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SEISMIC DEMAND ON A 9-STOREY RC COMMERCIAL BUILDING OF C-SHAPE PLAN WITH DIFFERENT a/l RATIOS

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Abstract

Earthquake is one of the important displacement dynamic load occuring underneath the structure which excites the mass resulting in random cyclic oscillatory motion. Regular symmetric buildings subjected to seismic loads will have translatory initial modes without much influence of torsion in comparison with asymmetric irregular buildings. In the present study six irregular buildings with plan resembling C-shape having different mass and stiffness are considered and the analysis is performed using Etabs structural software. Linear dynamic analysis using response spectrum method as per IS1893-2016 considering all the seismic zones and soil type-II is used for study. The influence of static eccentricity on the service load parameters lateral displacement, storey drift ratio and torsional irregularity ratio are analyzed and compared with code limits. Accelerations, storey shear,t orsional moment and overturning moment demand on the structure using strength models are compared with regular square model. The results of analysis are presented in the form of tables and figures which are used to facilitate interpretation of software results to draw conclusions on the effect of plan irregularity which results in torsional coupling increasing demands.

Keywords: Earthquake, asymmetric, C-shape, eccentricity, Etabs, demand, storeydrift, storeyshear, torsional coupling.

1. INTRODUCTION

The economy of any country lies in its infrastructure development funding. This aspect of economy is attracting huge investments in construction of building structures of residential, commercial and industrial nature from public and private sector. This increases the demand for innovations in architectural and structural designs encouraging the research community to engage in finding solutions to ensure safety and serviceability of structures. Many multi storeyed frame structures are being constructed to cater to the needs of people, which has created shortage of space in urban areas giving rise to, constructions to be carried out in available sites with odd shapes. This necessitates the construction of buildings irregular in plan and elevation.

These structures need to be designed not only for dead load, live load and wind load but also for resistance against earthquakes which have high degree of uncertainty in occurrence.

Due to earthquakes structures are subjected to random cyclic oscillations resulting in reversal of stresses of ground and the building there off. The seismic waves contain different frequency, duration and time period, which has to be analysed and statistically quantified to store data which helps to prepare response spectra useful for structural

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analysis and design.

An attempt is made in the present study of structures irregular in plan to quantify different response parameters to understand better the seismic behaviour.Oscar A Lopez et.al 1999 opine that environmental and functional needs can be attained if structures are designed with different irregular plan shapes from architectural point of view;but from the structurally need innovative ways in framing the structural components to withstand ill effects of irregularity. Discussed statistical findings on many verticals of architecture and the advantages it brings when different irregular plan shapes used for construction. The progress in the area of irregularity is reviewed by Mario De Stefano et.al 2007 suggested that prediction of inelastic response of a multi storey building using single storey model requires to be reconsidered looking at the responses of multi storey structures in the inelastic range. A more performance based analysis was preferred by them over force based methods. Some passive methods are also mentioned in the literature.

Raúl González Herrera et.al 2008 studied the ill effects of irregularity particularly plan irregularity during series of earthquake since 1980. An analysis was performed on different L shaped structures excited by variety of accelerations and compared the behaviour with the failure of real structures. Conclusions were derived on the importance of finding measures to control torsion.

L.Tereza Guevara-Perez 2008 This paper put more emphasis on importance of architectural configuration to be done keeping structural framing requirements for acceptable performance of any structure. H.Gokdemir et.al 2013 noted that top storey of any structure will have maximum displacements though relatively less drift ratio. In case of adjacent buildings it was observed that code limitations are not sufficient to avoid pounding between them causing failure in many earthquake hazards. The effect of torsional irregularity due to eccentricity of mass and rigidity and the torsional irregularity co-efficient provided by ASCE code was studied by Yavuz Durgun et.al 2014 with six rectangular building frames with different shear wall position to counter torsional rotation. And concluded that rotation about the vertical axes attaining maximum values when shear walls are farthest! Shehata E. Abdel Raheem et.al 2018 studied torsional coupling due to plan irregularity with different L shaped buildings. Most of the parameters which define the seismic response of building structure were studied for both stiffness and strength aspects. The results are compared with three different codes and conclusions were drawn. Most of the important research work done on the effects of irregularity when structures are excited by seismic forces are reviewed and many references were provided to help the community working in this domain PK Das, SC Datta, TK Dutta,2020. It was reported that work done on plan irregularity was relatively far lesser than vertical irregularity. the scope for research in both types of irregularity to understand the behaviour and to minimise uncertainties in analysis and design was presented with statistics.

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2. DETAILS OF BUILDING

From the above review it is evident that research work done on behaviour of buildings with plan irregularities is relatively far less than vertical irregularity for an L-shaped building with different plan areas Bharath khanal et.al 2020 concluded there exist torsional coupling due to plan irregularity.

Plan irregularities which tend to twist the building frames globally about vertical axis and its stiffness and strength demands at joints during seismic excitation envisaged the importance of research in this area as indicated from the above review PK Das et.al Provision of ductile joints during inelastic deformation to dissipate seismic energy effectively. This demand made to consider special moment resisting frames for all buildings in the present study.

A 9- storey commercial building is selected with C- shape in plan having varying plan area obtained by omitting certain areas from a regular square building(RRM) of overall size 45m x 45m as shown in fig.1

The details of the building considered are as follows,

Slab thickness – 130mm

Size of columns -500 x 500mm

Size of beams – 250 x 500mm

Seismic zone -II, III, IV & V

Soil type-II

Number of storey-9

Typical storey height -3m

Ground storey – 4m

Total height-28m

Spacing of columns-4.5m centre to centre in both X and Y direction

Live load-3kN/m2

Partition walls-1.5kN/m2

Boundary walls-12kN/m2

Frame-Special Moment Resisting Frame

Importance factor – 1.2

Response reduction factor – 5

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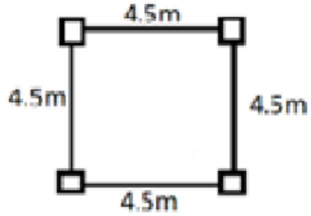
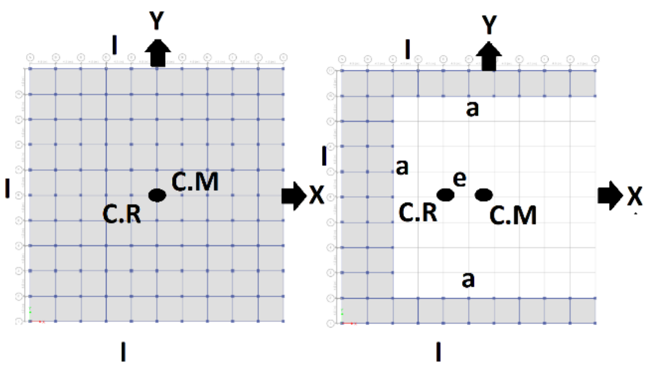


