Incremental dynamic analysis of RC building with stiffness irregularity

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Abstract - *Man has no super power. Irregularity and imperfections are always associated with him. Some irregularities in structures are needed as a part of its aesthetical and functional requirements. Asymmetrical placing of infill induces stiffness irregularity. Compared to regular buildings irregular buildings are very weak. Studies and research shows that the building with stiffness irregularity attracts huge storey shear and add instability to structure. Seismic risk assessments of these types of stiffness irregular buildings are under the consideration of the project.*

This case study includes the seismic risk assessment of irregular tall RC structure of ten storeys (far fault) under the action of seismic event. Finite element model of this regular and irregular structure is to be established using software SAP2000 v. 19. 2. 0. The fragility curves for these buildings are evaluated using incremental dynamic analysis.

Key Words: Stiffness irregularity, Infill, Seismic risk assessment, Incremental dynamic analysis, Fragility curve

1. INTRODUCTION

Earthquakes are most unpredictable and devastating disaster. The behaviour of a structure under earthquakes depends on several factors such as adequate lateral strength and ductility, lateral stiffness, mass distribution, simple and regular configurations etc. Regular geometry and uniformly distributed mass and stiffness in both plan and elevation make a structure resistant to earthquake. Most recent earthquakes show that the irregular structures are prone to damage during tremors. Irregular structures are those which have non- uniform distribution of mass and stiffness and irregular geometry. Some of them were to meet the functional and architectural needs and on other hand some of them were due to improper designing and construction practices. Seismic risk assessment of a structure can be defined as its susceptibility to failure during ground motions. Fragility curve is a statistical tool for finding the probability of collapse of the structure. Results from these assessments can be used as an input for the loss mitigation during such scenario. In the revised code of IS 1893-2002, a new condition were added under the stiffness irregularity index. The clause gives emphasis on considering the infill in the seismic analysis. Studies conducted by Guido MAGENES and Stefano PAMPANIN shows that infill imparts stiffness to the structure. Irregular placing of infill walls in a structure due to some functional needs such as avoiding infill in the basement for parking lot is the best example for the stiffness irregularity.

2. Stiffness Irregularity due to Infill Irregularity

Stiffness indicates the rigidity of the structure when a load acting on it.

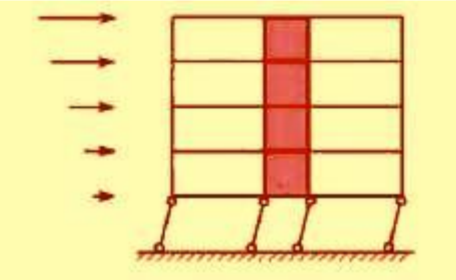

Fig-1: Stiffness Irregularity

Stiffness irregularity can be due to change in the column size in the ground floor, due to with or without infill, presence or absence of columns in any storey etc. A soft storey is one in which the lateral stiffness is less than 70 % of that in the storey above or less than 80% of the average stiffness of the three storey above. The failure starts at the point where the stiffness changes abruptly.

3. Infill Modelling

Infill was modelled as per IS 1893-2016 infill walls are modelled as equivalent diagonal strut.

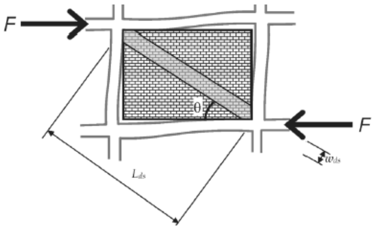

Fig-2: Equivalent Diagonal Strut (Source [2])

The width of equivalent diagonal strut without any opening is taken as equation (1).Thickness of equivalent diagonal strut shall be taken as thickness t of original infill wall, provided $h/t < 12$ and $l/t < 12$.

$$w_{ds} = 0.175\alpha_h^{-0.4} L_{ds} \qquad (1)$$

$$\alpha_h = h \sqrt[4]{\frac{E_m \, t \sin 2\theta}{4 \, E_f \, I_c h}} \qquad (2)$$

Where,

E_m and E_f = moduli of elasticity of materials of infills and RC frame

θ = angle of diagonal strut

t = thickness of infill

h = clear height of URM infill wall between top beam and bottom floor slab

l = clear length of URM infill wall between vertical RC elements.

