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Study Of Seismic Performance of Asymmetric RCC Building Through Different Angle of Earthquake Incident

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Abstract: Damage to the structure is initiated through the weak plan of the structure and these weak plans exist in the structure due to irregularities. Structural irregularities are induced in the structure due to irregular distribution of mass and stiffness in horizontal or vertical direction which in turn causes the torsional irregularities or plan irregularities. Complex shape (plan irregular) buildings do not have the predefined principal plan axis as regular structures may have and it is not predefined that lateral load acts along the principal plan axis as there is uncertainty in the location of the epicentre. Vertical geometric irregular buildings are also having stiffness, mass, and torsional irregularity. Study shows that torsional irregular buildings are sensitive to the different angle of earthquake incident. Therefore, not only Horizontal (plan) irregular buildings but also some vertical irregular buildings having the setback are vulnerable to different angles of earthquake incidents. The present study evaluates the plan irregular structure under the different angles of earthquake incidents. For seismic analysis of the structure, the Response spectra method using IS 1893:2016 and linear time history analysis is used to derive the Engineering demand parameters. For linear time history analysis far-fault and near-fault ground motion data is selected for the seismic analysis. Results indicate that structures with eccentricity in both directions (Torsional coupled) are more sensitive to the different directions of earthquake incidents. There is a significant increase in the responses of the building model was reported in a particular angle of earthquake incident.

Keywords: Angle of incident, Plan irregularity, eccentricity, Response spectrum analysis, Time history analysis.

I. INTRODUCTION

Structures are generally having irregularities due to aesthetic, functional, different constraints at the planning level, irregularly distributed mass or stiffness, and complex geometry. Irregular structures are more susceptible to earthquake damage than regular one therefore different country codes are defining the limits for different kinds of irregularities. In general, irregularities of structures are classified in plan (horizontal) and elevation (vertical). Table 1 shows the different types of vertical and horizontal irregularities as mentioned in the IS 1893:2016 code.

TABLE I TYPES OF IRREGULARITIES

Vertical Irregularities	Horizontal Irregularities
Stiffness Irregularities	Torsional irregularities
Mass Irregularities	Re-entrant Corner
Strength Irregularities	Opening in slab
Floating Column	Non-parallel lateral load system
In Plan Discontinuity	Out of plane offsets

Although there are many types of irregularities defined in different codes, there are mainly three types of irregulates 1) Mass Irregularities 2) Stiffness Irregularities 3) Torsional Irregularities. All other irregularities are a combination of these three irregularities.

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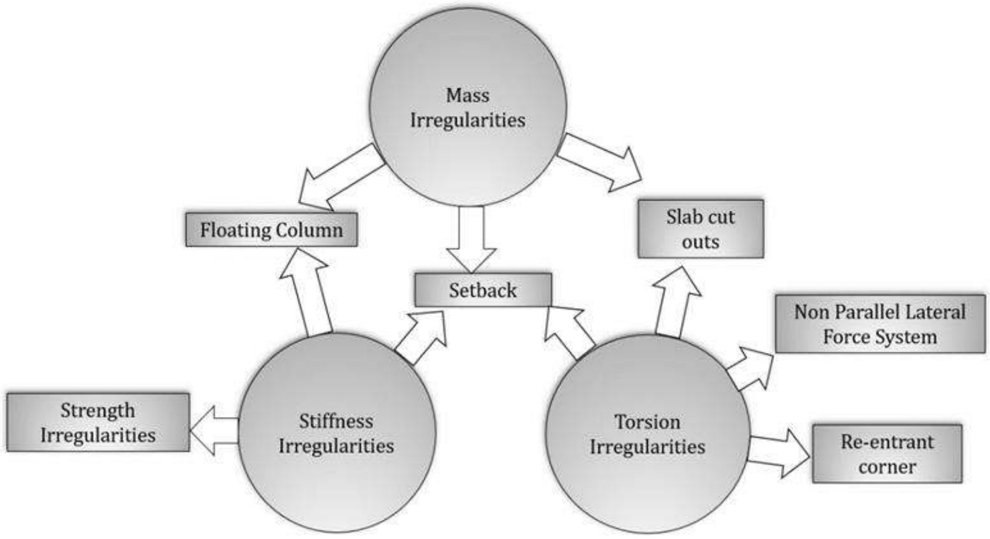

Figure 1 Grouping of Irregularities

The asymmetric building having torsional irregularities causes severe damage to the structures. Torsional irregularities are generally caused by plan irregularities. Some of the vertical irregularities such as Vertical geometric irregularities (setback), asymmetric distribution of mass, and stiffness can also induce the eccentricity in structure. Fig has shown the reasons for the torsional irregularities which are given in IS 1893:2016.

Torsional Irregularities are generally caused due to the emergence of eccentricity between the centre of mass and centre of rigidity which is in turn caused by the uneven distribution of mass or stiffness in the Horizontal direction. Structures with vertical geometric irregularities (Setback) can have all three types of irregularities (mass, stiffness, torsion). These irregularities generally cause the coupled lateral-torsional responses since the centre of mass and centre of stiffness do not coincide in this type of irregular building due to the asymmetrical distribution of mass and stiffness.

