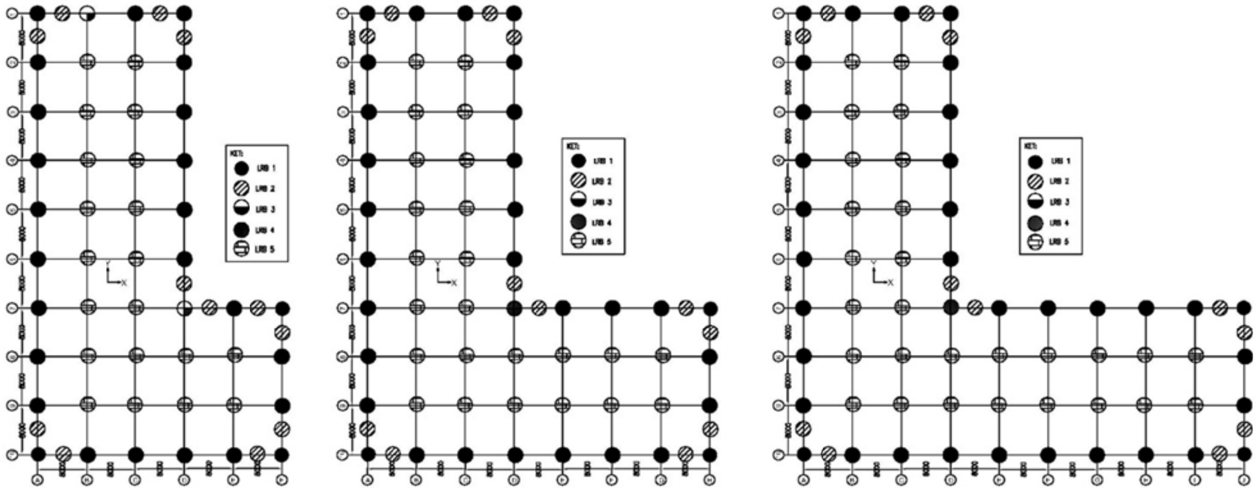
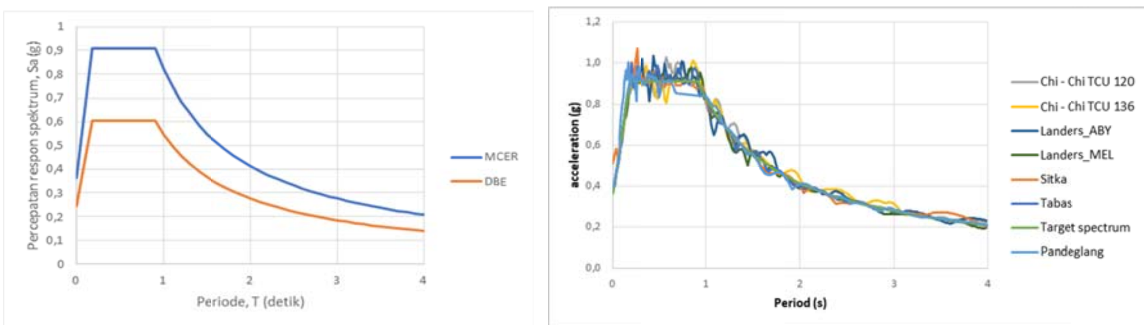


Fig. 4 Layout of base isolation on L1, L2, and L3 models

5. NONLINEAR TIME HISTORY ANALYSIS (NLTHA)

In base-isolated models, nonlinear modelling is only given to the LRB isolator element (U2 and U3 direction). Structural elements in superstructure are not given nonlinear modeling since the inner forces happened are insignificant. Furthermore, the material nonlinearity property needs to be defined across the model using ETABS software. According to [1], nonlinear time history analysis (NLTHA) will involve not less than seven pairs of horizontal scaling ground motion records, either by scaling or spectral matching. Later, the seven selected ground motion records were processed to match the target spectrum MCER Jakarta of soft soil.



