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Analytical study on shallow foundation for High-Rise Buildings

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Abstract

Today in this fast developing world there is a great demand of high-rise buildings in the urban areas. In order to construct these buildings, it requires a great skill and experimental study. The analysis of high-rise building and its foundation is very complex. In certain circumstances it becomes very difficult to predict the actual behaviour of the structure because of the stress developed in soil. In this study the combined efforts of two well known finite elements based programs STAAD and ANSYS are used to study high-rise building and its foundation. The content of this paper is limited to 3D finite element analysis by assuming a 22 storey building with Raft on silt clay and loose sandy soil.

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1. Introduction

In earlier 1920's concerted efforts were made to study and understand the physical laws governing the behaviour of sub surface materials, i.e., soil strata from which foundations derived their support and on whose behaviour its own behaviour depends. Due to the efforts made in the field of soil mechanics, we are now able to select various different types of foundation systems and predict their behaviour. One of the very popular structures seen today is the high-rise building and this high-rise building has some particular requirement regarding support system, which need to be satisfied on a serious note. Generally foundation in clay as well as loose sands tends to be more problematic for a high-rise building. In the recent years many methods have been developed related to the foundation design and analysis of high-rise building foundations. In general a high-rise building may be supported by piles, raft or raft supported by piles. The choice of these foundation systems depend on the site conditions encountered and the forces transferred by different types of structures on the foundation. In this study a raft is provided and studied for various parameters. The study is carried out in two phase. The first phase comprises of seismic analysis and design of 22 storied residential building. The second phase involves the modelling and analysis of raft foundation in ANSYS.

2. Finite Element Analysis of Building

The Finite Element model of building in STAAD is by default one dimensional. Analysis performed with STAAD delivers satisfactory results for framed structure. The seismic analysis performed by response spectrum method in which the peak response of a structure is obtained directly from the earthquake spectrum. A peak response is generated by considering the earthquake loading. The model of the building comprises of basement, stilt, parking floor and 20 storeys above. Shear walls are modelled as lateral load resisting system in the assumed model. As from the point of view of plan all the dimensions and parameters of building are in accordance to the earthquake resistant design criteria. The loads considered according to the normal circumstances encountered by the building delivers the typical response of such building which is well utilised in loading of the raft provided underneath. The building considered is a RCC framed building in area of moderate risk. The building is modelled as 23 storied RCC framed building including stilt, parking and basement floors with shear walls. At some places there is a problem related to the strata for foundation of such buildings. In this study the building represents a constitutive model having similar issues regarding foundation. The building is liable for various forces other than its self weight and live loads which are; wind load and Earthquake loads. The analysis of such buildings has to be performed by considering all such loads and has to be checked against failures. The modelling and computer analysis of the present building is done using STAAD representing the above case delivering acceptable results. The model in STAAD is 1-Dimensional and 4-node Plate elements are used only for the modelling of shear walls and not for the slabs. Slabs are not modelled identically though their effects on beams are very well considered. The building is restrained against any displacement and moments at the base.

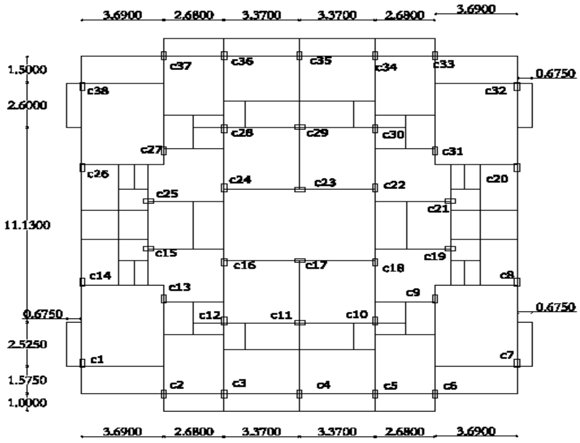

Figure 1-Structural Plan

The wind pressure is calculated according to IS 875 (Part 3)-1987:

$$p_z = 0.6\, v_z^2$$

p_z = Design wind pressure

v_z = Design wind velocity

Dead Load of slab is considered as 7.62 kN/m^2 including floor finish. The live load at all floor levels is 3 kN/m^2 except terrace floor where 2 kN/m^2 is considered.

