Fragility Assessment of GFRP Reinforced Shear Wall at Different Locations in Multi-Storied Building

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Abstract - *Multi-storied buildings are generally constructed with shear walls to withstand high lateral loads such as earthquake and wind loads. Shear wall systems provide greater strength and high stiffness to withstand heavy horizontal loads and sustain gravity loads. To construct a cost-effective and corrosion-free lateral resistant system, steel reinforcements in the shear walls are replaced with Glass Fibre Reinforced Polymer (GFRP) bars. There is more concern about the placing of shear walls in reinforced concrete buildings because it affects the seismic behaviour of the structure against the external lateral forces acting on it. The major reason for the appropriate orientation and placement of shear walls in the RC structure is to avoid the torsion generated in the building due to the eccentricity caused by the improper arrangement of shear walls. This study employs Incremental Dynamic Analysis (IDA) to assess the vulnerability of a G+7 storied building with different shear wall locations of idealised structure using seismostruct software. Fragility curves are generated using the guidelines from FEMA 58-1, which provides the probability of exceedance in different structural models. In this study modelling and analysis are done in buildings with different location of shear wall to find out the most preferable arrangement of shear wall to resist the lateral loadings and probability of collapse ratio is analysed. Ten different far field ground motion data is collected and IDA has been performed for each structural arrangement.*

Key Words: Shear wall, Lateral loads, Glass Fiber Reinforced Polymer Bars, RC Structure, Incremental dynamic analysis, Fragility

1.INTRODUCTION

Considering the current scenario, multi-storied RC buildings are constructed to withstand the lateral loads including earthquake and wind loads. RC Buildings which are constructed in seismic areas collapses due to severe earthquakes. To resist these loads vertical structural members such as shear walls can be implemented and stability of the building can be increased. These shear walls are rigid vertical diaphragm capable to sustain the combined axial, moment, and shear loads brought on by the earthquake and wind loads [16]. Now-a-days high rise buildings are most common in the construction field due to the shortage of land and many factors such as the growing population rate, increase in the cost of land, urbanisation and many more. Construction of high-rise buildings can solve all these problems, but more concern should be taken in the lateral load combinations while increasing the height of the building. Hence framed structures are constructed with shear walls which acts as vertically oriented wide beams, starts from the foundation level and extends throughout the building's height that can carry lateral loads together with the gravity loads [15]. To dissipate the earthquake loads and energies, recent advances in seismic studies has been arrived to use GFRP bars as the primary reinforcement in the seismic resistant buildings due to its inelastic deformation. These GFRP bars are used as the reinforcement material rather than traditional steel rebars because of its corrosion free property and better durability than steel bars. It can be utilized in the construction of buildings in coastal areas, bridge decks, superstructure in waterbodies etc., due to its economic benefits, better material properties and its availability. These GFRP bars has dielectric properties, high tensile strength and possess light weight characteristics [19].

In multi-storied buildings, shear walls are most important in designing process. Thus, shear wall design and construction are done with high supervision so that positioning of shear wall should be done with more accurately and efficiently. It is necessary to check the position of mass centre and hardness centre of the structure in deciding the distance of shear wall location from the mass centre of the structure for the proper shear contribution in shear wall. [15]. To obtain the seismic behaviour of RC Structure, a method known as Incremental Dynamic Analysis (IDA) has been adopted in recent researches in which one or more ground motions are chosen and modified so that they fit the different Intensity Measure (IM) using a scaling factor. Then Non-Linear Time History Analysis has been done for each Intensity Measure levels until the structure attains its structural instability and measures its level of damage [6]. Since high rise buildings shows more dynamic properties, seismic probabilistic analysis is developed using fragility curve and thus seismic vulnerability can be measured [2].

2. METHODOLOGY

2.1 Description of Building

The research has been done using an idealised G+7 storied structure with geometric properties listed in table 1. In this study shear wall has been placed in different locations to resist the lateral loadings and further fragility assessment has been done for knowing the probability of damage of the structure. Thus, the best positioning of shear wall in the structure can be obtained.

