INFLUENCE OF EARTHQUAKE INCIDENCE ANGLE ON SEISMIC RESPONSE OF IRREGULAR RC BUILDINGS

By

M. SRI KANYA *

B. D. V. CHANDRA MOHAN RAO **

** PG Scholar, Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, India.*
*** Professor, Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, India.*

ABSTRACT

Multistorey RC framed buildings, irregular in plan, often exhibit unfavorable seismic behaviour. In this study, the influence of the earthquake incidence angle on the seismic response of irregular RC framed buildings is examined. Three multistory RC buildings, One regular in plan and Two plan irregular buildings (C-shape, L-shape) are investigated for critical seismic incidence angle. For a good comparison, all the three buildings having the same floor plan area are modeled. The Linear Time History Analysis (LTHA) has been carried out for these three buildings by considering the twelve different earthquake directions and rotating the direction by 15^0 for each analysis, ranging from 0^0 to 180^0. All these three buildings are modeled using ETABS Software and are subjected to Northridge earthquake accelerogram. It is observed from the study that, the seismic behavior of these three buildings is considerably influenced by the seismic incidence angle. The various parameters observed in this study are axial forces in columns, storey drift, storey shear and maximum storey displacement. The results reveal that the direction of earthquake incidence angle considerably influences the response of multistorey RC buildings.

Keywords: Earthquake Incidence Angle, Buildings Irregular in Plan, Linear Time History Analysis, Column Axial Forces, Storey Drift / Shear / Displacement.

INTRODUCTION

Buildings having simple regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much less damage than buildings with irregular configurations. It is learnt from the past earthquakes that the multistorey buildings irregular in plan, is one of the most frequent sources of severe damage. In this study, multistory RC buildings are analyzed by Linear Time History Analysis. In this technique, the mathematical model of the building is subjected to accelerations from earthquake records that represent the expected earthquake at the base of the structure.

Three multistorey RC buildings, One regular in plan and two plan irregular models are considered in the present study. Three buildings i.e. Regular, C-shaped and L-shaped buildings are modeled in ETABS. The seismic input has been applied in 12 different directions ranging from 0^0 to 180^0 with an increment of 15^0. Three multistorey RC buildings are analyzed by Linear Time History Analysis for ground acceleration data recorded at the station Los Angeles-Baldwin hills for Northridge Earthquake occurred on January 17, 1994. The various parameters observed in this study are axial forces in columns, storey drift, storey shear and maximum storey displacement.

1. Objectives of the Study

The primary objective of this study is to investigate the influence of earthquake incidence angle on seismic response of the multi-storey RC buildings. The buildings are subjected to Northridge earthquake accelerogram in twelve directions ranging from 0^0 and 180^0 degrees, with an increment of 15^0.

The main objectives of the present study are as follows:

- To model various regular and plan irregular RC framed buildings (C-Shape, L-Shape) having same floor plan area in ETABS and to analyse using Linear Time History Analysis method of seismic analysis as per IS 1893 (Part 1) : 2002.
- To compare the dynamic response parameters like

base shear, storey drift and storey displacement of regular and plan irregular buildings by varying the shape (Regular, C and L).

- To compare the axial forces in the columns of regular and plan irregular buildings for various seismic incidence angles.
- To draw some useful conclusions regarding the behaviour of the buildings with different plan shapes when they are subjected to seismic forces.

2. Literature Review

Mahmood Hosseini and Ali Salemi (2008) carried out the Nonlinear Time History Analysis (NLTHA) on two 5-storey steel buildings with square and rectangular plan configurations using the accelerograms of two horizontal components of previously recorded earthquakes. Accelerograms used in this study are having the same PGA level and angle of excitation varies from 0^0 to 90^0 with an increment of 10^0. It was observed that column axial forces enhanced by around 50% by varying the seismic angle of excitation.