Eartquake Load are according to IS 1893: 2002 for monolithic RCC structure located in Zone III with Importance Factor = 1. Damping Ratio= 0.5

Earthquake response of systems would be affected by different types of foundation systems in addition to variation of ground motion due to various types of soils.

Load combinations are considered according to IS 456-2000 and IS 1893:2002. Some of the load combinations are critical and give peak response of the structure. The base forces and moments given by the various load combinations at support are considered for the further analysis of raft foundation.

Analysis of Raft

Raft is a very efficient type of foundation system for resisting various stresses developed when it supports a high-rise building. FEA analysis of raft by computer program is done by using ANSYS. Apart from all the literature generated in the field of FEA analysis there is always a need for development of new methods to obtain better results. In phase II of study attempt is made to analyze the raft foundation and to study its deformation characteristics under the stresses developed due to peak static loads. The modelling of raft comprises of a plate supported on elastic quantum representing the soil mass or the strata. The raft can also be modelled as plate on elastic springs having stiffness 'K' representing the modulus of sub grade reaction. In the proposed model following properties are assigned in order to fulfil the material characteristics.

Table-1 Properties of material

Properties	Raft	Soil	
		Silt clay	Loose sand
Modulus of Elasticity, *E*	33.5×10^3 Mpa	56 Mpa	70 Mpa
Poisson's Ratio, µ	0.17	0.35	0.2

The behaviour of raft model is observed for two different soil conditions viz; 1) clay containing silt 2) loose sand. These soils are considered because they produce large stresses in the raft and adjacent soil layers. Hence it becomes very important to study the actual behaviour of the raft and its adjacent soil. A linear elastic model shows the approximate behaviour as the properties control the deformation of raft and adjacent soil mass.

While modelling the boundary condition is kept restrained at bottom for the soil model and a minor frictional value is assigned between the raft and soil interaction. The raft plate is kept simply supported on soil, so that the deformations at different points in the raft are correlated with the displacements in the soil.

The loads from the phase-I analysis are being transferred to the raft plate in the form of point loads. Generally in design of any foundation the uplift pressure is calculated and considered. It is evident that the FEA analysis in the computer software package calculates all the values and we get the output in an animated and graphical form. A manual check has to be given for validation of the results.

In this present study the generated mesh does not require any further refinement as the auto mesh is sufficient to define the geometry and boundary condition. The meshing is done in the following way for the raft-soil model.

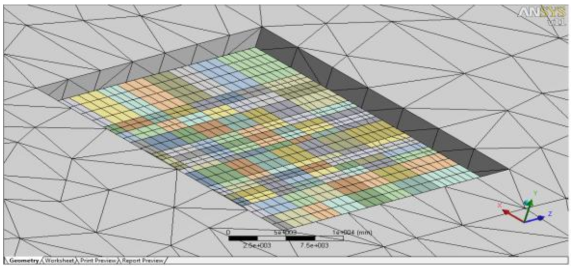

Figure-2 Raft soil meshing

Results and Discussion

The raft has been analysed to check the various characteristics such as the deformations viz; total deformation and directional deformation. The values obtained after successful analysis of the model by complete auto meshing are mentioned in the table-2

The total deformation of the raft may be treated as the total initial settlement when the raft is loaded. From Figure No.04 it can be observed that the value of settlement is unacceptable for a thickness of 0.8m, however the settlement reduces for the increase of the thickness. The settlement value is acceptable at raft thickness greater than 2.0m.

The actual soil condition is not a linear problem instead it becomes non-linear, when it is assumed that the soil condition is linear the parameters can be used near to the least values, so that the analysis results may be obtained and a safe design can be achieved.

