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# SEISMIC PERFORMANCE OF RE-ENTRANT CORNER BUILDING UNDER THE DIFFERENT EARTHQUAKE DIRECTION

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*Abstract*— **In the modern area, Irregularities in building is common phenomenon. But because of increase in irregularity the structure becomes more vulnerable against the earthquake. In this study a re-entrant corner type of plan irregularity is considered. For the sake of study two G +7 R.C. frame buildings that is one regular and one plan irregular is taken satisfying the criteria given in IS 1893 (2016). Linear dynamic analysis done using Response Spectrum Analysis (RSA) and Nonlinear Dynamic Analysis done using Time history analysis (THA). For Nonlinear dynamic analysis, seven different time histories were considered and is applied in twelve different direction at an interval of 300. Linear dynamic analysis does not shows the much effect of direction of earthquake in terms of relative displacements. But in case of nonlinear dynamic analysis, the incident angle that produces increase up to 50 % in terms on relative displacements. From the analysis result it is concluded that one should go for the nonlinear dynamic analysis for the safer design of**

***Keywords— Re-entrant plan irregularity, RSA, THA, IS 1893 (2016), Earthquake direction.***

## I. INTRODUCTION

Irregularities in the building lead to the uncertainty in behaviour of the structure. Because of increase in irregularities seismic demand of increases in specific element which is insufficient in strength and ductility leads to the early collapse under strong seismic motion. Plan irregularity impart torsional effect in the building whereas vertical irregularity increases the seismic demand.

In the Athanatopoulou et.al. (2005) study the structural response was considered using the variation in the incident angle under two horizontal translational components of ground motion. Massaloni, G. et.al. (2012) considered the effects of seismic input on structural response of r.c. frame building according to Eurocode 8. Srinivas et.al. (2017) deals with study of seismic behavior of irregular plan building subjected to different ground motions of two earthquakes. Jadhav et. al. (2017) considered the effect of seismic excitation angle.In this study a re-entrant type of plan irregularity as per IS 1893 (part 1):2016 [1]. A two G + 7 building models in which one is regular and another is re-entrant type irregular building is considered. IS 875. (Part I) (1987) is used for the dead loads and IS 875. (Part II) (1987) is used for the live loads. Linear dynamic analysis (RSA) and Nonlinear dynamic analysis (THA) is carried out on the considered model using SAP 2000 software. Linear dynamic analysis is carried out according to IS 1893 (2016) and Nonlinear dynamic analysis is carried out by taking seven different time histories which is applied in twelve different direction and rotating the direction of both orthogonal components by $30^0$ for each analysis (from $0^0$ to $360^0$).The aim of the study is to consider the seismic behaviour of plan irregular building under the different earthquake direction.

## II. RESEARCH METHODOLOGY

In this study, two G + 7 buildings were considered. Figure 1(a) and 1(b) shows plan view of regular and re-entrant corner building, First building is regular type and another is re-entrant plan irregular building as per IS 1893 (part 1):2016. Interstory height between the floors is 3 m. Column of size 0.6 m X 0.6 m and beam of size 0.23 m X 0.5 m is considered in both type of buildings. Three different types of groups were considered according to their reinforcement requirement. M 25 grade of concrete and Fe 415 grade of steel is considered for the analysis. The assumed seismic data is type of soil as medium, Seismic Zone as V and damping as 5 %.Also the different type of loading considered is live load as 3 kN/$m^2$, Roof live load as 1.5 kN/$m^2$ and floor finish as 1 kN/$m^2$. Thickness of wall is taken as 230 mm having density of 20 kN/$m^3$. Each Slab is having area of 4m X 4 m.