Paolo Emidio Sebastiani, Laura Liberatore, Andrea Lucchini and Fabrizio Mollaioli (2014) studied the effect of directionality on the building response by means of non-linear dynamic analyses. The seismic incidence angles are varied from 0^0 to 180^0, with an increment of 22.5^0. They observed that the equivalent linear and nonlinear two d.o.f. models are adequate to predict the most critical angle of incidence.

Antonio Bruno Rigato (2007) investigated the influence of seismic angle of incidence of the applied bi-directional ground motions on various parameters for inelastic structures. The models considered plan irregularities, various degrees of inelasticity, 5% damping ratios, and fundamental periods that ranged from 0.2 sec. to 2.0 sec. They observed that the critical seismic incidence angle is varying with the increase in degree of inelasticity.

C. Cantagallo, G. Camata and E. Spacone (2012) studied the seismic directionality effects by considering four different structures subjected to different scaled and un-scaled bi-directional ground motion records oriented along nine incidence angles, whose values are from 0^0 and 180^0, with an increment of 22.5^0.

I.-K.M. Fontara, K.G. Kostinakis and A.M. Athanatopoulou (2012) investigated the influence of orientation of the ground-motion reference axes, the seismic incidence angle and the seismic intensity level on the inelastic response of asymmetric RC buildings.

A study considering the bi-directional effects and the seismic angle variations in building design is carried out by Iván Fernandez-Davila, Silvana Cominetti and Ernesto F Cruz (2000). Different parameters such as the transverse seismic component and the variation of incidence angle of the ground motion are studied. They observed that the maximum response in any structural element due to the application of a bi-directional seismic movement with the angle of variable incidence may not coincide with any of the two principal directions of the building.

M.A. Archila and C.E. Ventura (2012) studied the effect of ground motion directionality on seismic response of tall buildings. Their work demonstrates the sensitivity of the non-linear dynamic response of tall buildings to the horizontal ground motion directionality. A 44 storey RS building located in downtown Vancouver, British Columbia, Canada is taken for the case study. Numerous Non-linear Time History Analyses were performed on the structural models considered using the recorded horizontal ground-motion orthogonal components. Their study reveals that the ground motion directionality is very important for the non-linear analysis of tall buildings and this has to be taken into account, for better seismic resistance.

SriKanya and B D V Chandra Mohan Rao (2015) studied the influence of earthquake incidence angle on the seismic response of irregular RC framed buildings (+ Shape, H-Shape).

3. Methodology

3.1 Time History Analysis

Time-History Analysis is a step-by-step analysis of the dynamic response of a structure to a specified loading that may vary with time. The analysis may be linear or nonlinear. This study describes Time-History Analysis in general, and linear time-history analysis in particular. Time - history analysis is used to determine the dynamic response of a structure to arbitrary loading. The dynamic equilibrium equations to be solved are given by:

$$K u(t) + C \dot{u}(t) + M \ddot{u}(t) = r(t) \quad (1)$$

where, K is the stiffness matrix; C is the damping matrix; M is the diagonal mass matrix; u, u&, and u&& are the displacements, velocities, and accelerations of the structure respectively; and r is the applied load. If the load includes ground acceleration, the displacements, velocities, and accelerations are relative to this ground motion.

3.2 Loading

The load, r(t), applied in a given time-history case may be an arbitrary function of space and time. It can be written as a finite sum of spatial load vectors, pi, multiplied by time functions, f i (t), as:

$$r(t) = \Sigma fi\,(t)\,pi \quad (2)$$

The program uses load patterns and/or acceleration loads to represent the spatial load vectors. The time functions can be arbitrary functions of time or periodic functions such as those produced by wind or sea wave loading.

If acceleration loads are used, the displacements, velocities, and accelerations are all measured relative to the ground. The time functions associated with the acceleration loads mx, my, and mz are the corresponding components of uniform ground acceleration, u&&gx, u&&gy, and u&&gz respectively.