SIZE OF EACH MODULE



a = Projection beyond re-entrant corner

l=Plan dimension in the given direction

e=Eccentricity

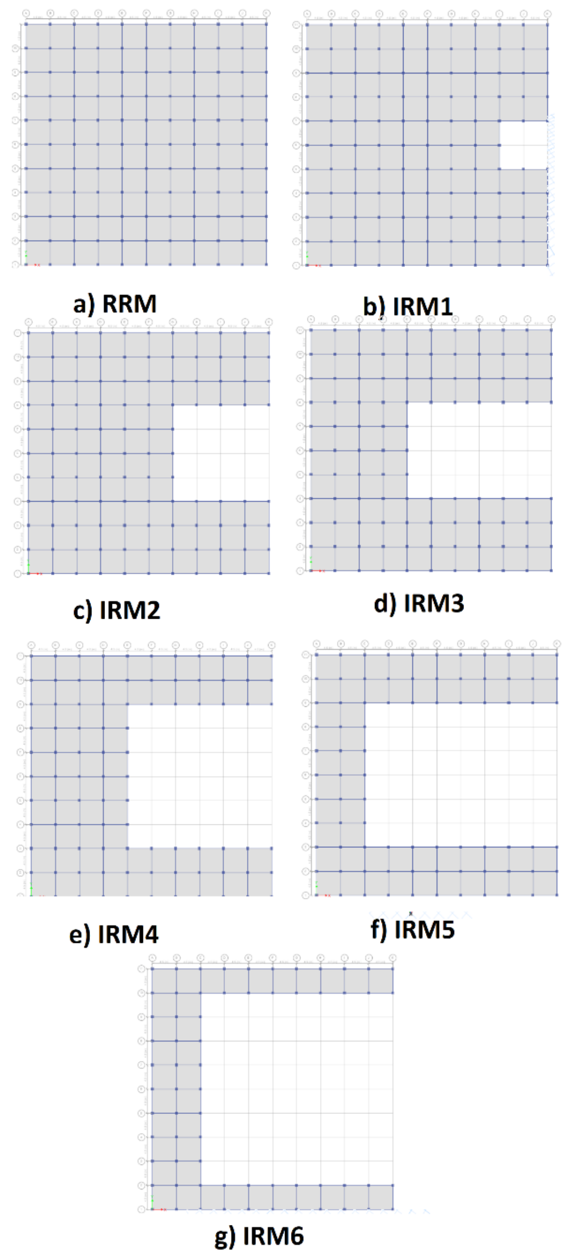


Fig.1 Plan showing Regular model(RRM)&Irregular models(IRM)

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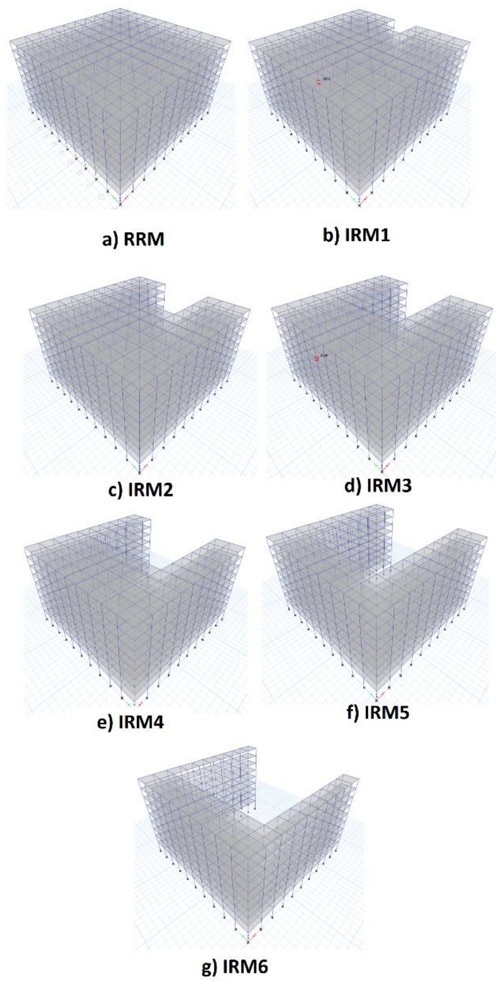

Fig.2 Etabs 2018 3D model showing regular(RRM) and Irregular buildings(IRM)

TABLE 1

A/L RATIO OF ALL THE CONSIDERED MODELS

SL NO	DIRECTION	REGULAR	C-SHAPE					
		RRM	IRM1	IRM2	IRM3	IRM4	IRM5	IRM6
1	X-Dir-a/l	0	0.2	0.4	0.6	0.6	0.8	0.8
2	Y-Dir-a/l	0	0.2	0.4	0.4	0.6	0.6	0.8

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TABLE 2

FUNDAMENTAL NATURAL PERIOD IN SECS

SL NO	REGULAR	C-SHAPE					
	RRM	IRM1	IRM2	IRM3	IRM4	IRM5	IRM6
1	3.649	3.677	3.723	3.595	3.811	3.88	3.88

TABLE 3

ECCENTRICITY IN M

SL NO	TYPE	REGULAR	C-SHAPE					
		RRM	IRM1	IRM2	IRM3	IRM4	IRM5	IRM6
		ex	ex	ex	ex	ex	ex	ex
1	STATIC	0	0.341	0.777	0.952	1.496	1.666	3.2045
2	DESIGN	2.250	2.762	3.415	3.678	4.494	4.749	7.057

Fig1 shows the regular model(RRM)which is regular in plan and symmetrical about both Xand Y axis and the plan irregular models IRM1 to IRM6 which are symmetrical about X-axis. The size of the module is 4.5m x 4.5m and 100 such modules used to make a square regular model with overall size of 45m x 45m.The dimensions of the irregular models are expressed in terms of ‘a’ and ‘l’ where ‘a’ is Projection beyond re-entrant corner and‘l’ is plan dimension in the given direction equal to 45m for both regular and irregular models.In irregular models,the values of ‘a’for IRM1,IRM2,IRM3,IRM4,IRM5 and IRM6 respectively are as shown in fig1.

Ratios a/l of all the irregular models in both X and y-direction are chosen to exceed IS1893-2016 code prescribed limit of a/l not greater than1.15, which says the projection beyond re-entrant corner (a) in the given direction shall not exceed the plan dimension in the same direction(l) by 15%.From table1 Irregular model IRM1 has minimum a/l ratio of 0.2 which is 1.33 times more whereas IRM6 having maximum a/l ratio 0.8 is 5.33 times more than the code limit.

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3. METHOD OF ANALYSIS

Dynamic linear elastic force based response analysis is done considering the gravity loads as per IS875 and seismic loads as per IS1893-2016 using Etabs 2018 version software.Response Spectrum Analysis is performed on RC bare frame commercial framed structure having boundary wall with with self weight of 12kN/m2 ‘No infilled frame action’ is considered in the analysis.P-Δ effects considered with no live load reduction as we go up the storey.Ritz method is used to calculate natural period of free vibration combining the cyclic rapid response of degrees of freedom at all floors using complete quadratic combination method (CQC).,the method allowed to combine amplitudes of vibration of parameters of study by IS1893-2016.Fig2 show the models taken from Etabs 2018 structural software from CSI used for the present research.

4. RESULTS & DISCUSSION

The effects of plan irregularity of different C-shaped buildings are analysed by interpreting the results obtained from Etabs software of all the parameters and representing them using tables and charts.

4.1. a/l ratio eccentricity and Natural period

The static and design eccentricity as per IS1893-2016 are shown in table3 and fig3.The eccentricity remained same in both X and Y direction of excitation.The rate of increase is almost similar between IRM1 to IRM5,where as static and dynamic amplifications of eccentricity is steep between model IRM5 and IRM6 which has a/l ratio 0.8.

The natural period of all the models are almost similar.IRM3 recorded the minimum of 3.595 sec and the maximum of 3.88sec for IRM6.The ratio of mass and stiffness remained almost same for all the models, though their magnitude differ individually.This aspect is the primary cause for similarity in fundamental natural periods of free vibrations.

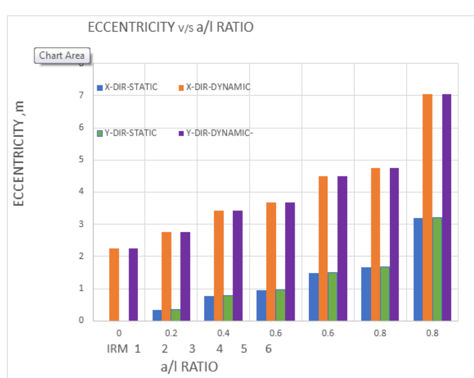

Fig3: Comparison showing the variation between eccentricity and a/l ratio.

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The response of irregular structures depends on the static eccentricity between centre of mass and centre of resistance and the applied design eccentricity as per IS1893-2016 which takes into account accidental eccentricity and dynamic amplification factor to account for torsional irregularity.

