STUDY OF SEISMIC AND WIND EFFECT ON MULTI STOREY R.C.C., STEEL AND COMPOSITE BUILDING

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ABSTRACT

Structural engineers are facing the challenge of striving for the most efficient and economical design solution while ensuring that the final design of a building must be serviceable for its intended function, habitable for its occupants and safe over its design life-time. As the our country is the fastest growing country across the globe and need of shelter with higher land cost in major cities like Mumbai, Delhi, Ahmadabad, Vadodara where further horizontal expansion is not much possible due to space shortage, we are left with the solution of vertical expansion. Engineers, designers and builders are trying to use different materials to their best advantage keeping in view the unique properties of each material Structurally robust and aesthetically pleasing building are being constructed by combining the best properties at individual material & at the same time meeting specific requirements of large span, building load, soil condition, time, flexibility & economy high rise buildings are best suited solution. Also Wind & Earthquake (EQ) engineering should be extended to the design of wind & earthquake sensitive tall buildings. This paper discusses the analysis & design procedure adopted for the evaluation of symmetric high rise multi-storey building (G+30) under effect of Wind and EQ. forces. In these building R.C.C., Steel, & Composite building with shear wall considered to resist lateral forces resisting system. This study examines G+30 stories building are analysed and design under effect of wind and earthquake using ETABS. Total 21 numbers of various models are analysed & designed & it proves that steel-concrete composite building is better option. Analytical results are compared to achieve the most suitable resisting system & economic structure against the lateral forces.

KEYWORDS: *Composite beam, Composite slab, Displacement, Seismic force.*

I. INTRODUCTION

High rise building means the building are tall say, “more than twelve storeys” [1] or in present context, high-rise building is defined as a structure “if height more than 35 meter” says tall building. Steel – concrete composite construction is a faster technology which saves lot of time in construction which will help the planners to meet the demand with minimum time in real estate market. This technology provides more carpet area than any other type of construction. Composite construction also enhances the life expectancy of the structure.

The aftermath of an earthquake manifests great devastation due to unpredicted seismic motion striking & also due to the increase the height of building developed critical wind effect on the structure due to this extensive damage to innumerable buildings of varying degree, i.e. either full or partial. This damage to structures in turn causes irreparable loss of life with a large number of casualties. Structures are designed to resist moderate and frequently occurring earthquakes & wind must have sufficient stiffness and strength to control displacement and to prevent any possible damage. However, it is inappropriate to design a structure to remain in the elastic region, under severe earthquakes & wind lateral forces, because of the economic constraints. The inherent damping of yielding structural elements can advantageously be utilized to lower the strength requirement, leading to a more economical design. This yielding usually provides the ductility or toughness of the structure against the sudden brittle type structural failure. A building must have a complete structural system

capable of carrying all gravity loads to its foundation in life span of building. While dealing with lateral forces, there is a natural trend to manage these forces with same methods used for gravity loads.
Introduction to Composite in the past, for the design of a building, the choice was normally between a concrete structure and a masonry structure. Failures of many multi-storied and low-rise R.C.C. and masonry buildings due to earthquake have forced the structural engineers to look for the alternative method of construction. [2] Use of composite or hybrid material is of particular interest, due to its significant potential in improving the overall performance through rather modest changes in manufacturing and constructional technologies. Two different materials are tied together by the use of shear studs at their interface having lesser depth in composite construction. It saves the material cost considerably. Thermal expansion (coefficient of thermal expansion) of both, concrete and steel being nearly the same. Therefore, there is no induction of different thermal stresses in the section under variation of temperature. General composite slab-beam arrangement is shown in (Fig. 1) **[9]**. A steel concrete composite beam consists of a steel beam, over which a reinforced concrete slab is cast with shear connectors. The composite action reduces the beam depth. Rolled steel sections themselves are found adequate frequently for buildings and built up girders are generally are not necessary. The composite beam can also be constructed with profiled sheeting with concrete topping or with cast in place or precast reinforced concrete slab. The profiled steel sheets are provided with indentations or embossments to prevent slip at the interface. Re-entrant form, itself enhances interlock between concrete and the steel sheet. Profiled slab acts as a platform and centering at construction stage it also serves the purpose of bottom reinforcement for the slab. Different types of profile sheet shown in (Fig. 2). [9]

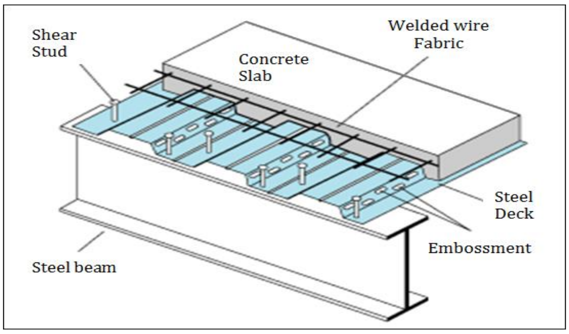


Fig. 1 : General Composite Arrangement (Sketch)

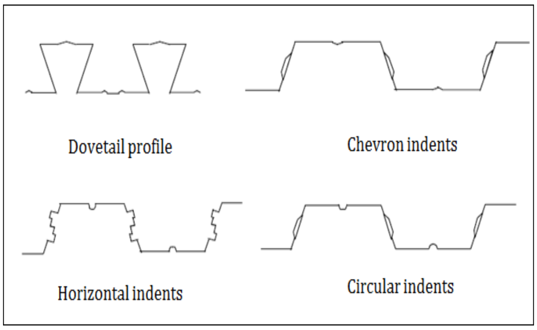


Fig. 2: Different Types Of Profile Sheets

This study examines the building R.C.C., Steel, & Composite with shear wall structure in the modeling of earthquake and wind flow around tall buildings of cross sectional shape, but same cross sectional area, consequently predicting the response of the structures under generated wind loads. It focuses on analysis of tall structures under earthquake and wind loading. ETABS 9.7.1 software has been used to analysis of the models for this study.

