Effect of Different Soil Condition on Foundation Design of Tall Buildings

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Abstract- *In the past two decades, development of tall structures with a height of more than 150m and a nearly exponential rate of expansion has increased considerably. A considerable number of these structures have been built throughout the Middle East and Asia and many more are either under construction or planned. "Super-high" structures above 300m high provide significant difficulties to engineers, especially with regard to structural and geotechnical design. Many of the conventional design techniques cannot be implemented confidently, and require extrapolation well beyond previous experience, and structural and geotechnical developers are thus compelled to use more complex analytical and design methodologies. Geotechnical engineers in particular engaged in the construction of foundations for super-high structures increasingly abandon empirical techniques and use state-of-the-art procedures. A G+18 square building with 3 m floor-to-floor height was assessed in Zone III using the ETABS software. The shape of the selected plan is square. For the structure, static and dynamic wind and seismic forces were analysed. Structures have been built for soil types that are hard, medium and soft.*

Keywords- IS:875(Part-3):2015, ETABS Software, Tall Buildings, Soil Conditions, Gust factor, Storey drift, Story Displacement, Design of Footing.

I. INTRODUCTION

Tall Buildings: -

The last two decades have seen a remarkable increase in construction of tall buildings in excess of 150m in height, and an almost exponential rate of growth. A significant number of these buildings have been constructed in the Middle East and Asia, and many more are either planned or already under construction. "Super-tall" buildings in excess of 300m in height are presenting new challenges to engineers, particularly in relation to structural and geotechnical design. Wind analysis is important in case of tall buildings. Figure 1 shows the significant growth in the number of such buildings either constructed. Many of the traditional design methods cannot be applied with any confidence since they require extrapolation well beyond the realms of prior experience, and accordingly, structural and geotechnical designers are being forced to utilize more sophisticated methods of analysis and design. In particular, geotechnical engineers involved in the design of foundations for super-tall buildings are increasingly leaving behind empirical methods and are employing state-of-the art methods.

The investigations have been carried out by many researchers on the structural behaviour of tall buildings with SSI by considering many parameters like foundation type, soil conditions, lateral forces, ratio of flexural stiffness of beam and column etc. Very few investigations have been carried out on soil-structure interaction of tall buildings under clayey soil conditions, particularly in Indian seismic zones.

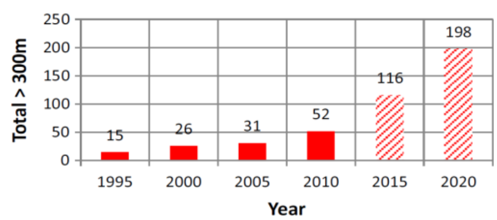

Fig 1: Total number of buildings in excess of 300 m tall

There are a number of characteristics of tall buildings that can have a significant influence on foundation design, including the following:

1. The building weight increases non-linearly with increasing height, and thus the vertical load to be supported by the foundation, can be substantial.
2. High-rise buildings are often surrounded by low-rise podium structures which are subjected to much smaller loadings. Thus, differential settlements between the high and low-rise portions need to be controlled.
3. The lateral forces imposed by wind loading, and the consequent moments on the foundation system, can be very high. These moments can impose increased vertical loads on the foundation, especially on the outer piles within the foundation system.

4. The wind-induced lateral loads and moments are cyclic in nature. Thus, consideration needs to be given to the influence of cyclic vertical and lateral loading on the foundation system, as cyclic loading has the potential to degrade foundation capacity and cause increased settlements.

Soil Condition: -

The soil condition is an essential fled of analysis in earthquake engineering; this soil condition is defined as, "The physical condition of the soil and its dynamic properties, which can be divided according to standard Indian code into; hard soil (Rocky), medium soil, soft soil (loose). In view of structural engineering, the engineering community discussed SSI only when the basement motion by interaction forces as compared to the ground motion of freefell. The force and deformation in the supporting soil cause vibration of structure and produce base shear, moment and displacement.

During the recent decades, extensive researches have been conducted regarding the effects of soil-structure interaction (SSI) on the seismic responses of the structures. It was found that the interaction between soil and structure results in a decrease of the fundamental frequency of the response and modification in the energy dissipation, which is attributed to radiation and material damping in the soil. In spite of the buildings are of the same region, same configuration and same earthquake magnitude, the damages that occur during the earthquake are not of the same pattern. This means that there are some factors that affect the damage pattern like ground motion characteristics, soil condition under foundations, structural system of plan, mass, stiffness, and vertical irregularities.

