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Response Quantities of Framed Buildings under Dynamic Excitation

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Abstract*: *Seismic analysis of structure is employed to make the structure enable to resist the seismic forces and perform against the factors causing the failure of the structure under dynamic excitation. Among various response factors, the base shear and time period of buildings are predominant factors used in the analysis and design of the structure.The prime objective of the paper is to present an analytical study on non-linear seismic analysis of moment resisting framed buildings (as per Indian code IS1893 – 2016) to evaluate the base shear of different configurations of buildings according to different mode combination methods. The obtained results have been presented the comparative analysis of different combination methods. The paper also presents the evaluated results in the form of the time period values of the different buildings depending upon variation in its configuration. As a result, the responses of multistoried moment-resisting framed buildings have been evaluated for various models of considered buildings based on different mode combination methods, and the results of obtained responses have been analyzed in a comparative manner to understand the behaviour of buildings under various methods and configuration conditions.

The work presented in the paper can support to develop better understanding of structural response and efficient designing of structures.

Keywords: Base shear, dynamic excitation, mode combination, predominant.

I. INTRODUCTION

Numerous low rise buildings can be observed as designed without proper seismic provisions which can cause of the adversely affected performance of structures under seismic loading.

Reinforced concrete (RC) framed buildings are the most general form of buildings in construction practices in the country. During the life span of the buildings, several forces including earthquake force are supposed to be acted upon.

The difference in the manner to incorporate inputs of analysis of earthquake and process of idealization differentiates the methods among the available ones.

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The equivalent static force method and non-linear dynamic analysis (response spectrum method) can be considered the most common analysis procedures of structural analysis among various available methods of seismic evaluation. For the different degree of freedom, the considered structural model gives an approximation of deformations in nonlinear dynamic analysis. The different combination methods can be employed to get model responses.

Following are the different mode combination methods to find the ultimate responses combining modes as per the proposed formulae of design codes to find an appropriate estimate of peak responses.

Response spectrum method is a dynamic method in which all final Eigenvalues are used with minimum mass participation value as 90 %. For a combination of responses, any of the ABS method, CSM method, SRSS method, and TEN (10PCT; 10 per cent method) methods can be used.

The ABS; the Absolute sum method. CSM; Closely-Spaced Modes grouping method, in which, the Absolute sum method is used to combine the peak response quantities for closely-spaced modes and SRSS method is used in case of widely spaced modes.

SRSS; Square Root of Summation of Squares method. TEN (10PCT); Ten Percent Method is used for combining closely spaced modes. These modes can be defined as modes having frequencies within 10% variation with respect to each other and the absolute sum is presented for the responses of closely spaced modal.

Maximum value of expected lateral force that can occur at location of the base of a structure due to dynamic seismic action is evaluated as base shear, which depends upon several factors, such as; the natural period of vibration of the structure, ductility and overstrength associated with various structural configurations, condition of soil strata at the site, total weight of the structure etc.

In pushover analysis, the base shear is distributed at each floor level and then load is uniformly increased until the stage of collapse comes. And the strength reserve ratio is calculated as the factor over the design base shear.

The present study compares the resulting base shear obtained by different combination methods and values of the time period obtained by dynamic analysis.

II. LITERATURE STUDY

Bourahla [4] discussed general philosophy of various equivalent static lateral force method covering its domain of application, the procedure of force calculation and referred it as a simplified method in which, a static force can be used distributing it laterally on the structure to substitute the dynamic loadings for purpose of design the structure. In this paper, concepts of ground acceleration, ground condition, behaviour factor, distribution of static force horizontally and vertically, base shear, overturning moment etc have been discussed. Author summarised that in general, the seismic force, assuming the dynamic response of the building in fundamental lateral mode, is calculated in two directions which are parallel to the main axis of the structure, for which, to avoid torsional movement, low rise building be symmetrical.