Table-1: Details of building

Sl. No	Specifications	Size
1	Plan dimensions	16.8 x 12m
2	Length in X direction	16.8m
3	Length in Z direction	12m
4	Floor to floor height	3m
5	Total height of building (G+7)	24m
6	Slab thickness	0.125m
7	Type of Structure	OMRF with SW
8	Response Reduction Factor	5
9	Importance Factor	1
10	Seismic Zone Factor	0.36
11	Time Factor	0.963
12	Grade of Concrete	M30
13	Grade of steel	Fe 415
14	Floor beam size	0.35 x 0.4m
15	Outer column size	0.45 x 0.6m
16	Inner column size	0.45 x 0.45m
17	Thickness of shear wall	0.25m
18	Rebar used in shear wall	GFRP bars
19	Rebar used for column, beam and slab	Steel

2.2 Structural Models

Different structural models have been adopted for the evaluation with different shear wall locations and it have been subjected to non-linear time history analysis for further studies. One of the models is analysed without shear wall and three of them with GFRP reinforced shear wall in different orientations in the structure which is depicted in Figure 1.

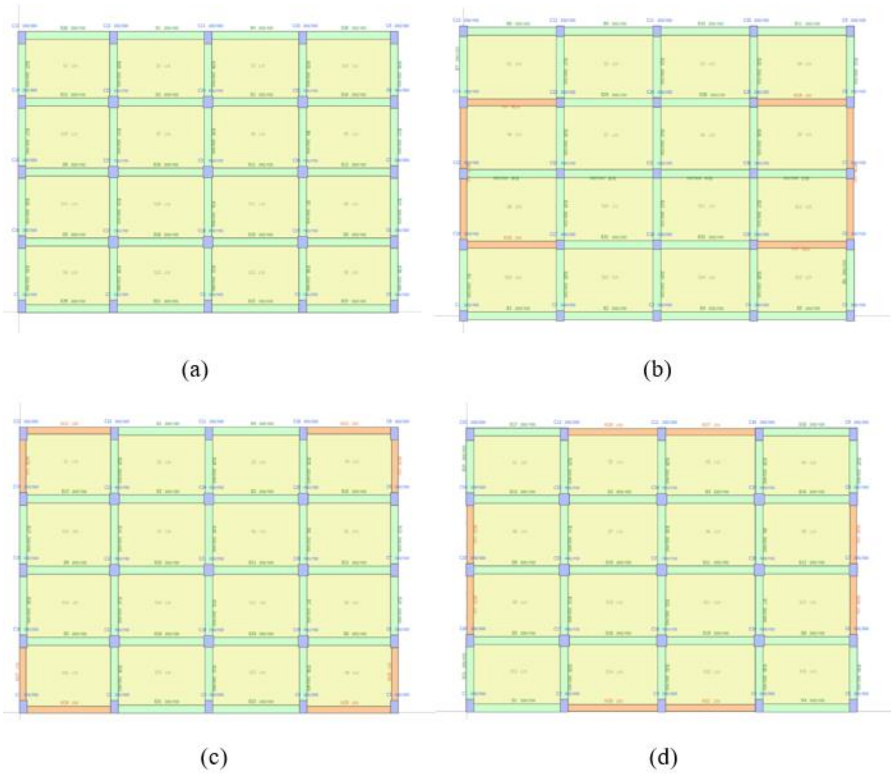


Fig-1: Plan view of building with (a) No SW (b) SW at sides and inner walls (c) SW at corners (d) SW at periphery

2.3 Incremental Dynamic Analysis

A technique for seismic analysis called incremental dynamic analysis allows for the determination of a structure's capacity as well as its demand. By utilizing the relationship between the incremental dynamic analysis and the static pushover, Vamvatsikos and Cornell [12] developed a rapid and accurate approach for determining the seismic demand as well as capability of first mode dominated multi-degree-of-freedom systems. IDA is a parametric analytic technique in seismic engineering which provide the estimates of demand measure for intensity measure statistics. The objective of IDA is the relation of response and potential level of ground motion records [3]. When conducting a comprehensive analysis that involves a wide range of earthquake data records and nonlinear time history analyses at increasing levels of intensity and this IDA involves performing numerous nonlinear time history analyses, systematically scaling ground motions to progressively higher earthquake intensities, and recording the structural response until collapse initiates in the structure. This analysis generates a dispersed set of data points at different seismic intensities, which can be used to determine collapse fragility using a lognormal distribution.

