EFFECT OF BUOYANCY ON STITCHED RAFT OF BUILDING HAVING THREE BASEMENTS IN PRESENCE OF GROUND ANCHORS

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Abstract- Buildings with deep basements and without substantial weight of the super-structure, when constructed within highly fluctuating rise and fall of underground water level, experiences significant uplift pressure due to buoyancy effect. Use of pre stressed rock anchor is a prominently accepted technique to fix the structure to the ground against the excess hydrostatic pressure, when the sound rock is available at the level of basement stitched raft. The efforts are made in this study to suggest a suitable design approach and arrive at appropriate constitution of various parameters like locking of anchors to partial capacity, residual load in anchors, spacing of anchors, raft thickness and reinforcement consumption in raft, to achieve practical and economical solution which will help maintain structure in position.

Keywords- Deep basement, Buoyancy, Stitched Raft, Pre-stressed rock anchor, Lock off load, Residual load in anchor.

I. INTRODUCTION

Large scale developments in building construction and lack of available space on account of cluster development has produced demand to go deep into the ground to manage parking and other services of the building.

At places, where fluctuations in the underground water are quite considerable and the water is expected to rise up to or above the ground level due to heavy floods during monsoon, the basement rafts are designed for the critical case. This critical case is the net total uplift force arrived at after deducting the self weight of the structure from weight of the volume of water displaced by the structure.

The solution to the above problem, sometimes, is done by increasing the self weight of the structure by counter weight filling. However, in the deep and large basements, this may not be an appropriate solution. In regions like Mumbai, where the strong rock is available at about 9 to 10 meters below the ground level, use of the pre-stressed rock anchors in deep basement stitched raft is significantly accepted solution to counteract the uplift due to the buoyancy.
In the present study, suggested solution for the mentioned problem is presented.

The suggestion includes use of permanent ground anchors instead of heavy counter weight systems or tension piles to stabilize substructure of the building against floatation. The Sub soil drainage system is also one of the systems occasionally adopted to reduce the uplift due to buoyancy. However, in view of the challenges and difficulties observed while maintaining the overall system in running condition throughout the life of the building, this system is accepted at very few locations where the quantity of underground water is expected to be very less .

The Efforts are made in this study to understand the effect of locking off the ground anchors in design of the deep basement stitched rafts.

II. DESIGN PHILOSOPHY AND APPROACH

A multi basements parking building situated in Mumbai is considered for this study. A building with three numbers of basements is chosen for this study and comparison. Strong rock is located at foundation level of lowermost basement. The focus of this paper is on studying the action of internal forces in rock anchor on design of the reinforced concrete stitched raft. The design of stitched raft with anchors fixed in rock is proposed to be studied in this report. Appropriate factor safety to arrive at design load and spacing of these anchors is considered in this report. Suitable analytical simulation of anchors is adopted in this study to arrive at acceptable solutions. Different combinations are prepared in this report to arrive at reasonable value at which rock anchors can be stressed partially. As boundary conditions, in design of the stitched raft with anchors, care is taken such that there is no uplift in the footings and at the same time differential deflection in the raft slab is within permissible limits even when the anchors are locked to the part of their design load.

III. PARAMETERS

The parameters for this study are selected upon their contribution in composite design of stitched raft for hydrostatic uplift and are categorized as follows;

(a) Constant Parameters:

1. Composition of the Underground strata remains same for all conditions, SBC of 1000 Kn/Sq.m. with an estimated average settlement of foundation of 10 mm is assumed to remain constant for this study. This settlement is used to find out the sub-grade modulus for this study.

2. Depth of the Plum concrete (Counter weight filling) of 1200 mm. over the raft kept constant for this study.

3. Water table assumed to be at the ground level all the times.

4. Public Parking Building is chosen for this study with 3 Basements +Gr. floor, typical column spacing @ 9 m x 9 m. Bottom of raft is at 12 m. below the ground level.

(b) Variable Parameters:

Spacing of anchors is the first variable parameter which applicable for the above building.

1. Spacing between anchors = L/2
2. Spacing between anchors = L/3
3. Spacing between anchors = L/4

Where, L = Span between the columns (9 m. for this study)

The second unseen variable parameter in this study is the thickness of stitched raft, which is dependent on the spacing between anchors.

Thickness of raft is considered as "1/8th of the Spacing between anchors" for the all parameters considered in this study.

Third and very important parameter is "locking of anchors to the part of their design load".