4. Modeling and Analysis

In the present study, 5 storey building frame is considered for performing Time History Analysis of ground acceleration data recorded at station Los Angeles - Baldwin Hills for Northridge earthquake occurred on January 17, 1994. The same analysis is performed for the following models of buildings:

- Regular (R) Building
- C-shaped Building
- L-shaped Building

4.1 Northridge Earthquake Data

- Peak Acceleration = 234.182 cm/sec/sec at 10.40 sec
- Peak Velocity = 14.773 cm/sec at 15.68 sec
- Peak Displacement = 5.791 cm at 28.14 sec
- Hypocentre distance = 18 km

SPECIFICATION	VALUES
Live Load	4 kN/m^2
Density of RCC	25 kN/m^3
Thickness of slab	150 mm
Depth of beam	400 mm
Width of beam	230 mm
Dimensions of column	400x400mm
Density of infill	20kN/m^3
Thickness of wall	230mm
Height of each floor	3 m
Type of structure	Important service & community buildings

Table 1. General Specifications of Buildings

- Magnitude = 6.69 (Moment Magnitude Scale)
- Time Interval = 0.02 sec
- Number of Acceleration Data Points Recorded = 3001

The general specifications of the buildings are given in Table 1.

The 3D view of regular building is shown in Figure 1. Typical plan views of all buildings are shown from Figure 2 to Figure 4 and Accelerogram of Northridge Earthquake is shown in Figure 5.