2.3.1 Selection of Ground Motion

Ten records of far field ground motion data have been obtained from PEER next generation attenuation (NGA) database. Table 2 presents the information of the ground motion considered for the study. This includes specifics such as the date and magnitude of the earthquake event, the recording station, the peak ground acceleration (PGA).

Table-2: Properties of selected ground motions

Designation	Magnitude	Year	Name	Recording station	PGA (g)
EQ1	6.9	1995	Kobe, Japan	Shin-Osaka	0.224
EQ2	6.19	1966	Parkfield	Shandon Array #12	0.051
EQ3	6.69	1997	Northridge	Canyon Country	0.402
EQ4	6.19	1966	Parkfield	Shandon Array #5	0.121
EQ5	6.95	1940	Imperial Valley	El Centro Array #9	0.281
EQ6	7.28	1992	Landers, California	Yermo Fire Station	0.244
EQ7	7.28	1992	Landers, California	Lucerne	0.652
EQ8	7.51	1999	Kocaeli, Turkey	Duzce	0.310
EQ9	7.62	1999	Chi-Chi	TCU045	0.473
EQ10	6.5	1976	Fruili	Tolmezzo	0.327

2.3.2 Scaling Factors

The peak ground acceleration (PGA) is selected in such a way that it should increase uniformly and would result in the initiation in collapse of the structure. For the Incremental Dynamic Analysis, scale factors are calculated using the required PGA and with the PGA of selected earthquakes as shown in Table 3. For the seismic analysis 0.1g has been selected as the increment to arrive the PGA which ranges from 0.1g to 1.0g.

Table -3: Scale factors of selected ground motions

Ground Motion	Scaling Factors									
	0.1g	0.2g	0.3g	0.4g	0.5g	0.6g	0.7g	0.8g	0.9g	1.0g
EQ1	0.446	0.893	1.339	1.786	2.232	2.679	3.125	3.571	4.018	4.464
EQ2	1.957	3.914	5.871	7.828	9.785	11.742	13.699	15.656	17.613	19.569
EQ3	0.249	0.298	0.746	0.995	1.244	1.493	1.741	1.990	2.239	2.488
EQ4	0.826	1.653	2.679	3.309	4.132	4.959	5.785	6.612	7.438	8.264
EQ5	0.356	0.712	1.068	1.423	1.779	2.137	2.491	2.847	3.203	3.559
EQ6	0.410	0.820	1.230	1.639	2.049	2.459	2.869	3.279	3.689	4.098
EQ7	0.153	0.307	0.460	0.613	0.767	0.920	1.074	1.227	1.380	1.534
EQ8	0.323	0.645	0.968	1.290	1.613	1.935	2.258	2.581	2.903	3.226
EQ9	0.211	0.423	0.634	0.846	1.057	1.268	1.480	1.691	1.903	2.114
EQ10	0.306	0.612	0.917	1.223	1.529	1.835	2.141	2.446	2.753	3.058

2.4 Fragility Assessment

The likelihood of attaining a specific conditional degradation state of a structure is termed as fragility. Some of the factors, like spectral acceleration (Sa), peak ground velocity, peak ground acceleration and spectral displacement are used to express the fragility of a structure. Fragility theory dictates that fragility curves for all the models have been analysed in this study and the vulnerability and probability of damage is assessed. When evaluating the probabilistic damage to a structure's seismic safety, as demonstrated by Equation (1), it is important to take into account the failure probability of each individual structure [11].

$$F_i(D) = \emptyset\left(\frac{\ln\left(\frac{D}{\theta_i}\right)}{\beta_i}\right) \quad (1)$$

Where, Ø is the standard normal cumulative distribution function, θ is the median value of this probability distribution and βi is the dispersion of the data.