Earthquake:

Earthquake analysis methods to incorporate the forces during event of an earthquake. Intensity of these forces depends on the magnitude of the earthquake.
Linear Static: Equivalent Static Analysis [7]
This method is the simplified version of the modal response method applied to regular structure only. It is a static method of analysis for the structure which is likely to undergo single mode of vibration. The assumption is that the building has fundamental mode of vibration. The building must not twist under the effect of the ground motion. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or defined by the building code). The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces (e.g. force reduction factors). Similarly to the ‘equivalent’ force applied to the mass of the simple cantilever, it is possible to define in multi-storied buildings a set of ‘storied’ forces, which are applied at each storied level and which induce the same deformed shape as the earthquake.
Non Linear Static Procedure [10]

A simplified nonlinear analysis procedure, in which the forces and deformations induced by a monotonically increase lateral loading are evaluated using a series of incremental elastic analyses of structural models that are sequentially degraded to represent the effects of structural nonlinearity.

Non Linear Dynamic Procedure [10]

In nonlinear dynamic analysis procedure the response of a structure to suite of ground motion histories determined through numerical integration of the equation of the motion for the structure. Structural stiffness is altered during the analysis to conform to nonlinear hysteric models of the structural components. During earthquakes, buildings are generated to large inertia forces which cause members of buildings to behave in nonlinear manner. Nonlinear analysis, however, require a lot of input data related to material and section properties and loads, which are generally to obtain accurately. Most of the countries recommended nonlinear analysis for highly irregular and importance structures. The linear dynamic analysis is comparatively simpler. The main purpose of the linear dynamic analysis is to evaluate the time variation of the stress and deformation in structure caused by the arbitrary dynamic loads.

Wind:

Importance of Wind Loads On The Tall Building [11]

Buildings are defined as structures utilized by the people as shelter for living, working or storage. As now a days there is shortage of land for building more buildings at faster growth in both residential and industrial areas the vertical construction is given due importance because of which Tall Buildings are being built on a large scale. Wind in general has two main effects on the Tall buildings:-

- Firstly it exerts forces and moments on the structure and its cladding
- Secondly it distributes the air in and around the building mainly termed as *Wind Pressure*

Sometimes because of unpredictable nature of wind it takes so devastating form during some Wind Storms that it can upset the internal ventilation system when impasses into the building. For these reasons the study of air -flow is becoming integral with the planning a building and its environment.

Wind forces are studied on four main groups of building structures:-

i. Tall Buildings
ii. Low Buildings
iii. Equal-Sided Block Buildings
iv. Roofs and Cladding

Almost no investigations are made in the first two categories as the structure failures are rare, even the roofing and the cladding designs are not carefully designed, and localized wind pressures and suctions are receiving more attention. But as Tall buildings are flexible and are susceptible to vibrate at high wind speeds in all the three directions(x, y, and z) and even the building codes do not incorporate the expected maximum wind speed for the life of the building and does not consider the high local suctions which cause the first damage. Due to all these facts the Wind Load estimation for Tall Buildings are very much important.

II. PROJECT DETAILS

2.1 Architectural Details

To study the behavior of high rise building, a typical office building plan is selected with area covering 24 m x 42 m.

