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Seismic Analysis of RC Bare Frame Structure Replacing Ground Storey with Strut-Tie and Deep Beam

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***Abstract*— These days high rise buildings are preferred due to constraint in space. These edifices are subjected to high sway forces hence proven to be hazardous during quake tremor. To improve the performance of the structure during earthquake lateral load resisting systems must be acquired.**

The theses high spot the seismic analysis of reinforced concrete building with and without deep beam as well as replacing the deep beam with equivalent strut-tie model. The proportion of proposed building is 24m X24m. The overall height of the building is 33.3m which includes 3.5m ground storey height and remaining storey height is 3.2m. Parapet of 1 m height is provided. The building is considered to be located in seismic zone 5. Analysis is performed for 6 models using E-TABS 2013. Two methods of analysis name equivalent static method and dynamic method are adopted.

The study shows that the deep beams are effective compared to conventional model. But as the deep beams are not convenient in terms of price and mental synthesis, they can be replaced by equivalent strut-tie model which also proves to resist the lateral forces more efficiently.

Keywords*— *Lateral load resisting system, deep beam, strut-tie model, equivalent static method, dynamic method.

I. INTRODUCTION

Earthquake is sudden slip of earth's crust which causes the earth to shake and brings huge harm to the society. The area in the earth's crust which leads to earthquake is called faults. When the rocks in the region of fault are abruptly disturbed, an enormous amount of energy is released and the consequent vibrations outspread in all the directions from the origin of the agitation. An earthquake is a path of these vibrations. It is a natural phenomenon which is the most outrageous and devasting. The terrific part of earthquake is that it is unpredictable.

The source of earthquake in the inner part of the earth is termed as focus and the point perpendicular to it on the exterior of the earth is termed as epicenter. The dispersion of seismic energy during an earthquake takes place in the form of waves. These waves are classified as Body waves and Surface waves. The body waves travel through the interior of the earth where as the surface waves travel along the exterior of the earth. The body waves are further classified as P-waves and S-waves.

The P-wave is the primary wave that is the first wave to arrive followed by the S-wave or transverse waves which arrive after.[1]

Bare frame models do not contain filler material like brick masonary, hence not stronger compared to to infill models.

A. *Concept of Deep Beams*

Deep beams are part of structural element loaded as beams in which a major amount of load is transferred to the supports by a compressive impel which combines the load and the reaction. As an outcome, the strain dispensation is no more believed to be linear and the strain deformation gets decisive when pure flexure is considered.[4]. Deep beam is characterized by shear span effective depth ratio. A beam is termed as deep beam only if the shear span to depth ratio (a/d) is less than unity [5].

According to Indian Standards, a beam is designated as deep beam when shear span to depth ratio (l/d) is less than

a) 2.5 for continuous beam
b) 2 for simply supported beam

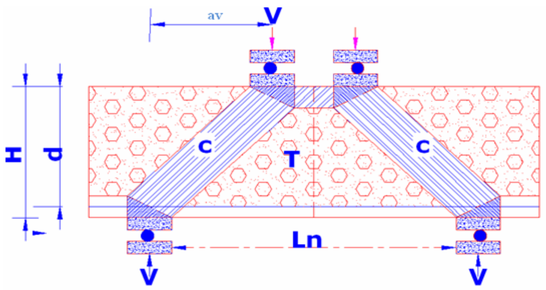


Fig. 1 Dimensions of Deep Beam

B. *Strut-Tie Model*

Strut and tie modeling is a straightforward method which well expresses complicated stress patterns as triangulated models. It is based on truss analogy and generally employed to design irregular components of concrete structure for example corbels, deep beams, pile caps, beam with holes etc. where the theory of normal beams cannot be applied essentially. The design engineer requires enough experience to impart clean engineering solution to composite structural problems.