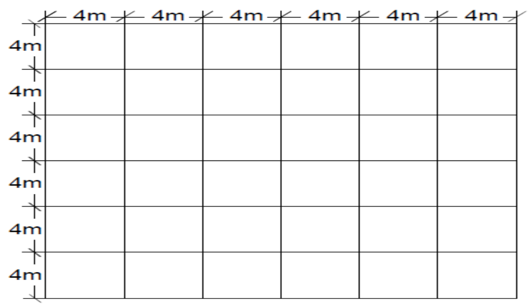

Figure 1 **(a)** Plan view of regular building

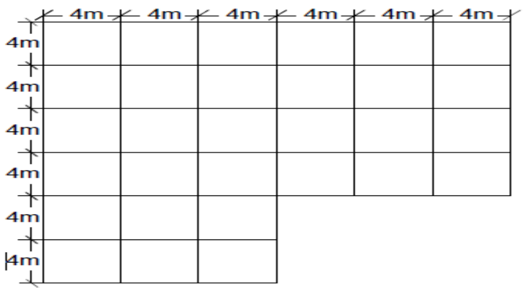


Figure 1 (b) Plan view of re-entrant corner building

## III. LINEAR DYNAMIC ANALYSIS (RSA)

Response Spectrum Analysis (RSA) is Linear Dynamic Method. The time period of the structure gives the spectral acceleration coefficient, Sa/g from Response Spectra given in IS 1893 (Part 1): 2016. Design horizontal seismic coefficient, Ah is calculated from Eq. (2) for all modes. Modal mass, Mk for the mode k is calculated as,

$$M_k = \frac{[\sum_{i=1}^{n} Wi\phi ik]^2}{g\ \sum_{i=1}^{n} Wi(\phi ik)^2} \quad \ldots\ldots\ldots (1)$$

Where, g = acceleration due to gravity, $\Phi_{ik}$ = mode shape coefficient at floor I in mode k, $W_i$ = seismic weight of floor I of the structure, n number of floors of the structure. Then, the modal participation factor, $P_k$ is calculated as,

$$P_k = \frac{[\sum_{i=1}^{n} Wi\phi ik]}{\sum_{i=1}^{n} Wi(\phi ik)^2} \quad \ldots\ldots\ldots\ldots..(2)$$

The Design lateral force at each floor in each mode is given by,

$$Q_{ik} = A_k\,\Phi_{ik}\,P_k\,W_i \quad \ldots\ldots\ldots\ldots(3)$$

The peak shear force acting on the storey i in the particular mode k is given by,

$$V_{ik} = \sum_{j=i+1}^{n} Qik \quad \ldots\ldots\ldots\ldots(4)$$

## IV. NONLINEAR DYNAMIC ANALYSIS (THA)

This method considers the nonlinear behavior of the material. Seven different time histories were considered as shown in Table 1. Figure 2 shows the scaled time histories with respect to the response spectra for V zone as per IS 1893 (2016).

Table 1 Set of earthquakes considered for the analysis.

| Earthquake | Date | Latitude | Longitude | Hypo central Distance (km) | PGA (cm/s) | PGV (cm/s) |
|---|---|---|---|---|---|---|
| Altadena | 04-10 1987 | 34.177 | -118.09 | 18.2 | 266 | -11.70 |
| Array | 15-10-1979 | 32.89 | -115.49 | 13.2 | 862 | -1.5 |
| Eureka | 21-12-1954 | 40.81 | -124.08 | 23.5 | -81.33 | 8.19 |
| Hollister | 12-08-1998 | 36.88 | -121.41 | 17 | 125 | 0.4 |
| LACC_NOR | 17-01-1994 | 34.06 | -118.42 | 23.7 | -113.2 | -8.7 |
| Loma Prieta | 18-10-1998 | 37.2 | -121.95 | 25.9 | 402 | - |
| Lucerne | 28-06-1992 | 34.56 | -116.61 | 2 | 798 | - |