Karakas et. al. [5] presented an analysis for reinforced concrete non-seismic buildings under different methods of nonlinear seismic analysis. Analysed three bay-four storied concrete frame building calibrating it with a numerical model and ICONS model was used. The ICONS model and numerical model presented a good correlation in properties. Authors used incremental dynamic analysis, time history analysis, pushover analysis methods for analytical study describing the merits and demerits of the methods and presented the results. They confirmed by the numerical results that the global response of the structure is shown by pushover analysis. The time history analysis uses three different peak ground accelerations showing inter-story drift profiles. Based on the first natural period of the structure, fragility curves are shown by the incremental dynamic analysis.

Riddell and Llera [7] presented a review of earthquake-resistant design and available methods for analysis. Authors highlighted the fact that the information system of this field is lacking to some extent even after significant advancements. They also presented some changes in design code provisions to ensure structural safety and proposed integrated design validation process with a discussion that design ground motion is as opposed to the validation ground motion concept.

III. METHODOLOGY

Analysis for desired quantities has been done using STAAD.Pro software with following structural, material and configuration parameters:

A. Parameters Considered:

Table- I: Configuration

Type of structure	Multistory rigid jointed plane frames
No. of storey	GF to G+11
Floor height	3.6m
No. of Grids	6×6, 10×10

Table- II: Material Properties

Material used	Concrete M-25 and Reinforcement Fe-415
Type of soil	Type -II, Medium soil as per IS-1893-2016
E_c	$5000\sqrt{f_{ck}}$ N/mm^2
f_{cr}	$0.7\sqrt{f_{ck}}$ N/mm^2

Table- III: Structural details

Size of columns	0.6×0.6m 0.5×0.5m, 0.4×0.4m, 0.3×0.3m.
Thickness of slab	150mm. 200mm
Walls-(a) External (b) Internal	200 mm 100 mm
Imposed load	4 kN/m^2
Floor finish	1 kN/m^2
Waterproofing	2.5 kN/m^2
Specific wt. of R.C.C	25N/m^2

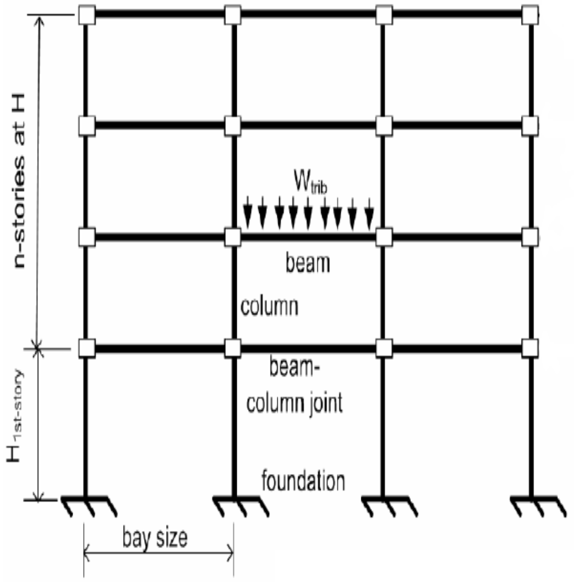

Fig. 1. A typical example of framed building elevation

IV. ANALYTICAL STUDY

Followings are the calculated responses of the different building configurations as per the considered parameters:

Table- IV: Time Period (T) in seconds: 10 Bay building with plan 30m dimension, Slab thickness = 150 mm

Number of Storey	Floor Height (m)	Column Size	
		0.5m×0.5m	0.3m×0.3m
G+11	43.2	1.61	3.18
G+10	39.6	1.47	2.91
G+9	36.0	1.34	2.65
G+8	32.4	1.20	2.38
G+7	28.8	1.07	2.12
G+6	25.2	0.93	1.86
G+5	21.6	0.80	1.60
G+4	18.0	0.67	1.34
G+3	14.4	0.54	1.09
G+2	10.8	0.41	0.83
G+1	7.2	0.28	0.58
GF	3.6	0.16	0.34

