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Behaviour of Coupled Shear Wall Building

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Abstract— High rise building has become need of today's era. High rise building is a structure vertically cantilevered from the ground level subjected to axial loading and lateral forces. Lateral forces generated either due to wind blowing against the building or due to the inertia forces induced by ground shaking which tend to snap the building in shear and push it over in bending. Shear walls have been the most common lateral force resisting elements for tall building besides frame systems. For building taller than 10-stories, frame action obtained by the interaction of slabs and columns is not adequate to give the required lateral stiffness. But it can be improved by strategically placing shear walls as it is very effective in maintaining the lateral stability of tall buildings under severe wind or earthquake loading. In present study twelve storied reinforced concrete building with coupled shear wall is analysed using soft tool SAP2000.The analysis done for the 2D and 3D structure by response spectrum method.
Keywords— High Rise Building, Coupled Shear Wall, Response Spectrum.

I. INTRODUCTION

Shear walls have been the most common lateral force resisting elements for tall building besides frame systems. It is an efficient method of ensuring the lateral stability of tall buildings and also efficient against torsional effects when combined together with frame structures. Their stiffness is such that sway movement under lateral load can be minimized.

For building taller than 10-stories, frame action obtained by the interaction of slabs and columns is not adequate to give the required lateral stiffness (Taranath 1998). It also has become an uneconomical solution for tall buildings. However it can be improved by strategically placing shear walls as it very effective in maintaining the lateral stability of tall buildings under severe wind or earthquake loading. Shear wall and coupled shear wall structures have been found to be economical up to the 30 to 40 story range, and shearwall/frame structures have shown their effectiveness up to 50 stories. Coupled shear wall is a continuous wall with vertical rows of opening created for windows and doors, coupled by beams that interconnecting the wall piers across the openings. These connecting beams are referred to as coupling beams.

It may be shallow or deep beam type constrained by the walls on either side. Coupling beam has to be ensured adequately strong and stiff under elastic loading, ductile and able to dissipate energy under inelastic loading to achieve desirable performance of these structures (Lam et al., 2005) as its behaviour and modes of failure are highly effect the mode of failure of shear wall.

II. PROBLEM STATEMENT

In present study 12 storied reinforced concrete building analysed in SAP2000 by response spectrum method with coupled shear wall as shown in fig.1, fig.2 and fig.3is considered for analysis. The lateral forces have been resisted by a dual system consisting of special moment resisting frames (SMRF) and reinforced concrete coupled shear walls. Floor to floor height is 3.1 m andplinth height is 1.2 m above footing bottom.Parapetwall height is 1.2 m at terrace.

Building is located in seismic zone IV. Hard soil strata is considered for analysis and soil structure interaction is neglected. Building importance factor is 1. Geometric properties of members are shown in table Response reduction factor R =5 has been opted for following two reasons.

A. The coupled shear wall and the SMRF system are designed to resist the total design lateral forces in proportion to their rigidities considering the interaction of the dual system at all floor levels.

B. The SMRF are to be designed independently considering not less than 25% of the design lateral forces as per IS 1893 (Part 1): 2002.

Volume 4 Issue XI, November 2016
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TABLE I

GEOMETRIC PROPERTY OF COMPONENTS

Sr. No	Section Details	Dimensions
1	Beams	400 x 700 mm
2	Columns	900 x 900 mm for first 4 storeys and 750 x 750 mm for all above storeys
3	Slab Thickness	150 mm
4	Outer Wall Thickness	230 mm
5	Inner Wall Thickness	150 mm
6	Shear wall thickness	300 mm

TABLE III

MATERIAL PROPERTY

Material	Unit weight (kN/m3)	Yield Stress (MPa)	Expected Tensile strength (MPa)	Compressive Strength(MPa)
Concrete	25	-	-	25
Reinforcement	76.9729	415	518.750	-
Brick	20	-	-	-

Building plan and elevation is shown in fig.1 and fig.2 respectively which also shows location of shear wall. Fig.3 indicates typical sectional details of coupled shear wall