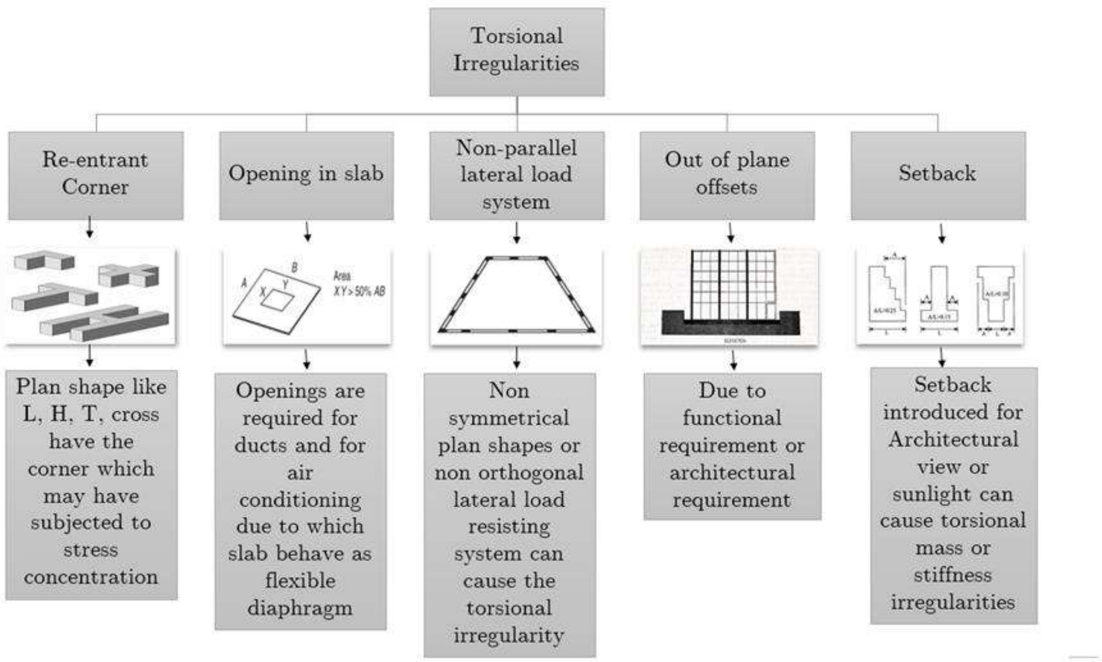

Figure 2 Different Types of Torsional Irregularities

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Such asymmetrical building if subjected to ground motion in the x-direction, its motion would not be restricted to only in translational direction but its moves in two horizontal directions (x & y) and torsion about the z-axis. A study shows that a small amount of eccentricity can cause substantial torsional responses. Torsional coupled behaviour of building under the earthquake can increase the translational displacement of edge vertical element by about 50% in case of large eccentricity [2]. This behaviour is predominant when uncoupled translational and torsional natural frequencies are closer. That is the reason which IS code 1893:2016 [1] defines the limits for the torsional irregularities and discourages the occurrence of torsional mode as the first two fundamental modes. Buildings with complex plan shapes always have eccentricities in both or one principal plan direction, therefore, their behaviour is mostly governed by the torsional displacement and it can cause the stress concentration at the re-entrant corner due to unusual mode of oscillation.

Problems with building with complex plan shapes:

1) Undesirable mode of oscillation: Torsional mode, Diagonal mode, Dog tail wagging, opening-closing mode. Torsional mode and Diagonal mode are undesirable for the seismic performance of the building. particularly dog tail wagging and opening-closing mode cause the stress concentration at the re-entrant corner [3]

2) Direction of earthquake incident: Typical rectangular buildings have the two-principal axis in their plan and it is easily definable. Ground motion can act along any angle in the horizontal direction and different angles of earthquake incidents can yield different responses. In the case of complex buildings having the column's diagonal parallel or at some angle to one of the principal axes, could be under-designed as force will be divided into two directions. Buildings having different plan shapes or complex 3D shapes can also have the angle at which engineering demand parameters are maximum.

Therefore, such complex-shaped buildings are analysed under the different angles of earthquake incidents using response spectra or time history analysis. The use of different angles in analysing the stage can be exhausting. Therefore, IS code 1893:2016 has the two methods to account for the above reason to increase the design force in the member. 30% rule & Square root of the sum of square (SRSS). According to the code, the SRSS method could be uneconomical to design the building.

100%/30% rule	SRSS
a) $\pm EL_X \pm 0.3\, EL_Y$, and b) $\pm 0.3\, EL_X \pm EL_Y$,	$EL = \sqrt{(EL_X)^2 + (EL_Y)^2}$

Figure 3 Combination Rules

SRSS method results are not dependent on the user-defined principal plan axis and result in equal member strength in all directions. But the results of 100/40 or 100/30 rules are dependent on the different angles of a user-defined axis [4]. The numerical results obtained in one of the study leads to the conclusion that the current codes' combination rules are conservative (particularly for buildings of greater significance) since a safe value of =0.20 0.25 (20%, 25% rules) looks suitable for structures with normal load carrying systems [5]. The seismic responses are underestimated by 25% in comparison to the "precise" response using the 30 percent and square root methods for asymmetrical building [6]. The problem is earthquake responses are dependent on the angle of the earthquake incident hence it depends upon the angle of the principal plan axis and the study shows that irregular buildings are more sensitive to the angle of the principal plan axis. The study also shows that buildings with torsional irregularities are generally more sensitive to the angle of earthquake incidents [7],[8]. Most of the torsional irregularities are induced due to plan or horizontal irregularities in the structures, therefore, they need to study this topic.

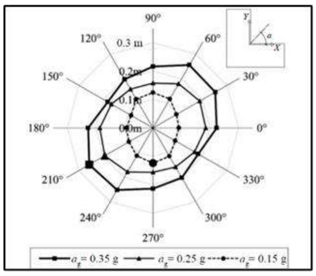

Figure 4 Displacement of structure under the different angle of earthquake incident [9]

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Various Study had prepared graphs of different engineering demand parameters vs incident angle and prepared radial graphs. One example of a radial graph is shown in the figure 1.3 [9]. This figure shows the displacement of plan-irregular buildings from a different angle of earthquake incident for different ground motion intensity. Displacement is shown in radial directions.

II. NUMERICAL STUDY

For the present study, the structural model adopted is a structure with 5 stories with a plan area of 405 m2 with 4.5 m bay in x and y direction with Different plan shape (L, T, U, plus). While adopting these configurations, similarities in the form of area of plan and weight of the building is maintained for comparison of Engineering design parameters. And then 6 different RCC buildings with shear wall models are prepared and analysed in structural analysis and design tool ETABS. Shear wall thickness adopted for analysis is 150mm and locations of the shear wall is shifted for to induce eccentricity. Structures are analysed by Response spectrum analysis and Linear (modal) Time History analysis. The sectional properties and loads & seismic factors are given in table-2.1 & table-2.2.

TABLE II SECTIONAL PROPERTIES OF MODEL

SECTIONAL PROPERTIES	
Size of Beam	250mm X 400mm,
Size of Column	450mm X 450mm,
Shear Wall thickness	150mm
Slab thickness	120mm
Grade of concrete	M25
Grade of Steel	Fe415

TABLE III LOADS AND SEISMIC FACTORS OF MODELS

LOADS AND SEISMIC FACTORS	
Dead Load	1 kN/m^2
Live Load	3 kN/m^2
Wall Load	14.03 kN/m
Parapet Wall Load	4.6 kN/m
Seismic Zone	V
Seismic Coefficient (zone factor)	0.36
Response Reduction factor	5
Importance Factor	1
Soil Conditions	Soft

For Time History Analysis 3 near-fault and 3 far-fault ground motions are used for analysis. For Selection of ground motion, different ground motion parameters are there. Ground motion parameters are very important for describing the important characteristics of ground motion which represent the similarities and dissimilarities among the ground motion which can be occurred in the future. Many parameters for describing the amplitude, frequency content, and duration of strong ground motions have been proposed; some of the researchers describe only one of the parameters and some may define two or three. Because of the complexity of earthquake ground motions, identification of a single parameter that accurately describes all-important ground motion characteristics is regarded as impossible [10],[11]. In present study, selected parameters are based on study of Kalkan and Chopra [12].