5. Results and Discussion

The results of Time History Analysis in the form of maximum

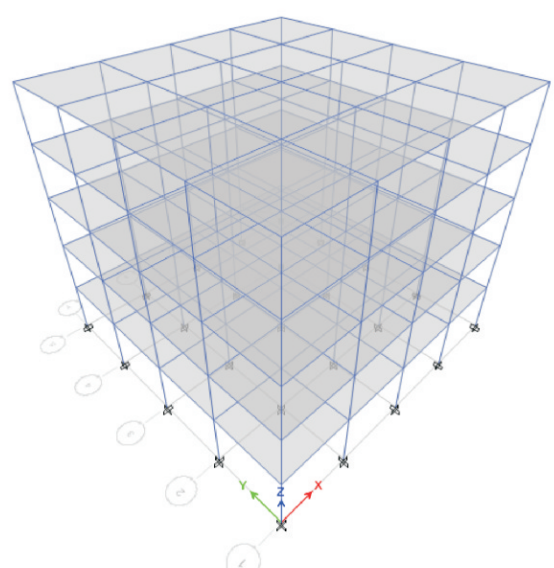

Figure 1. 3D View of Regular Building

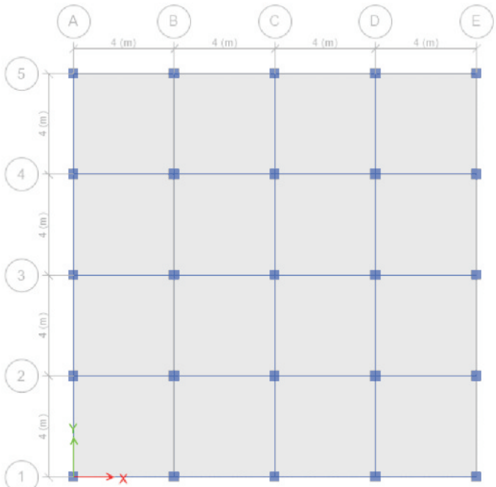

Figure 2. Plan View of Regular Building

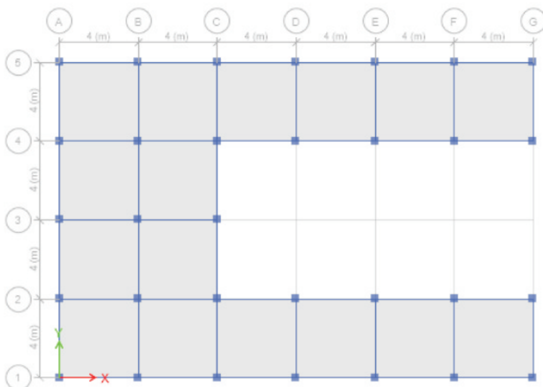

Figure 3. Plan View of C-Shape Building

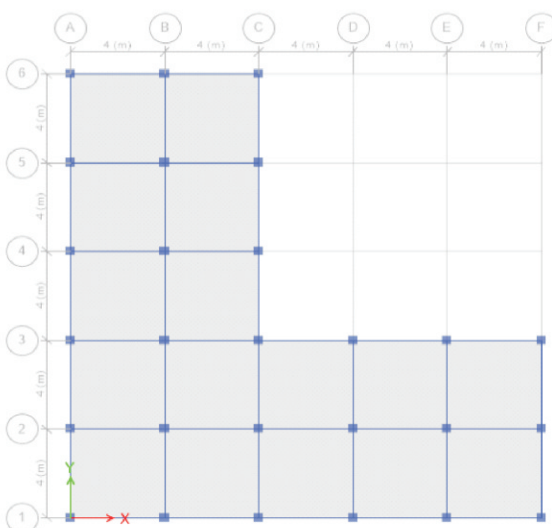

Figure 4. Plan View of L-Shape Building

column forces, maximum displacement and storey shear for all the buildings and their percentage variation with respect to regular building were studied.

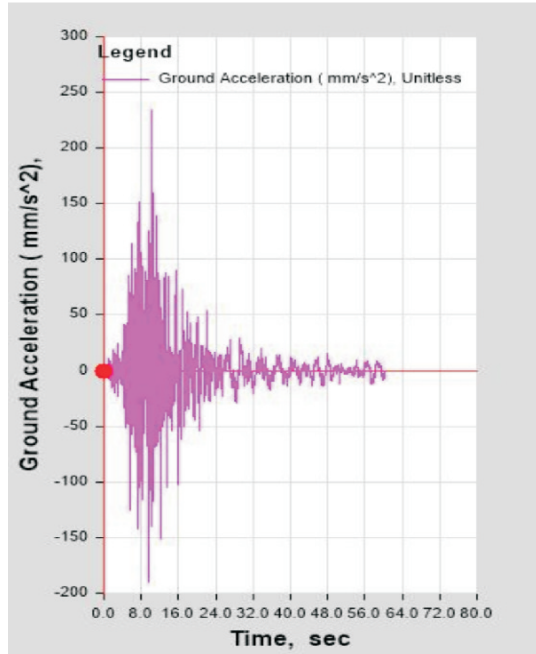

Figure 5. Accelerogram of Northridge Earthquake

5.1 Maximum Column Forces

The values of maximum column forces and the variation with incidence angle is shown in Figure 6 and Table 2.

For Regular building, the maximum column forces occurred when the peak ground acceleration is applied at 135 degrees, the value increased by 54% with respect to 0 degrees. For C shaped building, the maximum column forces have occurred when the peak ground acceleration is applied at 45 degrees, the value increased by 32% with respect to 0 degrees. For L shaped building, the maximum

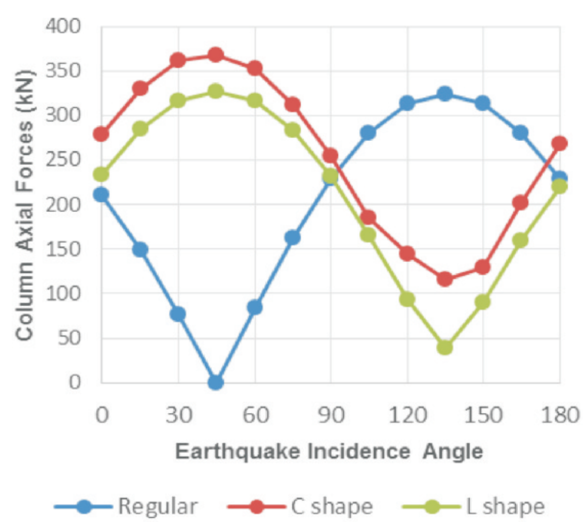

Figure 6. Column Axial Forces Variation with Incidence Angle

column forces have occurred when the peak ground acceleration is applied at 45 degrees, the value increased by 40% with respect to 0 degrees. Sri Kanya M. and Chandra Mohan Rao (2015).