3. RESULTS AND DISCUSSION

3.1 Eigen Value Analysis

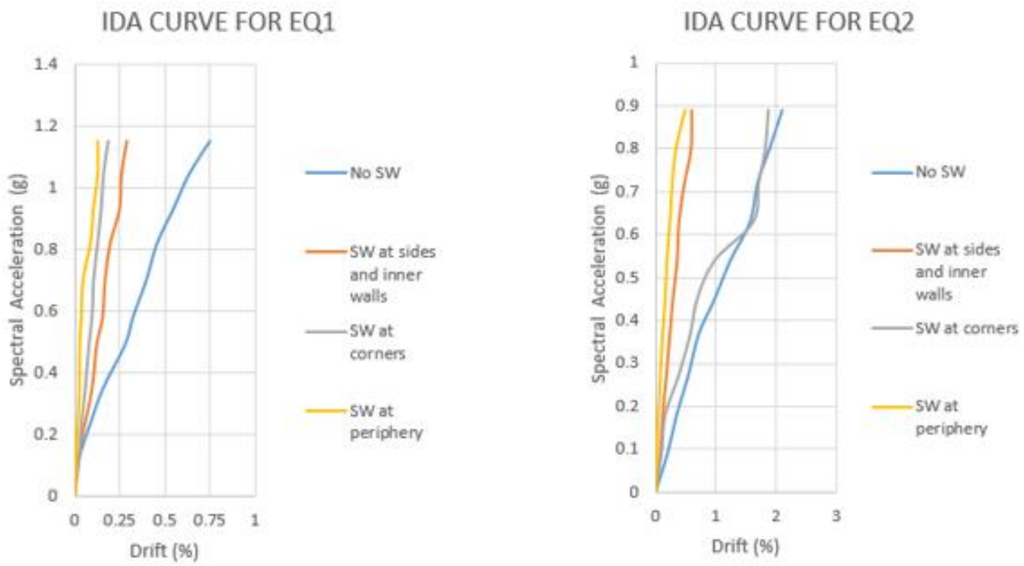
The Eigen value analysis is done to obtain the first modal time period as well as the natural frequencies of first five modes of the proposed structures for the further analysis and studies. Table 4 given below shows the natural frequencies obtained for first five modes for the specified structure.

Table-4: Natural Frequencies of building models

Type of Structure	Natural Frequencies				
	1	2	3	4	5
No SW	0.283	0.623	0.987	1.987	2.365
SW at sides and inner wall	0.301	0.325	1.026	2.258	2.985
SW at corners	0.258	0.266	1.124	1.369	1.985
SW at periphery	0.217	0.219	0.807	1.023	1.242

3.2 IDA Curve

The ground motions selected for the analysis are scaled such that the PGA of each earthquake ranges from 0.1g to1.0g. The structures are subjected to each of the scaled ground motion in one dimension along the shear wall's direction. As a result, each structure has undergone 100 dynamic time history analyses, and response for each of the ground motion with particular peak ground acceleration has been obtained. The spectral acceleration (Sa) of the structure at 5% damping is selected as the intensity metric for the evaluation. Drift (%) is considered as the damage measure which is obtained from the analysis for each intensity measure. IDA curve is generated by plotting Intensity measure vs Damage measure. Figure 2 shows the IDA curve obtained after the analysis for each of the structures.



(a) (b)

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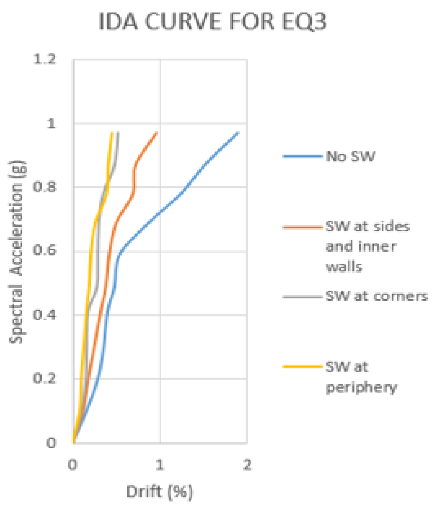