Table-2 Directional and Total Deformation of soil and raft in soft silt clay

Thickness of Raft	Y-directional Deformation in mm	
	Surrounding soil	Raft
0.8	0.49	160.27
0.1	0.49	150.48
1.2	0.48	140.14
1.4	0.48	130.07
1.6	0.48	120.82
1.8	0.47	112.28
2.0	0.46	104.64
2.2	0.45	97.814

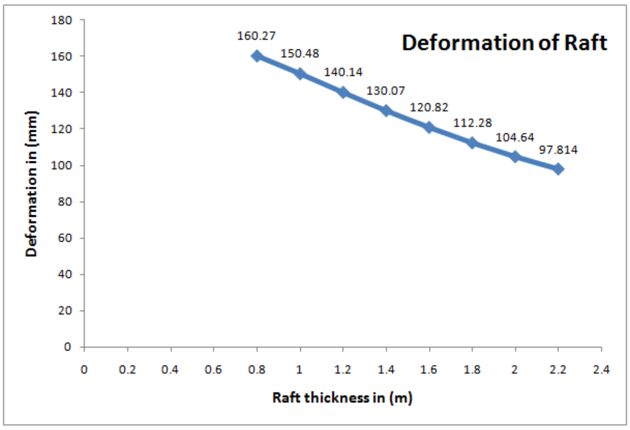

Figure-3 Deformation of Raft in soft silt clay

For studying the deformation and settlement of raft it becomes very important to assume number of thickness values depending on the results obtained by the previous post processing results.

Table-3 Foundation Soils and Raft Thickness.

Raft thickness (m)	
Silt clay	Sandy soil
0.8m,1.0m, 1.2m, 1.4m, 1.6m, 1.8m, 2.0m, 2.2m.	

The settlement observed in the nearby vicinity of the raft area is very small as compared to the raft settlement, but the characteristic deformation of the adjacent soil mass produces dramatic effect when seismic loads are encountered. In this present study the peak settlement of the adjacent soil is 0.3% to 0.4% of raft settlement.

The total deformation of the raft may be treated as the maximum settlement when the raft is loaded. From the graph below it can be observed that the value of settlement is unacceptable for a thickness of 0.8m, however the settlement reduces for the increase of the thickness. The settlement is acceptable at raft thickness greater than 2.0m.

The above chart gives the deformation in soils below and adjacent to raft. It is very clear from the above chart that the settlement is reduced as raft thickness increases. The increment of thickness is done by 0.2 m for every trial. This was done to attain the permissible deformation.

The settlement is considered as the maximum settlement of the raft under any circumstances. Similarly, the same raft is judged against the loose sand. In this soil the initial settlement is considered as the peak settlement as the settlement occurs immediately after the loading is applied.

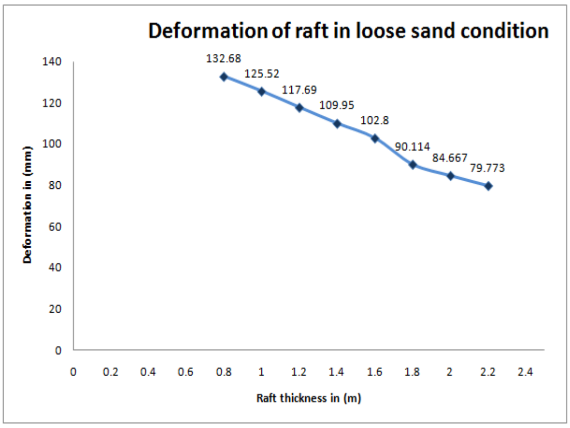

Figure 4 Deformation of Raft in loose sand.

The maximum deformations observed in the raft for thickness of 0.8m and 2.2 m in loose sand show a difference of 52.9 mm. while it is 62.45 mm in soft silt clay.