The deep beams support the whole structure. The structural behavior of the deep beam is influenced by the stability and safety of the structure. Since the stress allocation is not linear, the theory of linear elasticity cannot be relevant. Consequently the ACI code insists on deep beams designed by the use of non-linear analysis or by Strut-Tie models.[8]

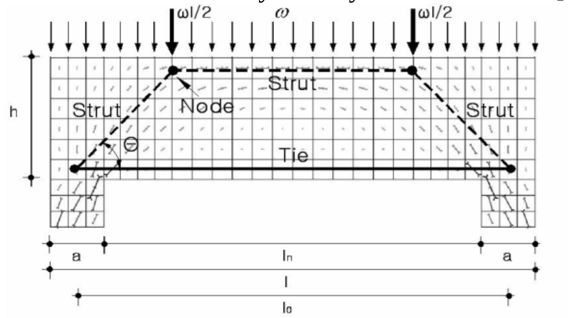


Fig. 2 Strut-Tie Model

II. METHODOLOGY

A. Problem Defination

1. Size of bay - 6m X 6m
2. Storey numbers - 10
3. Height of bottom storey - 3.5m
4. Height of above storey's - 3.2m
5. Column size for bottom storey - 950mm X 950mm
6. Column size for upper storey - 600mm X 600mm
7. Depth of deep beam used for width of strut and tie - 3000mm
8. Size of deep beam - 300mm X 3200mm
9. Size of normal beams - 300mm X 400mm
10. Thickness of slab - 150mm
11. Wall thickness - 230 mm
12. Parapet wall - 150mm

Table 1. Concrete Properties

Concrete Properties	
Concrete Grade	M30
Elastic Modulus	27386.12 MPa
Poisson's Ratio	0.2
Concrete Density	25 kN/m³

Table 2. Properties of Reinforcement Steel and Masonry

Properties of Reinforcement Steel and Masonry	
Grade of steel	Fe 415
Elastic Modulus	210000 MPa
Poisson's Ratio	0.3

Table 3. Seismic Parameters as per IS 1893-2002

Seismic Parameters as per IS 1893-2002	
Zone	V
Soil Type	Medium Soil
Impact Factor	1

B. Modelling

The model is analyzed by the following steps

1. Material properties such as grade of concrete, grade of steel, masonry etc are defined
2. Definition of section properties.(beam, column, slab)
3. The sections are inputted and the columns in the base are restrained.
4. The DL and LL are assigned and data related to load pattern and load cases are put in
5. Diaphragm is defined and assigned for the whole structure.
6. Various load combination are assigned to analyze the structure.
7. The following model is analyzed.

C. Models Considered for Analysis

In particular this study comprises of 6 models enrolled in table below.

Table 4. Models Considered for Analysis

Model number	Description of Models
Model 1	Conventional Model
Model 2	Model Comprising 3m Deep Beam at Ground Storey
Model 3	Model Comprising 3.2m Deep Beam at Ground Storey
Model 4	Model with Strut-Tie Configuration 1
Model 5	Model with Strut-Tie Configuration 2
Model 6	Model with Strut-Tie Configuration 3