1. Locking of anchors @ 100% of its capacity
2. Locking of anchors @ 80% of its capacity
3. Locking of anchors @ 60% of its capacity
4. Locking of anchors @ 30% of its capacity
5. Locking of anchors @ 15% of its capacity

Parameters used for this study are mentioned below in Table 1.

TABLE-I: VARIABLE PARAMETERS FOR THE STUDY

No.	Parameters					
1	Spacing of Anchors(Sa)	L/2	L/3	L/4		
2	Raft thickness	Sa/8	Sa/8	Sa/8		
3	Locking of anchors @	100%	80%	60%	30%	15%

IV. ANCHOR DESIGN LOAD AND SPACING

To begin with design optimization, global stability check to safeguard structure against uplift due to hydrostatic pressure become of primary importance.
As stated in the design philosophy, appropriate factor of safety is considered to arrive at the design load of the rock anchors. Safety factor of "1.5" has been taken as basis for this study.

Design capacity of anchors and their respective spacing for three numbers of basements is arrived at as shown below in Table 2.

TABLE-II: DESIGN LOAD OF ANCHORS FOR 3 BASEMENTS

No.	Design Components			Basements -3 Nos.		
	Description of Parameters		Unit	Spacing Of Anchors		
				L/2	L/3	L/4
1	Basement Foundation System Details	No. of basements	Nos.	3	3	3
		Basement floor height	m.	3.5	3.5	3.5
		Spacing between columns	m.	9	9	9

		Spacing of anchors	m.	4.5	3	2.25
		Thickness of raft	m.	0.6	0.4	0.3
		Finished Basement level Below ground floor	m.	10.5	10.5	10.5
		Basement Top PCC Thickness	m.	0.1	0.1	0.1
		Plum Concrete Thickness	m.	1.2	1.2	1.2
		Bottom Level Of Raft	m.	12.4	12.2	12.1
2	Uplift Force	Hydrostatic Pressure	kN/ Sq.m.	-124	-122	-121
3	Downward Loading	Top PCC	kN/ Sq.m.	2.4	2.4	2.4
		Plum Concrete	kN/ Sq.m.	24	24	24
		Raft	kN/ Sq.m.	15	10	7.5
4	Total Downward Loading		kN/ Sq.m.	41.4	36.4	33.9
5	Net Upward Unbalanced load excluding self weight of structure		kN/ Sq.m.	-82.6	-85.6	-87.1
6	Structure Details	Grid Spacing in "X" direction	m.	9	9	9
		Grid Spacing in "Y" direction	m.	9	9	9
		No. OF floors Supported above	Nos.	3	3	3
		Average floor thickness	m.	0.3	0.3	0.3
		Dead Load Intensity per floor	kN/ Sq.m.	7.5	7.5	7.5
	Total Downward Intensity of Structure at base level		kN/ Sq.m.	22.5	22.5	22.5
	Reduced dead load intensity for uplift calculation(10% deduction)		kN/ Sq.m.	20.25	20.25	20.25
	Net Upward Unbalanced load Including self weight of structure (Load to be taken by rock anchors)		kN/ Sq.m.	-62.35	-65.35	-66.85
7	Rock Anchor Arrangement Details	Number of anchors in one bay	Nos.	4	9	16
		Factor of Safety in capacity		1.5	1.5	1.5
		Rock Anchor Capacity	T.	190	90	55

V. MODEL AND ANALYSIS

As stated in the design philosophy, engineering models are prepared for various combinations as per list mentioned below. Software "SAFE" version 12.3.0 is used for finite element analysis of stitched raft in presence of anchors.

List of the mathematical models for optimization study are mentioned in Table 3.

TABLE –III: LIST OF MATHEMATICAL MODELS

Sr. No.	Analysis Model No.	Parameters			
		Number Of Basements	Anchor Spacing	Raft Thickness	Locking anchor @
1	Model 1	3	L/2	Sa/8	100%
2	Model 2	3	L/2	Sa/8	80%
3	Model 3	3	L/2	Sa/8	60%

4	Model 4	3	L/2	Sa/8	30%
5	Model 5	3	L/2	Sa/8	15%
6	Model 6	3	L/3	Sa/8	100%
7	Model 7	3	L/3	Sa/8	80%
8	Model 8	3	L/3	Sa/8	60%
9	Model 9	3	L/3	Sa/8	30%
10	Model 10	3	L/3	Sa/8	15%
11	Model 11	3	L/4	Sa/8	100%
12	Model 12	3	L/4	Sa/8	80%
13	Model 13	3	L/4	Sa/8	60%
14	Model 14	3	L/4	Sa/8	30%
15	Model 15	3	L/4	Sa/8	15%

In continuation to the statement made in the design philosophy, the mathematical simulation of anchors is very crucial for this study. Instead of modeling anchors as support for all conditions, they are modeled as point load when they are stressed for full of their capacities and are modeled as point load plus point spring in tension for residual load when they are locked for part of their design capacities.

