Proceedings of IOE Graduate Conference, 2019-Summer
Peer Reviewed
Year: 2019 Month: May Volume: 6
ISSN: 2350-8914 (Online), 2350-8906 (Print)

A Case Study for the Influence of Earthquake Directions on the Seismic Behaviour of Plan Irregular RC Infilled School Buildings of Kathmandu Valley

Diwash Panta [a], Gokarna Bahadur Motra [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] link2diwash@gmail.com, [b] gmotra@ioe.edu.np

Abstract

Evaluation of the recent and past earthquake trends regard to the irregular buildings confirms that they are much very vulnerable under seismic action. In the contest of high seismic zone such as with the case of our country, the presence of irregular buildings increases the risk of both life and property. Increase urbanization and lack of space within the Kathmandu valley give measure rise over the irregular building type. The concern of our study relates to the horizontal irregularity of Kathmandu valley schools considering the various angle of incidence. Three dimensional infill model of rectangular and irregular L-shaped government school building was analyzed using ETABS after the accumulation of the site data. Here one rectangular school and five other plan irregular L-shaped school buildings are analyzed using Linear Time History Method considering different earthquake i.e. Kobe, Imperial Valley and Darfield earthquakes. The analysis of L-shaped school was carried out by rotating the direction of both the orthogonal components by 30 degrees for each analysis for various seismic responses such as top lateral displacement, inter story drift ratio, torsion irregularity coefficient, normalized base shear and normalized overturning. It could be concluded that the ratio of the maximum SRSS response to that of the global response for the 'L'-shaped buildings with infill wall having 3 to 4 story height with varying weights lies between 1.11 to 1.54. Here the ratio varies proportional with the time period, eccentricity of the buildings and response parameter under consideration. As well seismic evaluation of rectangular buildings with L-type concludes that the L-shaped buildings are more vulnerable than rectangular one regard to the critical responses due to re-entrant corner and the lateral torsional coupled responses with deviation of torsion irregularity coefficient from the code limit by 18 percentage.

Keywords

Horizontal irregularity, RC infilled L-shaped buildings, Linear time history, Bi-directional earthquake, Seismic angular response, ETABS

1. Introduction

Among the various natural hazards on the list, earthquake is the most unpredictable and devastating type with the loss of both life and property. Nepal lies in the boundary of Indian plate and Eurasian plate, which makes Nepal seismically active [1]. Nepal has seen many major earthquakes over past 100 years, including: Nepal-Bihar (1934), Bajhang (1966, 1980), Udayapur (1988), Gorkha (2015) etc. Many lives have been lost by these events. The Gorkha earthquake (2015) has destroyed approx of about 30,000 classrooms and 6,000 government buildings. The Vulnerability of the schools is illustrated by the 1988 Udayapur earthquake in eastern Nepal.Nine hundred and fifty school buildings were destroyed in this event, luckily during off school hours[2]. Similarly, the Gorkha earthquake too occured in off school hour which is the boon so far. Most of the buildings here are constructed without the input of trained engineer with the suitable knowledge on seismic influence. The irregularity effect in other hand increases the vulnerability of the building there by concentration of the stresses at re-entrant corner and torsional effects. The complex response of the building leads the easy failure of the buildings there by risking both the life and property.

Currently, there are about 133 L-shaped buildings and 50 other shaped plan irregular buildings and remaining are of square and rectangular type among 650 governmental schools in Kathmandu Valley. Most of the school building being irregular type and located in the high seismic zone, the effect due to seismic influence directly involves the life of the students which is psychologically more vulnerable comparative to other building type. Considering the seismic risk faced by the schools and their role in disseminating awareness, the Schoo earthquake safety program (SESP) was initiated under the Kathmandu Valley Earthquake Risk Management Project (KVERMP) in 1998 which was further extended by Nepal Society for Earthquake Technology (NSET) and others over the time in different parts of the country. The program provided opportunity for the strengthening of school buildings and their non-structural components[3]. Regard to the above contribution, many horizontal irregular buildings doesn't meet the detail seismic analysis to overcome the high seismic responses. The detail evaluation regarding the various seismic factors needs to be over-viewed so far thus the necessary further precautions could be implemented for the existing plan irregular buildings and upcoming new school buildings.