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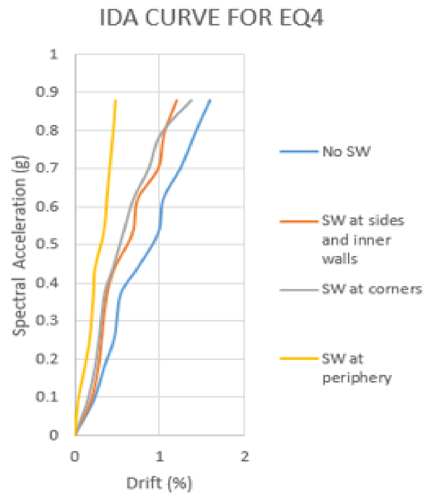

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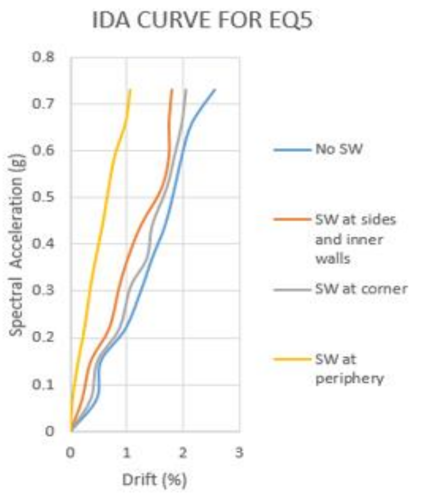

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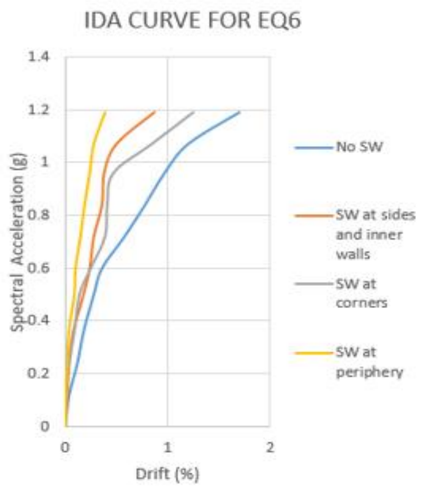

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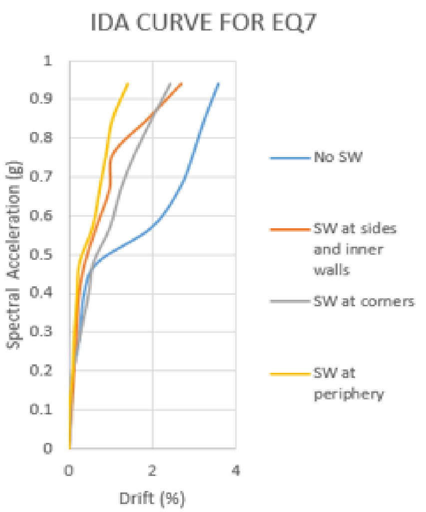

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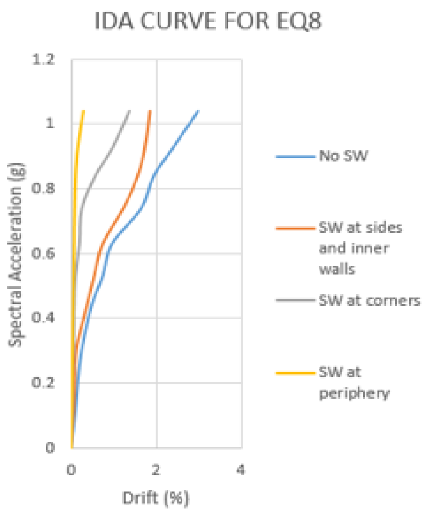