The effect on behavior of the raft deflection due to adopted simulation under the effect of uplift force produced by ground water is shown in Fig.1 to 6.

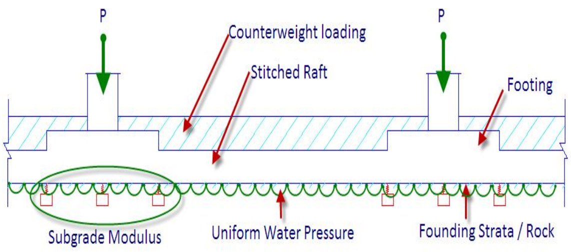

Fig. 1. FBD of Loadings on Raft- Analytical Simulation

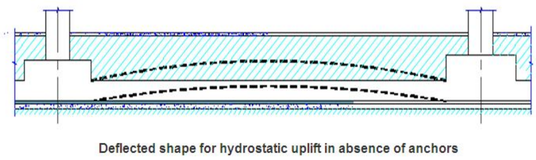

Fig. 2. Deflected Shape of raft In Absence Of Anchors

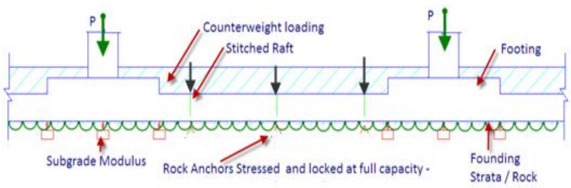

Fig. 3. FBD of Loadings on Raft –Analytical Representation (In presence of anchors stressed and locked for full capacity)

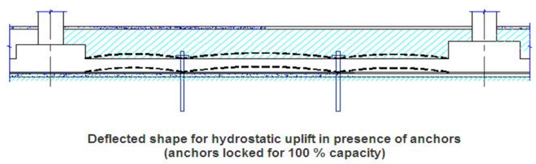

Fig. 4. Deflected shape of Raft in Presence Of Anchors (Locked at full Capacity)

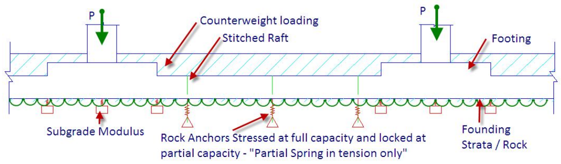

Fig. 5. FBD of Loadings on Raft –Analytical Representation (In presence of anchors stressed and locked at partial capacity)

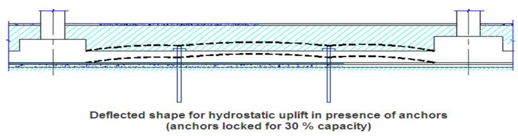

Fig. 6. Deflected shape of Raft in Presence Of Anchors (Locked at partial Capacity)

Conditions shown in Fig. 3 and 5 are modeled in "SAFE" models for various combinations of the basements and spacing of the anchors as mentioned in Table 1. Loading is applied as shown in the design Table 2 mentioned in earlier section for three numbers of basements.

Plan showing raft modeled in SAFE analysis software and the images of the deflected shape of the raft due to buoyancy uplift are indicated below in Fig.7 and 8.

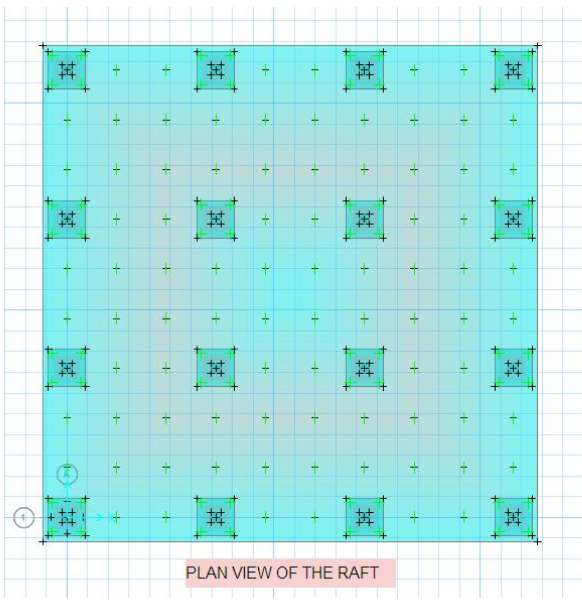

Fig. 7. Plan View of the Stitched Raft (Image From SAFE)