The effect of the angular excitation has not been evaluated regards to the plan irregular buildings in the context of Nepal, accordingly the various research paper has been analyzed for the study so far. L-shaped building includes two wings whose oscillation is not uniform during the seismic influence. Movement of wings during earthquake results in high shear stresses combined with the stress at re-entrant corner[4]. The earthquake motion could be considered along two horizontal and one vertical direction. Nearly all design codes suggest the simultaneous implementation of the two horizontal earthquake components[5]. Analytic formulas has been provided for the maximum response and maximum angle for linear responses[6]. Nonlinear dynamic analysis is carried out for a L-shaped building by considering earthquake directions under the interval of 30 degrees there by rotating both the orthogonal components, accordingly the considerable amount of displacement response variation has been found. The critical angle provides the variation of about 37 percentage than that of the response regard to the global direction for displacement and plastic hinge rotation. The coefficient of variation for both the responses was found to be 0.06 to 0.13 respectively[7]. The displacement response of L-shaped RC framed building with re-entrant corner having 40 percentage projection in X-direction and 50 percentage projection in Y-direction using time history analysis was carried out where the top displacement was found to be 90 percentage more than that of the global direction along the Y-direction[8]. A single story frame models with torsion balanced and torsion unbalanced type was considered. The building was bidirectionally influenced with the 39 ground motion pairs using non-linear time history method. The building undergoes various degree of in-elasticity with the fundamental time period ranges from 0.2 to 2 sec for both torsion balanced and unbalanced model types. It was found that the ratio of the maximum response to the global response was found in the range of 1.1 to 1.6[9].The five story moment resisting frame with square plan having shear walls at corners which undergoes the linear time history method with five-degree increment in the excitation angle from 0 to 90. Maximum displacement differences are calculated as 54.54 percentage and 37.14 percentage for x-y directions, respectively. The column forces exceed the normal by about 44 percentage. Also, the principal stresses are changed as 12.34 percentage[10]. The maximum response for five story building with centrally placed double T wall was compared with 100+30 rule and SRSS for global direction response accordingly variation of 25 percent was found along the member forces[11].

2. Study area and typical school buildings

Based upon the study and the presence of the plan irregular quantity within the Kathmandu Valley,L-shaped school buildings with various story and considerable re-entrant irregularity are taken for the analysis. Typical governmental school buildings within Kathmandu valley are located over the Bafal, Paropakar, Soalteemode, Chauni ,Bhimsensthan, Jayisidewol and Tripueshwor area.

One rectangular and five plan irregular L-shaped buildings with considerable re-entrant corner are taken under consideration. The school buildings under consideration ranges from 3 to 4 story numbers with varying weight. The various structural components sizes such as beam, column, masonry wall, slab etc. also varies but not in large ranges. Normal sizes of the column types are of 300mm X 300mm ,320mm X 320mm,300mm X 270mm and 320mm X 300mm whereas that of beam size ranges from 300mm X

300mm, 270mm X 270mm. The thicknesses of slab type are of 120mm and 150mm. The thicknesses of masonry are 230mm, 150mm, 110mm and 120mm. These data has been surveyed from the site whereas the data such as various grade of concrete, reinforcement,cement mortar grade, brick size etc has been carried out based upon the literature review due to unavailability of the data from the site.