The results of all the parameters are discussed under the following division

A.The effect of zones Z-II to Z-V on all the parameters considered taken maximum response across the storey in both the orthogonal directions of excitation.

B.The effect of storey height on the considered parameters for zone-IV only in both orthogonal directions of excitation.

Also,active direction response and passive direction response of earthquake excitation are discussed.,

4.2. Lateral displacements

4.2.1. Effect of different seismic zones

The cyclic random sway due to seismic forces which acts through the displaced center of mass and idealized to be concentrated in the floors induce lateral displacements to and fro in a rapid random fashion.This demands smooth tranfer of seismic energy from the floors to the ground.The inelastic deformation during high seismic activity requires minimum strength and minimum stiffness to imbibe ductility to absorb and dessipate seismic energy effectively.

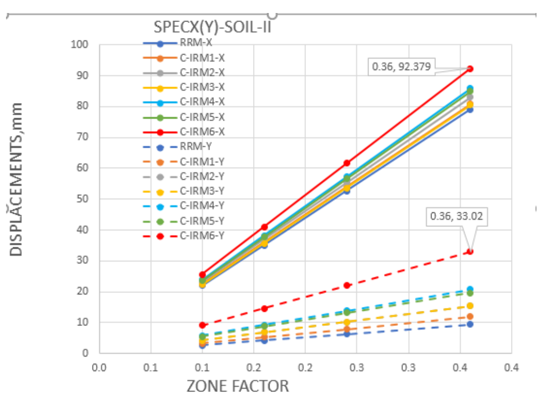

Fig.4Variation of lateral displacement with zone factor in orthogonal directions for X-direction excitation

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The rate of increase of displacement in active direction of excitation as shown in fig4 shows linear behavior across all the models and zones.The rate of increase stayed same for all the zones across different models recording highest for IRM6 at 17% as indicated by table4.The jump from 7% for IRM5 to 17% IRM6 is the effect of a/l ratio region between 0.6 and 0.8 respectively between the models.

The X-direction excitation recorded a maximum displacement of 92.379mm in zone V for IRM6 model for an obvious reason it is less stiffer than other models.In comparison with regular model the irregular models IRM1 to IRM6 show 2.3%,5%,1.79%,8.67%7.45% and 16.89% more displacements respectively in the active direction of excitation as shown in fig4.In IRM1 to IRM3 there is not much increase in displacements as a/l ratios are low and eccentricity not affecting the response in that direction.For IRM4 to IRM6 the increase in displacements may be attributed to the less stiffness against lateral sway including gravity loads and P-D effect. The relative increase acoss the zones remain almost same as shown in table 4.

TABLE 4

COMPARITIVE RATIOS OF DISPLACEMENT OF IRM WITH RRM IN X-DIRECTION

SPEC-X-X	C-IRM6-X	C-IRM5-X	C-IRM4-X	C-IRM3-X	C-IRM2-X	C-IRM1-X	RRM-X	ZONES
S-II-Z-II	1.17	1.07	1.09	1.02	1.05	1.02	1.00	0.10
S-II-Z-III	1.17	1.07	1.09	1.02	1.05	1.02	1.00	0.16
S-II-Z-IV	1.17	1.07	1.09	1.02	1.05	1.02	1.00	0.24
S-II-Z-V	1.17	1.07	1.09	1.02	1.05	1.02	1.00	0.36

The passive direction response of excitation for IRM1 to IRM6 are 1.26,1.63,1.63,2.20,2.08 and 3.49 times the regular square model indicating the effect of torsional coupling due to static and dynamic design eccentricity as shown in table 5

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TABLE 5

COMPARITIVE RATIOS OF DISPLACEMENT OF IRM WITH RRM IN Y-DIRECTION

SPEC-X-Y	C-IRM6-Y	C-IRM5-Y	C-IRM4-Y	C-IRM3-Y	C-IRM2-Y	C-IRM1-Y	RRM-Y	ZONES
S-II-Z-II	3.49	2.08	2.20	1.63	1.63	1.26	1.00	0.10
S-II-Z-III	3.49	2.08	2.20	1.63	1.63	1.26	1.00	0.16
S-II-Z-IV	3.49	2.08	2.20	1.63	1.63	1.26	1.00	0.24
S-II-Z-V	3.49	2.08	2.20	1.63	1.63	1.26	1.00	0.36

In all the irregular asymmetric models Y-direction excitation of IRM6 resulted in 37% increase in comparison with RRM recording an absolute displacement of 108.439mm for Zone-V.The relative increase though remains same across the zones, within the zones in the active direction due to asymmetry displacements are higher in comparison with active X-direction as shown in fig5.

In passive Y-direction excitation it is 3.22,2.98 and 4.06 times the RRM in the models IRM3 to IRM6 respectively,IRM5 showing more resistance against torsional coupling consistently due to the box action in resisting torsional shear.

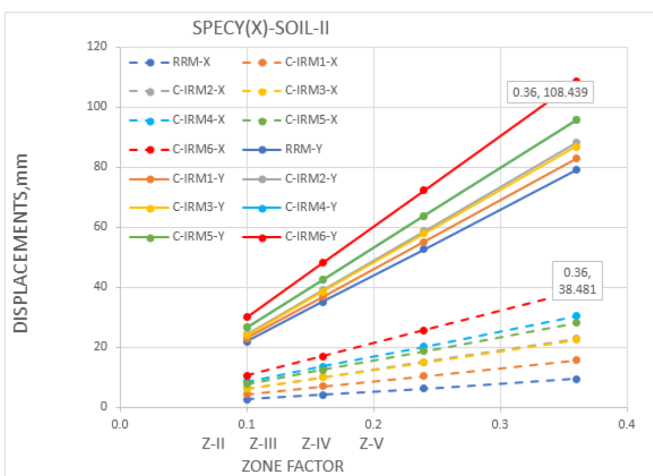

Fig.5Variation of maximum lateral displacement with zone factor in orthogonal directions for Y-directionexcitation

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4.2.2. Effect of Storey height on displacements

The mass and stiffness of all the models decrease as a/l ratio increases the irregular number increase and the seismic load also decreases as it is mass dependent.

Fig6 shows the lateral displacement across the storey height.Soil-II Zone-IV is taken for a typical study.The maximum displacement for IRM6 which is having static eccentricity 3.205m recorded 61.586mm for active X-directional excitation.The relative increase in displacement in comparison with RRM is 2.3% to 16.8%for IRM1 to IRM6 at the top storey,it is getting reduced as we go down the storey.Increase is a teep in lower storey in comparison with higher storey which are more towards free end of cantilever.Fig6 shows the shear behaviour in columns which have double curvature in deflection profile in a single storey.

In passive direction of X-direction excitation it is as high as 3.48 times the RRM in IRM6.The maximum passive displacement in IRM6 is 35.74% more than active direction excitation indicating the strong presence of torsion which needs to be controlled with appropriate remedial measures without affecting the architectural design.