1. Magnitude
2. Acceleration
3. R_{rup} (Closest distance from the recording station to rapture plane), R_{jb} (Joyner boore distance)
4. V_{s30} (Shear wave velocity)

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➢ Ground motion data extracted from PEER Strong Ground Motion Databases. Here unscaled ground motion is used as the directionality effects generated by the scaled spectrum-compatible records are in general lower than those acquired by the un-scaled records [13].

TABLE IV NEAR FAULT GROUND MOTION DATA

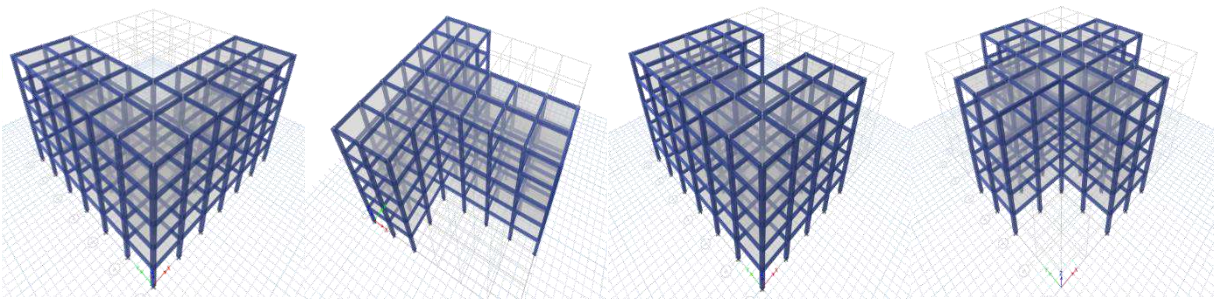
RSN	no	Event name	PGA (g)	Mag	V_{s30} (m/s)	R_{jb} (km)	R_{rup} (km)
716	1	Whittier Narrows-02	0.21	5.3	379.43	4.42	12
230	2	Mammoth Lakes-01	0.44	6.06	382.5	1.1	6.63
406	3	Coalinga-05	0.52	5.77	286.41	7.02	10.78

TABLE V FAR-FAULT GROUND MOTION DATA

RSN	no	Event name	PGA (g)	Mag	V_{s30} (m/s)	R_{jb} (km)	R_{rup} (km)
166	1	Imperial Valley-06	0.128	6.53	336.49	49.1	50.1
984	2	Northridge-01	0.208	6.69	301	36.39	41.17
322	3	Coalinga-01	0.288	6.36	274.73	23.78	24.02

For Response spectrum Analysis, IS 1893:2016 code is used. As per code, minimum eccentricity is static eccentricity plus 0.05 times the width across the plan is also induced in the modelling. For consideration of eccentricity in Dynamic analysis in particularly ETABS, mass source is modified in such a way that centre of mass shift position by certain percentage. Then nonlinear case is defined using this mass source and again it is utilized in modal case for consideration of eccentricity. These modal results are utilized in the dynamic time history analysis. This procedure of considering dynamic eccentricity is given at the CSI website [14].

❖ Prepared Models
  ➢ Different Plan shape RCC buildings



(a) (b) (c) (d)

Figure 5 (a) L shape (b) T shape (c) U shape (d) plus shape

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➢ RCC Buildings with Shear-wall models