Figure 1: Santi Nikunja School

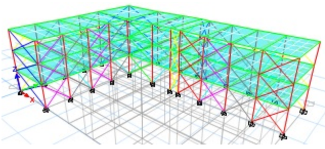

Figure 2: 3D model of Santi Nikunja School

Figure 3: Jhana Prabhat School

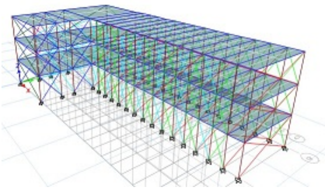

Figure 4: 3D model of Jhana Prabhat School

Figure 5: Paropakar School

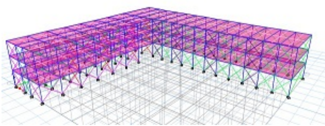

Figure 6: 3D model of Paropakar School

Figure 7: Rastriya Adharbhut School

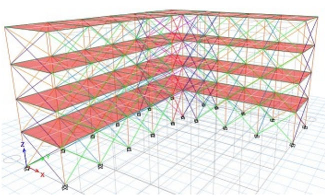

Figure 8: 3D model of Rastriya School

Figure 9: Vishwya Niketan School

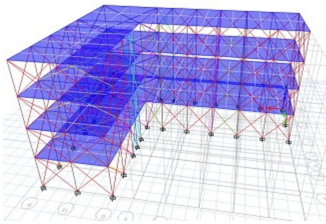

Figure 10: 3D model of Vishwya School

Figure 11: Ganodhaye School

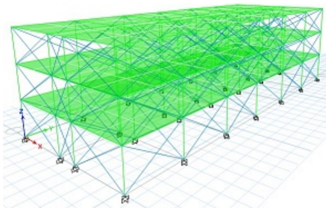

Figure 12: 3D model of Ganodhaye School

Table 1: Design Paramaters

Zone	V
Exposure	Mild
Imp. Factor	1.5
Soil type	Medium
Concrete	fck = 20 Mpa Poissons ratio = 0.2 E = 5000$sqrt fck$ MPa Shear Modulus = 9317 MPa
Steel	Fe415 E = 2.00E+8 MPa Ultimate tensile strain =0.090 Poissons ratio = 0.3 Density = 76.97 kN/m3
Masonry	1:4 Brick size =(230 X 110 X 55)mm Mortar thickness = 10mm Poissons ratio = 0.2 Brick Compressive strength= 5.6MPa E=700 * 5.6 = 3920MPa Density = 19.2 KN/m3
Loading	Floor Finish= 1.1 KN/m2 Service Live Load (LL) = 3KN/m2 Roof Load (RL) = 1.5 KN/m2 Parapet wall of 0.8 m = 4.42 KN/m Opening deducted infill wall load used

3. Methodology

The analysis of the buildings has been carried out using ETABS 2016. Here the synthetic time history has been generated using three earthquakes namely

Kobe earthquake (Japan), Imperial Valley (California, USA) and Darfield (New Zealand) with target spectrum taken as response spectrum given for the medium soil as per IS code 1893:2002. The peak input acceleration of the Kobe, Imperial and Darfield earthquake before matching was 0.203g for time period of 3.04 sec, 0.26g for time period of 0.433 sec and 0.22g for time period of 5.667 sec whereas after matching the accelerograms with the target spectrum the peak input was found to be 0.38g for 3.288 sec, 0.40g for 1.03 sec and 0.38g for time period of 5.655 sec respectively. For response evaluation of a structure, Non-linear analysis has been carried out as Non-linear dynamic analysis i.e. by using linear time history method.The linear time history analysis undergoes the solution to the dynamic equilibrium equation for the structural behavior (displacement, member forces etc.) at any arbitrary time using the dynamic properties of the structure and applied loading when a dynamic load is applied[12]. The linear time history analysis is carried out by modal superposition method and direct method.In case of modal method, the number of mode setting is important. This method is suitable for the large modal which carry out the analysis for short interval of time.In case of direct method, the time step setting is important. This method is suitable for the small modal which carry out the analysis for the long time period giving the accurate results so far[13]. Example of Darfield earthquake for the matched response spectrum with the target response spectrum as per IS code and correspondece synthetic time history has been listed in figure 13 and 14. As well the step wise procedure has been discussed below.

1. Based upon the literature review and the presence of the irregular plan school buildings in the Kathmandu valley, the quantity of the L-shaped plan irregular building was found to be maximum i.e. 133 numbers than other plan irregular buildings which lies within the range of 50. Accordingly, the five L-shaped school buildings having various re-entrant corner and one rectangular school are surveyed within the Kathmandu valley for the analysis purpose.
2. Create a model.
3. Assign the diagonal struts based upon the FEMA 273 and FEMA 356 there by consideration of the overall openings[14]. The two diagonal struts are assigned for the consideration of the both positive and negative effects into consideration there by releasing tension from the strut as strut are effective in compression so far.
4. Define load pattern like dead load, live load, floor finish etc. and assign to the frame objects.
5. Based upon the modal analysis the rebar percentage will be obtained in the frame structures.
6. The school buildings have been analyzed there by considering the 5 percent accidental eccentricity as the analysis has been carried out with the already established school buildings where design is not the acute importance which is overcome by the response under the seismic influence.
7. Since the analysis of the school buildings are to be formulated using the minimum of three earthquake based upon the FEMA, firstly the three earthquakes data which are closed to the target response spectrum based upon the IS 1893:2002 was obtained from the Peer Barkley NGA west database site. Here the data was carried out there by placement of the respective data such as the magnitude range, distance from the epicenter, fault type (normal), maximum number of records, initial scale factor (0.5) etc. Based upon the above procedure the three major earthquake which are closer to the target response spectrum was found to be Kobe earthquake (Japan), Imperial Valley earthquake (California, US) and Darfield (New Zealand) respectively.
8. Define the target response spectrum function based upon the IS 1893:2002 from Define options.
9. Define the time history function of the respective earthquake by going to define; time history function; choose function type as from file; make necessary arrangement based upon the obtained notepad data obtained from the Peer Barkley.
10. Matching of the practical earthquake response with the target response spectrum as define; time history function; function type; matched to response spectrum. Here the matching has been carried out based upon the spectral matching with time domain type. As per ASCE 7-10, the target response spectrum was considered to matched with the reference acceleration time history if the match range is within 0.2T to 1.5T where, T is the fundamental time period in sec.
11. Define the static load case and set analysis type as time history¿ linear model.