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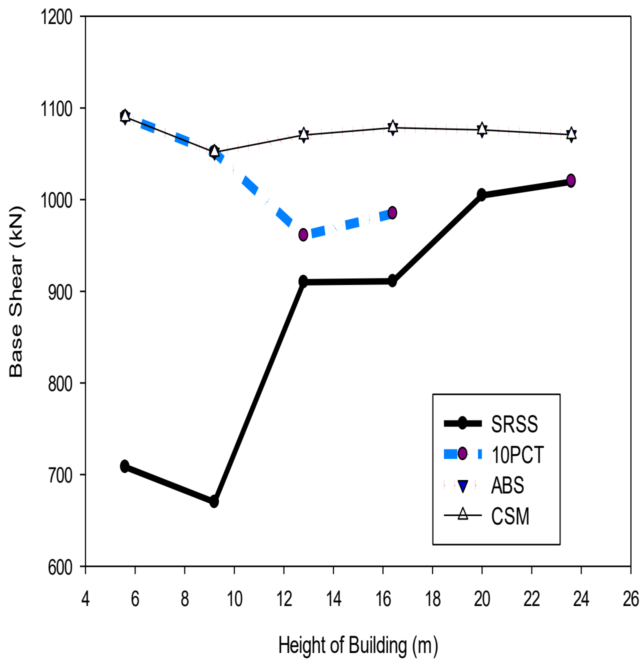

Fig. 2. Base shear of buildings (plan area = 48m×48m) with different model combinations

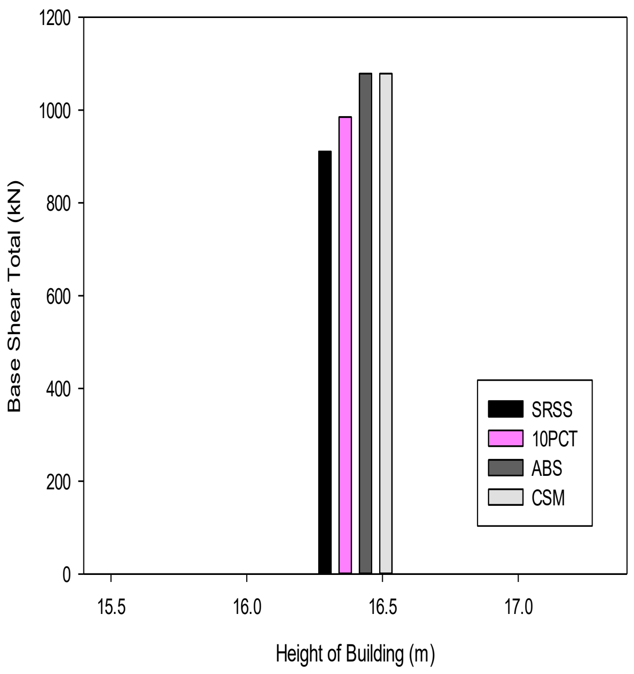

Fig. 4. Base shear of buildings (five-storied Building, plan area = 48m×48m) with different model combinations.

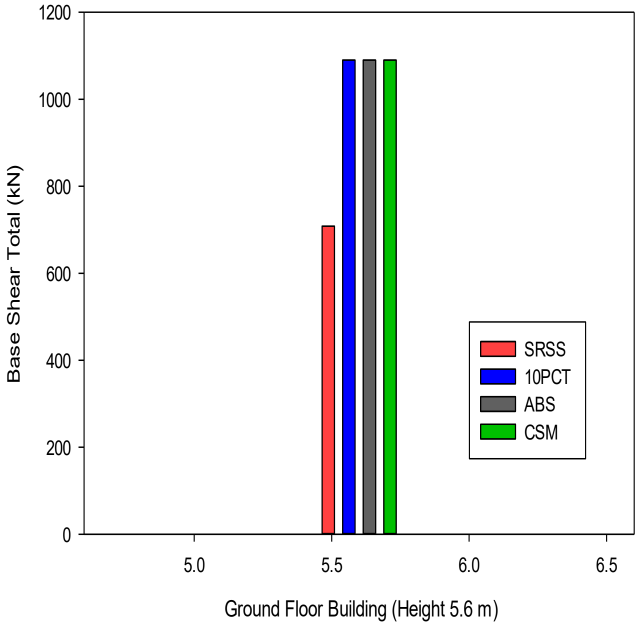

Fig. 3. Base shear of buildings (Ground Floor Building) with different model combinations.