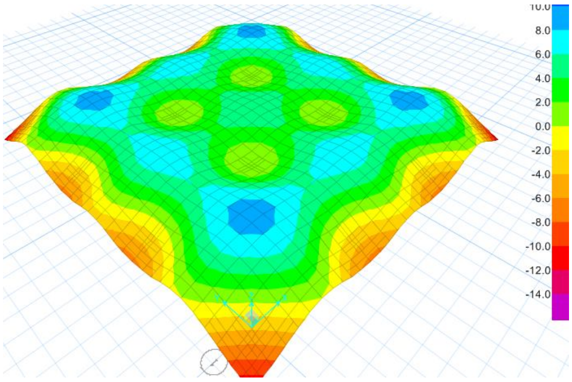

Fig. 8. Deflected shape of Raft in Presence Of Anchors (Image From SAFE)

VI. RESULTS AND DISCUSSION

A. Displacement Below Footings for Various Percentage Of Locking Of Anchors

Results obtained through these analysis files are transformed to plot graphs. These graphs shows how locking of anchors at partial load will result in behavior of the raft.

In addition, as mentioned earlier in the report, Boundary conditions of loss of contact in the footings and permissible differential deflection of the raft are carefully observed through results presented below.

Variation in the displacement below the footing for various condition of locking of the anchors is displayed below in Fig.9.

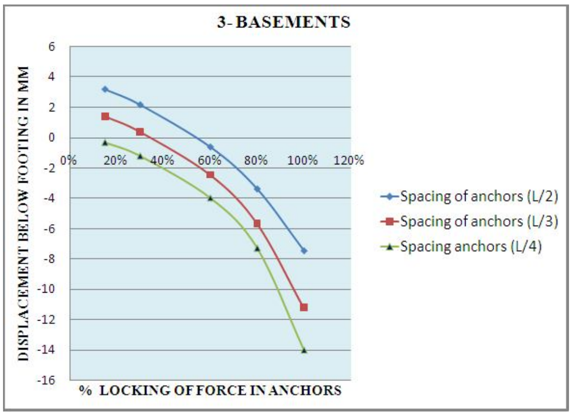

Fig. 9. Displacement below Footing for Various %age of Lock off Load in Anchor – For 3 Basements

Fig.9 shows “percent locking of anchors from 0% to 100%” on X-axis and “Displacement below Footing in MM” on Y-Axis

Fig.9 shows how stressing and locking load in the anchor influence the displacements below footing. On account of sub-grade modulus which is considered while performing the analysis in SAFE, footing tends to settle down by corresponding distance. When the anchors are stressed and locked for their full design load, the settlement below the footing is as per a criterion which was used to derive SBC at the founding level. The value of settlement below the footing for 100% lock off load condition nearly matches the value mentioned in the design parameters. However, the settlement appears to be reducing for lesser percentage of lock off loads in the anchors.

From Fig.9, it is observed that there exists tension in the footing when the anchors are locked at 55% and 35% of their design loads when they are placed at spacing of “L/2” and “L/3” respectively.

There is no tension observed below the footing when the anchors are placed at spacing of “L/4”. Even when the anchors are locked at lower loads, the footing do not dislodge from the ground. However, the other criteria of differential deflection in the raft become more important in this case, which is observed in next result.

B. Differential Deflection(settlement) in raft for Various Percentage Of Locking Of Anchors

Variation in the differential settlement (deflection) in the raft for various condition of locking of anchors is displayed below in Fig.10.