12. Since the linear analysis is under the action no consideration of the geometric and material non-linearity is carried out i.e. no consideration of the hinge and P-delta effect.

13. Arrange the load case type to acceleration; load name as U1 and U2; function as the matched time history type for the respective earthquakes; scale factor is considered as (IG/R) of EQx or EQy in case if the base shear of THx and THy are less than (IG/R) of EQx and EQy.

14. After the above arrangement the building are then rotated from 0 to 360 degree by consideration of the bi-directional earthquake influence. The arrangement will be carried out by going to advanced option of the load case type option.

15. Analysis of the maximum SRSS response to the global SRSS responses regard to the five plan irregular L-shaped school buildings regard to the responses such top displacement, inter story drift, torsional irregularity coefficient, Normalized base shear and Normalized overturning moment has been carried out.

16. The maximum SRSS response will then be compared with the rectangular building response and check with the variation in the code limit if any.

17. Particular maximum to global SRSS response ratio for the L-shaped strut buildings with three to four story height and having time period ranging from 0.3 to 0.59 sec could be analyzed along with the response of the plan irregular building with the rectangular one regard to the above five responses.

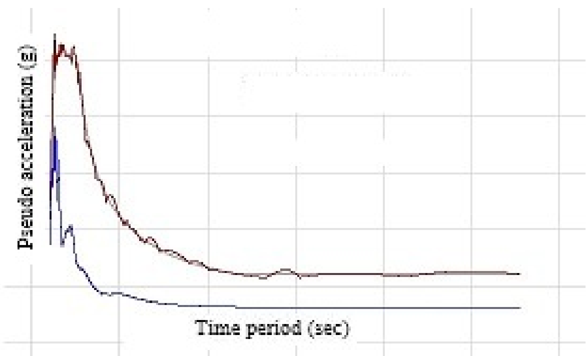

Figure 13: Response spectrum of original, matched and target spectrum for Darfield EQ

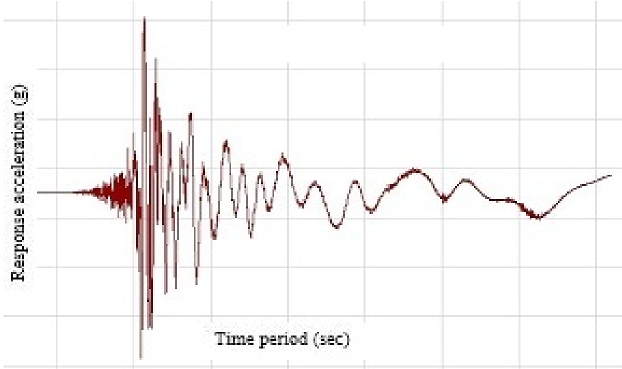

Figure 14: Synthetic time history of Darfield EQ

4. Results and Discussion

Table 2: Max. displacement response for L-shaped buildings from 0 to 180 degrees under 3 EQs

EQs	Angle	Max SRSS	Ratio X	Raio Y	Remarks
Darfield	0	10.08	1	1.23	Santi
Imperial	60	29.47	1.54	1.23	Jhana
Imperial	120	13.67	1.34	1.1	Paropakar
Imperial	120	17.31	1.25	1.09	Rastriya
Kobe	150	32.60	1.36	1.30	Vishwya

Table 3: Summary of max by global response ratio for L-shaped school buildings under 3 EQs

Model	Time	Drift	Inter story drift	Torsion coeff	Normal shear	Normal OM
Santi	0.3	1.23	1.2	1.11	1.13	1.17
Jhana	0.59	1.54	1.52	1.37	1.2	1.3
Paro	0.43	1.34	1.27	1.17	1.16	1.27
Rastria	0.39	1.25	1.22	1.13	1.16	1.25
Vishwa	0.55	1.36	1.29	1.22	1.18	1.29

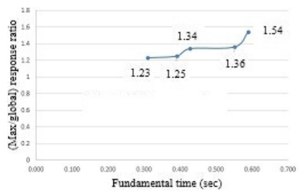

Figure 15: Variation of the max. by global response with time for displacement

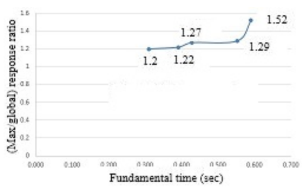

Figure 16: Variation of the max. by global response with time for inter story drift

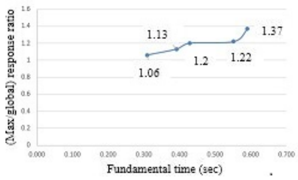

Figure 17: Variation t vs torsion coeff.