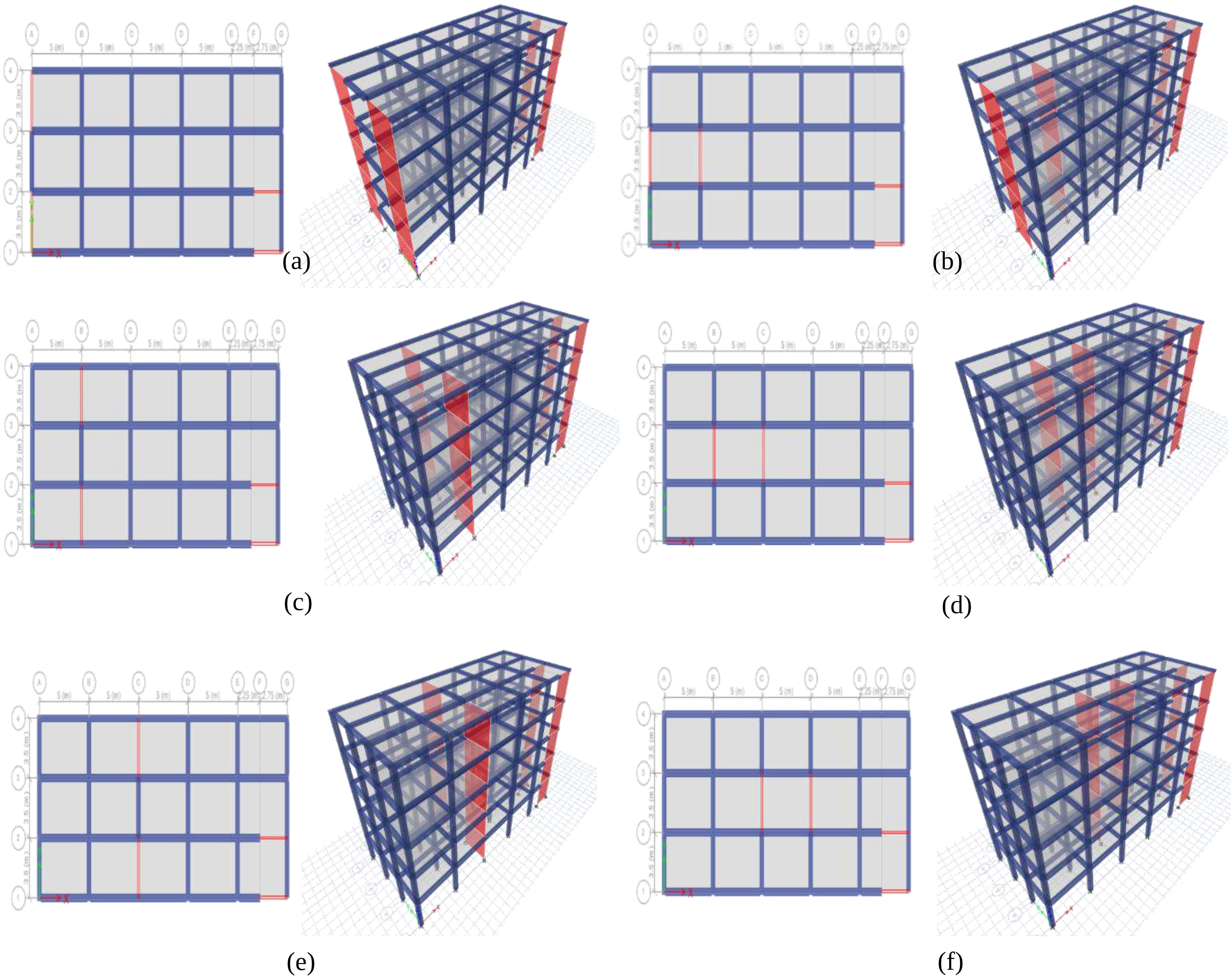

Figure 6 (a) Model 1 (b) Model 2 (c) Model 3 (d) Model 4 (e) Model 5 (f) Model 6

III. RESULT AND DISCUSSION

A. DIFFERENT PLAN SHAPE (L, T, U, Plus) RESULTS

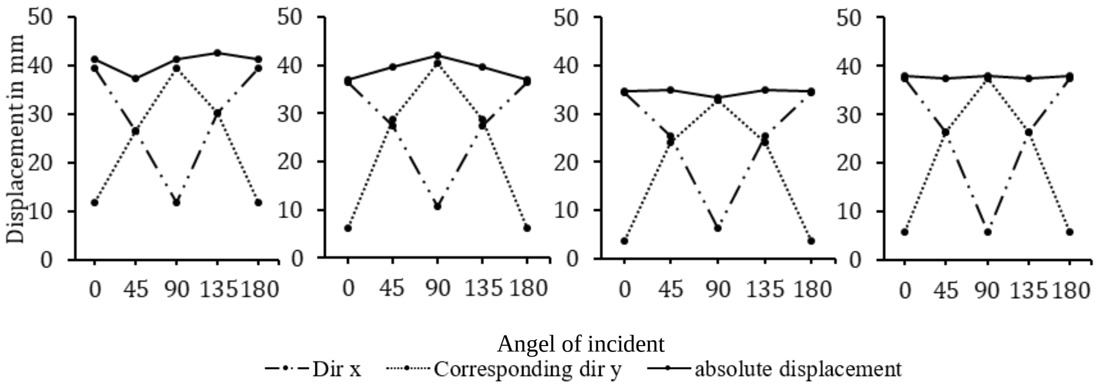

Figure 7 (a) L shape Response spectra Top storey displacement (a) T shape Response spectra displacement (a) U shape Response spectra displacement (a) plus shape Response spectra displacement

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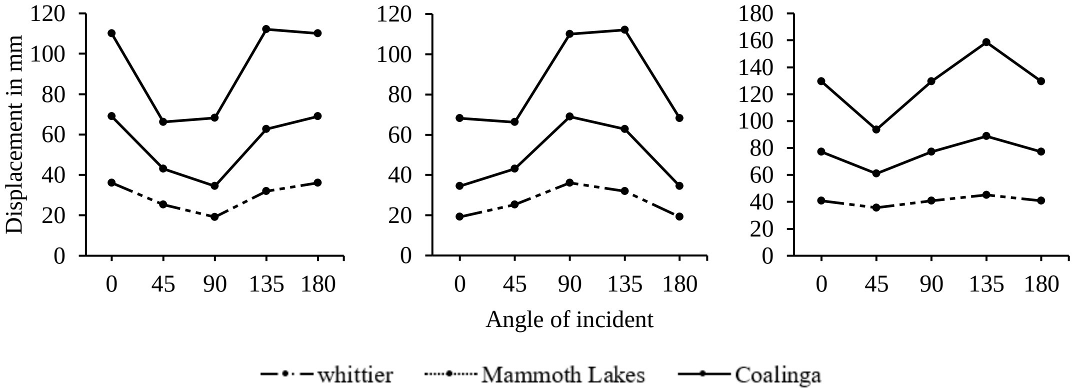
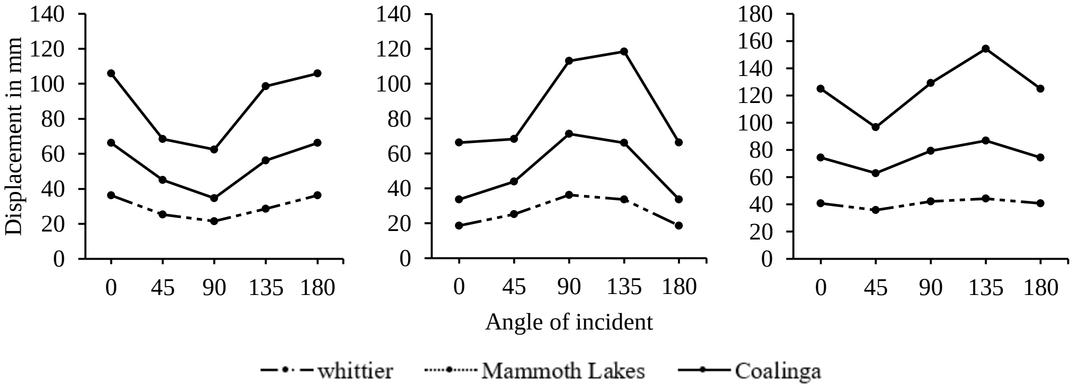


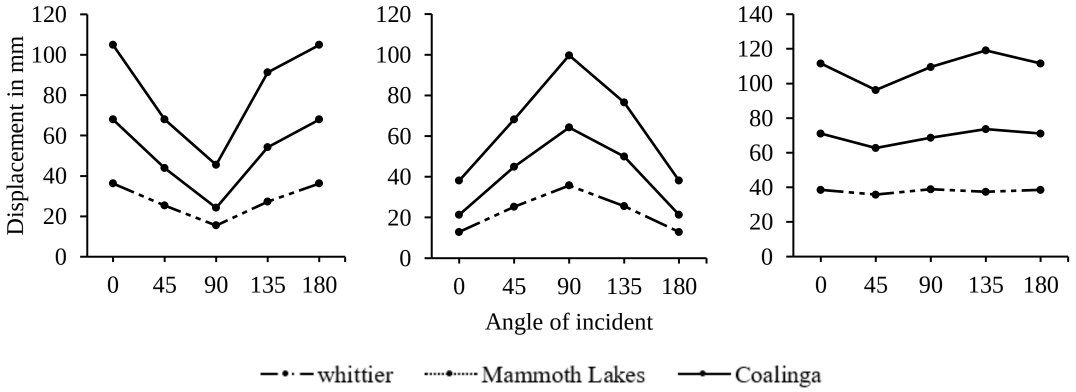
(a) (b) (c)

Figure 8 L shape Near fault Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)



(a) (b) (c)

Figure 9 T shape Near fault Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)



(a) (b) (c)

Figure 10 U shape Near fault Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)