Wind Loads on Tall Buildings: -

The action of a natural wind, gusts and other aerodynamic forces will continuously affect a tall building. The structure will deflect about a mean position and will oscillate continuously. Swami studied that if the wind energy that is absorbed by the structure is larger than the energy dissipated by structural damping then the aptitude of oscillation will continue to increase and will finally lead to destruction. The structure becomes aerodynamically unstable. The structure forms used these days have greater flexibility with less mass and damping than those used in olden days. Knowledge on the maximum steady or time averaged wind loads can ascertain the overall stability of a structure IS 875-part –III deals with wind load. The effect of wind is high in case of buildings over 10 storeys. Wind loads must be considered for the design of buildings over 10 storeys.

II. METHODOLOGY

A study involving dynamic effect of wind load on RC buildings and study the behavior of the buildings. The gust factor method is used to determining along wind load effect.

The methodology worked out to achieve the above-mentioned objectives is as follows:

1. Compilation of relevant research data from national and international journals, research papers web source, text books, reference books etc to get acquainted with past research.
2. Identification of scope of further research in the high-rise buildings subjected to wind effects.
3. Define the scope of specimen for research like height, plan size of building, input parameters from IS code, Material specifications, member specifications etc.
4. The E-TABS software is used to develop 3D model and to carry out the analysis. The lateral loads to be applied on the buildings are based on the Indian standard IS-875-Part 3: 2015.
5. Comparison of results which have significant effects on foundation design of tall building varies as per soil conditions and preparation of discussion summary.
6. Result and discussions.
7. Conclusion will be drawn based on the result of analysis.

Design Wind Speed (Vz): -

$V_z = V_b\ k_1\ k_2\ k_3\ k_4$

Vz = design wind speed at height z, in m/s

Vb= Basic wind speed

k1 = probability factor (risk coefficient)

k2 = terrain roughness and height factor

k3 = topography factor

k4 = importance factor for the cyclonic region

Design Wind Pressure (Pz): -

$P_z = 0.6\ (V_z)^2$

Pz = Design wind pressure in N/m^2 at height z,

Vz = Design wind speed at any height z in m/s.

Wind load (Fz): -

$F_z = C_f\ P_z\ G\ A_e$

Fz= Along wind load on the structure at any height

Cf = Force coefficient

Ae= Effective frontal area

Pz =Design wind pressure

G = Gust factor

Gust Factor: -

A gust factor (GF) is defined as the ratio between the peak wind gust of a specific duration to the mean wind speed for a period of time. It is a simple statistic but is dependent on numerous inputs, including the roughness length (exposure), distance from an upstream terrain change, stability, height, and, potentially, the presence of convection. Wind speed fluctuations are associated with pressure and force fluctuations on a building, and result in fatigue loading on various structural components. Understanding differences in the structure of the wind, which may exist in various high-wind environments, is imperative for proper wind load design.
Gust factor method is only the method of calculating load along wind or drag load by using gust factor method is given in the code since methods for calculating load across-wind or other components are not fully matured for all types of structures. However, it is permissible for a designer to use gust factor method to calculate all components of load on a structure using any available theory. However, such a theory must take into account the random nature of atmospheric wind speed.

Gust Factor as per IS-875 (part 3) 2015: -

Gust Factor(G) = Peak Load/Mean Load

$$G = 1 + r\sqrt{\frac{gv^2Bs\,(1+\emptyset^2) + Hsg_R{}^2SE}{\beta}}$$

Where,
r =Roughness factor
gv =Peak factor for upwind velocity fluctuatio
Bs =Background factor
ϕ = Factor to account for second order turbulence intensity
Hs =Height factor for resonance response
g =Peak factor for resonant response
S =Size reduction factor
E =Spectrum of turbulence
B= Damping coefficient of the building or structure

III. PROBLEM STATEMENT

In this project, a G+18 storey structure of a square building with 3 m floor to floor height has been analyzed Non-Linear Dynamic Analysis of Multi-storey R.C.C Buildings using ETAB software in zones III. The plan selected is Square in shape. The structure has been analyzed for both static and dynamic wind and earthquake forces. Hard, Medium and soft soil condition has been selected for the structure.