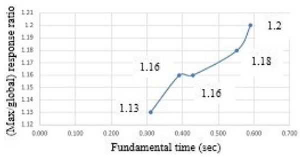

Figure 18: Variation t vs normalized base shear

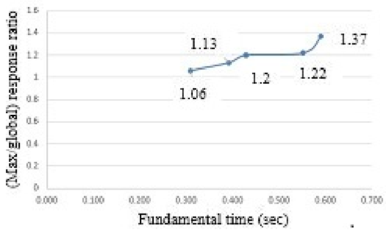

Figure 19: Variation t vs normalized overturning moment

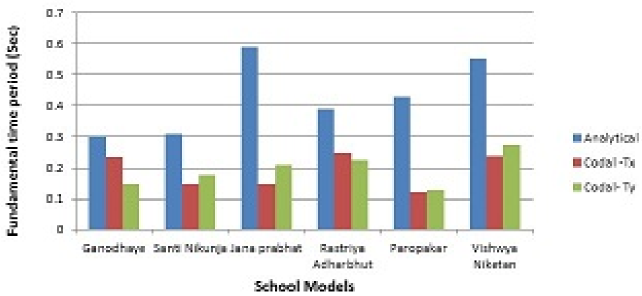

Figure 20: Variation of the analytical time period with the code along both directions

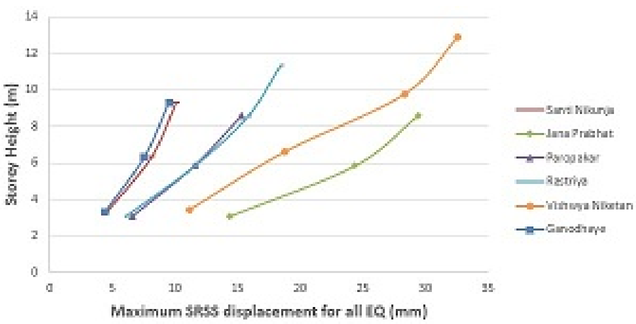

Figure 21: Comparative analysis of L-shaped with rectangular for max. SRSS displacement response

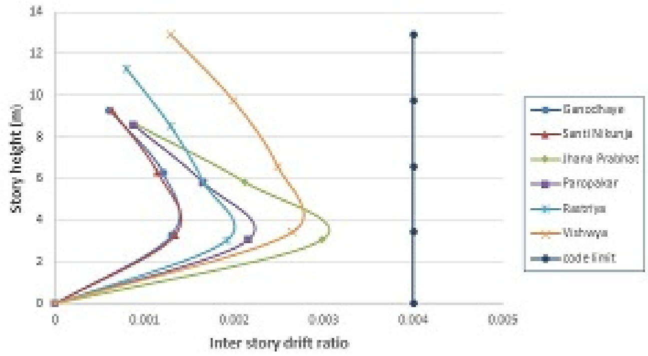

Figure 22: Comparative analysis of L-shaped with rectangular for max. SRSS inter story drift response

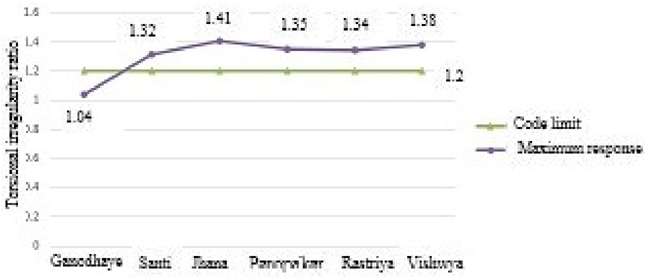

Figure 23: Comparative analysis of L-shaped with rectangular for max.SRSS torsion coefficient response

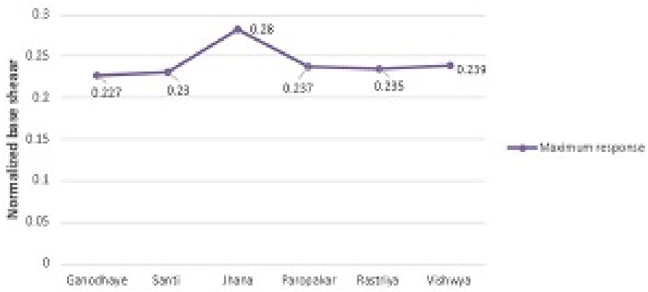

Figure 24: Comparative analysis of L-shaped with rectangular for max.SRSS normalized base response