Table-4 Deformation in loose sand

Raft	Adjacent	Raft
0.8	0.28	132.68
1.0	0.28	125.52
1.2	0.28	117.69
1.4	0.28	109.95
1.6	0.28	102.8
1.8	0.29	90.114
2.0	0.29	84.667
2.2	0.3	79.773

The above table gives the values of settlement of the rafts in loose sandy soil. The table also gives the values of the minimum and maximum deformations in vertically downward direction. The permissible values of settlement are obtained for very higher depth values of the Rafts. It is seen that the permissible value of the settlement in the sandy soil is 75 mm. the value of settlement attained by the thickness 2.2m is found satisfactory.

In sandy soil generally the adjacent structures are affected immediately as the soil strata containing soil undergoes immediate settlement.

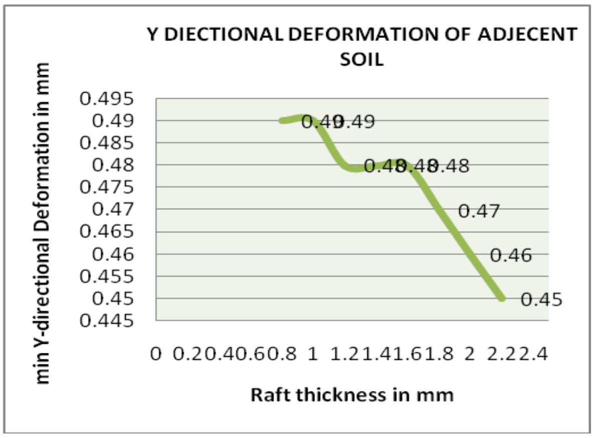

Figure 5 settlements around the structure

Stress range of Raft on soft clay.

The typical value of the stresses obtained from the table-5 helps in knowing the ultimate effect of the point loading on the raft surface. ANSYS is highly reliable software for the stress analysis, the results can be confirmed in accordance to the permissible settlements in the raft.

Table-5 Stress and deformation of Rafts in soft clay

Thickness of Raft	Max Equival-ent Stress	Min Equival-ent	Total Deformati -on(mm)
0.8	61.79	0.0127	160.27
1	79.09	0.0127	150.48
1.2	70.175	0.0136	140.14
1.4	60.241	0.0135	130.07
1.6	54.73	0.0139	120.82
1.8	50.18	0.0143	112.28
2.0	46.331	0.0148	104.64
2.2	43.07	0.0151	97.814

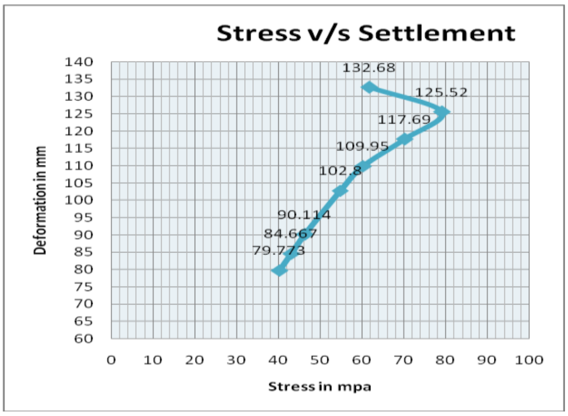

Figure 6 stress corresponding to settlement in silt clay

The above mentioned graph gives the values of maximum stresses observed at various nodes to the corresponding raft settlements. This helps in deciding the permissible stress values at typical raft thickness.

Table-6 Stress and total settlement of raft in loose sand.

Thickness of Raft	Max Equivalent Stress Mpa	Min Equivalent Stress Mpa	Total Deformation mm
0.8	61.776	0.0172	132.68
1.0	79.12	0.0171	125.52
1.2	70.229	0.0172	117.69
1.4	60.26	0.0175	109.95
1.6	54.775	0.0179	102.8
1.8	46.417	0.0192	90.114
2.0	43.161	0.0199	84.667
2.2	40.372	0.0207	79.773

As it is seen from the above readings the deformations in the raft is not acceptable for 0.8 m thick raft. The value of acceptance is achieved as thickness increases. Approximately it can be said that there is a difference in settlement by 5% to 6%.