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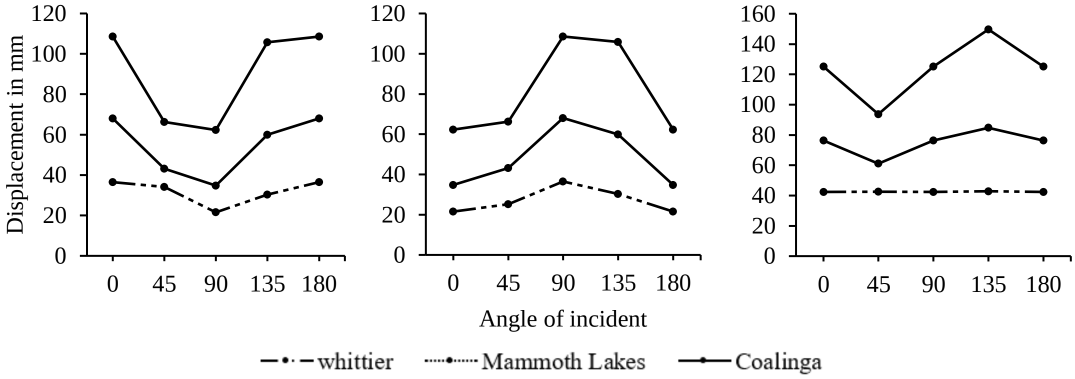
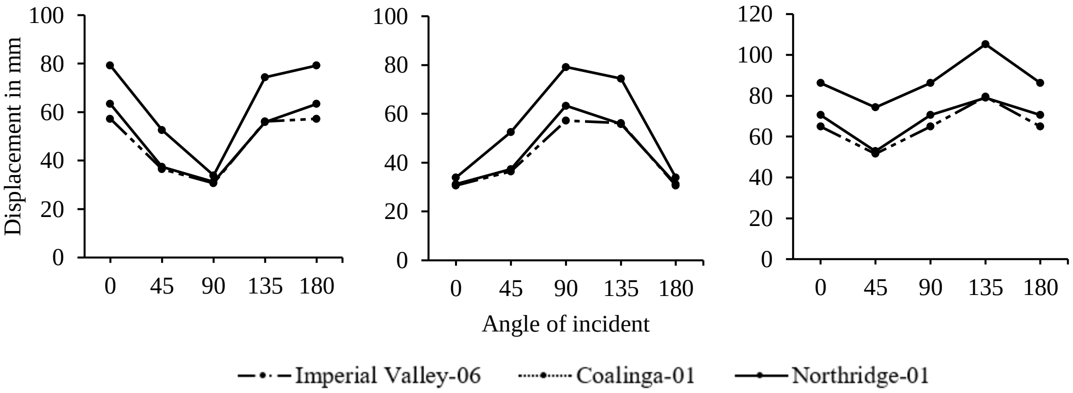


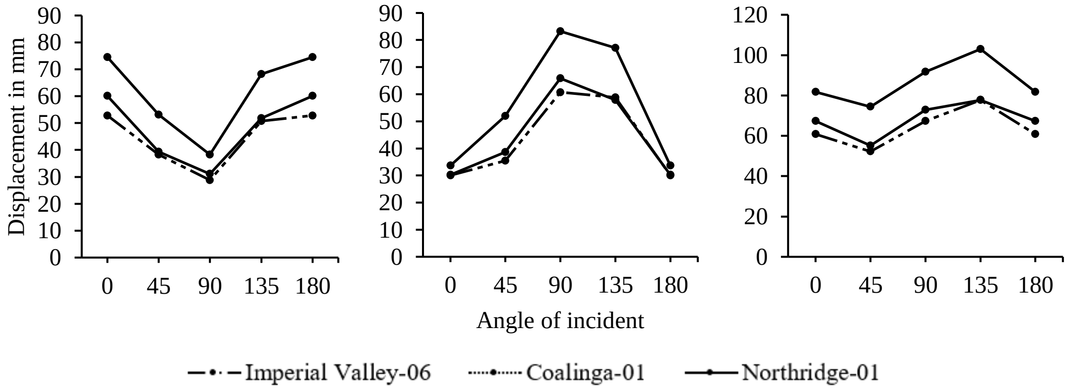
(a) (b) (c)

Figure 11 plus shape Near fault Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)



(a) (b) (c)

Figure 12 L shape Far-fault Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)



(a) (b) (c)

Figure 13 T shape Far-fault Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)

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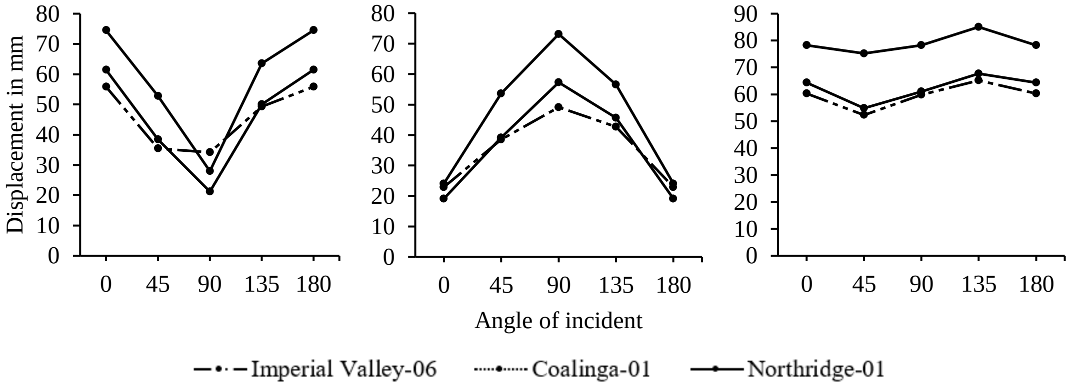
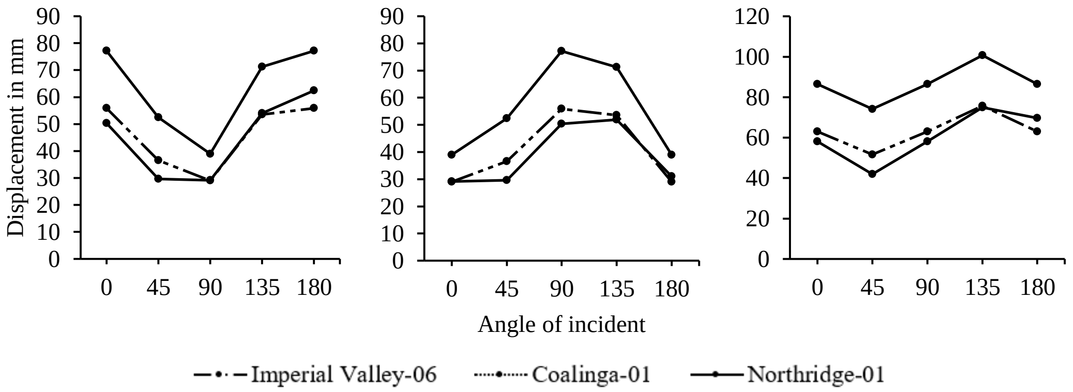