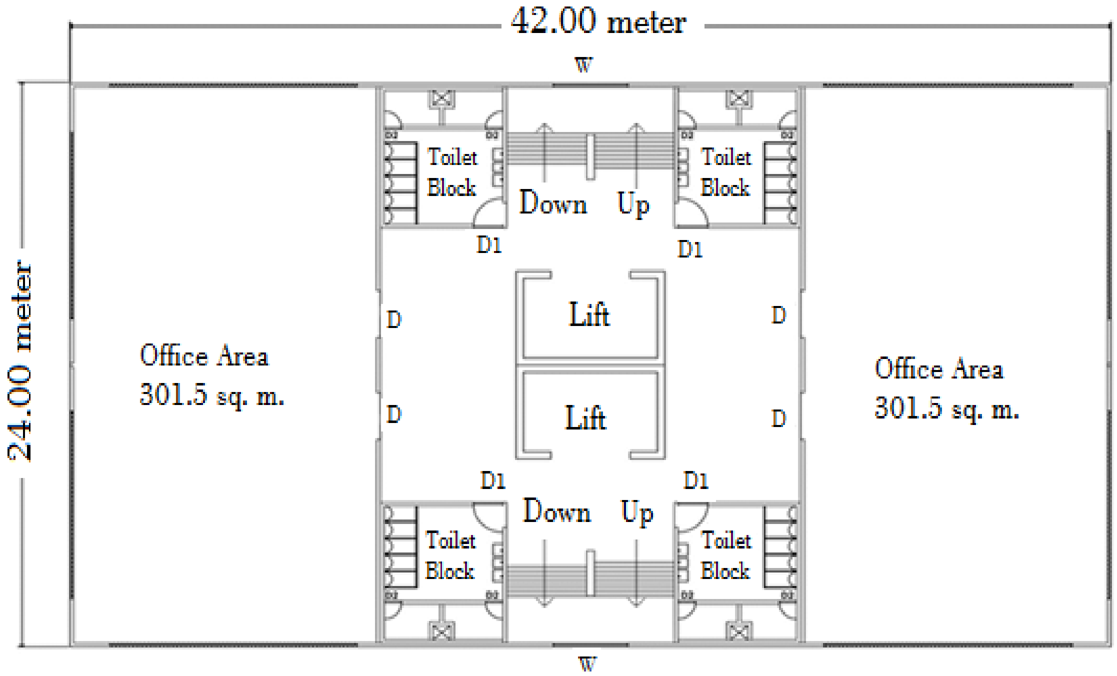


Fig. 1 : Architectural Layout

Architectural Details

Foundation Depth	9 Meter Below Natural Ground Level	No Basement Provided
Office Area	301.5 sq meter	2 No in each floor
Staircase	Two staircases	3 meter wide
No of Stories	Ground + 30 + stair cabin	3 m story height
Walls	All walls 230 mm thick	Regular brick masonry
Lift	Central lift shaft R.C.C. wall	

III. GENERAL DESIGN CONSIDERATIONS

3.1 Sizes of Different Elements

Slab depth : 80 mm thick for composite and 125 mm thick for RCC
Wall thickness : 150 mm
Lift shaft : 300 mm thick shear wall

3.2 Material Properties [3, 6]

Unit weight of masonry : 20 kN/m^3
Unit weight of R.C.C : 25 kN/m^3
Unit weight of steel : 79 kN/m^3
Grade of concrete : M40 for R.C.C, Steel and Composite model
Grade of steel : HYSD bars for reinforcement Fe 415
Fe 250 for Steel and Composite model
Modulus of Elasticity for R.C.C : $5000 \, X \sqrt{fck}$ N/mm^2
Modulus of Elasticity for Steel : 2.1×10^5 N/mm^2

3.3 Load Consideration [3, 4, 5]

Dead load : Self Weight
Live load in office area : 4 kN/m^2
Live load in passage area : 4 kN/m^2
Live load in urinals : 2 kN/m^2

Floor finish load	: 1.5 kN/m^2
Stair case loading	: 4 kN/m^2
Wind loading	: As per IS 875 (PART 3):

3.4 Load Combinations for Concrete, Steel & Composite Design Static Analysis

Table No. 1 : Wind Load Combination

Sr. No.	Name	Load Combination
1	1.5DL+1.5LL	1.5 x (Dead load + Live load)
2	1.5DL+1.5WL	1.5 x (Dead load + Wind load in Y direction)
3	1.5DL-1.5WL	1.5 x (Dead load - Wind load in Y direction)
4	1.2DL+1.2LL+1.2WL	1.2 x (Dead load + Live load + Wind load in Y direction)
5	1.2DL+1.2LL-1.2WL	1.2 x (Dead load + Live load - Wind load in Y direction)
6	0.9DL+1.5WL	0.9 x Dead load + 1.5 x Wind load in Y direction
7	0.9DL-1.5WL	0.9 x Dead load - 1.5 x Wind load in Y direction

Table No. 2 : Seismic Load Combination

Sr. No.	Name	Load Combination
1	1.5DL+1.5LL	1.5 x (Dead load + Live load)
2	1.5DL+1.5EQX	1.5 x (Dead load + Earthquake in X direction)
3	1.5DL-1.5EQX	1.5 x (Dead load - Earthquake in X direction)
4	1.5DL+1.5EQY	1.5 x (Dead load + Earthquake in Y direction)
5	1.5DL-1.5EQY	1.5 x (Dead load - Earthquake in Y direction)
6	1.2DL+1.2LL+1.2EQX	1.2 x (Dead load + Live load + Earthquake in X direction)
7	1.2DL+1.2LL-1.2EQX	1.2 x (Dead load + Live load - Earthquake in X direction)
8	1.2DL+1.2LL+1.2EQY	1.2 x (Dead load + Live load + Earthquake in Y direction)
9	1.2DL+1.2LL-1.2EQY	1.2 x (Dead load + Live load - Earthquake in Y direction)
10	0.9DL+1.5EQX	0.9 x Dead load + 1.5 x Earthquake in X direction
11	0.9DL-1.5EQX	0.9 x Dead load - 1.5 x Earthquake in X direction
12	0.9DL+1.5EQY	0.9 x Dead load + 1.5 x Earthquake in Y direction
13	0.9DL-1.5EQY	0.9 x Dead load - 1.5 x Earthquake in Y direction

IV. ETABS FOR DEFINITION OF EARTHQUAKE AND WIND ANALYSIS

4.1 Earthquake Definition (Equivalent Static Method)

Step 1 : Define Earthquake Load Cases

Definition of earthquake load cases are made from Menu > Define > Static Load cases. EQX represents earthquake load in X direction and EQY represents earthquake load in Y direction. (FIGURE. 2)