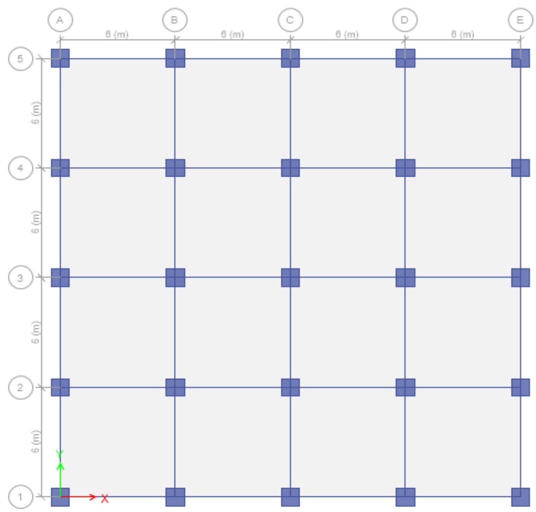


Fig.3 Plan for Model 1

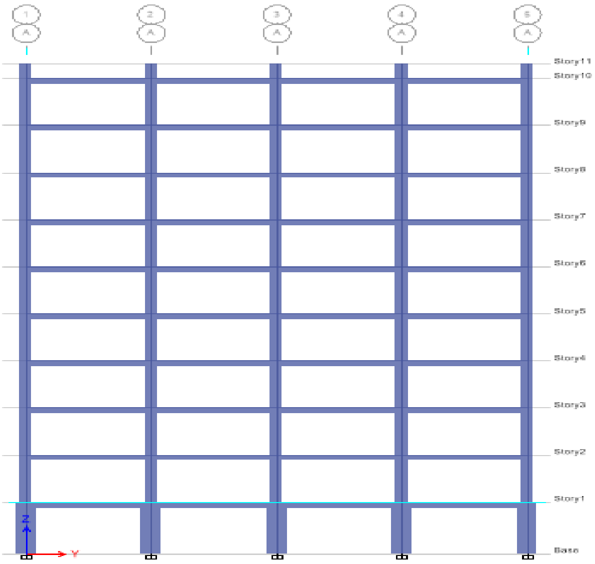


Fig. 4 Elevation for Model 1

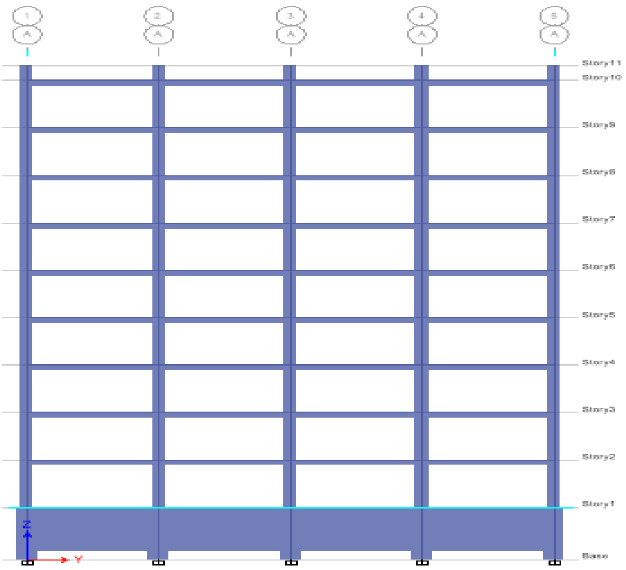


Fig. 5 Elevation for Model 2

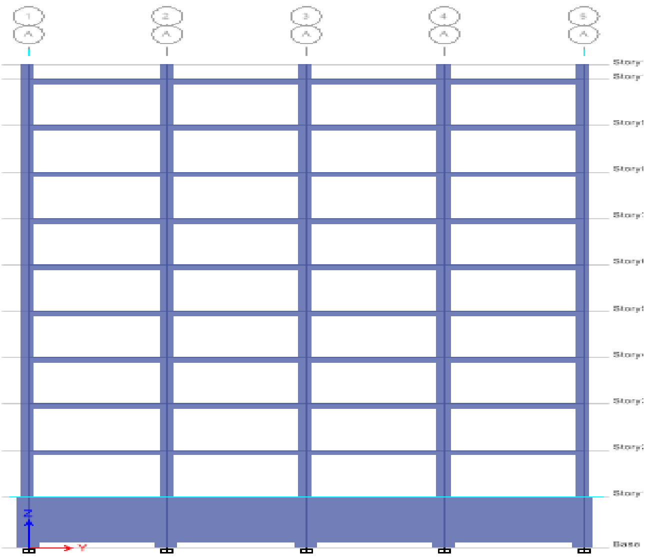


Fig.6 Elevation for Model 3

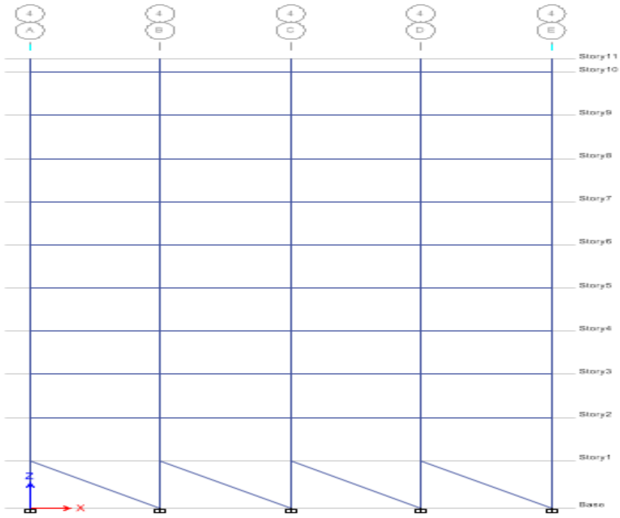


Fig.7 Elevation for Model 4

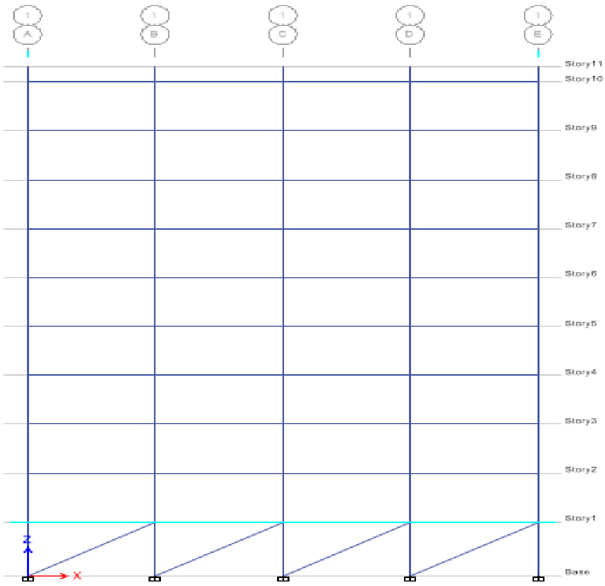


Fig.8 Elevation for Model 5

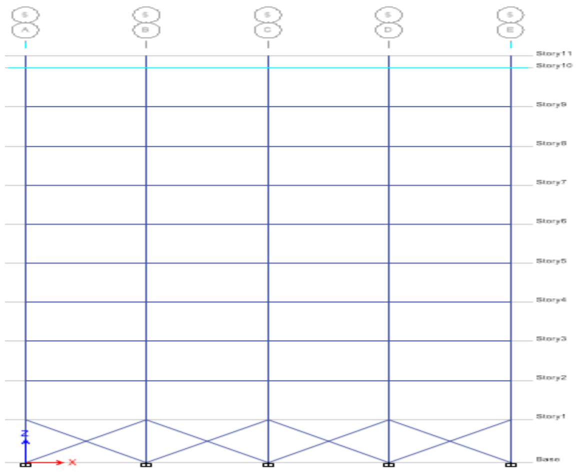


Fig.9 Elevation for Model 6

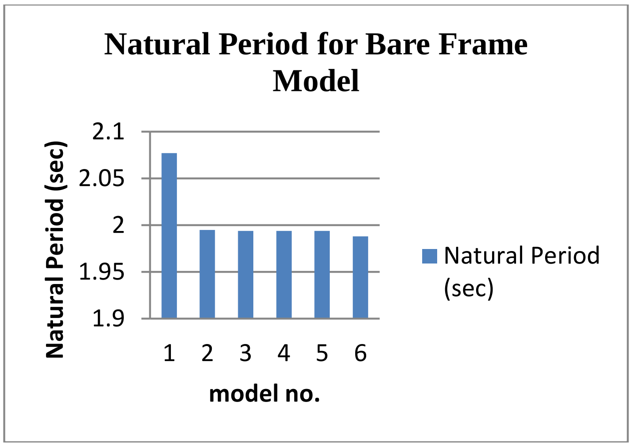
III. COMPARATIVE RESULTS

A. *Comparison for Dynamic Analysis*

1. Comparison for Natural Period

Table 5. Natural Period by Dynamic Analysis

Natural Period (secs)	1	2	3	4	5	6
	2.077	1.995	1.994	1.994	1.994	1.988



Graph no. 1 Combined Natural Period by Dynamic Analysis

The natural period of model 1 is 101.01% greater as compared to model 6.

2. Comparison for Base Reaction

Table 6. Base Reaction (kN) by Dynamic Analysis

Model No.	Base Reaction (kN)
1	71336.951
2	72965.769
Model No.	Base Reaction (kN)
3	73284.26
4	73052.14
5	73052.14
6	78578.306

In comparison to the 6 models the base reaction for model 6 is 101.1% greater than model 1.