Preliminary data required for Analysis

Table 1: Parameters to be consider for square geometry analysis

Sr.No.	Parameter	Values
1	Number of stories	G+18
2	Grade of concrete	M30
3	Grade of steel	Fe500
4	Floor to Floor ht.	3 m
5	Parapet Ht.	1.5m
6	Total height of Building	58.5m
7	Soil Types	Hard ,Medium, Soft
8	Floor Finish Load	1 KN/m^2
9	Dead Load	Calculated By Software
10	Wall Load	9 KN/m2
11	Imposed Load	3 KN/m2
12	Assumed City	Pune
13	Basic Wind Speed	39 m/s
14	Seismic zone	Zone III
15	Terrain Category	Type II
16	Frame size	18m X 18m building size
17	Grid spacing	3 m grids in X and Y-direction.
18	Size of column	750mm x 750 mm
19	Size of beam	300mm x 500 mm
20	Depth of slab	125 mm

Aim: - To investigate behavior of tall building of non-identical soil conditions on foundation design of tall buildings subjected to wind action.

Objectives: -

1. To calculate wind loads by Gust Factor Method as per IS 875 Part III.
2. To investigate behavior of Tall building in terrain category 2 under wind loading having different soil conditions such as Hard, Medium and Soft soil.
3. To interpret effect of different soil conditions on design of foundations of Tall building.
4. Validation of results by software and literature.

Table 2: Models

Model 1	G+18 In Soft Soil
Model 2	G+18 In Medium Soil
Model 3	G+18 In Hard Soil

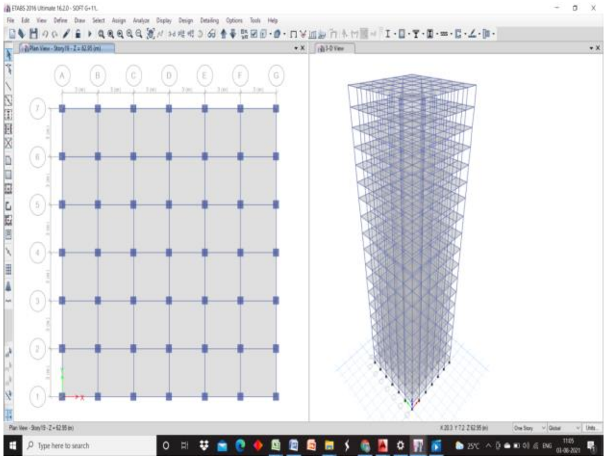

Fig 2: Prepare modeling in ETABS

VI. RESULT AND DISCUSSION

In this project, a G+18 storey structure of a square building with 3 m floor to floor height has been analysed Non-Linear Dynamic Analysis of Multi-storey R.C.C Buildings using ETABS software in zones III. The plan selected is square in shape. The structure has been analysed for both static and dynamic wind and earthquake forces. Hard, Medium and soft soil condition has been selected for the structure.

Results are given below:

Story Wise Wind Forces is Calculated in Following Table 3: -

Ht. from Ground (m)	Design wind pressure (Pz) (N/m^2)	Force Coeff. (Cf)	Effective frontal Area(Ae)(m^2)	Gust Factor (G)	Wind Load (Fz) (KN)
3	912.6	1.3	54	2.37	152
6	912.6	1.3	108	2.45	314
9	912.6	1.3	162	2.49	480
12	1006.14	1.3	216	2.52	714
15	1006.14	1.3	270	2.56	904
18	1044.84	1.3	324	2.58	1138
21	1150.91	1.3	378	2.60	1473
24	1144.77	1.3	432	2.63	1691
27	1144.77	1.3	486	2.65	1920
30	1154.87	1.3	540	2.67	2170
33	1249.26	1.3	594	2.69	2599
36	1249.26	1.3	648	2.7	2859
39	1249.26	1.3	702	2.7	3122
42	1249.26	1.3	756	2.76	3390
45	1249.26	1.3	810	2.78	3661
48	1249.26	1.3	864	2.80	3935
51	1403.21	1.3	918	2.81	4712
54	1403.21	1.3	972	2.83	5026
57	1403.21	1.3	1026	2.85	5342
60	1403.21	1.3	1080	2.87	5661

Comparison of Footing Design Due to Soil Effect: -

The design of footing below gives interprets effect of different soil conditions on design of foundations of Tall building.

Table 4: Comparison of footing design due to soil effect

	Type of Soil		
Data	Soft	Medium	Hard
Pu (Design Reaction) KN	2198.44	2125.59	2040.98
Adopted Size of Footing	x= 4.1 m y=4.1 m	x= 3 m y= 3 m	x=2.8 m y=2.8 m
Adopted depth of Footing	500 mm	500 mm	460 mm
Dia. And No. Of Bar Req.	16T-21	16T-13	16T-12

V. CONCLUSION

The study as a whole may prove useful in formulating design guidelines for foundation design of building frames incorporating the effect of soil flexibility. In this study, the effects of wind and SSI (Soil Structure Interaction) are analyzed for typical multi-story building using the ETABS programmed; a G+18 story square building with a 3 m floor-to-floor height was evaluated in zone III. Square is the form of the chosen plan. Static and dynamic wind and seismic forces have been analyzed for the structure for different soil conditions, the different soil conditions are directly affecting the design parameters of the foundation such as length, width, depth and reinforcement of the foundations, it also affects the displacement and storey drift of the structure. Structures have been designed for hard, medium, and soft soil conditions.