Fig. 2 : Definition Of Earthquake Load Cases

Step 2 : Lateral Load Definition [7]

Lateral loads are defined in Static load cases with Direction and Eccentricity values, Time period, Story Range, Response reduction factor R, Seismic zone factor, Soil Type and Importance factor I. Values of these are taken as mentioned below. (FIGURE. 3)

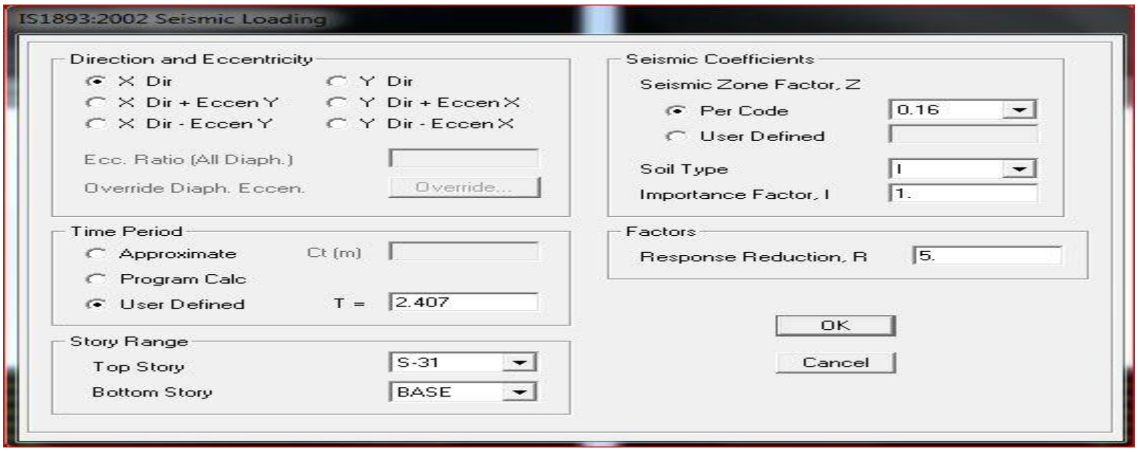


Fig. 3: Definition of Earthquake Loading

Define direction of the force	: X / Y with no eccentricity
Define time period	: 2.407 for R.C.C. model, 2.728 for Steel and Composite model
Seismic zone, Z	: 0.24 for ZONE IV, 0.16 for ZONE III
Soil type	: Hard soil
Importance factor, I	: 1
Response reduction factor, R	: 5 for R.C.C model
	: 4 for Steel and Composite model

T = Time period (Time of oscillation)

$T = 0.075 \text{ X } h^{0.75} = 0.075 \times 102^{0.75} = 2.407$ (For R.C.C. Frame)

$T = 0.085 \text{ X } h^{0.75} = 0.085 \times 102^{0.75} = 2.728$ (For Steel Frame)

Where, h = Height of building in meter.

4.2 Wind Definition (Equivalent Static Method)

Step 1: Lateral Load Definition [5]

Lateral loads are defined in Static load cases with Exposure and Pressure Coefficients, Wind Exposure Parameters, Exposure Height, and Wind Coefficients, Wind Speed, Terrain Category, Structure Class, Risk Coefficient Factor, Topography Factor Values of these are taken as mentioned below. (FIGURE. 4)

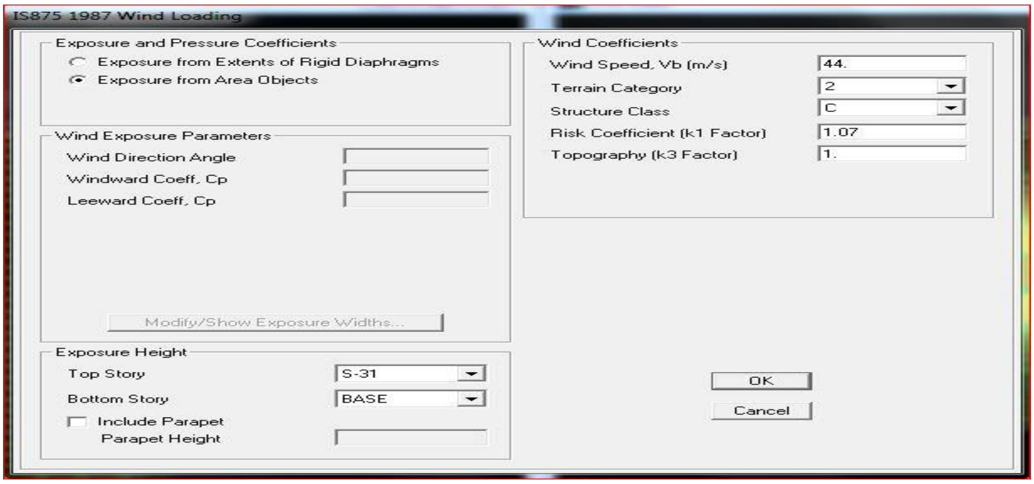


Fig. 4: Definition of Wind Loading

Exposure and Pressure Coefficients: Exposure from are object
Wind Exposure Parameters : Use only Y-Direction area forces

Wind Speed ($V_b = m/s$) : 44 m/s for Vadodara City
Terrain Category : 2
Structure Class : C