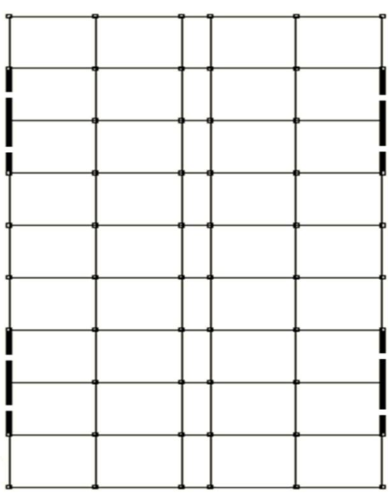

Fig.1 Plan

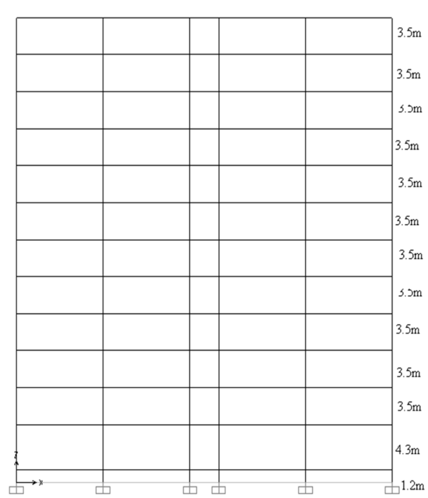

Fig.2 Elevation

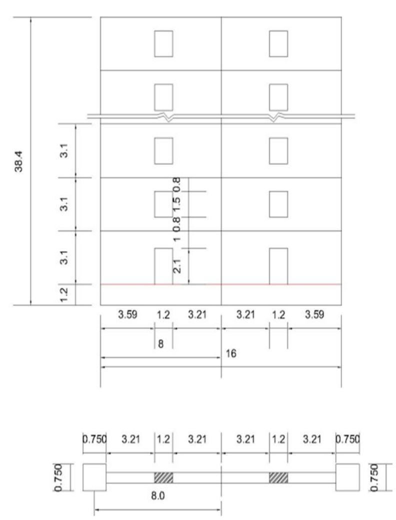

Fig.3 Coupled shear wall elevation and section

III. LOADING CALCULATION

The Dead loads are calculated as per IS 875: 1987(part1). The density of R.C.C is assumed to be 25kN/m^3 and the density of masonry (including Plastering) is assumed to be 20 kN/m^3, floor finishes load is 1kN/m2and roof treatment is 1.5 kN/m^2 .The Dead Load due to slabs has been transferred to beams by following yield line pattern of load distribution. Live load on floor is 3 kN/m^2 and Live load on roof is 1.5 kN/m^2.The seismic load is calculated, as per IS 1893:2002 (Part 1). Various load combinations using the primary load cases discussed above have been used to check the stability of the building as well as of its structural components. The following load combinations have been used and the structure has been designed for forces developed.

1) 1.5 (DL + LL) 2) 1.2 (DL+LL ±EQX) 3) 1.2 (DL+LL ± EQY) 4) 1.5 (DL ± EQX)
5) 1.5 (DL ± EQY) 6)0.9DL±1.5 EQX 7) 0.9DL±1.5 EQY

IV. MODELLING

In present study12 storied building is modeled as 2D frame and 3D building. Buildings can be analyzed by idealizing the structure into simple two-dimensional or more refined three-dimensional continuums. In Analysis of 2D frame a particular column line has been chosen to analyze the building, in which total effectiveness of the building seldom achieved. On other hand, in three-dimensional analysis the whole building is taken for the analysis and thus the structure can be modeled more realistically. The same geometric properties have been used for both 2D and 3D dimensional analysis. 2DModelling is done in Y direction since emphasis is to study the behavior of building in the direction of coupled shear wall.

The structures is modeled in SAP2000 v14. Line elements having 6 DOF per node is used for modelling beam and columns. The coupled shear wall is modeled using wide column analogy with Rigid beams at each floor level of the shear wall. Slab is not modeled andself-weight due to slab are imposed on the adjacent beams as dead load. The infill walls are also not modeled and weight due to it is taken as uniform loads over the periphery beams.