(a) (b)

Fig. 5 The comparison of DBE and MCER spectrum (a); seven selected ground motion are matching to target spectrum MCER (b)

6. RESULTS AND DISCUSSION

6.1 MODAL ANALYSIS

From the result of modal analysis (**Table 3**), the natural period of system was increasing around three times from fixed base models. Besides, the summation of mass participation over 90 percent (marked in red color) was easily achieved although they are assymetrical. It is more interesting to be noticed that torsion effect was avoided by the existence of bigger columns on perimeter and shearwalls on each corner. But it is not valid for isolated models, since the torsion was reduced by base isolation system layout and the shearwalls are used to provide stiffness enough to keep the integrity of superstructure

Table 3. The comparison of modal analysis of fixed base and base-isolated

Mode	Periode (s)	Sum - Mass			Mode	Periode (s)	Sum - Mass			Mode	Periode (s)	Sum - Mass			Mode	Periode (s)	Sum - Mass			Mode	Periode (s)	Sum - Mass			Mode	Periode (s)	Sum - Mass		
		UX	UY	RZ			UX	UY	RZ			UX	UY	RZ			UX	UY	RZ			UX	UY	RZ			UX	UY	RZ
1	1.00	0.44	0.34	0.01	1	3.06	0.55	0.44	0.01	1	1.03	0.42	0.37	0.00	1	3.16	0.52	0.47	0.00	1	1.08	0.40	0.40	0.00	1	3.16	0.50	0.50	0.00
2	0.90	0.79	0.77	0.02	2	3.04	1.00	0.97	0.03	2	0.94	0.79	0.78	0.01	2	3.14	0.99	0.98	0.03	2	0.99	0.79	0.79	0.01	2	3.15	0.98	0.98	0.03
3	0.72	0.79	0.79	0.76	3	2.91	1.00	1.00	1.00	3	0.75	0.79	0.79	0.77	3	3.00	1.00	1.00	1.00	3	0.80	0.79	0.79	0.77	3	3.01	1.00	1.00	1.00
4	0.28	0.89	0.82	0.77	4	0.54	1.00	1.00	1.00	4	0.35	0.79	0.79	0.77	4	0.55	1.00	1.00	1.00	4	0.45	0.79	0.79	0.77	4	0.56	1.00	1.00	1.00
5	0.25	0.89	0.83	0.77	5	0.50	1.00	1.00	1.00	5	0.29	0.89	0.84	0.77	5	0.52	1.00	1.00	1.00	5	0.30	0.86	0.86	0.77	5	0.53	1.00	1.00	1.00
6	0.25	0.93	0.94	0.77	6	0.40	1.00	1.00	1.00	6	0.26	0.93	0.94	0.77	6	0.42	1.00	1.00	1.00	6	0.28	0.93	0.93	0.78	6	0.43	1.00	1.00	1.00
7	0.20	0.93	0.94	0.91	7	0.16	1.00	1.00	1.00	7	0.22	0.94	0.94	0.91	7	0.17	1.00	1.00	1.00	7	0.24	0.94	0.94	0.92	7	0.18	1.00	1.00	1.00

6.2 BASE SHEAR

To acquire respon spectrum analysis (RSA) to be compared, this analysis considers 100% in critical direction and 30% in the perpendicular, in order to include any additional torsion. While the results of time history analysis are the average responses of seven selected ground motion records.

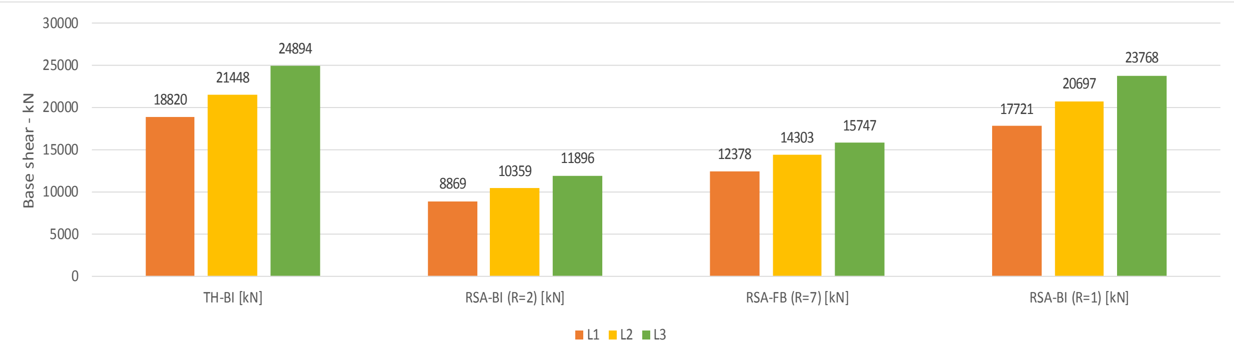


Fig. 6 The comparison base shear of fixed base and base-isolated

In **Fig. 6**, 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 design purposes is 7, however, when nonlinear static analysis is performed, the obtained R value may not equal to the initial design assumption. It depends on the number of hinge yielding occured during earthquake; when the number is increasing, the reduction factor becomes greater. The difference of both value can be obtained 34.23%, 33.31%, and 36.75%, respectively for L1, L2, L3 models.