Risk Coefficient Factor (K_1) : 1.07

Topography Factor (K_3) : 1 for slope < 3 degree

Where

$V_b = 44\ m/s$, basic wind speed for Vadodara city (as per IS 875-part-3, p-53, appendix A , fig-1 p-9) ,$K_1 = 1.07$, Probability factor (risk coefficient) (clause 5.3.1) (as per IS 875-part-3, p-11, table-1) , $K_2 = 1.1716$, Terrain, Height and Structure size factor (as per IS 875-part-3, p-12, table-2) (Clause =5.3.2.2) (terrain category -2, class – c , height – 102 m), K_3 =1, Topography Factor for slope < 3 degree

4.2.1 Force Coefficients for Unclad Buildings Calculation (Cf) [5]

a = least horizontal dimension = 24 m, b = max horizontal dimension = 42 m,

h = height of building G.L to Top level

$a/b = 24/42 = 0.571$, $h/b = 93/42 = 2.21$

$0.571\ for\ 2.21 > 1$

So, refer Fig. – 4A, (as per IS 875-part-3, p-39),

Value of C_f versus $\frac{a}{b}\ for \frac{h}{b} > 1$

$C_f = 1.2$

4.2.2 Codal Criteria for The Buildings to Be Examined for Dynamic Effects of Winds[5] [(as per IS 875-part-3, p-47-48) (Clause = 7.1)

a) $h/(\text{min. lateral dimension}) = 93/24 = 3.875 < 5$

b) $0.09 \times h/\sqrt{d} = 0.09 \times 93/\sqrt{24} = 1.7085$ natural period in sec.

Natural frequency = $2 * \pi / T = 3.677$ Hz

From above result do not require dynamic analysis in these Project models.

V. COMPARISON TABLE & GRAPH

Table No. 3 : Beam Shear Forces									
Case	**Wind**			**Eq. Zone = III**			**Eq. Zone = IV**		
Force Name	**V_2= Shear Forces (kN) (1.5dl+1.5ll) At S-15**								
Beam Position	**B91**	**B17**	**B130**	**B91**	**B17**	**B130**	**B91**	**B17**	**B130**
RCC	119	160	119	119	167	119	119	167	119
STEEL	107	223	266	114	162	275	114	200	277
(S+B)	107	264	268	114	155	275	114	160	275
(SSBC)	2	229	363	2	181	355	2	179	365
(SSBC+B)	2	225	363	2	187	354	2	125	328

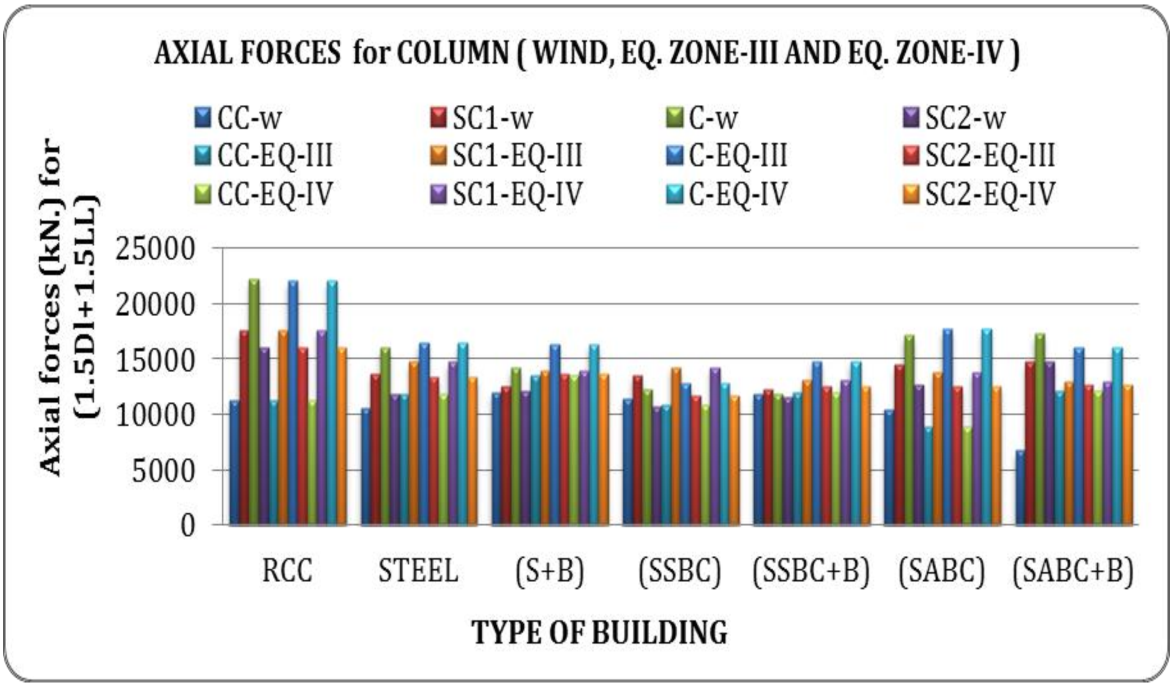
(SABC)	6	24	358	2	44	346	6	13	346
(SABC+B)	2	61	350	2	94	340	11	73	334