A. Modelling of coupled shear walls

Modelling of coupled shear walls is carried out as per assumption in the wide column frame analogy. Following are major steps involved in the modelling of coupled shear wall

Defining the coordinate:Shear walls are represented as two line element (center line of shear wall) and coupling beams are represented as line element (center line of beam) by joining each other with rigid link. In this column and coupling beam is defined with concrete material and rigid link is defined with rigid material as follows.

Defining material:The rigid material has been assigned to the rigid link which joins the coupled shear wall and frame at each floor level. The modulus of elasticity has been increased by 1000 times as compared to the concrete as shown in Table 3.

TABLE IIIII

BASIC MECHANICAL PROPERTIES OF MATERIALS

Material	UnitWeight KN/m^3	UnitMass KN-s^2/m^4	E1 KN/m^2	G12 KN/m^2	U12	A1 1/C
Fe415	7.6973E+01	7.8490E+00	199947978.8	-	-	1.1700E-05
M25	2.5000E+01	2.5493E+00	25000000.00	10869565.2	0.150000	9.9000E-06
rigid	0.0000E+00	0.0000E+00	2.500E+10	1.087E+10	0.150000	1.1700E-05

Assigning frame sections:The frame section is defined as per problem dimension for beam and column

Dimension of shear wall modeled as wide column

Depth of column = 3.2125 m and 6.425 m

Width of column = 0.3 m

Dimension of coupling beam

Depth of beam = 1.6 m and 0 .8 m

Width of beam = 0.3 m

1) *Assigning rigid link between column and beam joints*
2) *Assigning load*

Uniform load which includes dead and live load is applied on beam.

Volume 4 Issue XI, November 2016
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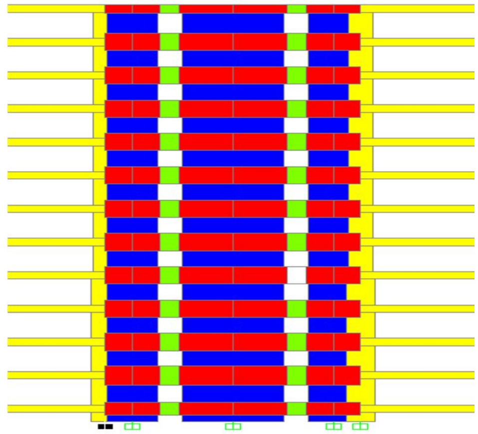

Fig 4 Modelling of coupled shear wall

B. Two-Dimensional Modelling In Y Direction

The building consists of two exterior frames with coupled shear wall and four interior frames with shear wall as shown in fig.5 inY direction. The two-dimensional plane frame model has been used for determination of lateral forces in frames with and without shear wall assuming no torsion effect.The mathematical model connects all plane frames in the direction of motion by assuming the same horizontal displacement in the floor. In present study framesmodeled as single lumped framewith double stiffness, strength and weight since they are identical to each other. The coupled shear wall has been modeled using wide column analogy. The adjacent columns are connected to the coupled shear wall by rigid links. Then these three lumped frames are connected with hinged rigid bars at each floor level as shown in the fig. 5 The Beams are made short, stiff such that their axial deformations are negligible. This is based on the assumption that the floor slab act as rigid diaphragms.

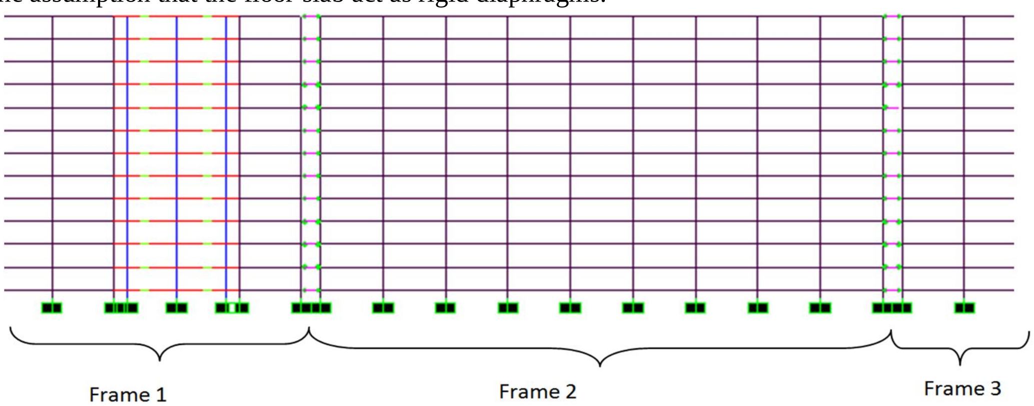

Fig 5. 2D modelling of the building in Y direction.

