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DYNAMIC PERFORMANCE OF L SHAPED ASYMMETRIC BUILDING WITH SOIL STRUCTURE INTERACTION

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ABSTRACT

A plan asymmetric building having L shape normally exhibits a complex response under dynamic loads. In this research work, effects of change of height and change in number of bays are studied separately. Different support conditions based on soil types are also considered for analysis under earthquake ground motion. A specific type of buildings where ten bays, eight bays, six bays, and four bays are considered in one wing, and the other wing contains ten bays of the nine storied plan asymmetric buildings have been chosen to compare the responses. Also, twelve, nine, six, and single storied buildings are considered for analysis with the interaction of soil structure. It has been observed that the time period is much more than the time period based on the empirical formulae used by different international codes. The magnitude of rotation around one of the horizontal axis of the building is found to be higher with the decrease in the number of bays. Base shear increases with the rise of height of building.

KEYWORDS: Time history analysis; soil-structure interaction; dynamic analysis; high-rise building; plan asymmetry

1. INTRODUCTION

Some third-world countries are developing very rapidly, and population growth is very fast. Mostly construction growth can see in the urban area. Highrise buildings, bridges, flyovers, towers, etc., are developing in the densely populated area of towns. Maximum construction is related to multistoried building structures. The buildings which are reported as collapsed are mainly due to dynamic loads. Most building structures are analyzed without considering walls and the differential properties of supporting soil. Moreover, lack of symmetry produces torsional effects which are difficult to assess and may lead to unsafe conditions.

Sivakumaran et al. (1992) analyzed ten storied asymmetric buildings on soft soil under time history load and concluded that lateral displacement increases whereas storey shear, twists, and torque decreases. Guler et al. (2008) compared fundamental periods of bare frame, infill frame, and plastered infill frame to estimate the elastic fundamental vibration period. Experiment with the lateral behavior of partially infilled two-storied frames under earthquake load has been carried out and the captive column effect is found [Subramanian and Jayaguru, 2009]. Pradhan (2012) analyzed partially infilled structures and concluded that beyond 70% opening, the strut width would be almost the same for all aspect ratios. In a few works of literature, plan irregular buildings are assessed and compared with the results of time history analysis [Bhatt and Bento, 2012]. Champion and Liel (2012) analyzed the seismic collapse risk of near field ground motion. Hatzigeorgious and Kanapitsas (2013) explored twenty different buildings and proposed an empirical formula for an estimate of the fundamental period. Tarbali and Shakeri (2014) assessed the seismic responses of asymmetric plan buildings and calculated the height-wise moment. Asteris et al. (2015) analyzed the symmetrical structure and found out that opening more than 85%, of the mass and stiffness of infill does not contribute to the fundamental period. Chakroborty and Roy (2016) analyzed the plan asymmetric structure and estimated the inelastic structural demand. Some researchers concluded that roof displacement is highest among bare frames, full in-filled walls, and open ground storey buildings [Reza et al., 2017]. Hosseini et al. (2017) studied the performance level of multistoried irregular plan structures under near-fault earthquakes and claimed that the Iranian code provisions still need improvement. Khanal and Chaulagain (2020) calculated responses of re-entrained corners of L shaped multistoried structures and concluded that the Indian standard seismic code has not been able to fulfill the design aspect of L shaped buildings. Das et al. (2021) reviewed asymmetric structures and explained the tremendous stress concentration at the corner, initiating early damage and resulting in the failure of plan asymmetric building.

The prior research is mainly focused on the analysis of symmetric and asymmetric buildings regarding the percentage of opening, life safety factors, and re-entrained corners of the building having L shaped under static seismic forces. However, analysis of L shape plans asymmetric building with a varying number of bays of one wing where bays of other are unchanged with different soil support conditions was not considered. Also, the literature survey reveals that the effect of change of height of building having L shaped on different support such as fixed base, hard soil, medium soil, and soft soil is very limited. In this paper, twelve, nine, six, and single-storied buildings with different supporting mediums under ground motion have been addressed.