4. Case Study Structure

RC structure which was designed as per IS 456-2000 was used for this study. The selected (G+9) RCC structure is assumed to be located in the seismic zone V with an importance factor of 1.5 for the post functional requirements as per IS 1893-2016. The all columns and beams passed the strong column weak beam concept. The infill was designed as equivalent diagonal strut as per clause 7.9 of IS 1893-2016. The building properties of the case study structures were as given in table 1. Hinges were incorporated in order to do non-linear analysis.

Table-1: Building Properties

Grade of concrete	M30
Grade of steel	Fe 415
Floor to floor height	3m
Slab thickness	150mm
Wall thickness	230mm
Column	500 x 500mm
Beam	230 x 300mm
Equivalent diagonal strut (Infill)	250 x 552mm
Live Load	3 kN/m^2

Three case study structures were modelled for the work. Type 1- fully infilled structure, Type 2- Ground floor without infill, Type 3- Ground and First floor without infill were the three case studies. The elevation and 3D view are given in figure 3, 4, 5.

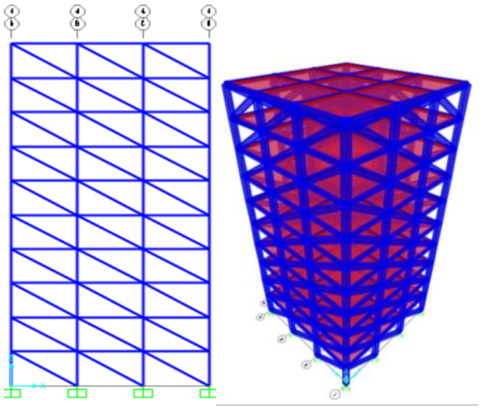

Fig- 3: Type 1 Structure

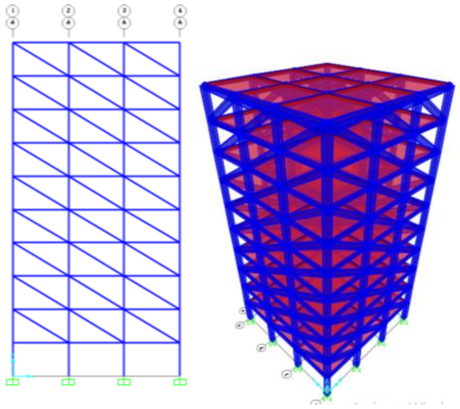

Fig- 4: Type 2 Structure

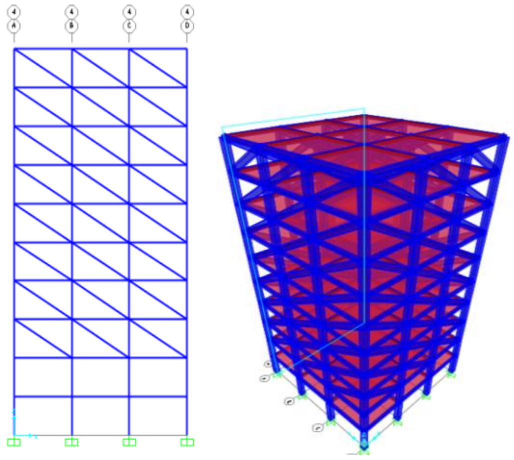

Fig- 5: Type 3 Structure

Totally 22 earthquakes were selected from "NGA strong motion record" database of Pacific Earthquake Engineering Research (PEER) center. The reliability of IDA largely depends on the number of earthquakes that chose for the analysis. According to Shome and Cornell (1999), twenty two accelerogram records are required to estimate limit state of capacity and limit state of demand of structures. Table 2 shows selected ground motions.