Table No. 4 : Beam B.M. Forces

Case	**Wind**			**Eq. Zone = III**			**Eq. Zone = IV**		
Force Name	**M_3 = B.M. (kN.m.) (1.5DL+1.5LL) at S-15**								
Beam Position	**B91**	**B17**	**B130**	**B91**	**B17**	**B130**	**B91**	**B17**	**B130**
RCC	221	201	221	221	218	221	221	218	221
STEEL	204	330	397	214	274	359	214	280	359
(S+B)	204	438	413	214	289	368	214	254	386
(SSBC)	3	1218	549	3	959	454	3	1116	550
(SSBC+B)	3	1327	595	3	702	440	3	759	318
(SABC)	9	88	432	3	137	406	9	76	388
(SABC+B)	3	203	422	2	273	382	16	386	320

NOTATIONS:-

- S = Storey
- EQ = Earthquake
- (S+B) = Steel + Bracing
- (SSBC) = Steel secondary beam composite
- (SSBC+B) = Steel secondary beam composite + Bracing
- (SABC) = Steel all beam composite
- (SABC+B) = Steel all beam composite + Bracing
- CC = Corner Column
- SC1 = Side column Y-Direction
- C = Center column
- SC2 = Side Column X-Direction
- W = Wind



Graph – 1 Graph of Axial Forces Vs type of building

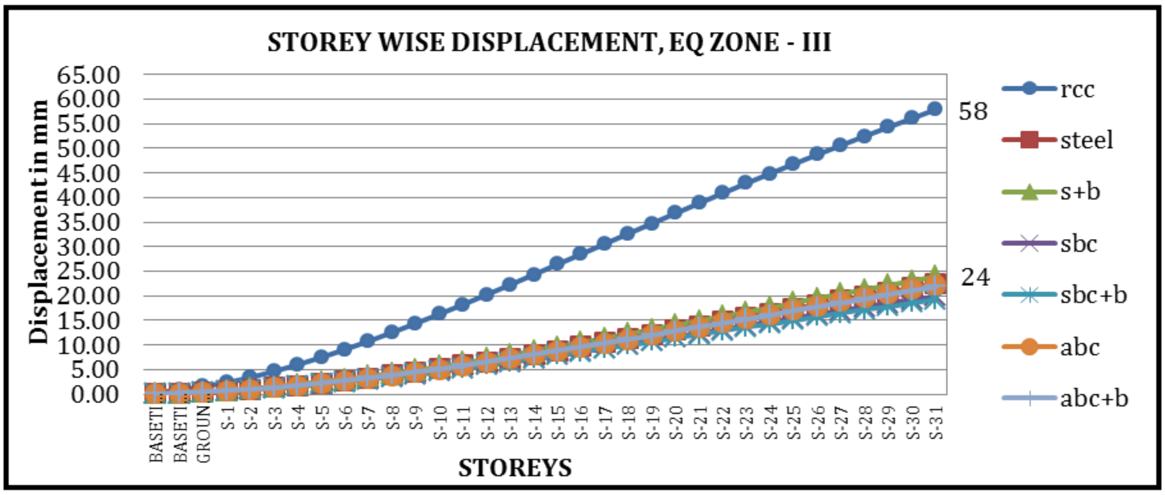
Graph 1 shows the column axial forces at the base of building for WIND, EQ. ZONE - III and EQ. ZONE – IV for RCC, STEEL and COMPOSITE Building. Column axial forces are selected at base of the building. In the result maximum axial forces are the near the same values but EQ. ZONE = III & ZONE = IV is 13 % more compare to the Wind model for the CC in (S+B) due to the DL+LL forces.

Maximum axial forces are the near the same values but EQ. ZONE = III & ZONE = IV is 0.20 % less compare to the Wind model for the SC1 in (RCC). Maximum axial forces are the near the same values but EQ. ZONE = III & ZONE = IV is 0.71 % less compare to the Wind model for the C in (RCC). Maximum axial forces are the near the same values but EQ. ZONE = III & ZONE = IV is 0.18 % less compare to the Wind model for the SC_2 in (RCC).

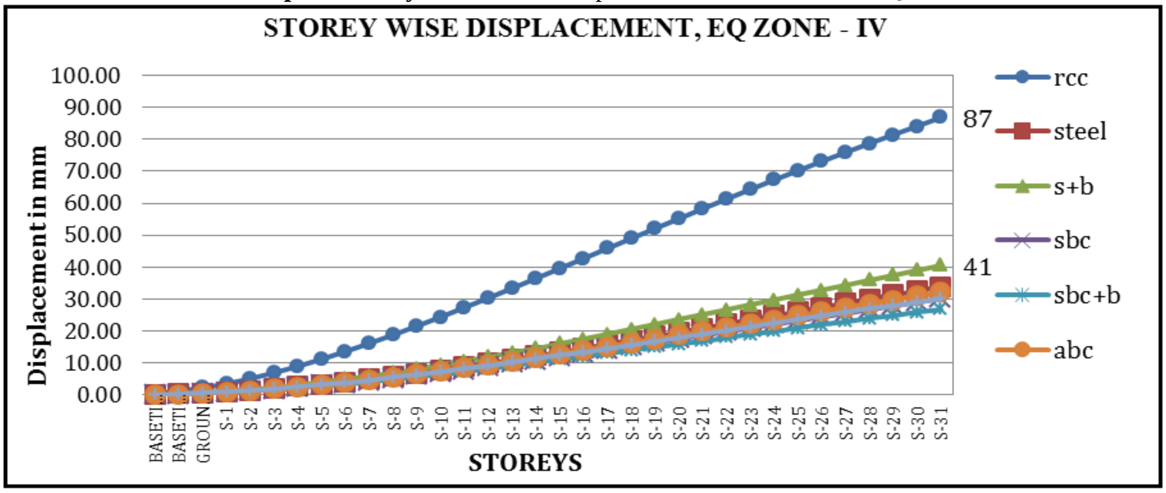
Table No. 5 : Displacement Due to Forces Wind