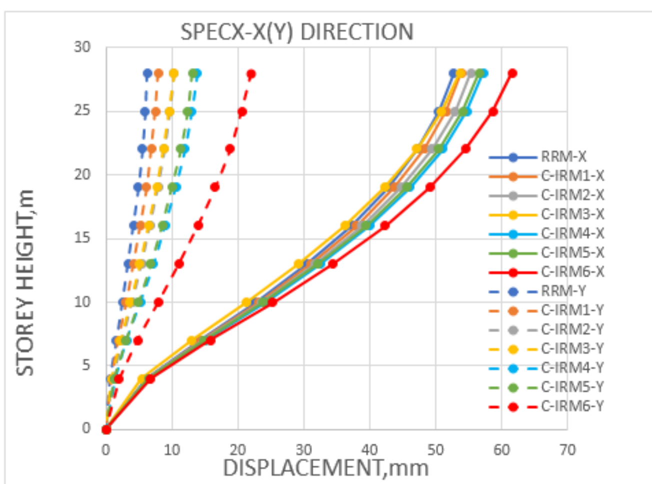

Fig.6Variation of lateral displacement with storey height in orthogonal directions for X-direction excitation

In case of active asymmetrical direction of excitation the maximum recorded displacement is 72.29mm which is more than the active X-direction by 10.7mm.The passive direction excitation recorded 35.49% relative displacement compared to RRM in IRM6 as shown in fig7

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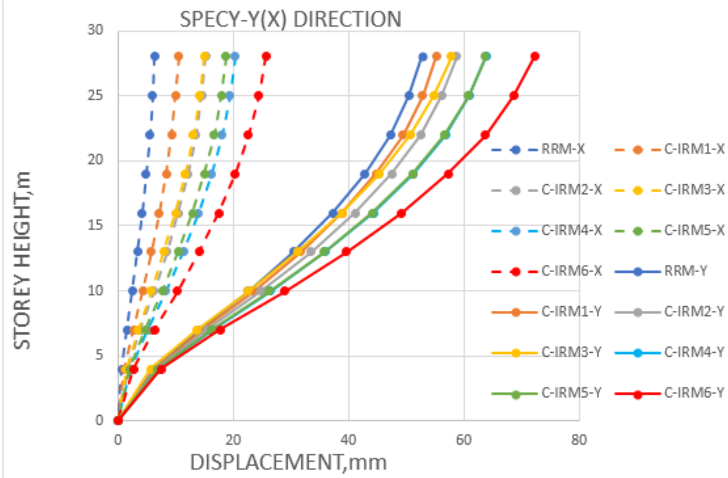

Fig.7 Variation of maximum lateral displacement with storey height in orthogonal directions for Y-direction excitation

4.3. Storey Drift Ratio

4.3.1.Effect of different seismic zones

Storey drift ratio is defined as the ratio between relative displacement within a storey and storey height between them.

Relative displacement between adjacent storey is an all important parameter to assess a fine balance between rigidity and flexibility of a structure to contribute to ductility of building to dissipate seismic energy through damping. In case of irregular structures to dissipate seismic energy effectively beyond elastic strength of a structure, the limitation of storey drift ratio is important for every joint to act in unison during seismic random cyclic oscillations.

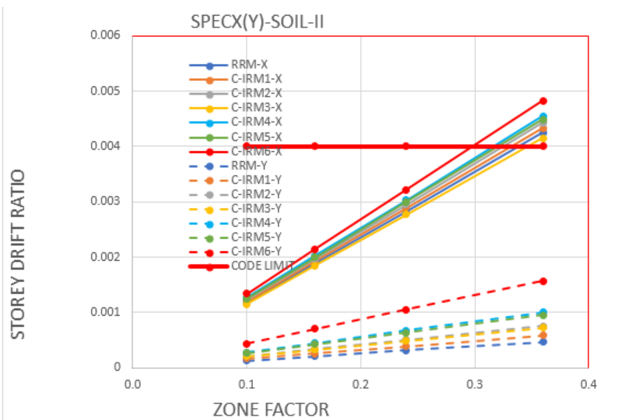

Fig.8 Variation of maximum storey drift ratio with zone factor in orthogonal directions for X-direction excitation

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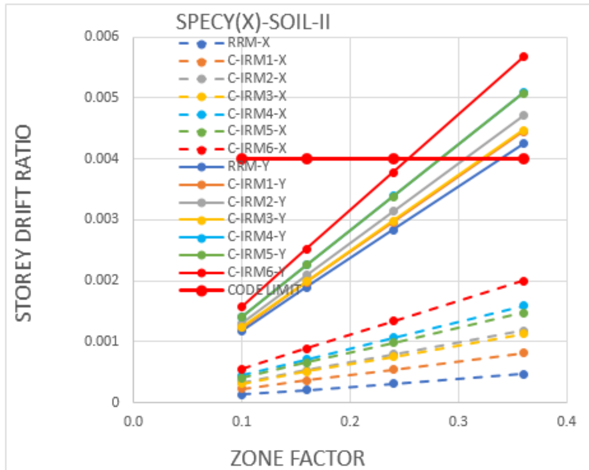

Fig.9 Variation of storey drift ratio with zone factor in orthogonal directions for Y-direction excitation

The Indian standard seismic code IS1893-2016 limits storey drift ratio to 0.004 for all zones upto V.From fig.8&fig.9 it is evident that drift ratio is well below the provisions of the code for all models in Zone-II, Zone-III& Zone-IV even for models which have high a/l ratio of 0.8>>0.15 recommended permissible value as per our code for plan irregular re-entrant corner buildings.

In case of zone-V even the models with a/l ratio 0.2 also cross the code prescribed limits in the active direction of excitation.The maximum recorded storey drift ratio is at storey-III for IRM6 0.005672 in active asymmetrical excitation direction.

In passive direction of excitation there is a relative rise in drift ratio of IRM6 which is 1.33 times more than RRM,where as in passive direction it is 4.28 times the regular model as shown in fig 9.The relative increase remains same across the zones.

Looking at the results of storey drift ratios it is required to control the response in zone-V and provide ductility against shear in columns and joints to withstand inelastic deformation.

4.3.2. Effect of Storey height onStorey Drift Ratio

Fig.10 & fig.11 represent storey drift ratio for X&Y direction excitation with passive direction influence due to torsion.

At the vicinity of the support always the drift ratios are high with a peak at second storey in both active and passive direction of excitation as shown in fig.10&fig.11.Hence the shear strength demands are high in lower storeys

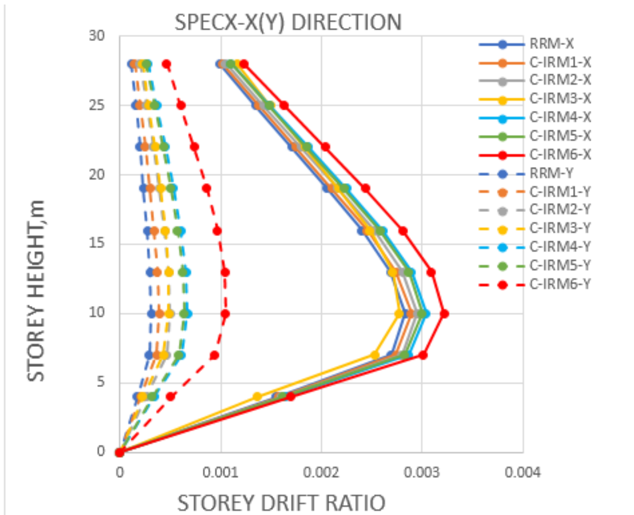

Fig.10Variation of storey drift ratio with storey height in orthogonal directions for X-direction excitation

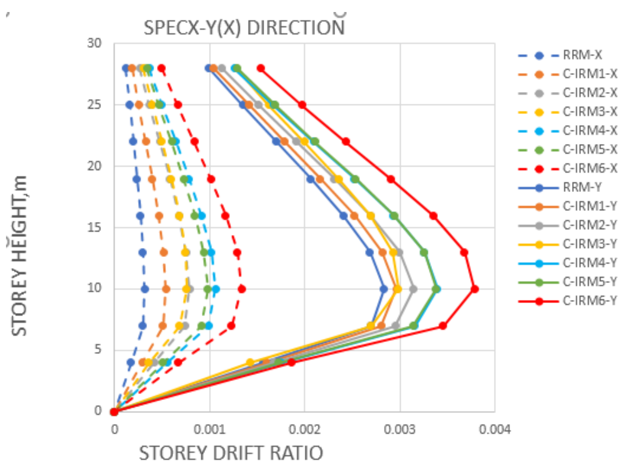

Fig.11Variation of storey drift ratio with storey height in orthogonal directions for Y-direction excitation

IS 1893-2016 recommends a limit of 0.4% drift in order to ensure energy dissipation through shear strength&ductility and the double curvature within a storey is carried well

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across the height of the building. All regular and irregular models are within 0.004 drift in both direction of excitation. but in the passive direction due to eccentricity there exists displacement and drift which rotates the building about the vertical axis. This inturn make the fundamental modes to couple with torsional oscilations.Measures to improve the performance in passive direction of excitation is required.