5.2 Maximum Storey Displacement

The values of maximum storey displacement and the variation with incidence angle is shown in Figure 7 and Table 3.

For Regular shaped building, the maximum storey displacement occurred when the peak ground acceleration is applied at 180 degrees, the value increased by 10% with respect to 0 degrees. For C shaped building, the maximum storey displacement occurred when the peak ground acceleration is applied at 180 degrees, the value increased by 4% with respect to 0 degrees. For L shaped building, the maximum storey

Incidence Angle	Regular	% Variation	C Shape	% Variation	L Shape	% Variation
0	210		278		233	
15	149	-29	330	19	284	22
30	77	-63	361	30	316	35
45	0	-100	368	32	327	40
60	84	-60	352	27	316	35
75	162	-23	313	12	283	21
90	229	9	255	-8	232	-1
105	281	34	185	-34	165	-29
120	312	49	144	-48	93	-60
135	324	54	115	-59	38	-84
150	313	49	129	-53	89	-62
165	281	34	201	-28	159	-32
180	229	9	269	-3	220	-6

Table 2. Maximum Column Axial Forces

Incidence Angle	Regular	% Variation	C Shape	% Variation	L Shape	% Variation
0	34.8		44.1		36.9	
15	33.7	-3	42.6	-3	35.4	-4
30	30.2	-13	38.3	-13	31.6	-14
45	24.6	-29	31.4	-29	25.6	-30
60	30.2	-13	31.7	-28	31.6	-14
75	33.7	-3	35.3	-20	35.4	-4
90	34.9	0	36.6	-17	36.9	0
105	33.7	-3	35.3	-20	35.8	-3
120	30.2	-13	31.7	-28	32.4	-12
135	27.0	-22	32.6	-26	27.7	-25
150	33.1	-5	39.8	-10	33.7	-9
165	36.9	6	44.3	1	37.5	2
180	38.2	10	45.8	4	38.7	5

Table 3. Maximum Storey Displacement

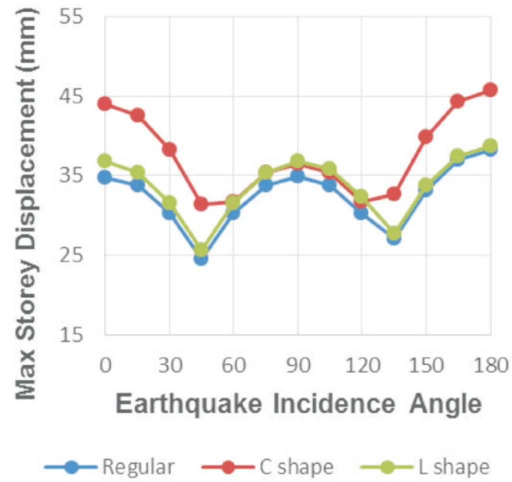

Figure 7. Maximum Storey Displacement Variation with Incidence Angle

Incidence Angle	Regular	% Variation	C Shape	% Variation	L Shape	% Variation
0	2849		3661		3003	
15	2752	-3	3537	-3	2903	-3
30	2468	-13	3171	-13	2605	-13
45	2015	-29	2589	-29	2130	-29
60	2469	-13	2721	-26	2605	-13
75	2752	-3	3035	-17	2903	-3
90	2849	0	3142	-14	3003	0
105	2752	-3	3035	-17	2898	-3
120	2468	-13	2721	-26	2596	-14
135	2015	-29	2379	-35	2117	-30
150	2353	-17	2914	-20	2555	-15
165	2624	-8	3250	-11	2852	-5
180	2717	-5	3365	-8	2954	-2