Table-7 Moment Reaction of Raft in soft silt clay

Thick-ness of Raft	Maximum Moment Reaction N.mm			
	x-axis	y-axis	z-axis	total
0.8	$3.47e^{10}$	-28407	$-1.60e^{11}$	1.64 11
0.1	$3.47e^{10}$	-55490	$-1.60e^{11}$	1.64 11
1.2	$3.47e^{10}$	-45439	$-1.60e^{11}$	1.64 11
1.4	$3.47e^{10}$	27860	$-1.60e^{11}$	1.64 11
1.6	$3.47e^{10}$	59958	$-1.60e^{11}$	1.64 11
1.8	$3.47e^{10}$	1.6037 5	$-1.60e^{11}$	1.64 11
2.0	$3.47e^{10}$	$1.886e^{5}$	$-1.60e^{11}$	1.64 11
2.2	$3.47e^{10}$	1.7175 5	$-1.60e^{11}$	1.64 11

Moment Reactions

Raft on sandy soil

Table-8 Bending Moment of raft in loose sand

Thick-ness of Raft	Maximum Moment Reaction N.mm			
	x-axis	y-axis	z-axis	total
0.8	$3.47e^{10}$	-8938.4	$-1.60e^{11}$	1.64 11
1.0	$3.47e^{10}$	5279.3	$-1.60e^{11}$	1.64 11
1.2	$3.47e^{10}$	19885	$-1.60e^{11}$	1.64 11
1.4	$3.47e^{10}$	61703	$-1.60e^{11}$	1.64 11
1.6	$3.47e^{10}$	79115	$-1.60e^{11}$	1.64 11
1.8	$3.47e^{10}$	189210	$-1.60e^{11}$	1.64 11
2.0	$3.47e^{10}$	189210	$-1.60e^{11}$	1.64 11
2.2	$3.47e^{10}$	163630	$-1.60e^{11}$	1.64 11

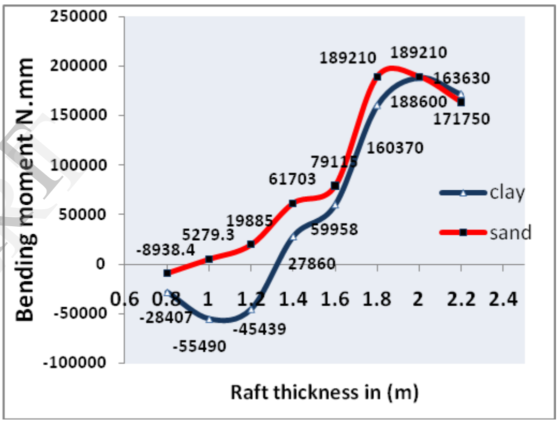

Figure-7 Bending Moment variation for Rafts in different soils.