2. METHODOLOGY

Some research gaps have been identified from the above literature survey, and accordingly, analyses have been carried out by applying time-acceleration series of near field earthquake ground motion. Stiffness and strength both the irregularities have been present in plan asymmetric open frame building. Four types of supporting conditions, namely fixed base, hard soil, medium soil, and soft soil, have been studied for comparison in different load combinations. Live load and dead loads are common in near field ground motion. Extensive analyses of reinforced concrete plan asymmetric building structures are performed considering the soil-structure-interaction (SSI) effect.L shaped plan asymmetric nine storied building has been considered with ten bays of equal length of 4.5m each in both directions in the horizontal plane. Each leg is regarded as two bays of equal width of 4.5m. Plan asymmetric building is modeled by using FEM-based analytical software STAAD Pro v8i. The analysis is mainly based on the followings. 1. Analysis of asymmetric plan building with a varying number of bays in one wing where the other wing has ten bayson fixed base, hard, medium, and soft soil base. 2. Analysis of equal bays of plan asymmetric buildings having different heights has been carried out to find out responses such as displacement, rotation, base shear, fundamental frequency, and time period under Chi-Chi ground motion.Also, a comparison of the fundamental period of empirical code formulas and the fundamental time period of dynamic analysis under Chi-Chi ground motion has been done.

3. FORMULATION

In this analysis, structures are supported over an elastic pad as a raft foundation with spring supports. Three translation springs, two in the principal horizontal direction and one in the vertical direction along with the rotational springs in the mutually perpendicular axes have been considered below the raft. Spring constants are adopted based on foundation base area, the moment of inertia, co-efficient of uniform compression, and co-efficient of uniform shear of supporting soil. Equivalent spring constants are taken in the lateral X direction, vertical Y direction, lateral Z direction, rocking about X-axis, torsional about Y-axis, and rocking about Z-axis. Soil stiffness of equivalent soil spring parameters has been adopted from the literature and code [Dutta et al. (2004) and IS 5249 (1992)].

The buildings are reinforced cement concrete structures with moment-resisting frames. Four nodded (quadrilateral) plate elements are adopted for the modeling of slab elements. The plate element has both membrane (in-plane) and bending (out of plane) properties. Four nodded beam elements have been considered for beams and columns. Local effects of stress and stress-resultants between the nodes are estimated for these beam elements. Multiple mesh regions are created automatically as per the texture of the model and the same is considered in the parametric models. The structure is considered in the category of an "important building." The validation of the model is done by comparing it with the results in existing literature for similar conditions such as building type, height, etc. [Khanal and Chaulagain, 2020].

The beam and column dimensions are chosen to have symmetry and better rigidity. Slab thicknesses of each floor are taken as 130 mm. The height of the nine-storied building is 27m and the width of the ten bays of the building is 45m. Each floor height is 3m and the width of the bays is considered 4.5m. The analysis is done considering raft footing of thickness 600mm resting on a fixed base, hard soil, medium soil, and soft soil. Responses are compared for the fixed base and different soil supports. Beam, column dimensions, and reinforcement detailing are considered as per design provisions of I.S. 456:2000, IS 13920:1993, and literature[Khanal and Chaulagain, 2020]. The significant properties of concrete material are Young's Modulus (2.17185x107 kN/m^2), Poisson's ratio (0.17), density (23.5616 kN/m^3), damping (5%), thermal expansion coefficient (0.00001 per degree Celsius) and shear modulus (9.28139x106 kN/m^2). The minimum yield strength of reinforcement is considered 415 N/mm^2.Live load is considered as an area load of magnitude 2.5 kN/m^2 which is acting in a vertically downward direction on each slab located on every floor. Dead load is considered as the self-weight of structure. Ground motion has been applied along the X-direction or along width of the building. Dynamic load is applied by using the time history of earthquakes Chi-Chi, Taiwan (1999) ground motions which have been taken from a subset of the PEER database (2014). Time period has been calculated based on the empirical expression of different codes of some countries.

The analysis has been carried out mainly for two different criteria. The first criteria are related to the same height building of nine storied where one wing contains 10 bays in combination with another wing of 10 bays, 8 bays, 6 bays, 4 bays in different support. Whereas for other criteria, both the wings have ten number of bays however the height of building changes as 36m, 27m, 18m, and 3m in different support mediums are considered. Two bays are considered in the transverse direction of each wing since maximum responses have been reported [Khanal and Chaulagain, 2020] in double bay cases. The dead load, live load, and Chi-Chi ground motion have been applied in each analysis.

4. RESULT AND DISCUSSION

The magnitude of base shear of a varying number of bays and different height buildings has been shown in Figure1a and Figure1b accordingly. The comparison of responses has been calculated on a fixed base, hard soil, medium soil, and soft soil conditions. The maximum expected lateral forces that will occur due to earthquake ground motion at the base level of the structure are estimated as base shear.