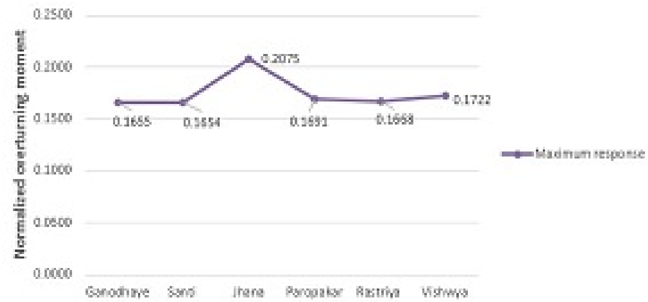

Figure 25: Comparative analysis of L-shaped with rectangular for max.SRSS normalized moment response

The analysis of the five response parameters has been carried out of which the top displacement response for the angular variation from 0 to 180 degrees for 30 degree interval has been shown by figure 15.Based upon the various table it was found that the critical angles for displacement and inter story drift response is (0, 60, 90, 120 and 150) degrees,(30, 60, 90, 120 and 150) degrees for torsion irregularity coefficient and normalized base shear whereas (0, 30, 60, 90, 120 and 150) degrees for normalized overturning moment respectively. Here the various earthquake has different angle of incidence for same building with same response parameter and same earthquake have different angle of incidence for different response quantities.

The global SRSS displacement values along the X-direction ranges from 2.88 percent to 53.99 percent with the max to global ratio from 1.03 to 1.54 and 3.34 percent to 30.35 percent along Y-direction from that of maximum SRSS values with max to gloabl ratio from 1.04 to 1.30 for three earthquakes under study for 30 degree interval.The coefficient of variation of global value with maximum ranges from 0.053 to 0.2.

The global SRSS inter story drift ratio values along the X-direction ranges from 1.91 percent to 51.68 percent with the max to global ratio from 1.02 to 1.52 and 1.16 percent to 29.45 percent along Y-direction from that of maximum SRSS values with max to gloabl ratio from 1.02 to 1.29 for three earthquakes under study for 30 degree interval.

The global SRSS torsional irregularity coefficient values along the X-direction ranges from 0.96 percent to 36.53 percent with the max to global ratio from 1.01 to 1.37 and 1.05 percent to 12.91 percent along Y-direction from that of maximum SRSS values with max to gloabl ratio from 1 to 1.13 for three earthquakes under study for 30 degree interval. The coefficient of variation of global value with maximum ranges from 0.023 to 0.124.

The global SRSS normalized base shear values along the X-direction ranges from 2.66 percent to 18.46 percent with the max to global ratio from 1.05 to 1.18 and 1.03 percent to 20.38 percent along Y-direction from that of maximum SRSS values with max to gloabl ratio from 1.01 to 1.20 for three earthquakes under study for 30 degree interval. The coefficient of variation of global value with maximum ranges from 0.037 to 0.136.

The global SRSS normalized overturning moment values along the X-direction ranges from 0.16 percent to 30.05 percent with the max to global ratio from 1.03 to 1.30 and 4.08 percent to 29.36 percent along Y-direction from that of maximum SRSS values with max to gloabl ratio from 1.04 to 1.29 for three earthquakes under study for 30 degree interval. The coefficient of variation of global value with maximum ranges from 0.038 to 0.144.

Figure 16 shows the summary of the maximum by global responses for the L-shaped school buildings where we can see that the maximum by global responses goes on increasing with the increase in fundamental time period. The graphical representation has been shown in figure 17-21. Accordingly, the ratio too goes on increasing with the increase in the resultant eccentricity of L-shaped school buildings. From this what we could see is that as the plan irregularity of the building goes on increasing there is increase in the maximum by global ratio so far.As well based upon the ratio we could categorize the L-shaped school buildings regard to the projection along X and Y direction i.e. in term of re-entrant irregularity. The school building for 3 story height (Santi Nikunja) with 78 percent projection in X and 68 percent projection in Y direction could have ratio ranging from 1.11 to 1.23, the building for 3 story height (Jhana Prabhat) with 74 percent projection in X and 50 percent in Y direction could have ratio ranging from 1.2 to 1.54, the building for 3 story height (Paropakar) with 77 percent projection in X and 75 percent in Y direction could have ratio ranging from 1.16 to 1.34, the building for 4 story height (Rastriya Adharbhut) with 72 percent projection in X and 77 percent in Y direction could have ratio ranging from 1.13 to 1.25 and the building for 4 story height (Vishwya Niketan) with 70 percent projection in X and 60 percent in Y direction could have ratio ranging from 1.18 to 1.36 respectively. Here based upon the result, the ratio somehow depends upon the response paramaters but does not varies immensely with each others.