Table 4. Maximum Storey Shear

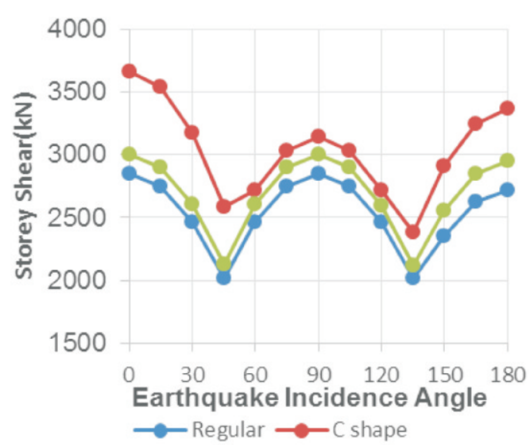

Figure 8. Maximum Storey Shear Variation with Incidence Angle

displacement occurred when the peak ground acceleration is applied at 180 degrees, the value increased by 5% with respect to 0 degrees.

5.3 Maximum Storey Shear

The values of maximum storey shear and the variation with incidence angle is shown in Figure 8 and Table 4.

For Regular shaped building, the maximum storey shear has occurred when the peak ground acceleration is applied along with principal axes (0 and 90 degrees), no percentage variation was observed with respect to 0 degrees. For C shaped building, the maximum storey shear have occurred when the peak ground acceleration is applied at 0 degrees itself. For L shaped building, the maximum storey shear has occurred when the peak ground acceleration is applied at 0 degrees itself.

Incidence Angle	Regular	% Variation	C Shape	% Variation	L Shape	% Variation
0	0.0039		0.0043		0.0041	
15	0.0037	-3	0.0042	-3	0.0039	-4
30	0.0034	-13	0.0038	-12	0.0035	-14
45	0.0027	-29	0.0031	-28	0.0028	-31
60	0.0034	-13	0.0034	-22	0.0035	-14
75	0.0037	-3	0.0038	-13	0.0039	-4
90	0.0039	0	0.0039	-10	0.0041	0
105	0.0037	-3	0.0038	-13	0.0040	-3
120	0.0034	-13	0.0034	-22	0.0036	-12
135	0.0028	-28	0.0033	-23	0.0029	-28
150	0.0034	-12	0.0040	-6	0.0035	-15
165	0.0038	-1	0.0045	4	0.0039	-5
180	0.0039	2	0.0046	7	0.0040	-2

Table 5. Maximum Storey Drift

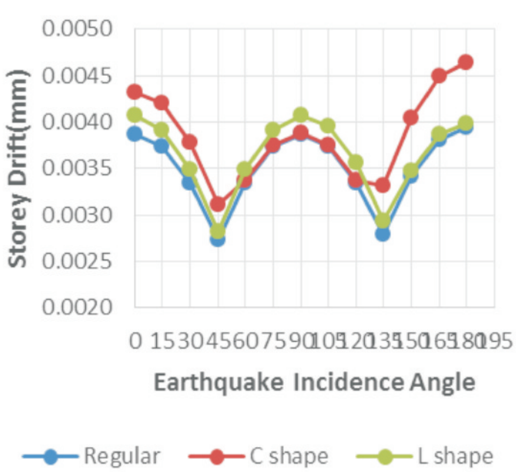

Figure 9. Maximum Storey Drift Variation with Incidence Angle

5.4 Maximum Storey Drift

The values of maximum storey drift and the variation with incidence angle is shown in Figure 9 and Table 5.