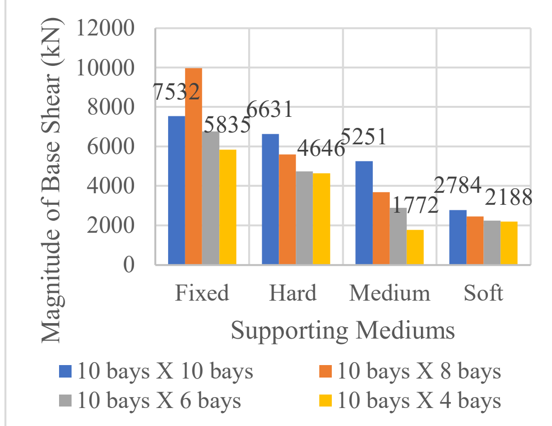


Figure1a. Base Shear in different bays for building having same height

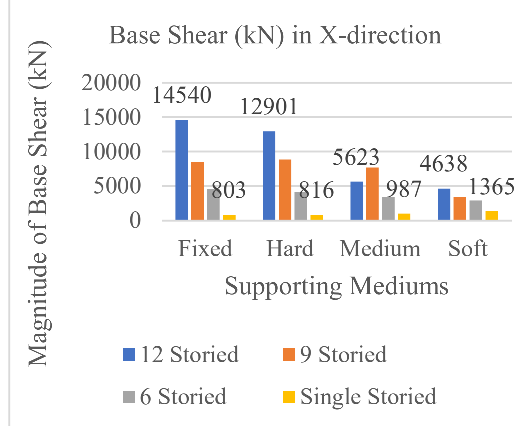
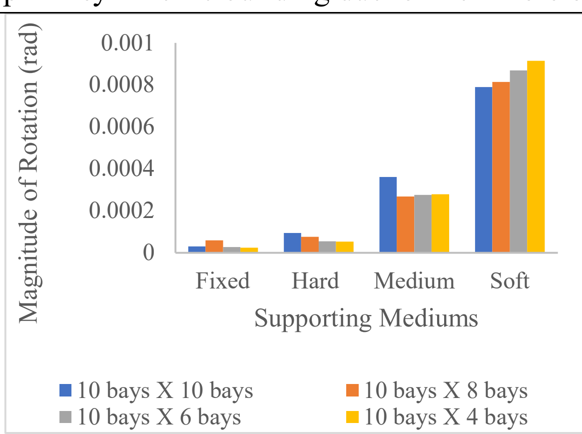


Figure1b. Base Shear in different height for building having equal number of bays

Figure1: Base shear (kN) along X-direction under Chi-Chi ground motion

Base shear decreases in accordance with the reduction in stiffness of supporting mediums. This is also true for the reduction of the number of bays of one wing. However, the reduction of base shear with respect to a decrease in height of the building is not correct. Compared to a fixed support, the reduction in base shear is varying from 62% to 76% in soft soil for a varying number of bays. The magnitude of 10X10 bays and 10X4 bays is shown in Figure1a. Magnitudes of base shear for twelve storied and single storied are shown in Figure 1b. Maximum variations of base shear between fixed base and soft soil have been seen around 70% in single storied building, whereas minimum base shear variation occurs in six storied building which is around 36%. The reduction of the number of bays reduces the base shear in any supporting mediums. However, the behaviors of the single storied building are quite different. In Figure1b, it is clear that minimum base shear occurs for single-storied buildings whereas buildings having twelve storied has been seen maximum value in each supporting condition except medium soil. Base shears are mostly deviated in plan asymmetric building due to lateral torsional coupling phenomena and radiation damping.



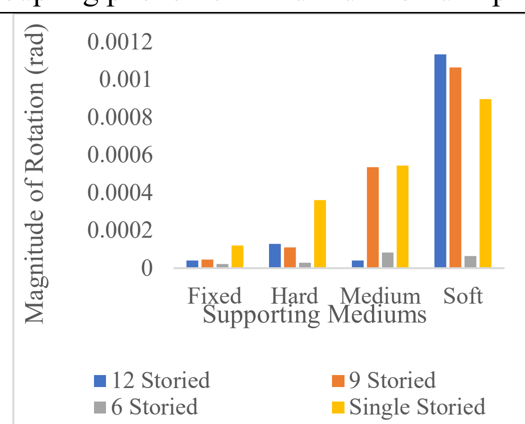


Figure2a. Rotation(rad) around X axis in different bays for building having same height	**Figure2b.** Rotation(rad) around X axis in different height for building having equal number of bays

Figure2: Maximum Rotation (rad) in various support under Chi-Chi ground motion

The rotation of buildings having the same height with the change of the number of bays is shown in Figure2a and for buildings with different heights having an equal number of bays has been shown in Figure2b. The rotation is measured at the base level where the corner column and foundation intersect. Irregular behavior has been seen in the case of rotation of buildings with unequal wings. The maximum rotation has been seen in 10x4 bays buildings in soft soil compared to other unequal wing buildings. However, in hard soil and medium soil maximum rotation has been seen for 10X10 bays building. It has been seen that a building in a fixed base has minimum rotation where wings are unequal and equal. Reduction of the number of bays of one wing has a significant effect on soft soil, and medium soil. In the case of building with different heights, the maximum rotation has been seen in the twelve storied buildings for soft soil support. However, the phenomena changes in fixed and hard soil. A building having a single storied of equal bays shows maximum rotation in hard soil and fixed base conditions. It has been seen that trend of responses changes in soft soil compared to other support.