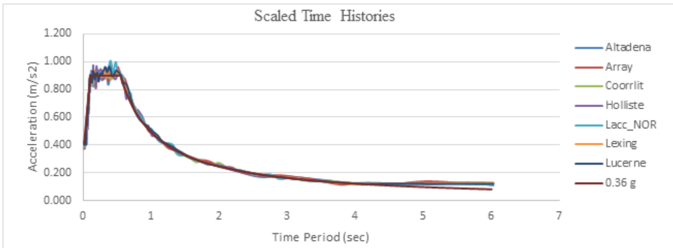


Figure 2 Scaled TH with 0.36 g response spectra

## V. RESULT

**Analysis results for Regular Building :-**

Regular building does not shows any effect of earthquake direction in any type of analysis i.e. Linear and Nonlinear dynamic analysis. It gives highest values of top floor displacement along the principal axis of the building. That means results obtained along principal axis need to be considered for the safer design of the regular building. Following Figure 3(a) and Figure 3(b) shows the values of relative displacements obtained from the linear dynamic analysis (RSA) in case of regular building at joint No.25 in both X and Y direction respectively. Figure 3(c) and Figure 3(d) shows the values of relative displacements obtained from the linear dynamic analysis (RSA) in case of regular building at joint No.74 in both X and Y direction respectively.

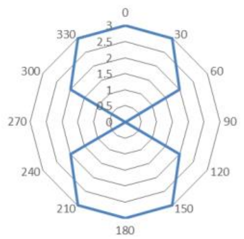

Figure 3 (a) Relative displacements at joint 25 in X direction
Obtained from RSA

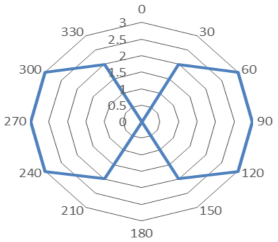


Figure 3 (b) Relative displacements at joint 25 in Y direction
Obtained from RSA

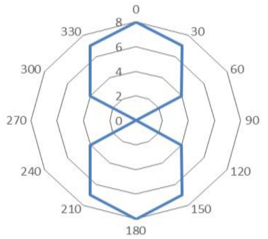


Figure 3 (c) Relative displacements at joint 74 in X direction
Obtained from RSA

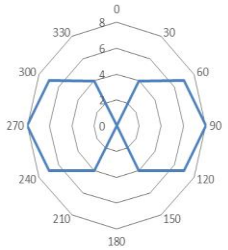


Figure 3 (d) Relative displacements at joint 74 in Y direction
Obtained from RSA

Figure 4(a) and Figure 4(b) shows the values of relative displacements obtained from the nonlinear dynamic analysis (THA) in case of regular building at joint No.25 in both X and Y direction respectively when a COORRLIT time history was applied.

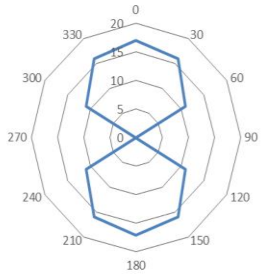


Figure 4 (a) Relative displacements at joint 25 in X direction
Obtained from COORRLIT time history

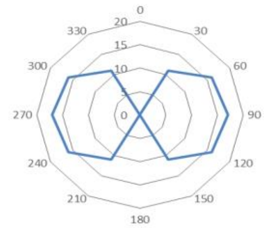


Figure 4 (b) Relative displacements at joint 25 in Y direction
Obtained from COORRLIT time history

Figure 4(c) and Figure 4(d) shows the values of relative displacements obtained from the nonlinear dynamic analysis (THA) in case of regular building at joint No.74 in both X and Y direction respectively when a COORRLIT time history was applied.

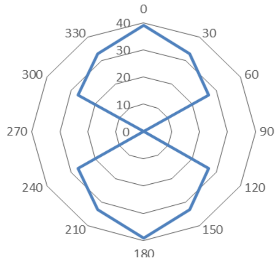


Figure 4 (c) Relative displacements at joint 74 in X direction
Obtained from COORRLIT time history

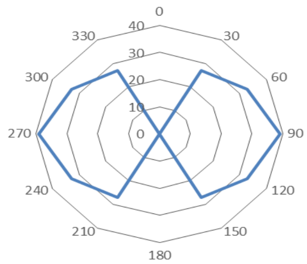


Figure 4 (d) Relative displacements at joint 74 in Y direction
Obtained from COORRLIT time history

Figure 5(a) and Figure 5(b) shows the values of relative displacements obtained from the nonlinear dynamic analysis (THA) in case of regular building at joint No.25 in both X and Y direction respectively when a LACC_NOR time history was applied.