4.4. Torsional irregularity

4.4.1.Effect of different seismic zones

The maximum allowable relative displacements measured at the end of each diaphragm at a floor shall not exceed 1.50 as per IS1893-2016 (Part-I), If it is between 1.5-2 dynamic analysis is mandatory.

Fig.12 shows the variation of torsional irregularity ratio with zone factor in both active X-direction and passive direction direction of excitation is shown,similar variation for Y-direction excitation is shown in fig13. It is observed that the torsional irregularity ratio for a particular model is uneffected by the zone factor.

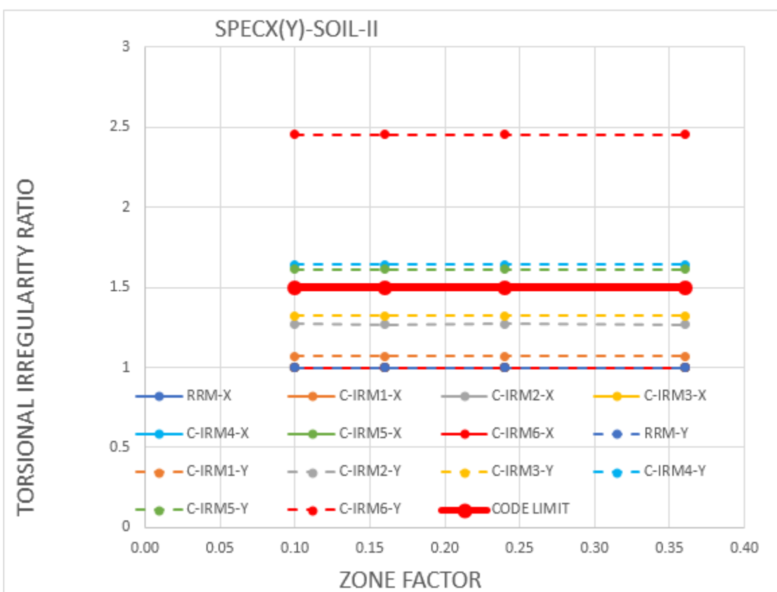

Fig.12Variation of torsional irregularity ratio with zone factor in orthogonal directions for X-direction excitation

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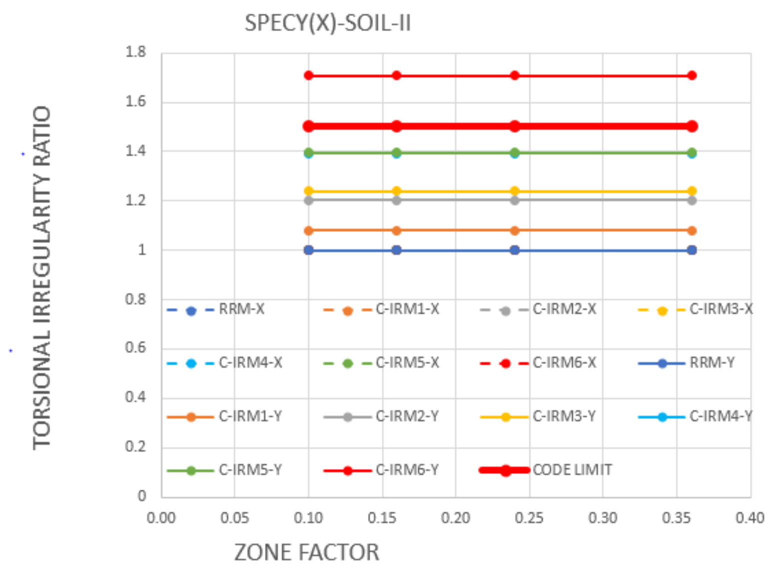

Fig.13Variation of torsional irregularity ratio with zone factor in orthogonal directions for Y-direction excitation

The asymmetrical passive direction of excitation record more than code prescribed limit of 1.5 in models IRM4 IRM5 and IRM6 due to eccentricity of mass with resistance.The maximum recorded torsional irregularity ratio is for IRM6 is 2.452 at the top storey.The models IRM4 & IRM5 recorded a maximum ratio of 1.61 & 1.64 respectively.It is as high as 63.47% in IRM6 model than the code prescribed limit in all zones. Fig13shows the response in the asymmetrical active direction of excitation which gives a maximum value of torsional irregularity ratio of 1.70 for IRM6.The reponse remains same across the zones.

4.4.2.Effect of Storey height on Torsional irregularity ratio

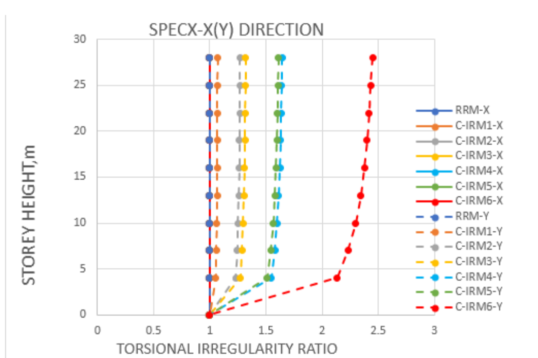

Fig.14Variation of torsional irregularity ratio with storey height in orthogonal directions for X-direction excitation

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The variation of torsional irregularity along the height of the structure almost remained same as shown in fig 14 for X-direction of excitation.The response though remained same along the height,it is maximum in passive asymmetrical direction of excitation for IRM6,IRM5 and IRM4 in that order.

It is interesting to note that the the ratio is almost same even in lower storeys though they are near to the support idicating the flexibility of the structure about the vertical axis.

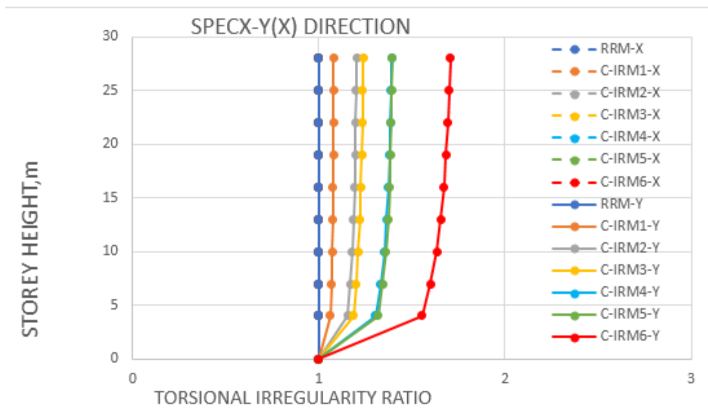

Fig.15Variation of torsional irregularity ratio with storey height in orthogonal directions for Y-direction excitation

When excited by the design force along Y-axis the active direction response along the height showed similar response as X-direction excitation but the response is relatively less, only IRM6 exceeding the limit.

4.5. Spectral Accelaration

4.5.1. Effect of different seismic zones

In the next part of the paper strength models are analysed for strength dependent parameters and the results are discussed and inferences made.