Table 2: Selected Ground Motions

Record Sequence Number	Earthquake Name	Magnitude
6	Imperial Valley-02	6.95
721	Superstition Hills-02	6.54
725	Superstition Hills-02	6.54
766	Loma Prieta	6.93
767	Loma Prieta	6.93
783	Loma Prieta	6.93
784	Loma Prieta	6.93
802	Loma Prieta	6.93
803	Loma Prieta	6.93
828	Cape Mendocino	7.01
848	Landers	7.28
864	Landers	7.28
900	Landers	7.28
960	Northridge-01	6.69
963	Northridge-01	6.69
987	Northridge-01	6.69
993	Northridge-01	6.69
1006	Northridge-01	6.69
1082	Northridge-01	6.69
1158	Kocaeli, Turkey	7.51
1602	Duzce, Turkey	7.14
1787	Hector Mine	7.13

5. Results and Discussion

The structure were analysed for all 22 earthquakes. The ground motions were scaled to different intensities and IDA curves were plotted.

5.1 Fundamental time period

Fundamental time period for three structures were found out. It has been found that the fundamental time period for the fully infilled structure is more than other two cases. It implies that infill imparts stiffness to the structures.

Table 3: Fundamental Time Period

Structure Type	Fundamental Time Period (sec)
Type 1	1.3864
Type 2	1.1871
Type 3	0.96

5.2 IDA Result

IDA curves were plotted for the 22 earthquakes. IDA curves were further developed into collapse fragility curve.

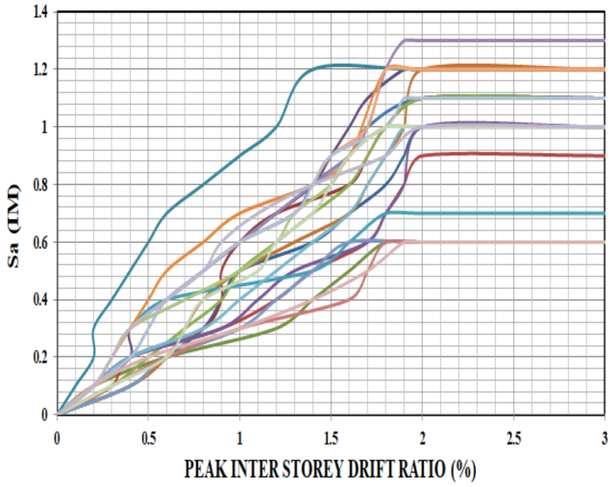

Fig- 6: IDA curve for fully Infilled Structure

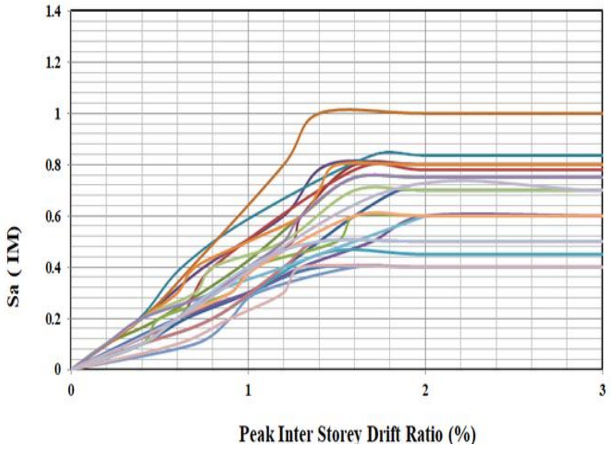

Fig- 7: IDA curve for Type 2 Structure

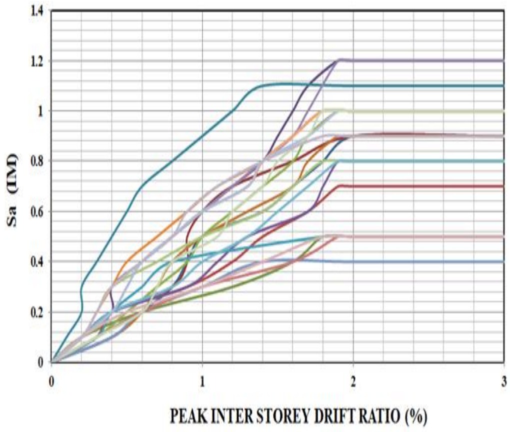

Fig- 8: IDA Curve for Type 3 Structure

5.3 Collapse Fragility Curve

Collapse fragility curve was plotted for three cases. It has been found that probability of collapse for type 3 structure is three times more than that of type 2 structures.