Furthermore, the results of time history analysis are giving closely to the elastic analysis by response spectra using R=1, with percentage difference of less than 6%. It does happened because the mass participation over 90% had occured in the first mode.

Therefore, by using response spectra to analyze isolated structure can be a reasonable alternative to acquire dynamics response.

6.3 DRIFT STORY

According to the results in **Fig. 7**, 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. In conclusion, the non-structural elements and residents inside the building are safe and secure from earthquake hazard.

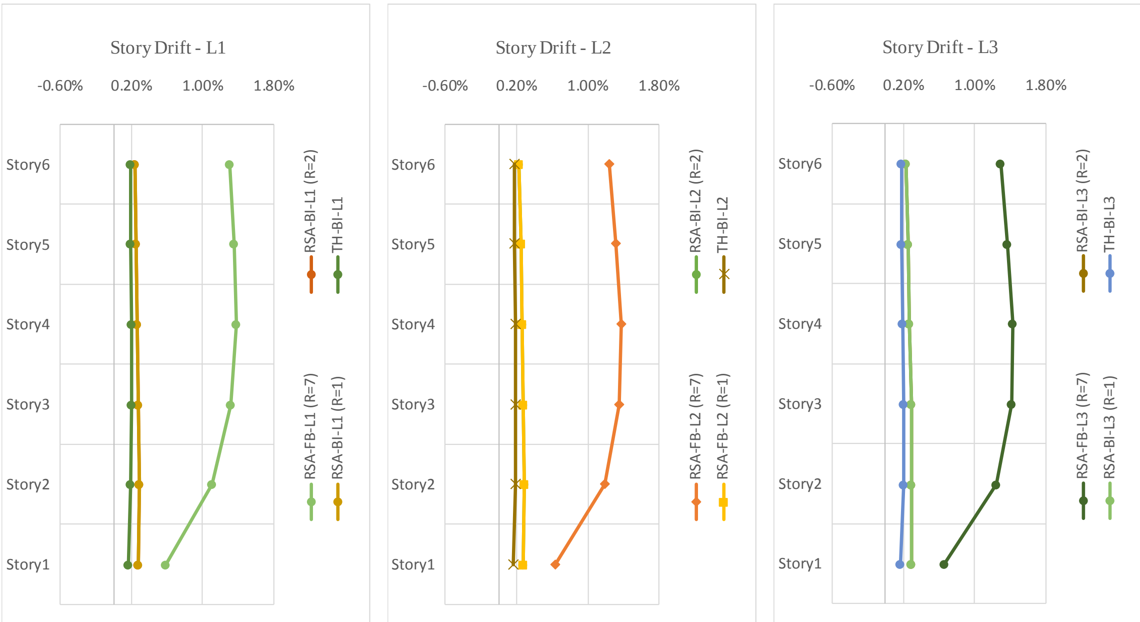


Fig. 7 The comparison drift story of fixed base and base-isolated on each models

6.4 REBAR DENSITY AND EQUIVALENT THICKNESS OF CONCRETE

Before comparing each other, it is crucial to note that all the isolated models are designed using reduction factor of 2 and following the linear vertical distribution of lateral forces on the upper structure based on the MCE parameter; while all the models of fixed base are designed using dual system in accordance with current earthquake design requirement. The results obtained is a calculation on several structural elements, including beams, columns, slabs, and shearwalls on the upper structure, but the detail of rebar calculation is not including the length of anchorage at the end and lap splicing. Overall results are obtained ideally by the ETABS program, so that the value might be smaller than the real one.

In **Fig. 8**, the density of fixed base was obtained consistently in the range of 136 – 140 kg/m^3. While in isolated model, the rebar density is increasing linearly proportional to the various asymetric 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 difference, i.e. the 239-242 mm range for model fixed base and the 229-234 mm for isolated models (**Fig. 9**). 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 upper structure over base isolated models with low ductility, in this way, the details of reinforcement between joints and larger local stress element can be done in simple procedure.