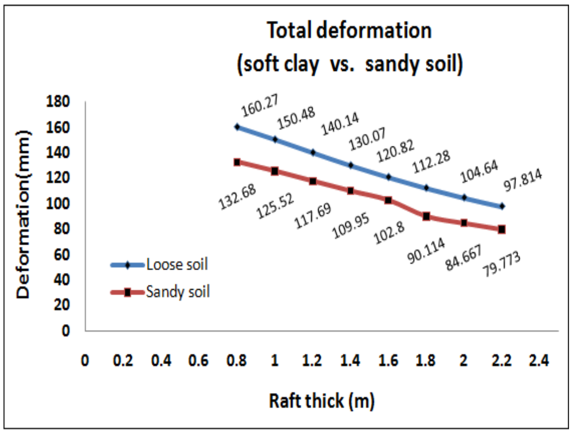

Figure-8 Settlements in sand and clay

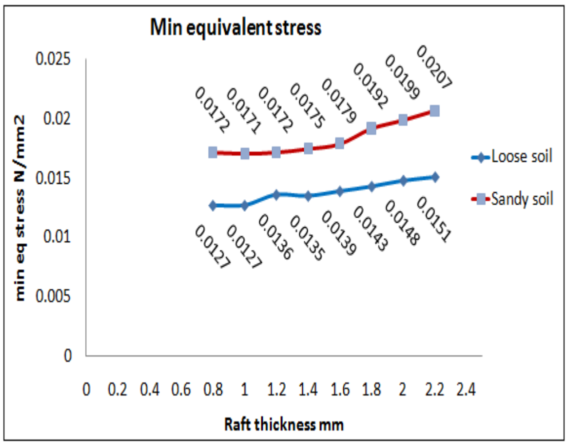

Figure-9 Minimum equivalent Stresses in Raft

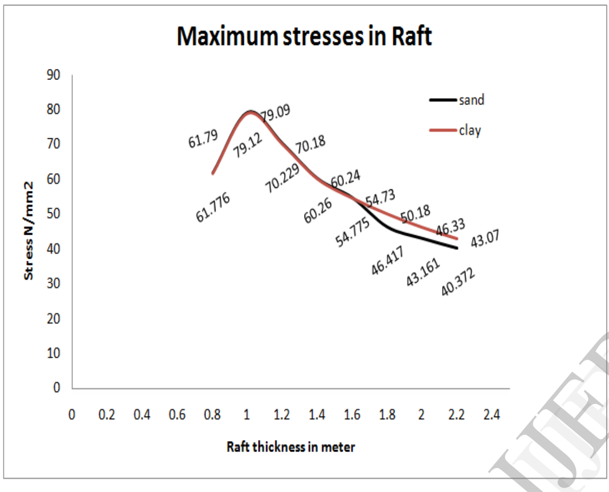

Figure-10 Maximum Stresses in Raft

It is clear from the above graph that the maximum stress value in the rafts is equal to some extent. It is seen that the maximum stress concentration is equal up to the thickness of 1.6m.The settlement observed for the thickness of 1.6m is 120.82 mm for clay soil and 102.80 mm for sandy soil. This is near to the allowable settlement.

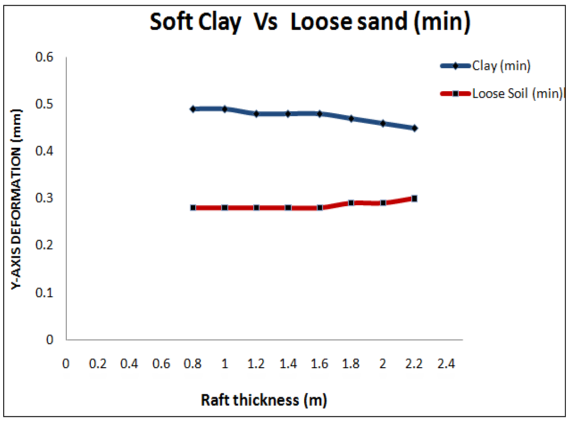

Figure settlement of surrounding soil.

From the above figure it is clear that the settlement of the surrounding soil is distinct from each other. The settlement has a very low value as 0.1 mm so that is negligible from the point of view.

Conclusions

The behaviour of Raft Foundation was analysed for different thicknesses and soil conditions under compressive load by using ANSYS. A 3D Axe-symmetric model is assumed for the study which delivered relevant Results.

In case of silt clay, the stress concentration and raft deformation are fairly acceptable. The stress contour of the different rafts helps to identify the maximum stress concentration region of the raft. In case of silt clay and loose sands the permissible stresses are observed in different raft thicknesses.