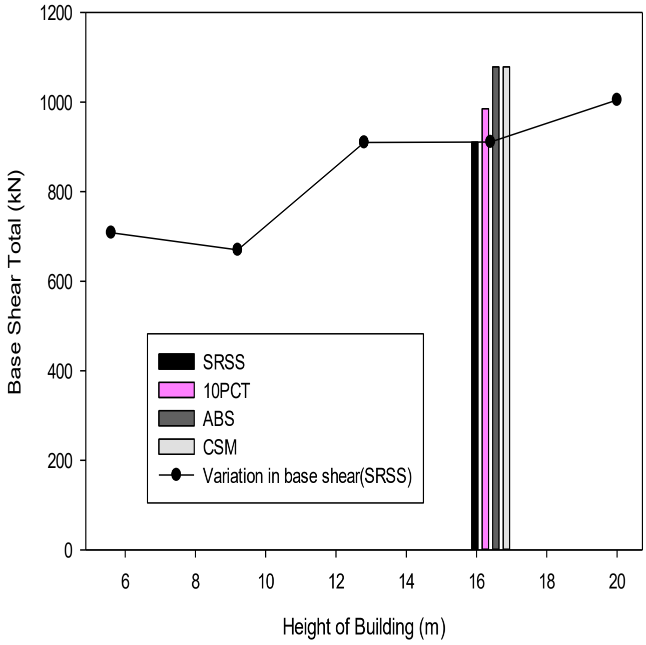

Fig. 5. Base shear of buildings (five-storied building, plan area = 36m×36m) with different model combinations.

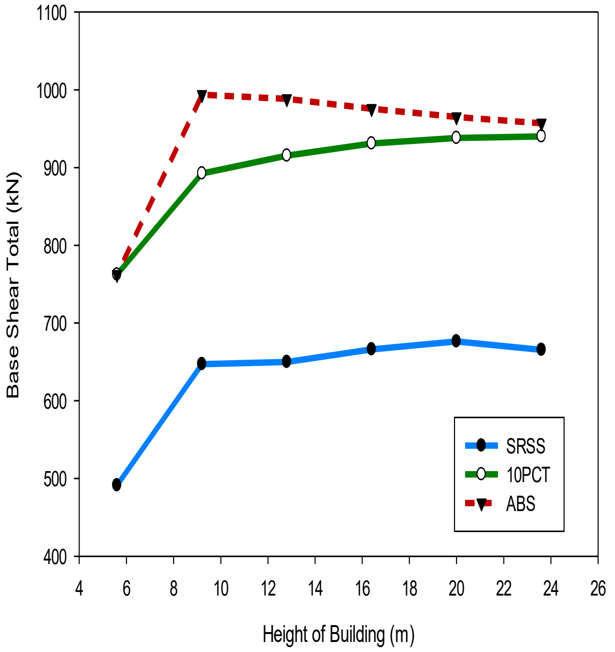

Fig. 6. Base shear of buildings (five-storied building, plan area = 36m×36m) with different model combinations.

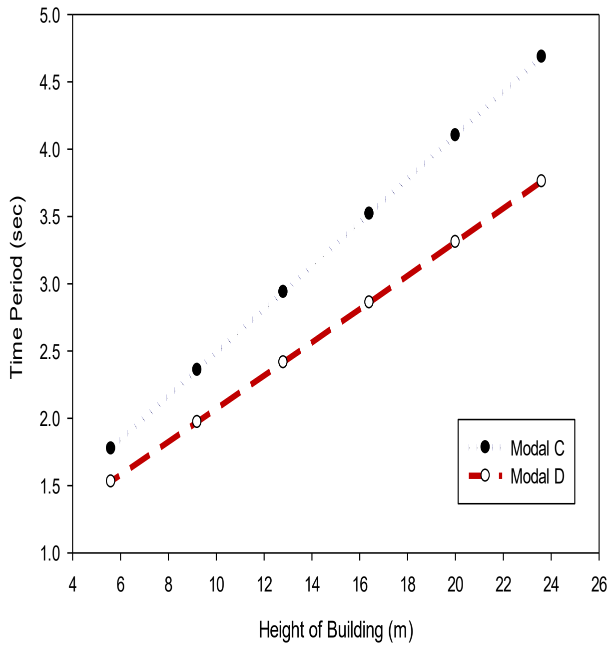

Fig. 8. Time period vs. Plan area of building with column size 0.3m×0.3m
Model C: Plan area of building = 48m×48m
Model D: Plan area of building = 36m×36m