Mode shape 1 of 2D building frame is shown in the fig.6 the time period is 0.807162 Sec observed.

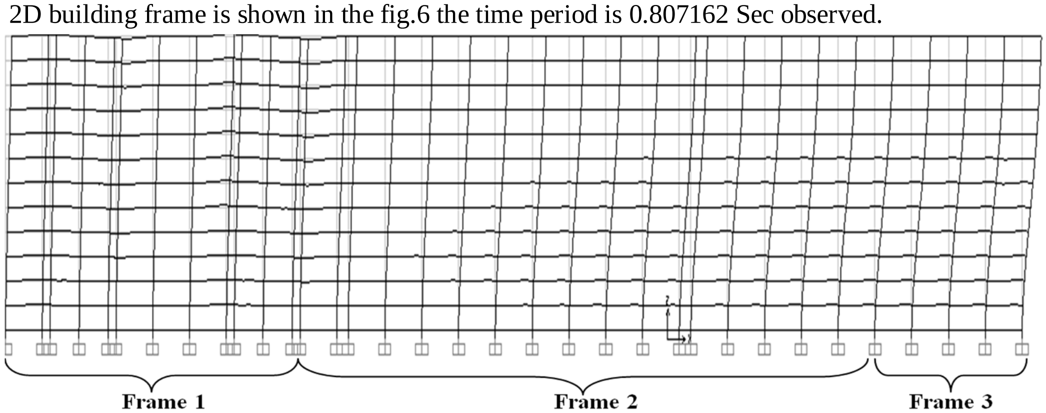

Fig.6 Mode shape 1 of 2D model

Volume 4 Issue XI, November 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

The lateral forces calculated by using guidelines laid by IS 1893:2002 are applied on the combined frame. The distribution of the lateral forces in frame1 and frame 2-3 is given in the Table4. The table reflects the fact that in frame shear wall systems, interaction between frame and wall under lateral load, the frame supports the wall at top while most of the horizontal shear is resisted by the shear wall at base. For this reason it is advised to check the upper storey columns. Therefore some of authorities advocate in case of the tall buildings, a minimum column reinforcement of 1.25% of gross column area in place of the usual 0.8% in upper most storeys. The table also indicates that two exterior frames with coupled shear wall take about 93% of the base shear and four interior frames take only about 7% of the base shear. According to IS 1893(Part 1):2002 in dual system moment resisting frames are designed to independently resist at least 25% of the design seismic base shear .

TABLE IVII

DISTRIBUTION OF SEISMIC STOREY SHEARS BETWEEN FRAME 1 AND FRAME2-3

Storey Level	Frame 1 and Exterior Frame		Frame 2 and Frame		Total storey shear (kN)
	Storey shear (kN)	% of Total (kN)	Storey shear (kN)	% of Total (kN)	
12	1802.425	43.07	2382.64	56.93	4185.0639
11	4594.66	54	3913.978	46	8508.638
10	7449.66	61.66	4632.18	38.34	12081.84
9	10363.48	69.2	4612.55	30.8	14976.13
8	12812.58	74.22	4450.4	25.78	17262.98
7	14832.704	78.01	4181.146	21.99	19013.85
6	16743.605	82.48	3556.595	17.52	20300.2
5	18209.45	85.92	2984.045	14.93	21193.5
4	19246.98	88.43	2518.24	11.57	21765.22
3	20004.02	90.57	2082.786	9.43	22086.81
2	20289.07	91.27	1940.65	8.73	22229.73
1	20555.78	92.32	1709.684	7.68	22265.47

C. Three Dimensional Modelling

In three dimensional modelling, building has been idealized as assemblage of the vertical frame and coupled shear wall system interconnected by horizontal floor diaphragms that are rigid in their placefig.7. Wide column analogy is used for modelling of coupled shear wall. The 3D analysis has been carried without the torsion effect. Table 5 shows the time period and modal mass participation.