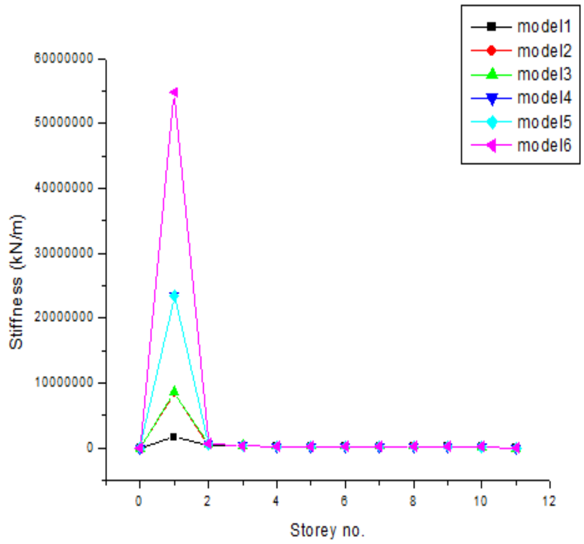
3. Comparison for Stiffness

Table 7.a Stiffness in kN/m by Dynamic Analysis

Storey No.	Model 1	Model 2	Model 3
11	18387.552	18698.828	18880.727
10	181096.632	182735.565	184550.232
9	244616.965	243674.405	245509.286
8	245602.173	246106.296	246240.57
7	241589.982	242353.315	242221.166
6	238246.974	237803.751	238636.345
5	239534.727	241162.268	241622.759
4	249942.579	256209.375	256143.207
3	286291.239	307109.771	307524.221
2	452483.677	616234.378	618462.089
1	1682452.542	8406322.7	8606931.81
base	0	0	0

Table 7.b Stiffness (kN/m) by Dynamic Analysis

Storey No.	Model 4	Model 5	Model 6
11	18761.33	18761.331	18093.38
10	183497.271	183497.281	177633.75
9	244698.136	244698.136	240353.22
8	245975.032	245975.031	245342.36
7	242006.617	242006.616	241678.94
6	238345.89	238345.887	236657.27
5	241341.21	241341.21	240463.11
4	255686.528	255686.528	256190.19
3	305817.924	305817.924	306719.5
2	600748.132	600748.138	614972.98
1	23454748	23454749	54788434
base	0	0	0



Graph no. 2 Combined Stiffness (Dynamic Analysis)

The following observations are made from the graph:

i. Model 6 is greatest of all the models in terms of stiffness. The stiffness of model 6 is greater by 132.56 % compared to model 1 at storey 1. The stiffness of other storeys is not significant as seen in graph. The strut tie configuration makes the storey 1 stiff in comparison to other storeys.

ii. Among the deep beam models and strut-tie models the stiffness for model 6 is 106.51% greater than model 2.

iii. At the top level i.e. storey 10 the stiffness of model 3 is greater than model 2 by 101.03%.

iv. When the deep beams are considered the stiffness of model 3 is significant by 101.2% in comparison to model 2.

v. Amongst the equivalent strut-tie model the stiffness of model 6 is significant by 102.33% compared to model 5.

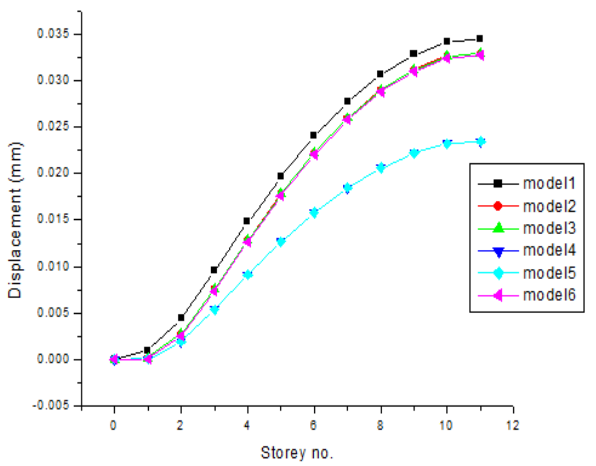
4. Comparison for Storey Displacement

Table 8.a Displacement (mm)