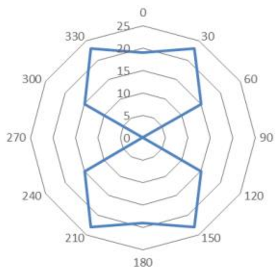


Figure 5 (a) Relative displacements at joint 25 in X direction
Obtained from LACC_NOR time history

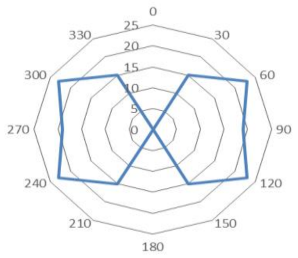


Figure 5 (b) Relative displacements at joint 25 in Y direction Obtained from LACC_NOR time history

Figure 5(c) and Figure 5(d) shows the values of relative displacements obtained from the nonlinear dynamic analysis (THA) in case of regular building at joint No.74 in both X and Y direction respectively when a LACC_NOR time history was applied.

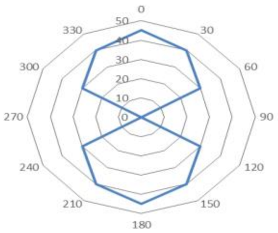


Figure 5 (c) Relative displacements at joint 74 in X direction Obtained from LACC_NOR time history

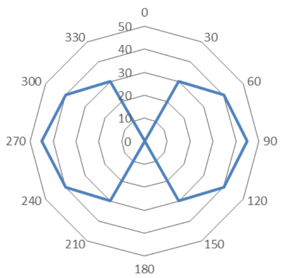


Figure 5 (d) Relative displacements at joint 74 in Y direction Obtained from LACC_NOR time history

**Analysis results for Re-entrant corner type plan irregular Building :-**

Earthquake direction effect on plan irregular building is concluded from this study. Following Table 2 shows the values of relative displacements obtained from the RSA for plan irregular building. It shows maximum results along the principal direction.

Table 2 Relative displacements at different joint number for the regular building obtained from linear dynamic analysis (RSA)

| Joint No. | Angle (Degrees) | X (mm) | Y (mm) | Joint No. | Angle (Degrees) | X (mm) | Y (mm) |
|---|---|---|---|---|---|---|---|
| | 0 | 3 | 0 | | 0 | 8 | 0 |
| | 30 | 2 | 2 | | 30 | 6 | 4 |
| | 60 | 2 | 2 | | 60 | 4 | 6 |
| | 90 | 0 | 3 | | 90 | 0 | 8 |
| | 120 | 2 | 2 | | 120 | 4 | 6 |
| | 150 | 2 | 2 | | 150 | 6 | 4 |
| | 180 | 3 | 0 | | 180 | 8 | 0 |
| 110 | 210 | 2 | 2 | 105 | 210 | 6 | 4 |
| | 240 | 2 | 2 | | 240 | 4 | 6 |
| | 270 | 0 | 3 | | 270 | 0 | 8 |
| | 300 | 2 | 2 | | 300 | 4 | 6 |
| | 330 | 2 | 2 | | 330 | 6 | 4 |
| | 360 | 3 | 0 | | 360 | 8 | 0 |

Following Tables shows the top floor displacement values obtained from the nonlinear dynamic analysis (THA) in case of plan irregular building. In both the analysis displacements of centrodal points of the floors were considered. Following Table 3 shows the variation in the considered joint displacements under the effect of COORRLIT earthquake on re-entrant corner plan irregularity.