(a) (b) (c)

Figure 14 U shape Far-fault Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)

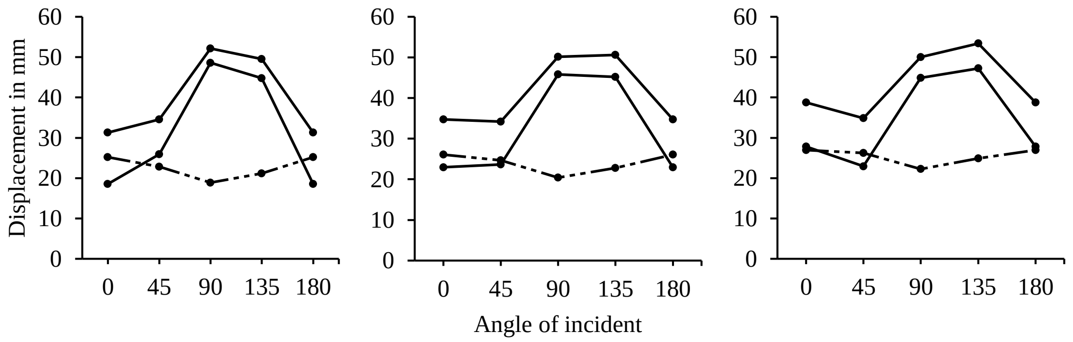


(a) (b) (c)

Figure 15 plus shape Far-fault Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)

B. BUILDING WITH SHEAR-WALL RESULTS

- Here, only for model 1 and 6 base shear and drift data is shown.



(a) (b) (c)

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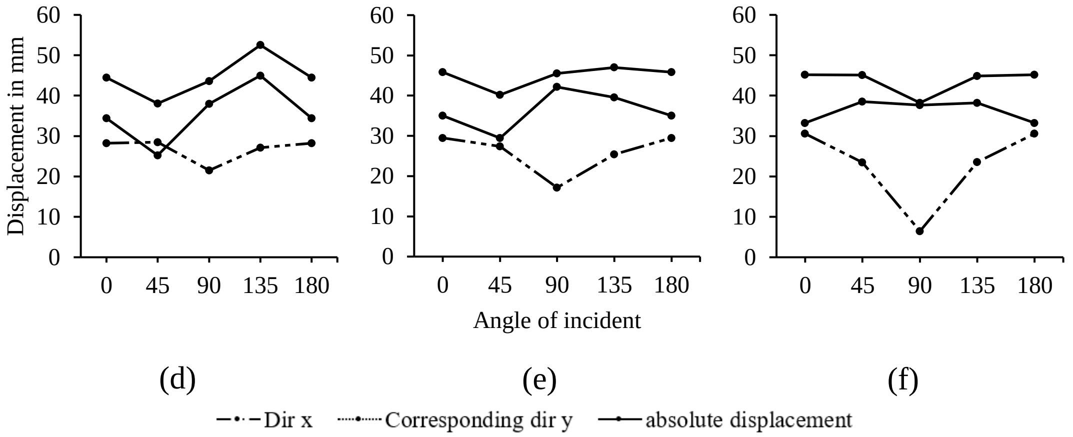

Figure 16 Response spectra Top Displacement (a) Model 1 (b) Model 2 (c) Model 3 (e) Model 4 (f) Model 5 (g) Model 6

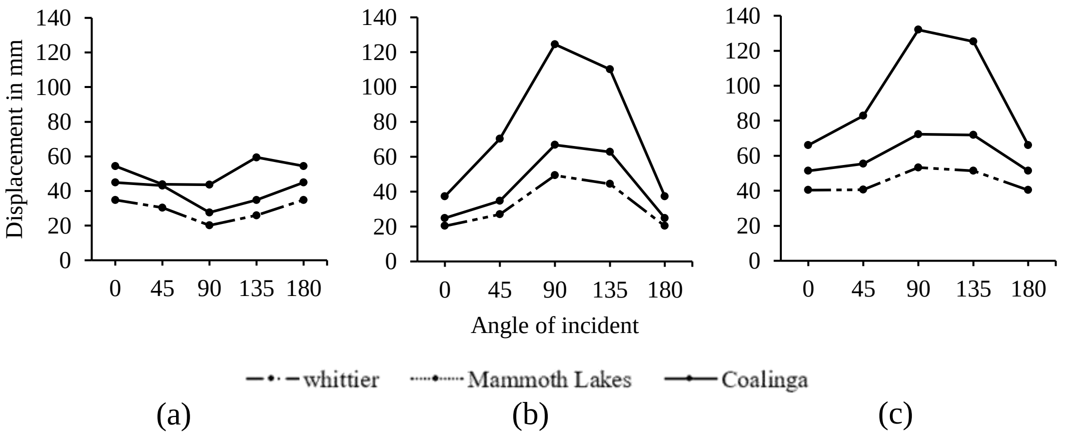

Figure 17 Model 1 near -fault Top Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)

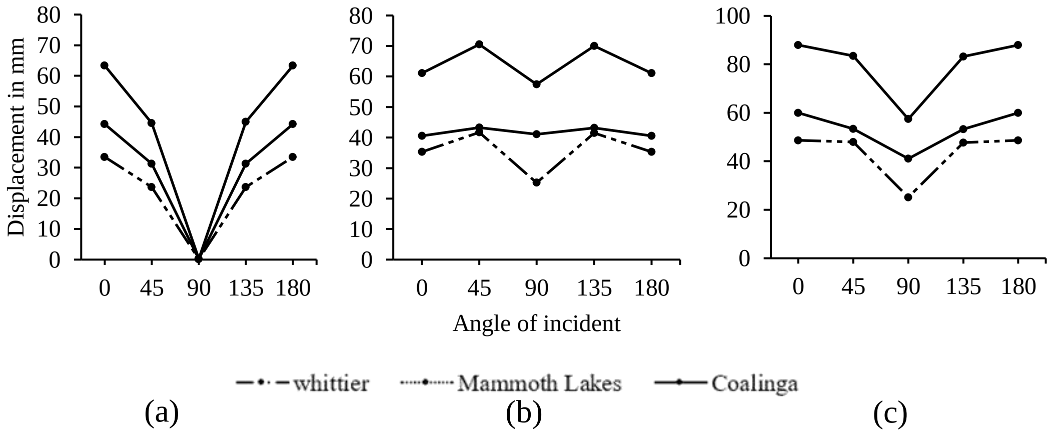

Figure 18 Model 6 near -fault Top Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)