Storey No.	Model 1	Model 2	Model 3
11	0.03451	0.03296	0.03295
10	0.03419	0.03263	0.03261
9	0.03278	0.03119	0.03117
8	0.03063	0.02898	0.02897
7	0.02769	0.02598	0.02596
6	0.02402	0.02224	0.02222
5	0.0197	0.01783	0.01781
4	0.01479	0.01286	0.01284
3	0.009518	0.007579	0.007569
2	0.004417	0.00273	0.002723
1	0.000952	0.000188	0.000184
base	0	0	0

Table 8.b Displacement (mm) by Dynamic Analysis

Storey No.	Model 4	Model 5	Model 6
11	0.02343	0.02343	0.03271
10	0.0232	0.0232	0.03238
9	0.02218	0.02218	0.03095
8	0.02061	0.02061	0.02875
7	0.01848	0.01848	0.02575
6	0.01581	0.01581	0.02202
5	0.01267	0.01267	0.01761
4	0.009129	0.009129	0.01264
3	0.005372	0.005372	0.007368
2	0.001907	0.001907	0.002542
1	0.00005123	0.00005123	0.00002824
base	0	0	0



Graph No. 3 Combined Displacements (Dynamic Analysis)

Observation made from the graph are as follows:

i. The conventional model undergoes the largest displacement among all the models. The displacement is significant by 101.47% compared to model 4. Model 4 and model 5 undergo least displacement because of Strut-tie arrangement.

ii. When considering strut-tie models and deep beams, the displacement for model 2 is significant by 101.40% when matched with model 5.

iii. At the last storey, displacement is 101.47% large for model 1 compared to model 4.

iv. The displacement for 3m deep beam is 101% larger in comparison to 3.2m deep beam.

v. Comparing the displacement amid strut-tie models, the displacement for model 6 is 101.4% larger than model 5.

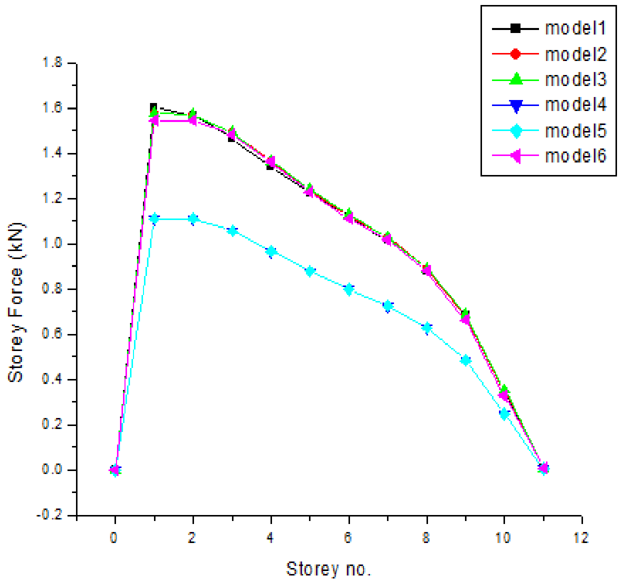
5. Comparison for Storey Forces

Table 9.a Storey Forces (kN) by Dynamic Analysis

Storey No.	Model 1	Model 2	Model 3
11	0.0081	0.0083	0.0084
10	0.3431	0.3483	0.3546
9	0.6818	0.6833	0.691
8	0.8799	0.8894	0.8891
7	1.0156	1.0266	1.0251
6	1.1195	1.1227	1.1282
5	1.2238	1.2368	1.2402
4	1.34	1.3651	1.364
3	1.4664	1.4917	1.493
2	1.5685	1.567	1.5708
1	1.6019	1.576	1.5801
base	0	0	0

Table 9.b Storey Forces (kN) by Dynamic Analysis

Storey No.	Model 4	Model 5	Model 6
11	0.0059	0.0059	0.0077
10	0.2482	0.2482	0.3291
9	0.486	0.486	0.6619
8	0.6284	0.6284	0.8785
7	0.7257	0.7257	1.0172
6	0.799	0.799	1.1108
5	0.8791	0.8791	1.228
4	0.9675	0.9675	1.3606
3	1.0581	1.0581	1.4819
2	1.1106	1.1106	1.5459
1	1.1122	1.1122	1.547
base	0	0	0