Table 3 Percentage variation in the joint displacements at different joint number

| Joint No. | Angle (Degrees) | X (mm) | Vari. (%) | Y (mm) | Vari. (%) | Joint No. | Angle (Degrees) | X (mm) | Vari (%) | Y (mm) | Vari (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 12 | | 0 | | | 0 | 33 | | 0 | |
| | 30 | 17 | 42 | 13 | 8 | | 30 | 36 | 9 | 21 | -36 |
| | 60 | 13 | 8 | 17 | 42 | | 60 | 21 | -36 | 36 | 9 |
| | 90 | 0 | -100 | 12 | 0 | | 90 | 0 | -100 | 33 | 0 |
| | 120 | 13 | 8 | 17 | 42 | | 120 | 21 | -36 | 36 | 9 |
| | 150 | 17 | 42 | 13 | 8 | | 150 | 36 | 9 | 21 | -36 |
| 110 | 180 | 12 | 0 | 0 | -100 | 105 | 180 | 33 | 0 | 0 | -100 |
| | 210 | 0 | -100 | 13 | 8 | | 210 | 36 | 9 | 21 | -36 |
| | 240 | 13 | 8 | 17 | 42 | | 240 | 21 | -36 | 36 | 9 |
| | 270 | 17 | 42 | 12 | 0 | | 270 | 0 | -100 | 33 | 0 |
| | 300 | 12 | 0 | 17 | 42 | | 300 | 21 | -36 | 36 | 9 |
| | 330 | 0 | -100 | 13 | 8 | | 330 | 36 | 9 | 21 | -36 |
| | 360 | 12 | 0 | 0 | -100 | | 360 | 33 | 0 | 0 | -100 |

And Table 4 shows the variation in the considered joint displacements under the effect of LACC_NOR earthquake on re-entrant corner plan irregularity.

Table 4 Percentage variation in the joint displacements at different joint number.

| Joint No. | Angle (Degrees) | X (mm) | Vari. (%) | Y (mm) | Vari. (%) | Joint No. | Angle (Degrees) | X (mm) | Vari. (%) | Y (mm) | Vari .(%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 110 | 0 | 16 | | 0 | | 105 | 0 | 24 | | 0 | |
| | 30 | 17 | 6.3 | 12 | -25 | | 30 | 36 | 50 | 24 | 0 |
| | 60 | 12 | -25 | 17 | 6.3 | | 60 | 24 | 0 | 36 | 50 |
| | 90 | 0 | -100 | 16 | 0 | | 90 | 0 | -100 | 24 | 0 |
| | 120 | 12 | -25 | 17 | 6.3 | | 120 | 24 | 0 | 36 | 50 |
| | 150 | 17 | 6.3 | 12 | -25 | | 150 | 36 | 50 | 24 | 0 |
| | 180 | 16 | 0 | 0 | -100 | | 180 | 24 | 0 | 0 | -100 |
| | 210 | 17 | 6.3 | 12 | -25 | | 210 | 36 | 50 | 24 | 0 |
| | 240 | 12 | -25 | 17 | 6.3 | | 240 | 24 | 0 | 36 | 50 |
| | 270 | 0 | -100 | 16 | 0 | | 270 | 0 | -100 | 24 | 0 |
| | 300 | 12 | -25 | 17 | 6.3 | | 300 | 24 | 0 | 36 | 50 |
| | 330 | 17 | 6.3 | 12 | -25 | | 330 | 36 | 50 | 24 | 0 |
| | 360 | 16 | 0 | 0 | -100 | | 360 | 24 | 0 | 0 | -100 |

## VI. Conclusion

From the above linear dynamic (RSA) and nonlinear dynamic analysis (THA), some conclusions were made which are :

1. From the analysis result shows it is concluded that re-entrant plan irregular building is more vulnerable towards seismic impact compared to regular building in terms of top floor displacements.
2. Linear dynamic analysis does not shows the much effect of direction of earthquake in terms of relative displacements in any type of building.
3. Result shows that re-entrant corner plan irregular building shows an increase up to 42% in considered joint displacement value when the effect of COORRLIT earthquake is taken into consideration.
4. Also, same re-entrant corner building shows an increase up to 50% in considered joint displacement value when the effect of LACC_NOR earthquake is taken into consideration. But in case of nonlinear dynamic analysis the incident angle that produces increase up to 38 % in terms on relative displacements. From the analysis result it is concluded that nonlinear dynamic analysis must be done in case of any irregular building considering the effect of earthquake direction for the safe design of building.
5. Analysis of the building conclude that for the safer design of the building one should go for the nonlinear analysis of the building and must considered the influence of earthquake direction in case of any irregularity in buildings.

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