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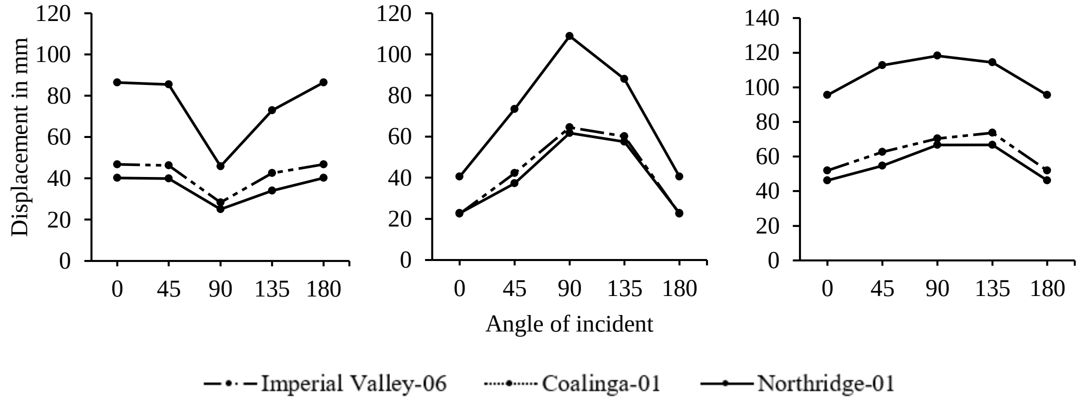

Figure 20 Model 1 far -fault Top Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)

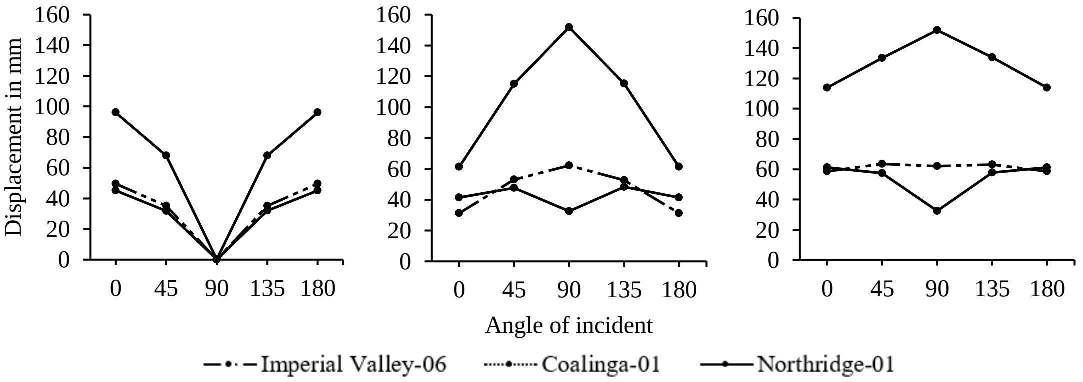

Figure 19 Model 6 far -fault Top Displacement (a) Displacement in x-direction (b) Corresponding displacement in y-direction (c) Absolute Displacement (SRSS)

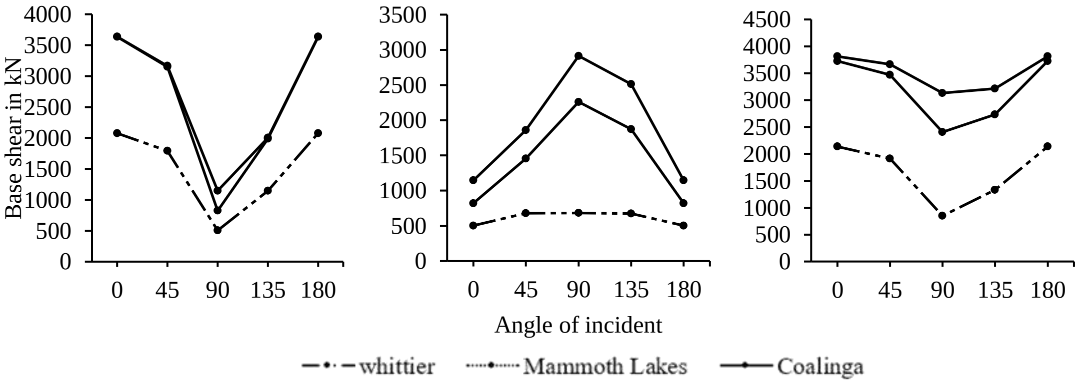

Figure 21 Model 1 Near -fault Base shear (a) Base shear in x-direction (b) Corresponding Base shear in y-direction (c) Absolute Base shear (SRSS)

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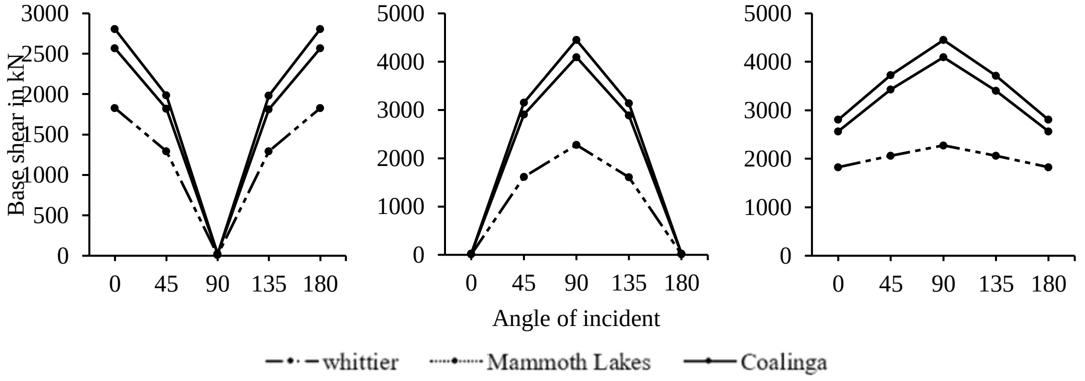
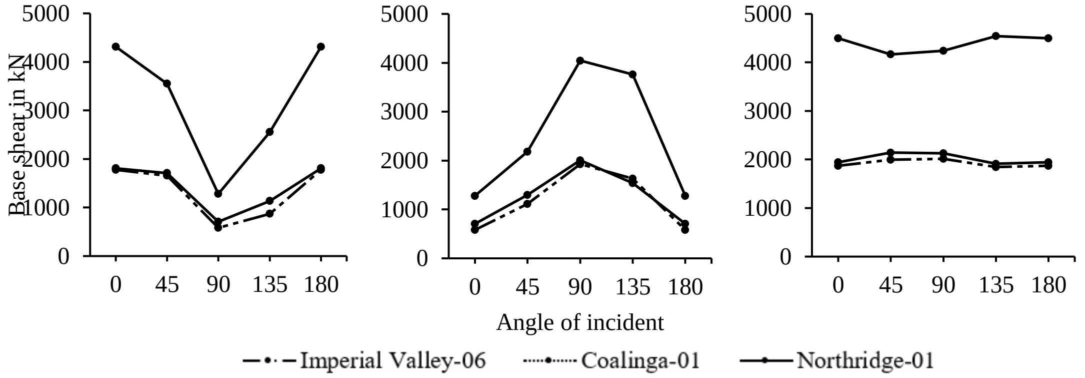