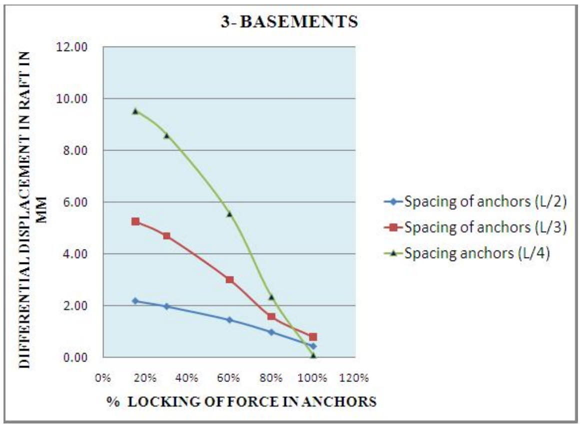

Fig. 10. Differential Deflection in Raft for Various %age of Lock off Load in Anchor – For 3 Basements

Fig.10 shows “percent locking of anchors from 0% to 100%” on X-axis and “Differential deflection (settlement) in Raft in MM” on Y-Axis for corresponding locking of Anchors Fig.10 shows the behavior of the raft during various stages of locking of anchors for building with three basements.

As the raft is resting on rock, deflection behavior of raft can be treated similar to that of flat slab. Taking the reference of one of the study carried out on actual deflection of the flat slabs, permissible deflection values for long term deflection may be considered as Span/1500. In this study, 6 mm is referred as the value for differentiation.

As noticeable for different values of lock off load in the anchors, it is observed that when the anchors are designed for lesser loads and are closely spaced, the differential displacement (i.e. upward deflection) in the raft increases in comparison to the other conditions when the anchors are placed at sufficient distance apart and designed for the higher loads.

C. Construction Cost Per Unit Area Of Stitch Raft for Various Percentage Of Locking Of Anchors

Variation in the construction cost per unit area of the stitched raft for various condition of locking of anchors is displayed below in Fig.11.

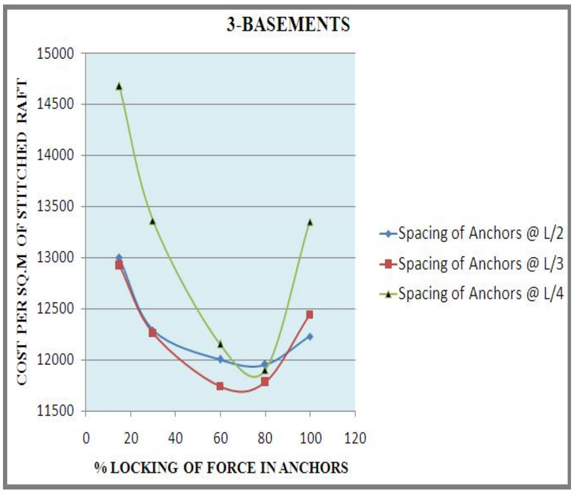

Fig. 11. Cost Per Sq.m Area of Raft for Various %age of Lock off Load in Anchor – For 3 Basements

Fig.11 shows “percent locking of anchors from 0% to 100%” on X-axis and “Construction Cost of Stitched Raft in Rupees per Sq.m” on Y-Axis for corresponding locking of Anchors.

Fig.11 shows the effect of various stages of locking of anchors on construction cost of stitched raft of building with three basements.

The constructions cost is worked out for parameters like concrete, reinforcement and for pre-stressed anchors. The optimum cost of construction is observed to be near to Rs.11,750 per.Sqm. for the anchor spacing of “L/3” and for lock off load of 70% of the anchor design load.

CONCLUSION

From the results shown in Fig. 9, and on the basis of discussion made thereon, it can be stated that when the rock anchors are spaced at “1/2 of the Span between the columns”, no uplift in the footing is observed when lock off load for the anchors is more than 55% of the design anchor load. Similarly, when the anchors are spaced at “1/3rd of the span between the columns”, no uplift is observed when lock off load is more than 35%.

Value of lock off load can be further reduced to 20% of the design load when the anchors are spaced at “1/4th of the span between the columns”.

From the results obtained from Fig. 10, it can be stated that for anchors spaced at “1/4th of the span between the columns”, the ideal value of lock off load for anchors is required to be more than 58% to restrict the differential deflection between the raft and footing to the appropriate value to avoid large upward deflections. However, when the anchors are spaced at “1/3rd and 1/2 of the Span between the columns”, no major differential settlement is observed even at lower percentage of lock off loads as the anchor loads are considerably high.

Conclusions made above provide information to the user to choose a safe partial lock off load for a given spacing of the anchors considering the mentioned two important measures.

From the results obtained from Fig. 11, it is understood that to get the optimum cost of construction for stitched raft of building having three basements, anchors shall be spaced at “1/3rd of the span between the columns”, the ideal value of lock off load for anchors is required to be more than 70% of the anchor design load.

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