Table 1 Fundamental Frequency (Hz) of buildings having changed bays on different support

	Fixed	Hard	Medium	Soft
10 bays X 10 bays	0.824	0.760	0.520	0.328
10 bays X 8 bays	0.820	0.745	0.504	0.293
10 bays X 6 bays	0.813	0.727	0.488	0.252
10 bays X 4 bays	0.799	0.704	0.397	0.207

The magnitude of fundamental frequencies with the unequal bay of nine storied buildings is shown in Table 1. It has been seen that a reduction in the number of bays, decreases the fundamental frequencies. Fundamental frequencies decrease around up to 3 % in fixed, 7% in hard soil, 23% in medium soil, and 36% in soft soil bases for comparison between 10X10 bays and 10X4 bays. It has been seen that fundamental frequencies reduce in decreasing the stiffness of supporting mediums. Minimum responses have been seen in soft soil.

Table 2 Fundamental Frequency (Hz) of buildings having changed height on different soil

Height	Fixed	Hard	Medium	Soft
12 Storied	0.603	0.564	0.385	0.253
9 Storied	0.721	0.692	0.496	0.343
6 Storied	1.276	0.887	0.840	0.659
Single Storied	2.793	2.644	2.460	1.794

Table 2 shows the fundamental frequency of buildings having different heights for different supporting conditions. It has been seen that fundamental frequency reduces with the reduction of the stiffness of soil. Maximum fundamental frequency has been seen in fixed base conditions and minimum has been seen in soft soil base. The difference in fundamental frequency between fixed base to soft soil is around 35% to 58%. Also, it has been seen that fundamental frequencies increase with the decrease in the height of the building.

Table 3 Displacement (mm) of top of building having changed bays of building on different soil

	Fixed	Hard	Medium	Soft
10 bays X 10 bays	0.128	0.915	5.146	19.360
10 bays X 8 bays	0.053	1.105	10.171	41.430
10 bays X 6 bays	0.122	1.470	15.300	59.345
10 bays X 4 bays	0.059	2.128	21.897	88.036

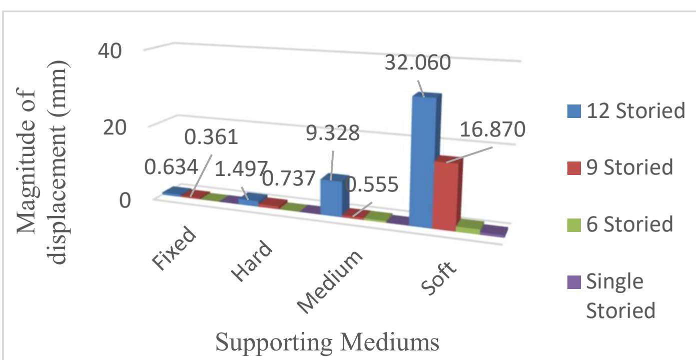


Figure3: Displacement (mm) in X direction in different height buildings

The maximum displacement of buildings having different bays has been shown in Table 3. The magnitude of displacement reduces with a decrease in the number of bays in fixed base conditions.

However, the magnitude of displacement of buildings having increasing numbers of bays decreases in different types of soil support. However, according to the stiffness of the supporting medium, displacement increases in a softer medium compared to a harder medium. The percentage change of displacement between 10X10 bays and the 10X4 bays is around 53% to 355%. Maximum displacement has been seen in soft soil conditions for buildings with 10X4 bays.Figure3 shows the maximum displacement of buildings having a change of height. Maximum displacement has been seen in soft soil base. Maximum displacement occurs in twelve storied buildings on soft soil and minimum displacement has been seen on six storied buildings on fixed bases. The percentage increase of displacement in soft soil compared to the fixed base is around 5860% to 1500 %.