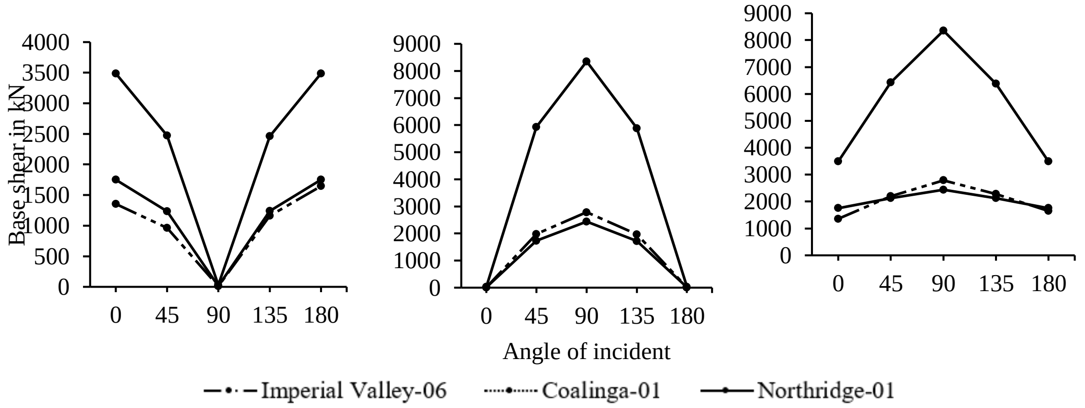
(a) (b) (c)

Figure 22 Model 6 Near -fault Base shear (a) Base shear in x-direction (b) Corresponding Base shear in y-direction (c) Absolute Base shear (SRSS)



(a) (b) (c)

Figure 23 Model 1 Far -fault Base shear (a) Base shear in x-direction (b) Corresponding Base shear in y-direction (c) Absolute Base shear (SRSS)



(a) (b) (c)

Figure 24 Model 6 Far -fault Base shear (a) Base shear in x-direction (b) Corresponding Base shear in y-direction (c) Absolute Base shear (SRSS)

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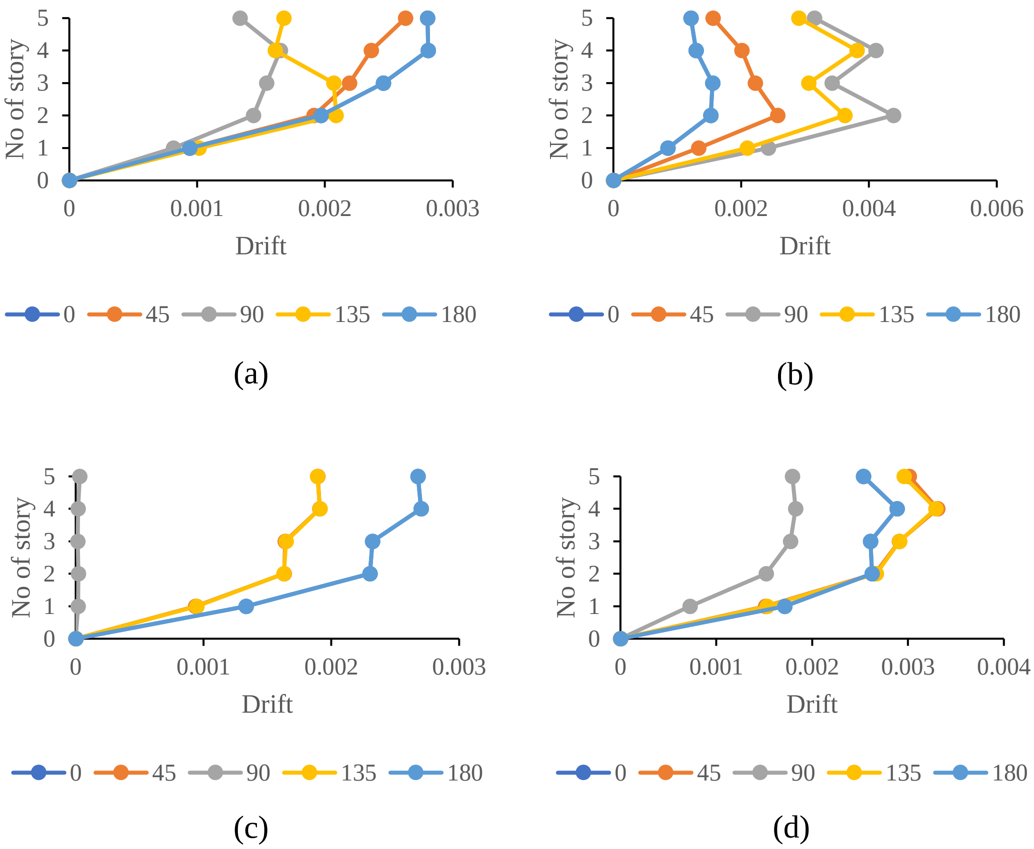

Figure 25 Drift data Whittier (a) model 1 x-direction (b) model 1 y-direction (c) model 6 x-direction (d) model 6 y-direction

IV. CONCLUSION

- Structures with eccentricity in both directions can have a different critical incident angle than the considered incident angle and it should be checked for different angles of earthquake incidents.
- Symmetrical U and Plus shape buildings give comparatively less displacement than the other two (L and T symmetrical shape) building models.
- For different plan shapes (L, T, U, Plus) building, the SRSS results of Displacement and Drift of is more at 135-degree while considering the eccentricity. Base shear (SRSS) is nearly same for the all the incident angles in far fault ground motion except for 135-degree (Decreases). In the near-fault results, the mammoth lake ground motion shows a different trend in the base shear than the other two ground motions.
- The maximum displacement axis varies as the magnitude of eccentricity in the shear wall building models. Displacement results are symmetrical about a 90-degree axis for model 6 as it is eccentric in one direction. Drift at 135-degree is nearly similar to 0-degree drift for the perpendicular direction responses. For far fault ground motion data, Coalinga ground motion gives the highest response than other ground motions.
- Critical angle of incident depends on the magnitude and direction of eccentricity and considered ground motion data. Results of the near-fault ground motion show different trends and the magnitude in Engineering Design parameters than the far-fault ground motion Results.
- It is evident that for near-fault ground motion a greater number of ground motion parameters are required to get more similarities between the ground motion.

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