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TABLE 6

MAXIMUM RECORDED ACCELERATIONS ACROSS THE ZONES IN X-DIRECTION OF EXCITATION MM/SEC2

SPEC-X-X	C-IRM6-X	C-IRM5-X	C-IRM4-X	C-IRM3-X	C-IRM2-X	C-IRM1-X	RRM-X	ZONES
S-II-Z-II	611.82	611.07	612.43	626.82	613.02	613.82	614.98	0.10
S-II-Z-III	978.92	977.72	979.89	1002.91	980.84	982.12	983.97	0.16
S-II-Z-IV	1468.37	1466.58	1469.84	1504.37	1471.25	1473.18	1475.96	0.24
S-II-Z-V	2202.56	2199.87	2204.76	2256.55	2206.88	2209.77	2213.94	0.36
SPEC-X-Y	C-IRM6-Y	C-IRM5-Y	C-IRM4-Y	C-IRM3-Y	C-IRM2-Y	C-IRM1-Y	RRM-Y	ZONES
S-II-Z-II	0.03	0.08	0.02	0.02	0.03	0.08	0.01	0.10
S-II-Z-III	0.05	0.13	0.03	0.03	0.05	0.13	0.03	0.16
S-II-Z-IV	0.07	0.2	0.04	0.05	0.07	0.2	0.01	0.24
S-II-Z-V	0.11	0.3	0.06	0.07	0.21	0.3	0.02	0.36

TABLE 7

MAXIMUM RECORDED ACCELERATIONS ACROSS THE ZONES IN Y-DIRECTION OF EXCITATION IN MM/SEC2

SPEC-Y-X	C-IRM6-X	C-IRM5-X	C-IRM4-X	C-IRM3-X	C-IRM2-X	C-IRM1-X	RRM-X	ZONES
S-II-Z-II	219.61	133.34	134.44	83.14	77.01	34.56	0.004754	0.10
S-II-Z-III	351.38	213.35	215.11	133.02	123.22	55.29	0.01	0.16
S-II-Z-IV	527.07	320.02	322.66	199.53	184.83	0.2	0.01	0.24
S-II-Z-V	790.61	480.04	483.99	299.29	277.25	124.4	0.02	0.36
SPEC-Y-Y	C-IRM6-Y	C-IRM5-Y	C-IRM4-Y	C-IRM3-Y	C-IRM2-Y	C-IRM1-Y	RRM-Y	ZONES
S-II-Z-II	816.39	716.25	703.77	671.72	649.16	621.76	614.98	0.10
S-II-Z-III	1306.22	1146	1126.02	1074.76	1038.65	1126.02	994.82	0.16
S-II-Z-IV	1959.33	1719	1689.04	1612.14	1557.97	1689.04	1492.23	0.24
S-II-Z-V	2938.99	2578.5	2533.56	2418.21	2336.99	2533.56	2238.34	0.36

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Table 6 and 7 show the magnitudes of spectral acceleration in both active and passive direction of excitation.The acceleration recording an highest of 2938mm/sec2 as shown in fig16. Acceleration increase as the zone number increases for the obvious reason that higher zones are subjected to more severe earthquake forces as all the parameters defining them increases as the zone numberincrease from II to IV.

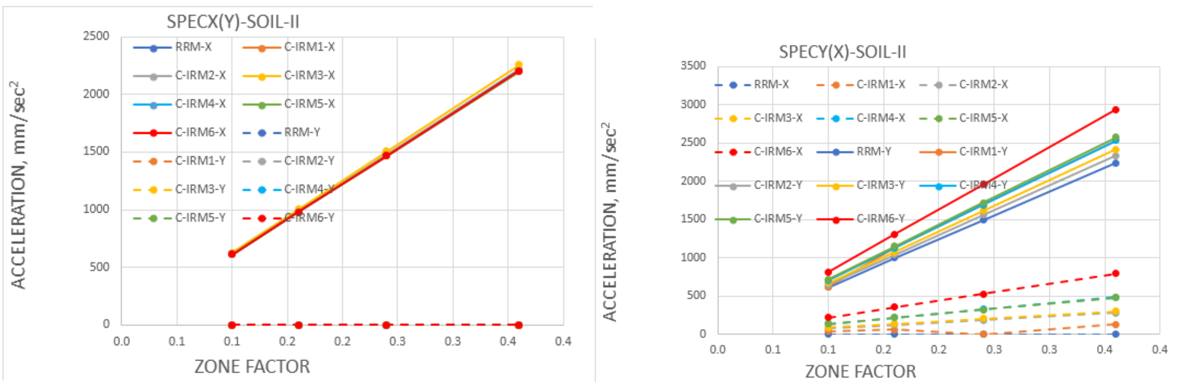

Fig.16Variation of acceleration with zone factor in orthogonal directions for X-direction and Y-direction excitation

4.5.2. Effect of storey height onacceleration

Maximum acceleration for all models and all storey remains almost same except at top storey where it is maximum, as it acts like a local cantilever.

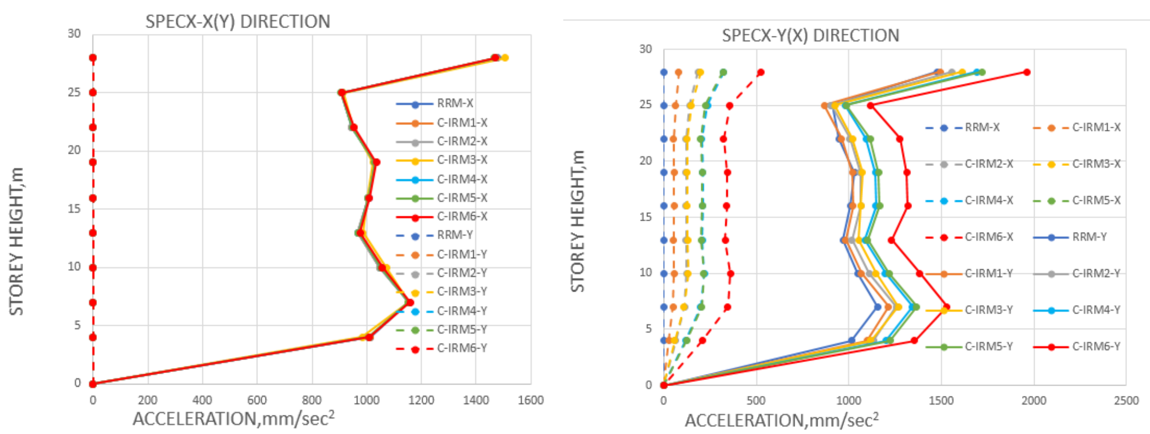

Fig.17Variation of acceleration with storey height in orthogonal directions for X-direction and Y-direction excitation

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X-direction of excitation has nothing to differentiate between the models as shown in fig 17,it remained same for all the models RRM to IRM6. No accelerations recorded in the passiv direction(asymmetry).

Y-direction of excitation for acceleration varied across the models and along the height as well as shown in fig17.

4.6. Base shear

4.6.1. Effect of different seismic zones

In all the strength models as per the code provisions $\bar{V}$B/VB is scaled up as most of the response spectrum storey shear VB values are below that obtained fromequivalent static method$\bar{V}$B.The method of finding fundamental natural period makes a difference between the base shear values obtained from different methods.

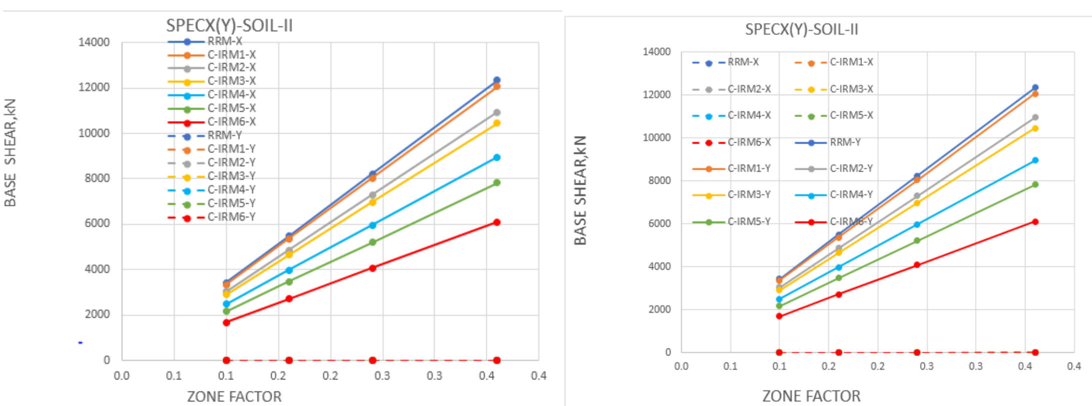

Fig.18Variation of storey shear with zone factor in orthogonal directions for X-direction and Y-direction excitation

Base shear as shown in fig18 is maximum for regular RRM model and it decreases as the mass decreases for all the irregular models.The highest and the lowest base ahear is 12338.48kN and 1695.381kN for RRM Zone-V and IRM6 Zone-II model respectively.