Graph no. 4 Combined Storey Forces (Dynamic Analysis)

The graph shows following observations:

i. The storey force for model 1 is greatest when compared with all the other models. It is sizeable by 101.01% as compared to model 3. From the graph it is also visible that the storey force is least for model 4 and model 5. The maximum force is generated at storey 1. The storey force gradually decreases for upper storey's.

ii. By measuring the storey force between the deep beams and strut-tie models, the storey force of deep beam model is observed to be significant by 101.40% compared to strut-tie model.

iii. At the last storey, displacement for model 3 is large by 101.42% than model 4.

iv. The comparison between the deep beams illustrated that the storey force for 3.2m depth beam is ample by 101% than 3m depth beam.

v. By judging the strut-tie models it is observed that the storey force for model 6 is greater by 101.39% than model 5.

B. Comparison for Static Analysis

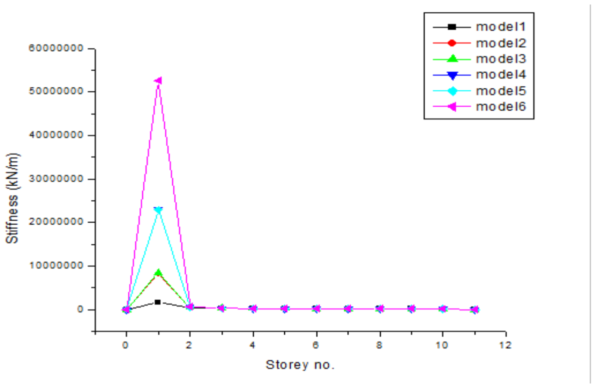
1. Comparison for stiffness

Table 10.a Stiffness (kN/m) by Static Analysis

Storey No.	Model 1	Model 2	Model 3
11	14737.858	14726.796	14727.038
10	149043.427	148971.016	148972.872
9	217876.816	217846.278	217848.259
8	229868.284	229928.376	229930.387
7	231456.391	231694.65	231697.369
6	231921.983	232587.208	232592.175
5	234448.817	236253.38	236264.683
4	243671.892	248890.487	248921.563
3	275199.012	293813	293924.777
2	430424.339	587488.885	588703.26
1	1623464.112	8285715.96	8483702.71
base	0	0	0

Table 10.b Stiffness (kN/m) by Static Analysis

Storey No.	Model 4	Model 5	Model 6
11	14746.258	14746.258	14761.447
10	149115.016	149115.016	149228.53
9	217980.044	217980.044	218090.27
8	230026.222	230026.222	230117.87
7	231762.405	231762.405	231852.27
6	232615.982	232615.982	232730.43
5	236200.106	236200.106	236398.8
4	248599.269	248599.269	249070.8
3	292564.875	292564.875	294150.1
2	573388.09	573388.09	589901.91
1	22952343	22952343	52574764
base	0	0	0



Graph no.5 Combined Stiffness (Static Analysis)

i. Among the 2 models of deep beams, the model 3 is stiff by 101.02% than model 2.

ii. Under the consideration of strut-tie model, model 6 is large than model 5 by 101.03%.

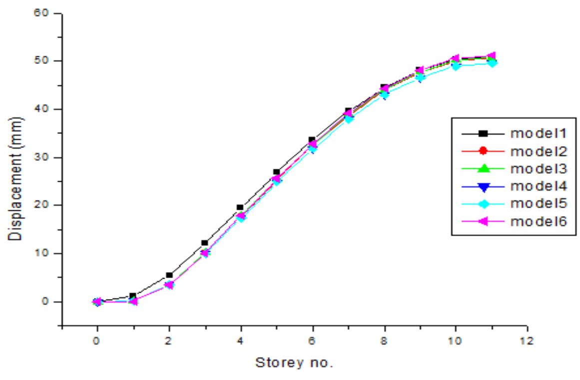
2. Comparison for Storey Displacement

Table 11.a Storey Displacement (mm) by Static Analysis

Storey No.	Model 1	Model 2	Model 3
11	50.9	50.7	50.8
10	50.4	50.1	50.3
9	48.1	47.7	47.8
8	44.5	43.9	44.1
7	39.7	38.8	38.9
6	33.7	32.6	32.7
5	26.9	25.4	25.5
4	19.6	17.8	17.9
3	12.2	10.2	10.2
2	5.5	3.6	3.6
1	1.2	0.2	0.2
base	0	0	0