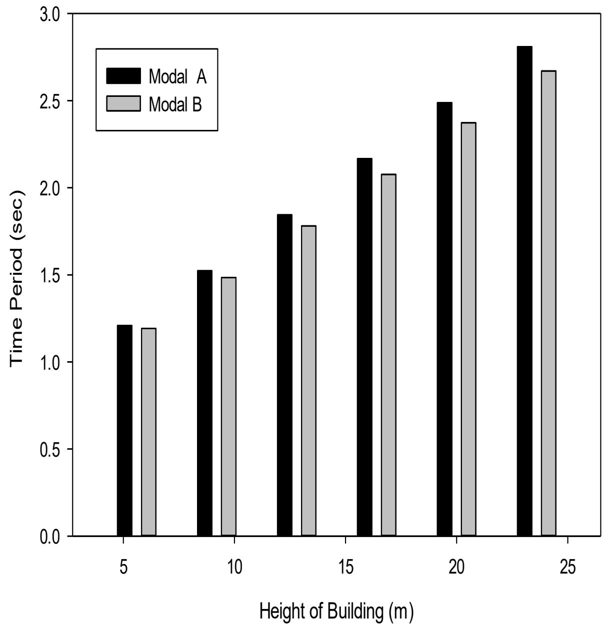

Fig. 7. Time period vs. Plan area of building with column size 0.6m×0.6m
Model A: Plan area of building = 48m×48m
Model B: Plan area of building = 36m×36m

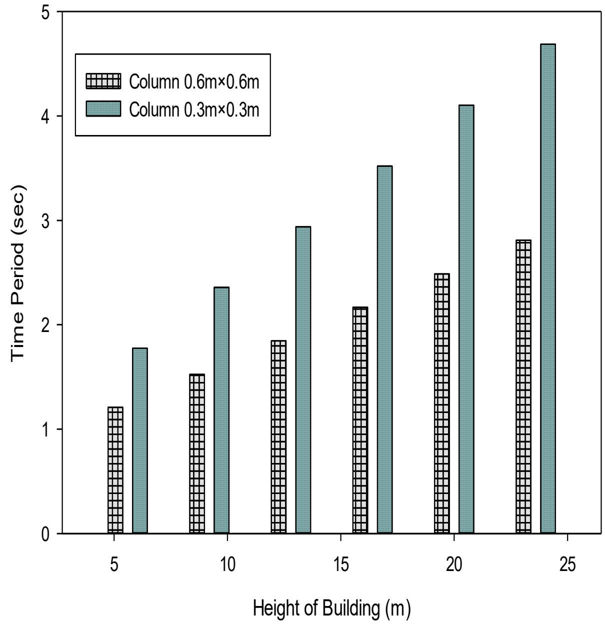

Fig. 9. Time period vs. Column Size of building with Plan Area = 48m×48m

Table- V: Time Period (T) in seconds: 7 Bay building with plan 30m dimension, Slab thickness = 150 mm

Number of Storey	Floor Height (m)	Column Size	
		0.5m×0.5m	0.3m×0.3m
G+11	43.2	2.17	4.11
G+10	39.6	1.99	3.77
G+9	36.0	1.80	3.43
G+8	32.4	1.59	3.03
G+7	28.8	1.44	2.75
G+6	25.2	1.26	2.41
G+5	21.6	1.09	2.08
G+4	18.0	0.91	1.75
G+3	14.4	0.73	1.42
G+2	10.8	0.56	1.09
G+1	7.2	0.39	0.77
GF	3.6	0.22	0.44