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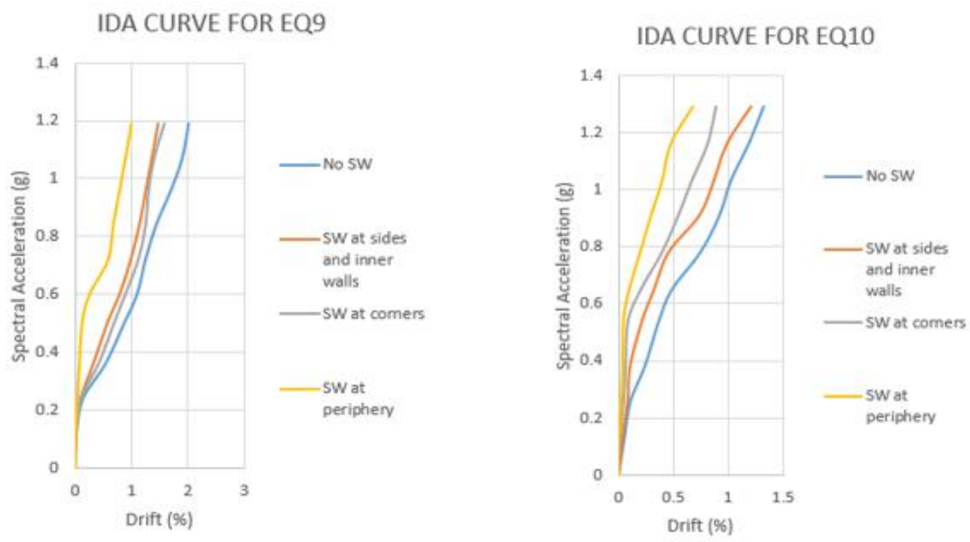

(i) (j)

Fig-2: IDA Curve for ground motions

3.3 Fragility Analysis

The likelihood of exceeding a limit state under a specific ground motion intensity is provided by the fragility curve. In this study probability of collapse is calculated from the lognormal distribution function along with the spectral acceleration (Sa) to obtain the fragility curves for all types of structure shown in Figure 3. As a function of the selected ground motion intensity, the expected degree of damage, specifically Collapse Prevention (CP), is represented by the fragility curve that is produced from the IDA curve. The collapse fragility curve shows that the Sa (spectral acceleration) of the ground motion on the x-axis is related to the probability of collapse (shown in the y-axis) [28].

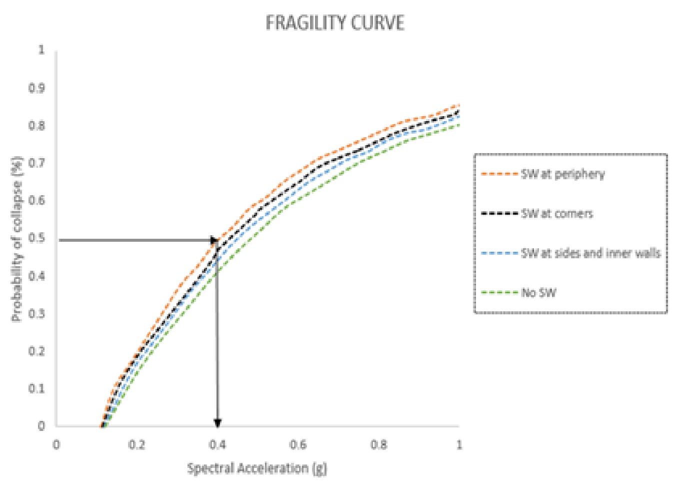

Fig-3: Fragility curve obtained for each model

4. CONCLUSIONS

The study's primary aim was to develop a fragility curve for a structure with various locations of GFRP-reinforced shear walls by performing incremental dynamic analysis (IDA) using ten far-field ground motions. The study assessed the probability of collapse for these structures and identified the optimal shear wall location for multi-storied buildings. The analysis concluded that factors such as drift percentage, spectral acceleration at a specific period, maximum base shear, and maximum peak interstorey drift angles significantly influence the optimal location of the shear wall. Fragility analysis revealed that structures with shear walls positioned on the perimeter demonstrated superior performance against lateral loads, reducing the likelihood of collapse and structural deformations. These findings align with the current investigation's observations, indicating that drift percentages determined through IDA analysis can effectively identify the best location for GFRP-reinforced shear walls.

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