4.6.2. Effect of storey height onStorey shear

The mass of live loads and dead loads with the introduction of acceleration in the lateral direction due to seismic excitation will be concentrated at all the floor levels.This dynamic force due to rigid diaphragm action give rise to base shear as shown in fig.19.

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Seismic force distribution in case of response spectrum method gives almost same rate of increase of storey shearat all the floors except at the top.This is a real representation of dynamic action that is seen in acceleration plots.It is reflected in fig.19 wherein storey shear gets increased with almost same amount from top storey to base,where the maximum base shear acts.

The rate of increase of storey shear almost remains constant due to the presence of same mass in all the floors.

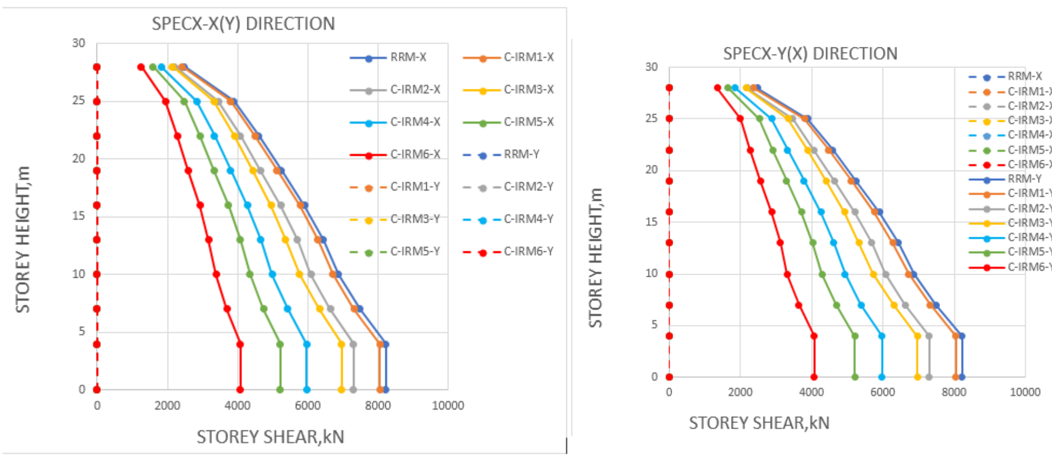

Fig.19Variation of storey shear with storey height in orthogonal directions for X-direction and Y-direction excitation

4.7. Torsional moment

The rotation of the structure about the vertical axis in the fundamental mode of oscillation introduce torsional moments.

4.7.1.Effect of different seismic zones

The demand of rotation, stiffness & strength at the jointsand at the foundation about the vertical axis is high.Torsional moment indeed is a prime & key factor to be taken care of for any plan irrgeular structure toperform effectively and efficientely during the seismic hazard.

The torsional coupling to certain extent is taken care of by IS:1893-2016 in the form of provision of design eccentricity.

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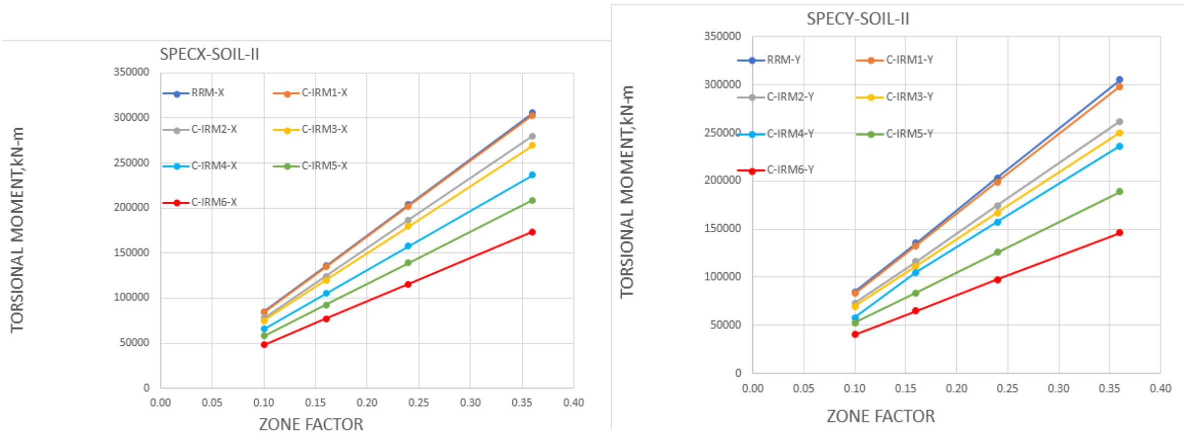

Fig.20Variation of torsional moment with zone factor for X-direction and Y-direction excitation

The torsional moment remains always same for both the horizontal direction of excitation.Fig.20 presentsis showing a plot wherein the regular model showshigh response because of more mass.Mass contributes to torsional demand, torsional stiffness and for mass moment of inertia, so it makes sense to distribute mass uniformly spatially.

In case of regular models the reason behind the torsional moments is due to the square shaped plan, which induce diagonal mode of oscillation where moment of inertia is low about the diagonal.

The torsional moment increases as the severity of the zone increases as shown in fig20.The rate of increase in torsional moment is very high for RRM and IRM1 due to higher masses compared to other models.The maximum torsional moment for RRM is 305377,4kN-m for zone-V and lowest for IRM6 is 40634.72kN-m in Zone-II.

4.7.2. Effect of storey height on torsional moment

The rate of increase of torsional moments remains almost same across the storey as shown in fig.21

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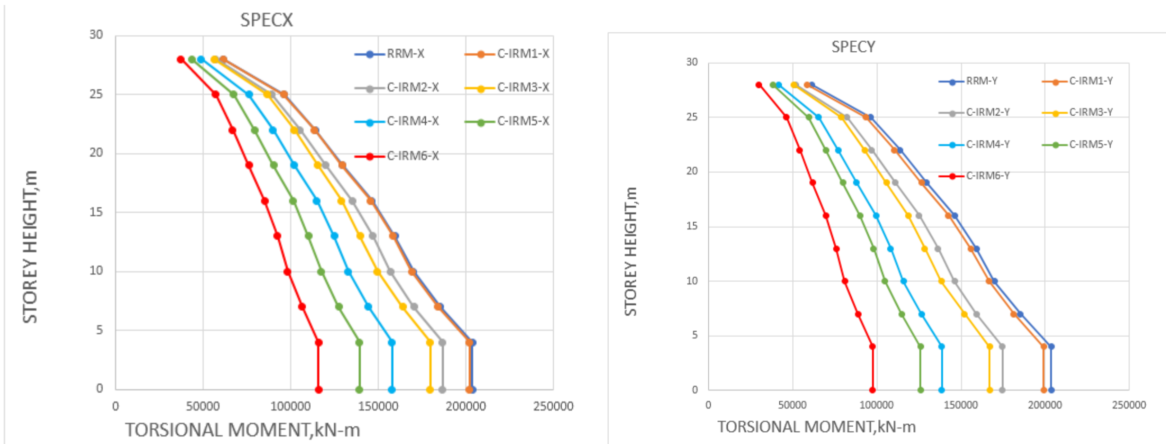

Fig.21Variation of torsional moment with storey height in orthogonal directions for X-direction and Y-direction excitation

Constraint to free rotation at the vicinity of the support increases the demand for torsional moment.Depending on the asymmetry the values will increases as shown in fig.21 which shows the continuous and almost linear rate of increase between floors.The lowest and the highest for Zone-IV is 1258.98kN-m and 8225.656 kN-m respectively for IRM6 and RRM model.