Table- VI: Time period (T) in seconds : Bay size 6×6, Slab thickness = 150 mm

Floors/ Height	Columns Size (m)			
	0.5×0.5		0.4×0.4	
	Bay length(m)		Bay length(m)	
	8	6	8	6
	Plan Area(m)	Plan Area(m)	Plan Area(m)	Plan Area(m)
	48×48	36×36	48×48	36×36
G+5 = 21.6 m	2.921	2.337	3.361	2.7
G+4 = 18 m	2.591	2.095	2.971	2.407
G+3 = 14.4 m	2.261	1.854	2.582	2.115
G+2 = 10.8 m	1.93	1.614	2.192	1.824
G+1 = 7.2 m	1.597	1.374	1.8	1.534
G.F. = 3.6 m	1.265	1.134	1.404	1.243

- It can be observed from Table-IV, for G+11 building, T_{max} value is 1.6 (sec) in case 0.5m sized square column, and 3.18 (sec) for 0.3m sized square column. Thus, 2.6 times decrease in cross-sectional area is showing 96% increase in period value. For 0.5m sized column, T_{max} value is 1.61(sec) for G+11 and it is 0.16(sec) for ground floor building. Here, a 12 times increase in height is showing a 10% increase in period value.
- Now, keeping all other factors same, with a decrease in no. of the bay; from ten to seven, time increasing to 2.17(Table-V) from 1.61(Table-IV) for G+11 building with 0.5m sized square columns.
- With 200mm thick slab, 0.6m×0.6m column and G+5 building (Table-VII), period value is 2.81(sec) for 48m×48m area, but it is 2.67 (sec) for 36m×36m.
- With 150mm thick slab, 0.4m×0.4m column and G+5 building (Table-VI), period value is 3.361(sec) for 48m×48m area, but it is 2.7 (sec) for 36m×36m.

Table- VII: Time period (T) in seconds: Bay size 6×6, Slab thickness = 200 mm

Floors/ Height	Columns Size (m)			
	0.6×0.6		0.3×0.3	
	Bay length(m)		Bay length(m)	
	8	6	8	6
	Plan Area(m)	Plan Area(m)	Plan Area(m)	Plan Area(m)
	48×48	36×36	48×48	36×36
G+5 = 21.6 m	2.81	2.67	4.687	3.761
G+4 = 18 m	2.488	2.373	4.103	3.31
G+3 = 14.4 m	2.167	2.077	3.52	2.861
G+2 = 10.8 m	1.845	1.781	2.939	2.415
G+1 = 7.2 m	1.524	1.485	2.359	1.971
G.F. = 3.6 m	1.209	1.192	1.775	1.53

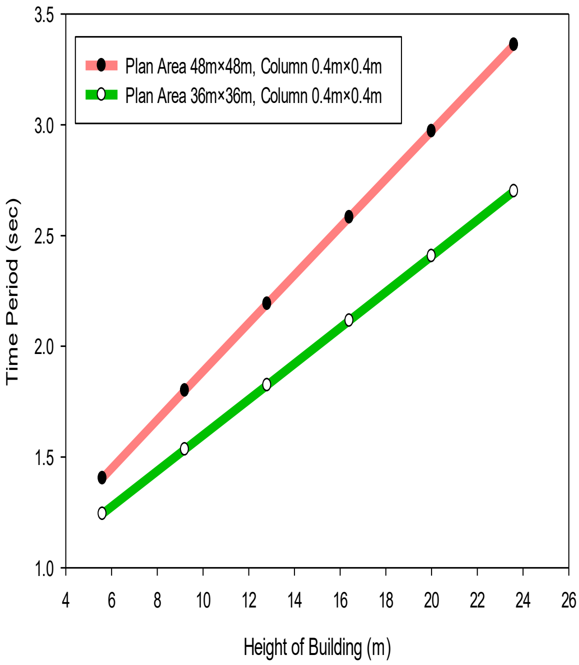

Fig. 10. Time period vs. Plan area of building with column size 0.4m×0.4m

- With Height =3.6m ground floor building (Table-V). Period value is 0.22 (sec) for 0.5m sized square columns, but it is showing twice increment as 0.44 (sec) with 0.3m sized square column building.
- Similarly, period value is 1.775(sec) for height 3.6m and it is 4.687(sec) for height 21.6m (Table-VII).