V. CORRECTION FOR BASE SHEAR

The total base shear obtained using the model is less than the empirical one due to the assumptions made in the model. Hence a correction has been applied to the response quantities such as member forces, displacements, storey forces, storey shear and base reactions. This is done by multiplying the design horizontal seismic coefficient $A_{hx}$with$\frac{\overline{VBx}}{VBX}$ and A_{hy} with $\frac{\overline{VBy}}{VBY}$.

TABLE VV

DISTRIBUTION OF SEISMIC STOREY SHEARS BETWEEN FRAME 1 AND FRAME2-3

	Manual (kN)	SAP (kN)
Seismic weight	377857.48	369093.243
Base in X Direction	$\overline{VBx}$ =16386.93	V_{BX} = 4397.813
Base in Y Direction	$\overline{VBy}$ = 22265.465	V_{BY} = 10201.54

$$\frac{\overline{VBx}}{VBX} = \frac{16386.93}{4397.813} = 3.72$$

Volume 4 Issue XI, November 2016
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International Journal for Research in Applied Science & Engineering Technology (IJRASET)

$$\frac{\overline{\text{VBy}}}{\text{VBY}} = \frac{22265.465}{10201.54} = 2.183$$

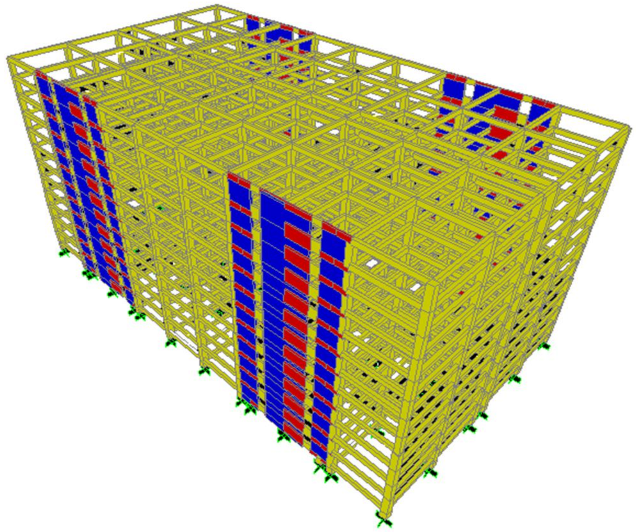

Fig. 7 Three-dimensional model

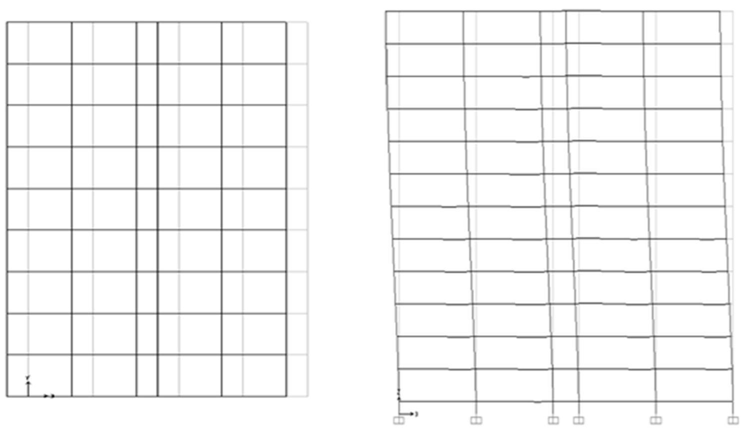

Fig. 8 Mode 1 Plan and elevation

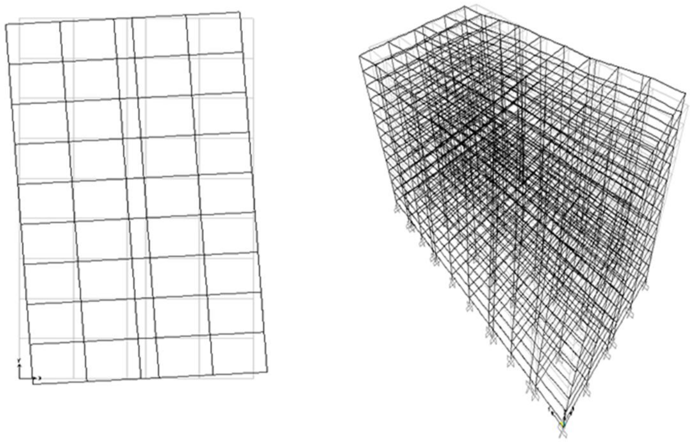

Fig. 9 Mode 2 Plan and 3D view

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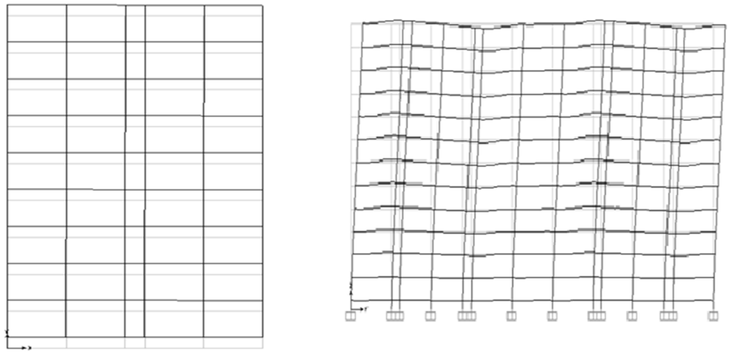

Fig. 10 Mode 3 Plan and Side view

TABLE V
MODAL PARTICIPATION MASS RATIO FOR VARIOUS MODES

Modal Participating Ratio					