Based upon the figre 22, the analytical time period goes on increasing with increase in irregularity. As per figure, the fundamental time period under code provisions are less than the analytical model so far as the code formula mainly depends upon the height and plan dimension where no consideration of mass and stiffness factor has been considered so far. The percentage variation range of analytical time period with code one along X-direction is found to be 30.954

to 301.086 percent and that to the Y-direction includes 75.343 to 235.514 percent. As well the maximum mode of vibration ranges from 5 to 7 for all degree of freedom except the vertical one.

Figure 23 represents the comparative analysis of the displacement response of various L-shaped critical SRSS responses with the rectangular SRSS response.The variation in CM and CR is higher in L-shaped comparative to rectangular one. Based upon the various mode of vibration results, the rectangular buildings only undergoes the translation mode of vibration whereas the L-shaped buildings undergoes the both translation and rotation i.e coupled response takes place from first or second mode with the amplification of the response accordingly the displacement of the L-shaped building rises considerably along the direction perpendicular to that of applied seismic load for various angle of incidence.It was found that the maximum SRSS displacement of the L-shaped buildings varies from 5.6 percent to 241.58 percent with that of the rectangular one for three to four story with uneven mass. Jhana Prabhat school undergoes the maximum SRSS displacement which has got larger eccentricity and time period.

As per figure 24 the inter-story drift ratio in the input direction of the seismic load increases non-linearly over the building' height and reaches its maximum value in the mid story level then decreases towards higher levels. The inter story drift ratio response increases with the growing of the building configuration irregularity from rectangular school to L-shaped schools.Here both the mass and stiffness of the column goes on decreasing with the height and reaches the optimal value at mid height and then again starts to increase. The maximum mid peak value ranges from 0.0013 for rectangular school to 0.00134 (3.277 percent), 0.00297(128.85 percent), 0.00216(66.07 percent), 0.0019(47.77 percent) and 0.0027(103.92 percent) for Santi, Jhana, Rastriya, Paropakar and Vishwya schools. The drift ratio along the perpendicular direction to the applied load becomes almost equal to the drift ratio in the direction of the input seismic load which is due to the lateral torsional coupled behavior affecting the reliability and serviceability of the buildings. Here the permissible value of 0.004 is well above the maximum SRSS demand responses.

Based upon the figure 25, the torsional irregularity coefficient goes on increasing with the increase in plan irregularity due to lateral torsional response. The torsion irregularity coefficient for rectangular building is 1 whereas the torsion coefficient exceeds the permissible limit of 1.2 for all L-shaped school buildings regard to maximum SRSS value.Thus, there is the differential deformation in the plan so far. From the analysis we could see that the torsion coefficient for the critical angle are found to be greater than that of the global one. The maximum variation of the torsional response from the limiting value rises upto 18 percent which is quite vulnerable.The torsional irregularity ratio is found to be higher for Jhana Prabhat school. Here the range of variation of the L-shaped buildings with the rectangular school ranges from 6.33 to 26.20 percent along X-direction and 17.30 to 35.58 percent along Y-direction.

Based upon the figure 26,the building with higher weight undergoes the higher base shear demand. The additional shear force developed in the perpendicular to the input earthquake direction could violates the safe design. This parameter allows the accurate comparisons between the buildings having different lumped mass and different areas.Based upon the comparison between L-shaped and rectangular building regard to the normalized base shear, the L-shaped buildings are more vulnerable than rectangular school as the normalized base shear goes on increasing with the increase in fundamental time period followed by the increase in the eccentricity.The SRSS normalized base shear of rectangular building was found to be maximum of 0.227 which goes on increasing as 0.231 (1.76 percent) for Santi Nikunja, 0.235 (3.524 percent) for Rastriya Adharbhut, 0.237 (4.40 percent) for Paropakar, 0.239 (5.286 percent) for Vishwya Niketan and 0.282 (24.22 percent) for Jhana Prabhat school. The normalized base shear is found to be higher for Jhana Prabhat school.

Based upon figure 27,the building with higher weight undergoes the higher overturning moment demand.Based upon the comparison between L-shaped and rectangular building regard to the normalized overturning moment, the L-shaped buildings are more vulnerable than rectangular school as the normalized overturning moment goes on increasing with the increase in fundamental time period followed by the increase in the eccentricity. The SRSS normalized overturning moment of rectangular building was found to be maximum of 0.1655 which is nearly equal to that of Santi Nikunja school as 0.1654 and goes on increasing from 0.1668

(0.786 percent) for Rastriya Adharbhut, 0.1691 (2.175 percent) for Paropakar, 0.1772 (7.069 percent) for Vishwya Niketan and 0.2075 (25.38 percent) for Jhana Prabhat school. The normalized base shear is found to be higher for Jhana Prabhat school.