- **DL = Dead Load**
- **LL = Live Load**
- **WL = Wind Load**
- **NWL = Negative Wind Load**

Storey	Load Case	RCC	STEEL	S+B	SSBC	SSBC+B	SABC	SABC+B
		Displacement In (mm) (At Top Storey)						
S-31	WIND	86	37	34	39	37	50	39
S-31	1.5DL+1.5LL	0	0	0	0	0	0	0
S-31	1.2DL+1.2LL+1.2WL	103	44	40	47	44	60	47
S-31	1.2DL+1.2LL+1.2NWL	103	44	40	47	44	60	47
S-31	1.5DL+1.5WL	129	55	51	58	55	75	59
S-31	1.5DL+1.5NWL	129	55	51	58	55	75	59
S-31	0.9DL+1.5WL	129	55	51	58	55	75	59
S-31	0.9DL+1.5NWL	129	55	51	58	55	75	59



Graph 2: Storey Wise Nodal Displacement for 0.9DL+1.5EQY.



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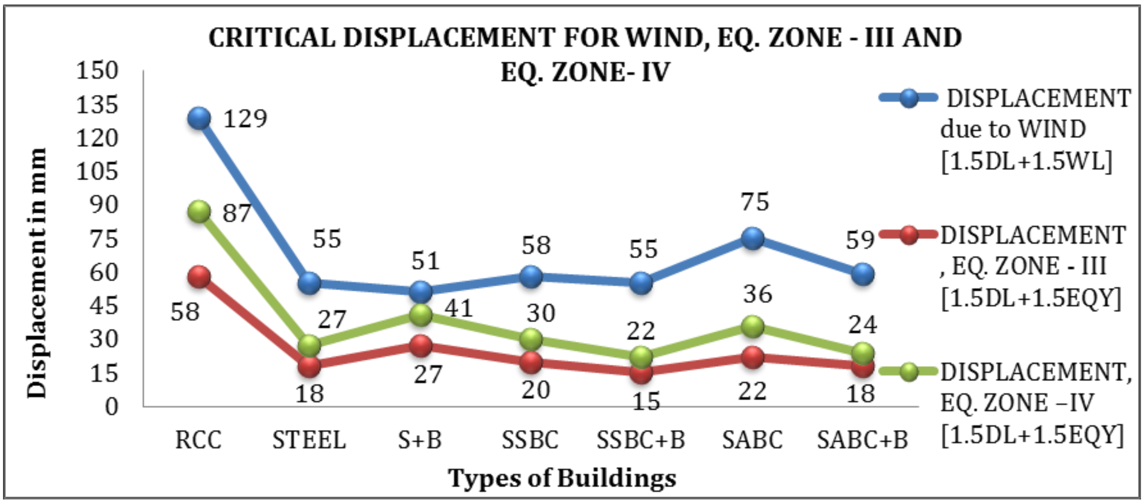


Graph 4 : Critical Displacement For Wind, Eq. Zone - III And EQ. Zone – IV

Above table no.-6 shows wind model all load combination displacement at top storey nodal displacement result for all 7 models. Results shows top storey of building are within the limits of criteria, $\frac{h}{500} = \frac{93000}{500} = 186\,mm\,,\ h - hight\ of\ building.$[8] And also EQ. ZONE-III and EQ. ZONE-IV Result of storey wise nodal displacement for Load case 0.9DL+1.5EQY is within the limits of criteria represented graphically in Graph 2, 3 and critical displacement are shown in Graph 4.

Table No. 6 : Support Reaction

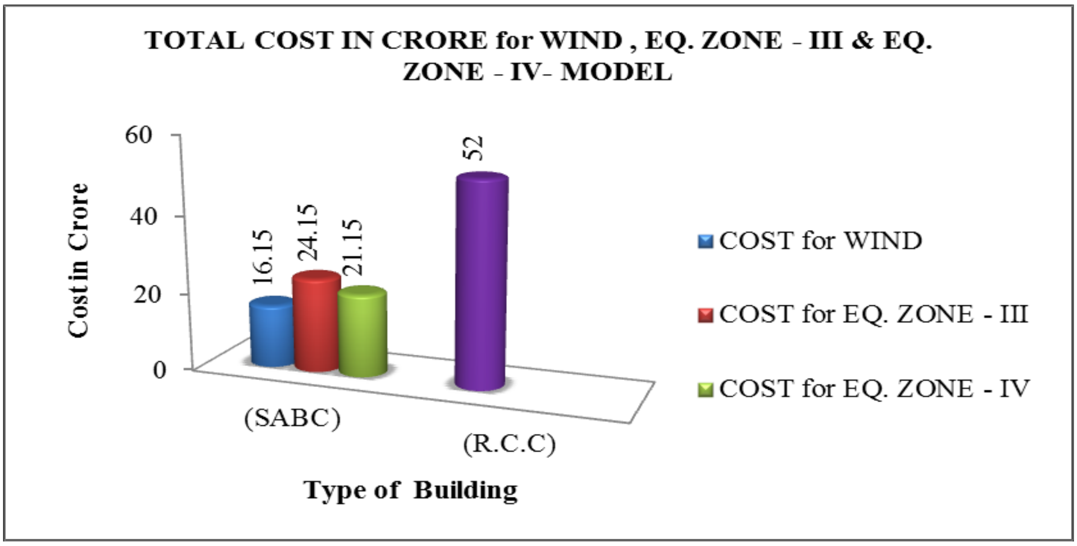
• DL = Dead load • LL = Live Load	RCC	STEEL	S+B	SSBC	SSBC+B	SABC	SABC+B
Case	**P = Support Reaction (kN) (1.5DL+1.5LL) at Bottom**						
WIND	634875	541964	553121	549023	555456	519057	529246
EQ. ZONE - III	637994	552447	556255	530019	551202	517804	535201
EQ. ZONE - IV	637994	553032	556646	550436	567136	519351	568678