With the increase in thickness of Raft foundation from 0.8 m to 2.2 m, the settlement is reduced and the load carrying capacity is increased. With the increase in thickness, settlement goes on reducing and so the stress level.
For raft in silty clay lower value of thickness is permissible for Raft the value obtained is 1.4m.
A higher value of raft thickness like 2.2m is obtained in case of loose sandy soil.
It may be concluded that the raft analysis is sensitive towards the two input parameters, Modulus of Elasticity and poisons ratio for soil and concrete.
If cost comparison of the raft on clay is done then it may tend to be more economical that that raft on loose sandy soil. Mat of size 40m x 40 m x 1.4m in silty clay gives a higher load carrying capacity with permissible settlement.
In loose sandy soil the Mat of size 40m x 40mx 2.2 m gives a higher load carrying capacity and permissible settlement.

Referances

1. Shrilakshmi.G., Rekha.B., (2011), "*Analysis of MAT Foundation using Finite Element Method,*" International Journal of Earth Sciences and Engineering, Volume 04, No.6, pp. 113-115.

2. Thangaraj D. D., Ilamparuthi.K., (2010), "*Parametric Study on the Performance of Raft Foundation with Interaction of Frame*." EJGE,Vol. 15, pp. 861-878.

3. Kame.G.S., Ukarande.S.K., Borgaonkar.K., Sawant.V.A., (2008), "*A Parametric Study on Raft Foundation*," The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), pp. 3077-3085.

4. Ukhov.S.B.,(2003),*" Beds and Foundations of High-Rise Buildings*," Soil Mechanics and Foundation Engineering, Vol. 40, No. 5, pp.173-175.

5. Ulitskii.V.M., Shashkin.A.G., and Shashkin.K.G., (2003),*"Geotechnical Problems associated with the Construction of High-Rise Buildings Foreign Experience and Domestic Practice,"* Soil Mechanics and Foundation Engineering, Vol. 40, No. 5, pp.176-184.

6. Poulos, H.G., (2010), "*High-Rise Building Foundations – A Limit State Design Approach*," ASCE, pp.501-516.

7. Ugalmugle.A., Namjoshi.A.G., "*Construction Of Raft Foundation In Deep Sandy Beds For Major Bridges Across Perennial Rivers*"

8. IS: 2950-1965, "*Indian Standard Code of Practice of design and construction of raft foundation"*, Bureau of Indian Standards, New Delhi, 1965

9. Indian Standard Code of Practice of design and construction of raft foundation, IS: 2950(Part 1)-1981, *Indian Standard Code of Practice of design and construction of raft foundation.* Bureau of Indian Standards, New Delhi, 1981.

10. Joseph E, Bowels, *Foundation Analysis and Design*, 2nd Edition, 1977.

11. IS 9214, 1979, *Method of determination of modulus of sugared reaction (K value) of soils in field*, Bureau of Indian Standards, New Delhi, 1979.

12. IS: 2720 (Part XI)-1971,*Method of tests for soils, Part XI, Determination of shear strength parameters of specimen tested in unconsolidated undrained triaxial compression test without the measurement of pore water pressure*. Bureau of Indian Standards, New Delhi, 1971.

13. IS: 456 -2000, "*Code of Practice for Plain and Reinforced Concrete*, Bureau of Indian Standards", New Delhi, 2000.

14. IS: 875-1987, "*Design loads (other than earthquake) for buildings and structures-Part2: Imposed Loads"*, Bureau of Indian Standards, New Delhi, 2000

.

15. IS: 875-1987, "*Design loads (other than earthquake) for buildings and structures-Part 3: Wind"*, Bureau of Indian Standards, New Delhi, 1987.

16. IS: 4326-1993, "*Earthquake Resistant Design and Construction of Buildings - Code of Practice (Second Revision)*", Bureau of Indian Standards, New Delhi, 1993.

17. Poulos.H.G., Grahame.Bunce., (2008) "*Foundation Design For The Burj Dubai – The World's Tallest Building*," 6th International Conference On Case History, Arlington, pp11-16.