Table 11.b Storey Displacement (mm) by Static Analysis

Storey No.	Model 4	Model 5	Model 6
11	49.6	49.6	51.2
10	49	49	50.6
9	46.6	46.6	48.1
8	43	43	44.3
7	38	38	39.2
6	31.8	31.8	32.8
5	24.9	24.9	25.6
4	17.4	17.4	17.8
3	10	10	10.1
2	3.5	3.5	3.4
1	0.1	0.1	0.03817
base	0	0	0



Graph no. 6 Combined Displacements (Static Analysis)

i. When the deep beams are matched for displacement, model 3 is significant by 101.02% than model 2.

ii. Amongst the strut-tie configuration the model 6 is effective in displacement by 101.03% I comparison to model 4.

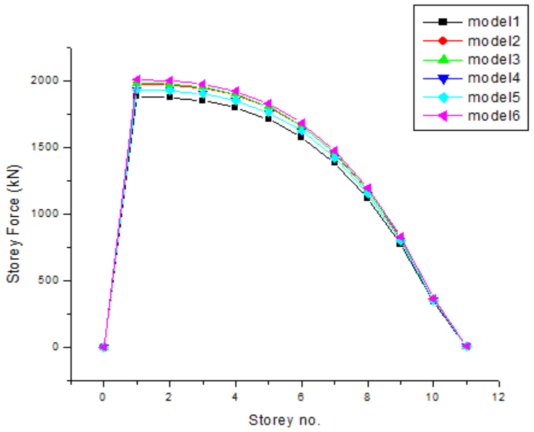
3. Comparison for Storey Forces

Table 12.a Storey Forces (kN) by Static Analysis

Storey No.	Model 1	Model 2	Model 3
11	7.7673	8.1726	8.2002
10	342.5024	360.3711	361.5873
9	775.0898	815.5271	818.2793
8	1117.7688	1176.084	1180.053
7	1381.0014	1453.05	1457.953
6	1575.2497	1657.432	1663.026
5	1710.9757	1800.239	1806.314
4	1798.6416	1892.479	1898.865
3	1848.7094	1945.158	1951.723
2	1871.6411	1969.287	1975.932
1	1878.3453	1977.053	1983.936
base	0	0	0

Table 12.b Storey Forces (mm) by Static Analysis

Storey No.	Model 4	Model 5	Model 6
11	7.9963	7.9963	8.2934
10	352.5964	352.596	365.6973
9	797.9328	797.933	827.5804
8	1150.711	1150.71	1193.466
7	1421.701	1421.7	1474.526
6	1621.674	1621.67	1681.929
5	1761.4	1761.4	1826.846
4	1851.65	1851.65	1920.449
3	1903.193	1903.19	1973.908
2	1926.801	1926.8	1998.392
1	1932.969	1932.97	2007.04
base	0	0	0



Graph no. 7 Combined Storey Forces (Static Analysis)

i. When the deep beams are analyzed for storey forces model 3 is noted to be significant by 101% than model 2.

ii. Among the 3 combinations of strut-tie model 6 is larger than model 5 by 101.03%.

IV CONCLUSION

1. The natural period is very high for conventional model compared to other models.
2. Model 4 and model 5 have the same natural period for the reason that the strut-tie configuration takes the forces in one direction only.
3. The natural period for model 6 is least due to its configuration which lets it to undertake storey forces in both the direction.
4. Observation show that the base reaction amplifies in the presence of strut-tie model.
5. The stiffness is maximum at storey 1 for the model 6. This is because the arrangement of strut and tie takes up both the compression and tension forces more effectively.
6. The displacement for all the models is almost same. The displacement is twice for model 4 in comparison to other models.
7. The storey force is maximum for model 1 and minimum for deep beam model.

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