4.8. Overturning moment

4.8.1. Effect of different seismic zones

During earthquake events lateral movement of soil induce seismic forces in the structure assumed to be distributed along the height of the structure at the storey levels.

Theoverturning moments about Y-direction in X-direction excitation & over turning moment about X-direction in Y-direction excitation is studied in this strength parameter, which gives insight into stability aspectsagainst overturning moments about plan axes.

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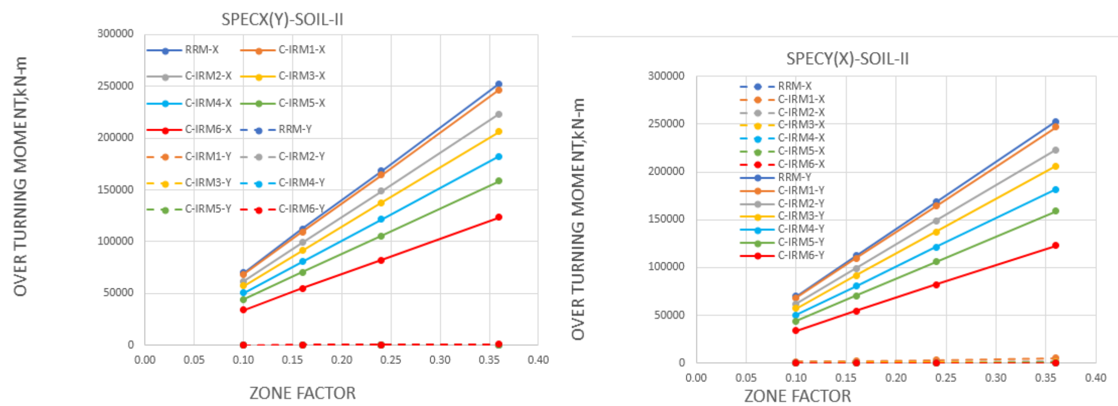

Fig.22Variation of overturning moment with zone factor in orthogonal directions for X-direction and Y-direction excitation

The active direction of excitation X from fig 22 shows the variation of overturning moments wherein the moment increases as the zone varies from II to IV and the rate of increase between the models also increase as the zone. The maximum overturning moment in RRM for zone-V is 252474.6kN-m and the lowest for IRM6 Zone-II is 34187.32kN-m.

4.8.2. Effect of storey height onoverturning moment

Overturning moments are important for stability of any structure.In case seismic events it becomes more important as lateral forces tend to rotate the foundation causing unequal pressure distribution at the base.

From fig23 as the excited mass getting accumulated from the top storey through all other storey and to the foundation.The maximum moment about the plan axes for RRM in Zone-IV is 168316.4kN-m and lowest for IRM6 is 3924.528kN-m. Passive direction stability demands are marginal though its implications in the global sense with other parameters are studied.

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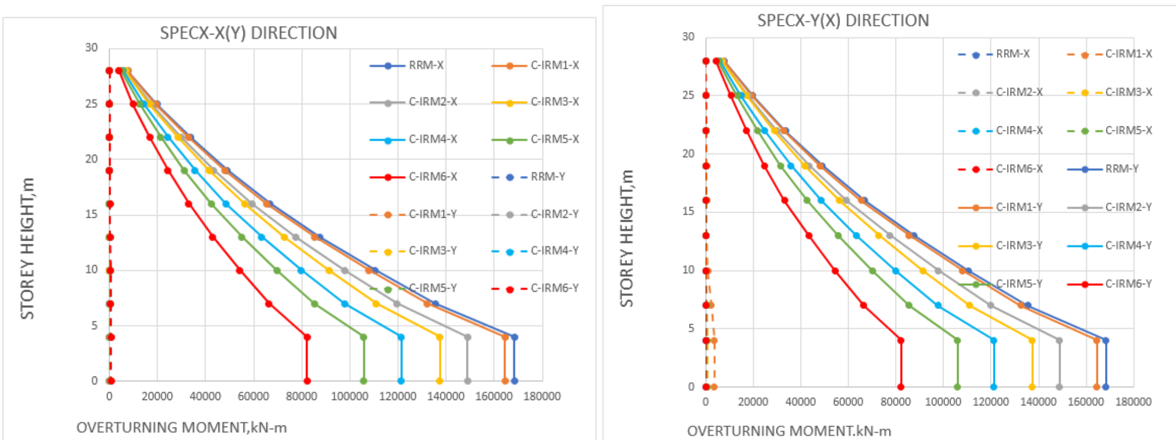

Fig.23Variation of overturning moment with storey height in orthogonal directions for X-direction and Y-direction excitation

5. CONCLUSIONS

A 9-storey residential building having irregular-C-shape plan with six different plan area having different a/l ratio (IRM).These plan irregular models compared with a square regular model (RRM). All buildings are subjected to a live load of 3kN/m2 in addition to dead loads and seismic loads. Analysis of building frames are carried out as per IS1893-2016 using response spectrum method.The responses namely displacement, drift ratio, torsional irregularity ratio, acceleration, base shear, torsional moment and overturning moment between different irregular and regular modelare compared considering zone II to V and soil type-II and also compared across the storey. Based on the limited study following conclusions are drawn,

The ratio of mass and stiffness being almost same for all the models, though their magnitudes differ individually.This aspect is the primary cause for similarity in fundamental natural periods of free vibrations.

Eccenticity of mass & stiffness & a/l ratio increase absolute displacements alarmingly in passive direction of excitation due to torsional coupling.

In comparison with regular model the irregular models IRM1 to IRM6 show 2.3%,5%,1.79%8.67%7.45% and 16.89% higher displacements respectively in the active direction of excitation for zone IV

In all the irregular models X-axis is the axis of symmetry.In Y-direction excitation IRM6 resulted in 37% increase in lateral displacement in comparison with RRM recording an absolute displacement of 108.439mm for Zone-V

In passive Y-direction excitation torsional shear is 3.22,2.98 and 4.06 times the RRM in the models IRM3 to IRM6 respectively.IRM5 showing more resistance against torsional

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coupling consistently due to the box action in resisting torsional shear.

In case of storey drift ratio in zoneVeven the models with least considered a/l ratio 0.2 also exceed the code prescribed limits in the active direction of excitation.The maximum recorded storey drift ratio is at storey-III for IRM6 of 0.005672 in active asymmetrical excitation direction in zone V.

The maximum recorded torsional irregularity ratio is found to be in IRM6 and is 2.452 at the top storey.The models IRM4 & IRM5 recorded maximum ratio of 1.61 & 1.64 respectively.It is as high as 63.47% in IRM6 model than the code prescribed limit of 1.5 in zone-IV.

It is interesting to note that the torsional irregularity ratio is almost same even in lower storeys though they are close to support idicating the flexibility of the structure about the vertical axis.

The highest base shear is 12338.48kN for RRM Zone-V which is 7.27 times more than the lowest 1695.381kN for IRM6 Zone-II model.

The torsional moment increases as the flexibility decreases to rotate about the vertical axis generating maximum torsional moment at the base where rotation is zero due to fixity. The maximum torsional moment for RRM is 305377.4kN-m for zone-V which is 7.51 times thelowest 40634.72kN-m for IRM6 in Zone-II.

Overturning moments are important for stability of any structure.In case seismic events it becomes more important as lateral forces tend to rotate the foundation causing unequal pressure distribution at the base.

As expected, increase in zones from II to V increases the effect of all parameters. All the plan irregular models in particular IRM5 and IRM6 with high a/l ratios suffered high increase in lateral displacement, storey drift ratio, torsional irregularity ratio and spectral acceleration which were higher than the regular model RRM due to torsional coupling.

However because of its higher area in plan and mass, the plan regular model RRM experienced higher magnitudes of base shear, torsional moment and overturning moment than all other plan irregularmodels.

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