5. Conclusion

1. The critical angle of incidence for the critical response is the uncertain parameter which depends upon the input earthquake parameters, symmetry of the buildings and various response parameters.

2. The critical angle of incidence has very large influence in the seismic demands which cannot be neglected as the maximum to global SRSS response ranges from 1.11 to 1.54 along with the coefficient of variation of global response with the maximum from 0.023 to 0.2 for the interval of 30 degrees.

3. The maximum to global SRSS response ratio for the bi-directional earthquake increases with increase in fundamental time period and eccentricity (i.e. increase in plan irregularity). Here the comparative analysis of the result for single story building and 3 to 4 story buildings has not much variation in the result i.e. the ratio does not varies much with the various response parameters.

4. The L-shaped buildings of various story and projections under the re-entrant irregularity could be characterized based upon the obtained maximum by global SRSS response as per the table which could be base point for the analysis and design purposes.

5. The maximum SRSS response regard to the inter story drift ratio lies within the permissible limit of 0.004 but that is not the case with the torsional irregularity coefficient where the maximum SRSS response deviate by about 18 percent from the code permissible limit of 1.2.

6. The analytical time period varies considerably with that of the code limit as fundamental time period of the code depends upon the height and plan dimension only but which lags the stiffness and mass parameters. Thus, design of lateral force along with the deployment of the critical response for the plan irregular buildings will give rise to harsh conditions.

7. The L-shaped schools are more vulnerable comparative to the rectangular one due to lateral torsion i.e. coupled response which leads to the amplification of the responses. As well the uneven movement of the two wings of L-shaped buildings leads to the concentration of the stresses at the re-entrant corner making them more vulnerable under critical responses. Here the vulnerability of the various L-shaped buildings as per the studied response in the descending order are Jhana Prabhat, Vishwya Niketan, Paropakar, Rastriya Adharbhut and Santi Nikunja.

References

[1] Seth Stein and Stéphane Mazzotti. *Continental Intraplate Earthquakes: Science, Hazard, and Policy Issues*. Geological Society of America. Google-Books-ID: yy0QVpE4E8wC.

[2] (7) (PDF) from the 1988 udaypur to the 2015 gorkha earthquake, nepal and beyond.

[3] (7) (PDF) earthquake risk reduction efforts in nepal.

[4] Momen M M Ahmed, Shehata E Abdel Raheem, Mohamed M Ahmed, and Aly G A Abdel-Shafy. Irregularity effects on the seismic performance of l-shaped multi-story buildigs. 44(5):24.

[5] C Cantagallo, G Camata, and E Spacone. The effect of the earthquake incidence angle on seismic demand of reinforced concrete structures. page 10.

[6] A.M. Athanatopoulou. Critical orientation of three correlated seismic components. 27(2):301–312.

[7] Sohel Ahmed Quadri. INVESTIGATION OF CRITICAL ANGLE OF SEISMIC INCIDENCE FOR THE ANALYSIS OF RCC FRAMES. 2(3):3.

[8] T.P. Prajwal, Imtiaz A Parvez, and Kiran Kamath. Nonlinear analysis of irregular buildings considering the direction of seismic waves. 4(9):9828–9832.

[9] Antonio B. Rigato and Ricardo A. Medina. Influence of angle of incidence on seismic demands for inelastic single-storey structures subjected to bi-directional ground motions. 29(10):2593–2601.

[10] Erol Kalkan, M Eeri, and Juan C Reyes. Significance of rotating ground motions on behavior of symmetric- and asymmetric-plan structures: Part 2. multi-story structures. page 21.

[11] Iván Fernandez-Davila, Silvana Cominetti, and Ernesto F Cruz. CONSIDERING THE BI-DIRECTIONAL EFFECTS AND THE SEISMIC ANGLE VARIATIONS IN BUILDING DESIGN. page 8.

[12] Anil K. Chopra. *Dynamics of structures: theory and applications to earthquake engineering*. Prentice Hall, 4th ed edition.

[13] Nikos D. Lagaros, Chara Ch. Mitropoulou, and Manolis Papadrakakis. Time history seismic analysis. In Michael Beer, Ioannis A.

Kougioumtzoglou, Edoardo Patelli, and Siu-Kui Au, editors, *Encyclopedia of Earthquake Engineering*, pages 3751–3767. Springer Berlin Heidelberg.

[14] Panagiotis G Asteris, Christis Z Chrysostomou, and Ioannis P Giannopoulos. *Masonry Infilled Reinforced Concrete Frames with Openings*. page 16.