For Regular shaped building, the maximum storey drift has occurred when the peak ground acceleration is applied at 180 degrees, the value increased by 2% with respect to 0 degrees. For C shaped building, the maximum storey drift has occurred when the peak ground acceleration is applied at 180 degrees, the value increased by 7% with respect to 0 degrees. For L shaped building, the maximum storey drift has occurred when the peak ground acceleration is applied along with principal axes (0 and 90 degrees).

Conclusions

It is concluded that regular and irregular buildings have shown a considerable increase in maximum column forces when the peak ground acceleration is subjected to various incidence angles. There has been no considerable changes in maximum storey displacement, maximum storey shear and storey drift.

It is observed that the internal forces of structural elements depend on the angle of incidence of seismic wave with respect to the axes of the building plan. Among various internal forces, the axial forces of columns are more sensitive to the angle of incidence.

For regular shape building, the maximum column forces occur at an incidence angle 135 degrees whereas for C and L shape buildings, the maximum column forces occur at 45 degrees.

It can be inferred that C and L shaped building is more vulnerable to earthquakes than the regular shaped buildings.

Recommendations of the Study

The present study may be helpful to the structural engineering community while planning the buildings for better seismic resistance.

The present research work can be further extended,

- to study the unsymmetrical floor plan shapes (+, H, and T) for various earthquake incidence angles,
- to study the variation in column axial forces and beam

forces for various plan irregular buildings, and

- to study the nonlinear Time History Analysis for various plan irregular buildings.

References

[1]. **Mahmood Hosseini and Ali Salemi, (2008).** "Studying the Effect of Earthquake Excitation Angle on the Internal Forces of Steel Buildings Elements by using Non Linear Time History Analyses". *The 14th World Conference on Earthquake Engineering,* Beijing, China.

[2]. **Paolo Emidio Sebastiani, Laura Liberatore, Andrea Lucchini and Fabrizio Mollaioli, (2014).** "Simple Models to Predict the Most Critical Incidence Angle for Buildings Under Bi-Directional Near-Fault Excitations". *Second European Conference on Earthquake Engineering and Seismology,* Istanbul.

[3]. **Antonio Bruno Rigato, (2007).** "Influence of Angle of Incidence on the Seismic Demands for Inelastic Structures Subjected to Bi-Directional Ground Motions". *Engineering Structures*, Vol. 29, No. 10, pp. 2593-2601.

[4]. **C. Cantagallo, G. Camata and E. Spacone, (2012).** "The Effect of the Earthquake Incidence Angle on Seismic Demand of Reinforced Concrete Structures". *The 15th World Conference on Earthquake Engineering,* Lisoba.

[5]. **I-K.M. Fontara, K.G. Kostinakis and A.M. Athanatopoulou, (2012).** "Some Issues Related to the Inelastic Response of Buildings under Bi-Directional Excitation". *The 15th World Conference on Earthquake Engineering,* Lisoba.

[6]. **Iván Fernandez-Davila, Silvana Cominetti and Ernesto F. Cruz, (2000).** "Considering the Bi-Directional Effects and the Seismic Angle Variations in Building Design". *12th World Conference on Earthquake Engineering*.

[7]. **M.A. Archila and C.E. Ventura (2012).** "Effect of Ground Motion Directionalityon Seismic Response of Tall Buildings". *The 15th World Conference on Earthquake Engineering,* Lisoba.

[8]. **Sri Kanya M and Chandra Mohan Rao B. D. V., (2015).** "Effect of Earthquake incidence angle on Seismic performance of RC Buildings". *International Journal of Research in Engineering and Technology,* Vol. 4, No.3, pp. 156-161.

ABOUT THE AUTHORS

M. Sri Kanya is currently pursuing M.Tech. in the Department of Structural Engineering at VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India.

Dr. B D V Chandra Mohan Rao is currently working as a Professor in the Department of Civil Engineering at VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India. He has 18 years of teaching experience and his research areas include Earthquake Engineering, Finite Element Analysis and Structural Optimization.