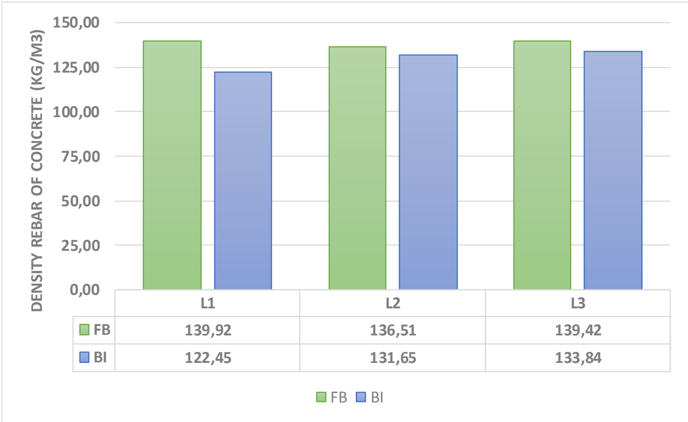


Fig. 8 The comparison of density rebar of a cubic concrete (kg/m^3) of fixed base and isolated base

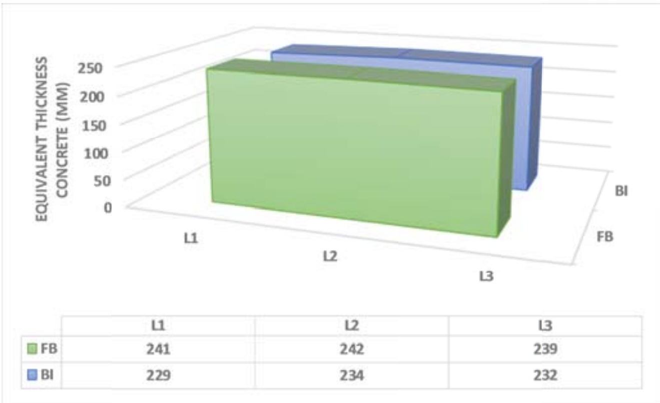


Fig. 9 The comparison of equivalent thickness concrete of fixed base and isolated base

Table 4. Detail of material saving of concrete and rebar on each variation

Variation	Component	Model FB	Model 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. CONCLUSIONS

From the study, the base isolation is proven to be effective in dissipate seismic energy and more efficient in design phase. 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 sufficient 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 stories, 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%.

REFERENCES

ASCE/SEI 7-16. (2017). *Minimum Design Loads for Buildings and Other Structures*: The American Society of Civil Engineers.

Bing, Y.B., Chang, K.C, & Yau, J.D. (2003). *Chapter 17: Base Isolation*, CRC Press LLC, 1–15.

Cancellara, D., & De Angelis, F. (2017). Assessment and dynamic nonlinear analysis of different base isolation systems for a multi-storey RC building irregular in plan. *Computers & Structures*, ***180***, 74–88.

Chopra, A. K. (2012). Dynamics of Structures. Boston: Prentice Hall.

Deng, P., Li, X., Dong, W., & Tai, L. (2014). Seismic Analysis of L-Shaped Irregular Plane Frame Structure with Viscous Dampers. *Applied Mechanics and Materials*, vol. **501–504**, 1547–1550.

Etedali, S., & Sohrabi, M. R. (2011). Torsional Strengthening of Base-Isolated Asymmetric Structures by Increasing the Flexible Edge Stiffness of Isolation System. *International Journal of Civil & Environmental Engineering*, vol.**2**.

Hameed , Asif & dkk. (2008). Effect of Lead Rubber Bearing Characteristics on the Response of Seismic-isolated Bridges. *KSCE Journal of Civil Engineering* (2008), 187-196.

Mazza, F., & Mazza, M. (2016). Nonlinear seismic analysis of irregular r.c. framed buildings base-isolated with friction pendulum system under near-fault excitations. *Soil Dynamics and Earthquake Engineering*, vol.**90**, 299–312.

Naeim, Farzad. (2012). The Seismic Design Handbook, second edition. Los Angeles: Springer Science & Business Media.

Ryan, K. L., & York, K. (2007). Vertical distribution of seismic forces for simplified design of base-isolated buildings. *New Horizons and Better Practices*.

Ryan, K. L., Asce, M., & Polanco, J. (2008). Problems with Rayleigh Damping in Base-Isolated Buildings, 1780–1784.