Table- VIII: Comparison of base shear with different methods

Bay Size 6×6, Slab Thickness = 150 mm								
Floors/ Building height	Columns Size = 0.6m×0.6m, Bay length = 8m Plan Area = 48m×48m				Columns Size = 0.6m×0.6m, Bay length = 6m Plan Area = 36m×36m			
	Base Shear Total (kN)				**Base Shear Total (kN)**			
	SRSS	**10PCT**	**ABS**	**CSM**	**SRSS**	**10PCT**	**ABS**	**CSM**
G+5/ (23.6m)	1019.53	1020.43	1070.93	1070.93	665.46	940.12	957.03	957.03
G+4/ (20m)	1004.60	1005.70	1076.07	1076.07	676.29	938.04	965.11	965.11
G+3/ (16.4m)	911.06	985.02	1078.46	1078.46	665.94	930.96	975.74	975.74
G+2/ (12.8m)	909.91	960.92	1070.51	1070.51	649.82	915.43	988.39	988.39
G+1/ (9.2m)	670.00	1051.71	1051.71	1051.71	647.08	892.41	993.89	993.89
G.F./ (5.6m)	708.22	1090.20	1090.20	1090.20	491.14	762.48	762.48	762.48

Table- IX: Comparison of base shear with different methods

Bay Size 6×6, Slab Thickness = 200 mm,								
Floors/ Building height	Columns Size = 0.6m×0.6m, Bay length = 8m Plan Area = 48m×48m				Columns Size = 0.6m×0.6m, Bay length = 6m Plan Area = 36m×36m			
	Base Shear Total (kN)				**Base Shear Total (kN)**			
	SRSS	**10PCT**	**ABS**	**CSM**	**SRSS**	**10PCT**	**ABS**	**CSM**
G+5/ (23.6m)	1067.80	1068.88	1124.34	1124.34	331.56	468.75	469.87	469.87
G+4/ (20m)	1051.70	1052.72	1128.93	1128.93	332.21	468.79	470.63	470.63
G+3/ (16.4m)	971.02	1030.59	1129.92	1129.92	331.48	467.89	471.21	471.21
G+2/ (12.8m)	951.66	1005.57	1119.64	1119.64	330.21	464.68	471.45	471.45
G+1/ (9.2m)	702.13	1100.43	1100.43	1100.43	321.49	454.57	470.51	470.51
G.F./ (5.6m)	744.62	1145.12	1145.12	1145.12	298.85	422.57	461.02	461.02

V. RESULT AND DISCUSSION

From Table -VIII and IX, as a discussion on few examples from results, it can be mentioned that the base shear data has been observed as its values 708kN and 744kN are for ground floor building having 150mm &200mm thick slab with plan area = 48m×48m under SRSS method. But, these values are 1090.20kN and 1145.12kN respectively under other combination methods. The respective differences in base shear values in comparison to SRSS method are 382kN and 401kN respectively.

Similarly, these values are 491.14 kN and 298.85 kN for ground floor building having 150mm &200mm thick slab with plan area = 36m×36m under SRSS method. But, these values are different under other combination methods as 762.48kN for 150mm thick slab condition, and 422.57 kN, 461.02 kN for 200mm slab condition. So, respective differences in total base shear values in comparison to SRSS methods exist as 271kN(in case, 150mm slab condition), and 124 kN &163 kN(in case, 200mm slab condition).

VI. CONCLUSION

In this paper, the reinforced concrete framed building has been analysed mainly for response quantities; the time period of building and base shear. Both quantities exhibit a governing role under the dynamic analysis and design of the structure.

The paper presented analytical data of time period of buildings having different configurations and dimensions of structural members and successfully presented the results to show the pattern by which the period depends upon the different parameters of the structure.

The study also presents the base shear of different building configurations evaluated by different mode combination methods. This study highlights the effect of mode combination methods on total base shear value. It can be remarked that the SRSS method gives the most conservative base shear among all considered methods. For the lesser height of buildings (in this paper, for 5.6m height) difference in base shear values are higher with respect to SRSS method. But, this difference decreases with increase in height of the building, thus, base shear values are close to each other for the higher vertical dimension of buildings, but with its lower side values under SRSS method.

Hence the work supports a better understanding of the response of structure for different configuration and mode combination methods. The use of this study can support for better response based design of the structure.

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