Mode	Period	UX in %	SUM UX	UY in %	SUM UY
1	1.887151	75.447	75.447	0	0
2	0.875478	0	75.447	0.025	0.025
3	0.737121	0	75.447	70.896	70.922
4	0.606817	11.023	86.47	0	70.922
5	0.3345	4.109	90.579	0	70.922
6	0.260963	0	90.579	0.016	70.937
7	0.219537	2.308	92.887	0	70.937
8	0.217495	0	92.887	19.49	90.427
9	0.174382	0	92.887	0	90.427
10	0.173476	0	92.887	0	90.427
11	0.172491	0	92.887	0	90.427
12	0.171621	0	92.887	0	90.427

VI. COMPARISON BETWEEN 2D AND 3D MODEL

The Table6 shows displacements of the joints of the exterior frame with coupled shear wall under 1.5(DL+EQX) load case. In Figure11, displacement obtained from two and three dimensional analysis has been plotted against building height for the frame with the coupled shear wall. It is evident from the figure that displacements obtained from two dimensional analysis are slightly greater than three dimensional analysis.

TABLE VI
DISPLACEMENTS OF EXTERIOR FRAME BY 2D AND 3D ANALYSIS

Output Case	Height in m	2D analysis	3D analysis
		Displacement (m)	Displacement (m)
1.5(DL+EQX)	0	0	0
1.5(DL+EQX)	1.2	0.00011	0.000171
1.5(DL+EQX)	4.3	0.001069	0.001375
1.5(DL+EQX)	7.4	0.002637	0.002843
1.5(DL+EQX)	10.5	0.004527	0.00449
1.5(DL+EQX)	13.6	0.006601	0.006255

1.5(DL+EQX)	16.7	0.008851	0.008152
1.5(DL+EQX)	19.8	0.011228	0.010111
1.5(DL+EQX)	22.9	0.013648	0.012095
1.5(DL+EQX)	26	0.016048	0.014067
1.5(DL+EQX)	29.1	0.01837	0.015991
1.5(DL+EQX)	32.2	0.020565	0.017842
1.5(DL+EQX)	35.3	0.022602	0.019573
1.5(DL+EQX)	38.4	0.024504	0.021139