Table no. 6 shows the total support reaction of the building. In the result of WIND, EQ. ZONE – III and EQ. ZONE – IV support reaction is linearly decreasing the value for RCC to the (SABC+B). in the (S+B) , (SSBC+B) and (SABC+B) support reaction are more compare to STEEL, (SSBC) and (SABC) building due to the bracing self-weight.

Table No. 7 : Base Shear

• DL = Dead Load • LL = Live Load	RCC	STEEL	S+B	SSBC	SSBC+B	SABC	SABC+B
Case	**P = Support Reaction (kN) (1.5DL+1.5LL) at Bottom**						
WIND	10778	10778	10778	10778	10778	10778	10778
EQ. ZONE - III	3392	2524	3185	2401	3149	2334	3037
EQ. ZONE - IV	5088	3792	4779	3774	4868	3511	4894

Table no. 7 shows the total base shear of the building. Max. base shear value for EQ. ZONE – III is 69 % less and EQ. ZONE – IV is 53 % less compare to the WIND model max. base shear for RCC building. In the result of WIND, EQ. ZONE – III and EQ. ZONE – IV support reaction is linearly degreasing the value for RCC to the (SABC+B).



Graph 5 : Total Cost in Crore for Wind , Eq. Zone - III & Eq. Zone - IV- Model

VI. CONCLUSION

1. We can conclude the table no.-3 & 4; beam S.F. & B.M. is more in the RCC, STEEL & (S+B) building. But, when we use the composite beam in the (SSBC), (SSBC+B), (SABC) & SABC+B) building the forces are reduced due to the reduced the section. In the (B130) S.F. & B.M. is increase due to the member size increase and self-weight because forces are increase in the member.
2. Displacement is within the limits for all building RCC, STEEL and COMPOSITE. Critical displacement for WIND is 129, EQ. ZONE-III is 58 & EQ. ZONE-IV is 87 is which is less than the permission limits is $(h/(500) = 186\,mm)$.
3. Support reaction is maximum in the RCC building which linearly reduce to RCC to (SABC+B) building in the WIND, EQ. ZONE-III and EQ. ZONE-IV type building.
4. Base shear forces more in the RCC building and linearly reduces the base shear RCC to the (SABC+B) building. Means wind forces more compare to the Earthquake.
5. Composite steel-concrete is relatively a new design concept in the Indian context and no appropriate updated codes are available for the design of same. The present work not only eliminates the costly experimentation required but also facilitates design with multiple options for the steel sections and shear connectors with adequacy checks.
6. Keeping span and loading unaltered, smaller structural steel sections are required in composite construction compared to non-composite construction. This reduction in overall weight of the composite structure compared to other structure results in less cost of structure and foundation.
7. Comparison of beam & column cost for all seven models [(STEEL), (S+B), (SSBC), (SSBC+B), (SABC), (SABC+B), (R.C.C)] buildings shows that under the effect of wind force there is percentage average reduction in cost at about 48.83 % w.r.t. R.C.C building structure, similarly, for EQ. ZONE - III there is percentage average reduction in cost at about 53.00 % w.r.t. R.C.C building structure and similarly, for EQ. ZONE - IV there is percentage average reduction in cost at about 46.67 % w.r.t. R.C.C building structure.
8. Comparison of all models buildings shows that composite buildings (SABC) are more economic for all other buildings structure.
9. We conclude from 21 models of various building in which R.C.C. building subjected to the wind is most critical case.

VII. FUTURE SCOPES

1. The research needs in regards to composite structures using precast concrete and even pre-stressed concrete in certain applications and steel, should also have good market

potential due to the economy that can be achieved by these components in saving time, labor and money.

2. The research needs in regard to composite structures for different soil conditions, different zones, effect of fire, different column orientations and different utility of buildings.
3. Idealizing the condition of joints here as rigid joints one can do research on non-linear joint response considering rotational stiffness, moment of resistance and rotational capacity.
4. Different shapes of high-rise buildings can be compared for R.C.C., Steel and Composite options for better guidelines of selection of system.
5. Indian standard is very silent about design of composite column, one can conclude such guidelines and format a proper design method for different types of composite columns.

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