REFERENCES

[1] K. Vishnu Haritha, Dr.I. Yamini Srivalli (2013) “Effect of Wind on Tall Building Frames - Influence of Aspect Ratio”. International Journal of Research in Civil Engineering, Architecture & Design Volume 1, Issue 1, July-September, 2013, pp. 01-06, © IASTER 2013 ISSN Online: 2347-2855.

[2] B. Dean Kumar and B.L.P. Swami (2010) “Wind effects on tall building frames-influence of dynamic parameters” Indian Journal of Science and Technology Vol. 3 No. 5 (May 2010) ISSN: 0974- 6846.

[3] Yin Zhou and Ahsan Kareem (1999) “Gust loading factors for design applications” J. Struct. Div., ASCE, 93(ST3), 11-34.

[4] Wakchaure M. R., Gawali Sayali (2015) “Effects of Shape on Wind Forces of High Rise Buildings Using Gust Factor Approach” International Journal of Science, Engineering and Technology Research (IJSETR), Volume 4, Issue 8, August 2015.

[5] Mohammed Asim Ahmed, Moid Amir, Savita Komur, Vaijainath Halhalli (2015) “Effect of wind load on tall buildings in different terrain category” IJRET: International Journal of Research in Engineering and Technology.

[6] K. Rama Raju, M.I. Shereef, Nagesh R Iyer, S. Gopalakrishnan (2013) “analysis and design of rc tall building subjected to Wind and earthquake loads” The Eighth Asia-Pacific Conference on Wind Engineering, December 10–14, 2013, Chennai, India.

[7] Singla Sarita, Kaur Taranjeet, Kalra Megha and Sharma Sanket (2012) “Behaviour of R.C.C. Tall Buildings Having Different Shapes Subjected to Wind Load” Proc. of Int. Conf. on Advances in Civil Engineering 2012.

[8] Md Ahesan, Md Hameed1, Salman Shaikh (2019) “Effects of Wind Load on Rc Buildings by Using Gust Factor Approach” International Journal of Emerging Technologies and Innovative Research, Vol.6, Issue 5, page no.329-335, May-2019. ISSN: 2349-5162.

[9] Prof. Syed Farroqh Anwar, Mr.Mohd Hashmath, Mohd Aslam Share Khan(2016) “Study On Soil Structure Interaction And Base Isolated System For Seismic Performance Of Structures Resting On Different Types Of Soils” Global Journal Of Engineering Science And Researches ,October 2016, ISSN 2348 – 8034 3(10).

[10] K. Nagarjuna1, Dr.S.R.K.Reddy (2018) “Response of High-Rise Buildings, Agains Earthquake Forces under Different Soil Conditions, and Wind Forces”. International Journal of Innovative Research in Science, Vol. 7, Issue 5, May 2018, Engineering and Technology ISSN(Online): 2319-8753.

[11] Harry G. Poulos1, Dist. MASCE (2012) “Foundation Design for Tall Buildings”. Conference Paper in Geotechnical Special Publication, May 2012.

[12] Mr. Rahul Sawant1, Dr. M. N. Bajad (2016) “Effect of Soil-Structure Interaction on High Rise RC Building”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 13, Issue 1 Ver. IV, PP 85-91 (Jan. - Feb. 2016) e-ISSN: 2278-1684, p-ISSN: 2320-334X.

[13] Harry G. Poulos (2016) “Tall building foundations: design methods and applications”, Innov. Infrastruct. Solut. (2016) 1:10 Springer International Publishing Switzerland 2016.

[14] Ilaria Venanzi, Diana Salciarini, Claudio Tamagnini (2014) “The Effect of Soil–Foundation–Structure Interaction on the Wind-Induced response of tall buildings”. journal homepage: Elsevier I. Venanzi et al. Engineering Structures 79 (2014) 117–130.

[15] Saurabh Kawale1 Dr. S.V. Joshi (2017) “Analysis of High-Rise Building for Wind Load”, IJSRD - International Journal for Scientific Research & Development, Vol. 5, Issue 03, 2017, ISSN (online): 2321-0613.