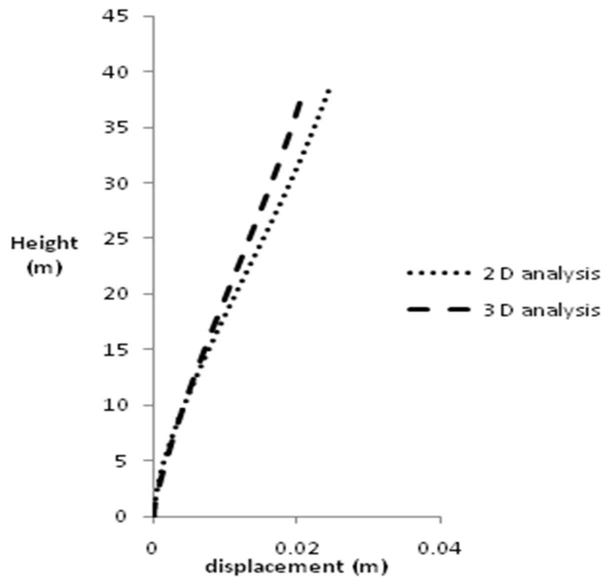

Fig11. Graph of displacement along the building height.

In effort to understand role of the analysis techniques, the ratio of shear force and bending momentobtained from 2D and 3D analysis are tabulated in the Table 7 and Table 8. The shear force and bending moment tabulated are of one complete column(from ground storey to upper most storey). It is interesting to note that ratio of V_{2-D}/ V_{3-D} oscillates between 1to 2. The 2D analysis gives upper bound forces. Similarly ratio of M_{2-D} /M_{3-D} is nearby 1, in this also 2D analysis provide higher forces.

TABLE VII

SHEAR FORCE OF EXTERIOR COLUMN BY 2D AND 3D ANALYSIS

Output Case	2D analysis V_{2-D}	3D analysis V_{3-D}	V_{2-D} /V_{3-D}
1.5(DL+EQX)	279.29	194.849	1.43
1.5(DL+EQX)	308.24	142.596	2.16
1.5(DL+EQX)	287.38	140.37	2.047
1.5(DL+EQX)	237.39	119.314	1.98
1.5(DL+EQX)	244.9	137.272	1.784
1.5(DL+EQX)	204.8	112.193	1.81
1.5(DL+EQX)	229.89	128.602	1.78
1.5(DL+EQX)	226.26	126.634	1.79
1.5(DL+EQX)	226.75	127.054	1.78
1.5(DL+EQX)	225.11	124.65	1.81
1.5(DL+EQX)	221.71	125.521	1.76
1.5(DL+EQX)	198.7	112.891	1.71
1.5(DL+EQX)	250.29	153.59	1.63

Volume 4 Issue XI, November 2016
ISSN: 2321-9653
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TABLE VIII

BENDING MOMENT OF EXTERIOR COLUMN BY 2D AND 3D ANALYSIS

Output Case	2D Analysis M_{2-D}	3D Analysis M_{3-D}	M_{2-D}/M_{3-D}
1.5(DL+EQX)	1432.598	1242.67	1.153
1.5(DL+EQX)	1374.372	1131.04	1.215
1.5(DL+EQX)	953.6259	991.28	0.962
1.5(DL+EQX)	642.8956	538.46	1.194
1.5(DL+EQX)	517.3072	447.43	1.156
1.5(DL+EQX)	387.6652	297.51	1.303
1.5(DL+EQX)	403.2968	330.72	1.219
1.5(DL+EQX)	354.924	264.87	1.34
1.5(DL+EQX)	324.2218	298.59	1.086
1.5(DL+EQX)	292.8182	213.83	1.369
1.5(DL+EQX)	262.5051	210.61	1.246
1.5(DL+EQX)	234.8291	172.0706	1.365
1.5(DL+EQX)	270.332	207.07	1.306

VII. CONCLUSION

A. Short coupling beams were subjected to huge Shear.

B. The beams which are connected to coupled shear wall were subjected to huge shear forces, due to the rigid beam action of the shear wall.

C. Frame with coupled shear wall carries almost 93% of total base shear and frames without coupled shear wall carries only about 7% of total lateral load. Therefore it is essential that frames without coupled shear wall are to be designed independently for 25% of total lateral forces.

D. In Frame coupled shear wall systems, frame supports the wall at top while at base most of the horizontal shear is resisted by the shear wall.

E. 3D modelling of the coupled shear wall building modelled as wide column analogy gives fundamental time period as 1.88seconds.