Table 4 Fundamental period for unequal wings of same height building obtained from empirical expression of code and THA

Code	**Empirical Expression**	**Height of Building (m)**	**As per code Time period (Sec)**	**Time period (Sec) for any number of bays**
IS Code (1892-2016)	$T=0.075\ H^{0.75}$	27.00	0.888	0.888
ASCE 7 -10(2010)	$T=0.028\ H^{0.80}$	27.00	0.391	0.391
UBC97 (ICBO 1997)	$T=0.049\ H^{0.75}$	27.00	0.580	0.580
EC8 (ECS 2004)	$T=0.075\ H^{0.75}$	27.00	0.888	0.888
NBCC (1995)	$T=0.05\ H^{0.75}$	27.00	0.592	0.592
Time History Analysis → **Support↓**	**10 bays X 10 bays (Sec)**	**10 bays X 8 bays (Sec)**	**10 bays X 6 bays (Sec)**	**10 bays X 4 bays (Sec)**
Fixed base	1.213	1.219	1.231	1.252
Hard Soil	1.316	1.343	1.376	1.419
Medium Soil	1.925	1.984	2.165	2.516
Soft Soil	3.051	3.408	3.966	4.835

Table 4 shows the variation of the fundamental time period based on the building codes of different countries for a nine storied plan asymmetric building. Results of 10X10 bays are compared with the result of time history analysis (THA) for a varying number of bays of one wing where other wings are ten bays in different supporting conditions. In dynamic analysis, it has been seen that the fundamental period increases in accordance with the reduction of the number of bays of one wing. With the decrease in soil stiffness, the time period increases immensely. As per the empirical formula of codes, for any number of bays, the time period is the same for equal height and it is less than one for nine storied buildings. However, a huge difference has been noticed in the fundamental period for L shaped buildings having unequal bays under dynamic analysis. The variation time period between fixed base and soft soil varies from 150% to 290%. Maximum variation has been seen in L shape buildings having 10X4 bays. The magnitude of the periods is more than one in time history analysis, in most cases, it is more than the double magnitude which is derived from the empirical formula. There are no such provisions in the code where magnitude can be calculated accurately for asymmetric structures.

Table 5 Fundamental period for buildings having different heights obtained from empirical expression of code and THA

Code	**Empirical Expression**	**12 Storied (Sec)**	**9 Storied (Sec)**	**6 Storied (Sec)**	**1 Storied (Sec)**
IS Code (1892-2016)	T=0.075 H^0.75	1.102	0.888	0.655	0.171
ASCE 7 - 10(2010)	T=0.028 H^0.80	0.492	0.391	0.283	0.067
UBC97 (ICBO 1997)	T=0.049 H^0.75	0.72	0.58	0.428	0.112
EC8 (ECS 2004)	T=0.075 H^0.75	1.102	0.888	0.655	0.171
NBCC (1995)	T=0.05 H^0.75	0.735	0.592	0.437	0.114
Fundamental period from Time History Analysis					
Support	**Method**	**12 Storied (sec)**	**9 Storied (sec)**	**6 Storied (sec)**	**1 Storied (sec)**
Fixed base	THA	1.659	1.387	1.276	0.358
Hard Soil	THA	1.774	1.446	1.003	0.378
Medium Soil	THA	2.595	2.017	1.191	0.406
Soft Soil	THA	3.955	2.915	1.517	0.557

The fundamental period in various support of buildings having varying heights has shown in Table 5. Twelve stories, nine storied, six storied, and single storied buildings of equal wings with ten bays have been chosen for analysis. In the empirical formula, it has been seen that in most of the cases, fundamental frequencies are less than one except in two cases (Code of IS and EC8) of twelve storied buildings. However, in the case of dynamic analysis, the magnitude of fundamental frequencies is much higher. Huge variations were found between fixed base and soft soil. The minimum percentage deviation of the fundamental period has been seen in buildings having six storied and the maximum deviation has been seen in twelve storied buildings. The magnitude of the fundamental period varies between fixed base to soft soil around 18% to 139%, so there is a need for separate code formulas for calculating the fundamental period for hard, medium, and soft soil support of L shaped building.

5. CONCLUSION

The L shaped buildings are analyzed and the major findings are as follows:

- Base shear decreases with the reduction of the stiffness of soil.
- Rotation about the horizontal axis increases with a decrease in the number of bays of the perpendicular wing.
- The rotation varies inversely with building height and soil hardness.
- Decrease in the number of bays causes reductions of fundamental frequencies.
- Increase of stiffness of soil rises fundamental frequencies of buildings.
- Fundamental frequencies decrease with the increase of store height of buildings having equal bays.
- Increase in the number of bays of a particular wing of a building reduces the top displacement.
- The time period increases with decreasing stiffness of the soil.

However, it has been seen that the time period in the dynamic analysis is much more than the time period of the empirical formula of International codes. It is obvious that structural design based on code-based formulas may give erroneous results in most cases. So, this result will definitely help the researcher in future work.

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