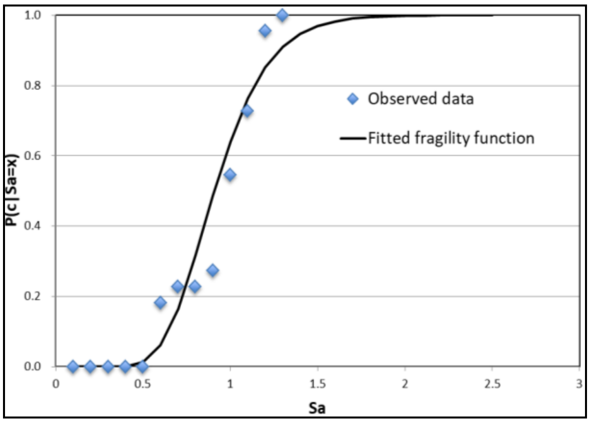

Fig- 9: Collapse Fragility Curve for Type 1 Structure

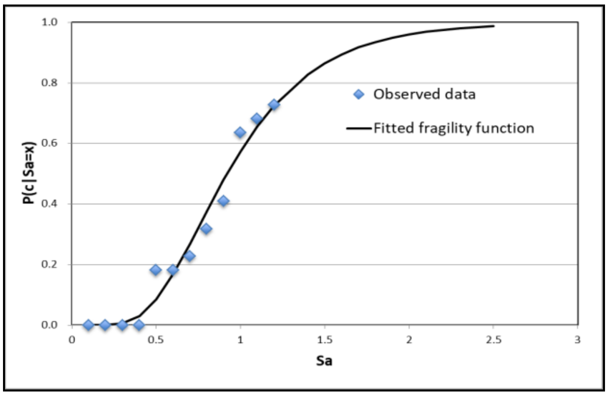

Fig- 10: Collapse Fragility Curve for Type 2 Structure

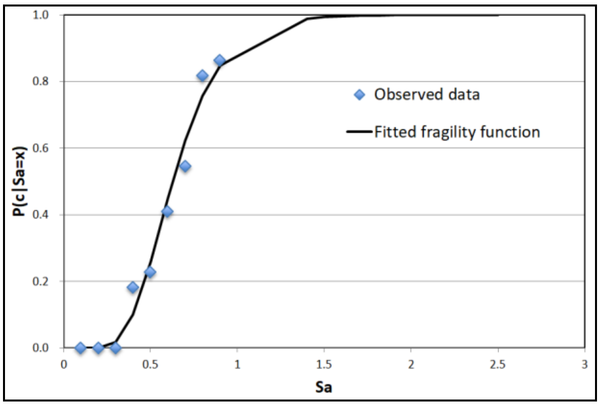

Fig- 11: Collapse Fragility Curve for Type 3 Structure

6. Conclusion

The collapse point for each case found to be very different. Results shows that as number of weak storeys increases, the collapse begins at lowest spectral acceleration

Table 3 spectral acceleration

Type	Minimum spectral acceleration of collapse (g)
Type 1	0.6
Type 2	0.5
Type 3	0.4

Results shows that corresponding to a regular structure the probability of collapse of irregular structure increase by 3 times when irregularity is only at ground floor. The probability of collapse of irregular structure can be reducing by proper techniques like base isolation, damper, bracings etc. The failure or storey drift is more at the weak storey than in any other stiffer storeys. Storey drift is the reason for failure is such structures. The peak –inter storey drift ratio is more for the irregular structures than in regular structures. From the fragility curve analysis the irregular structures shows more vulnerability toward seismic loading.

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