F. Ratio V_{2-D}/V_{3-D} oscillates between 1to 2 and ratio of M_{2-D}/M_{3-D} is nearby to 1.

G. In building analyzed both by two and three-dimension, displacements obtained from two dimensional analyses are slightly greater than three dimensional analyses.

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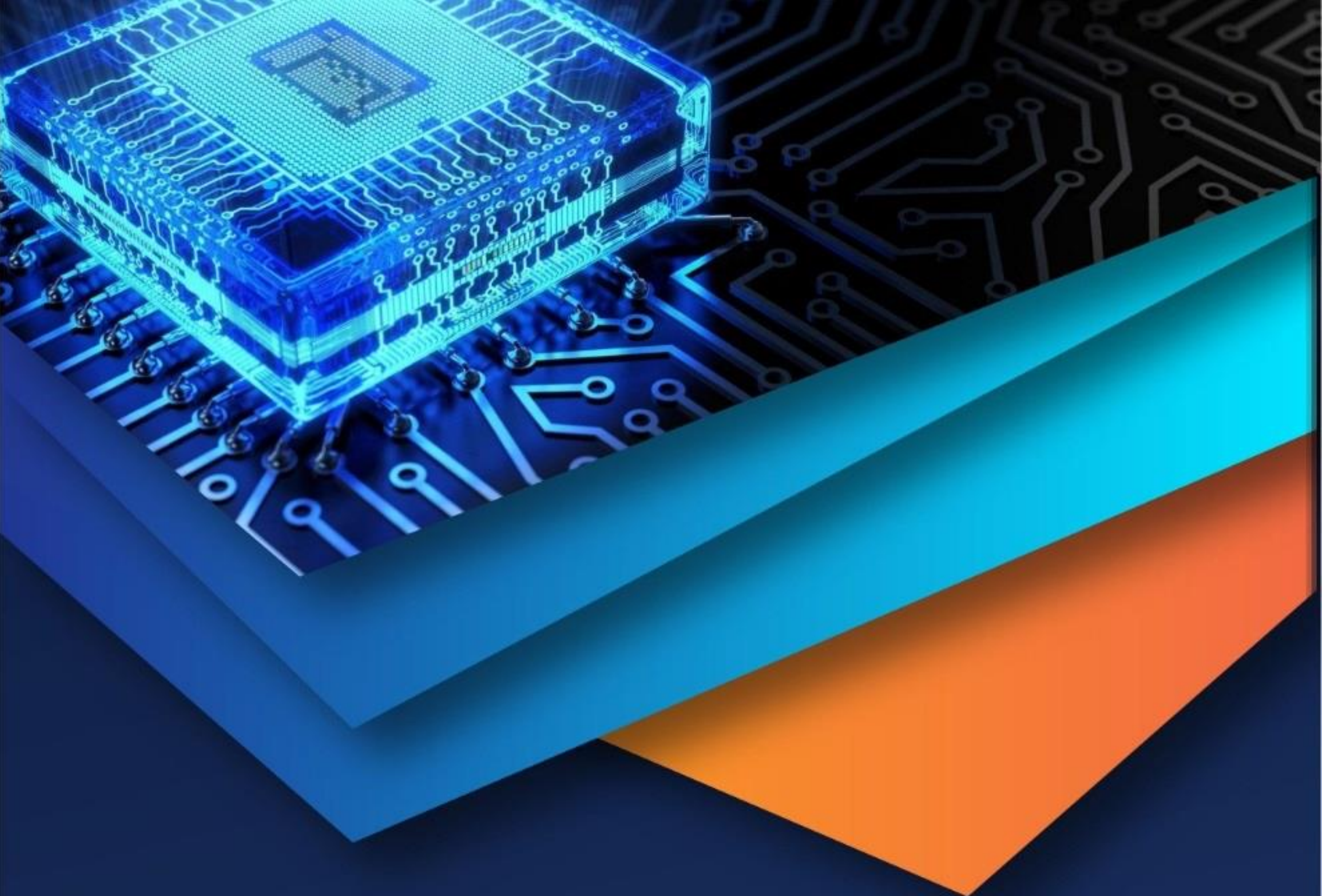

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