Bell-Shaped Anchor with Geotextile Ties Embedded in Clay- A Numerical Study

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Abstract. A parametric numerical simulation has been carried out to study the behavior of bell-shaped anchor with and without geotextile ties within clayey soil. The study has been done with help of FEM software ABAQUS. Three types of soil and one typical model belled anchor with diameter 0.125 m have been considered for the numerical analysis. Properties of geotextile sheets and soil mass have been studied and reported in the present work. Variation of uplift capacity with different parameters such as embedment ratios (H/D) of anchor, cohesion of soil etc. have also been studied. In the numerical study weight of the soil as well as gravity has been taken into account. A sensitivity analysis and a mesh convergence study also have been performed to determine the model dimension and meshing criteria. Breakaway condition has been adopted here as no resistance is acting below the anchor against the soil mass. Both the anchor and the geotextile sheet as linear material and clay mass as elasto-plastic material have been considered in the analysis. With introduction of geotextile tie to the anchor the uplift capacity of anchor with tie increases. Optimum value of L_g/D (Lg- diameter of geotextile sheet) is found to be 3 from the current investigation. Optimum numbers of geotextile tie layers is found to be 3 for a specific type of soil. Stress profile also has been plotted to identify the maximum stress in geotextile.

Keywords: Bell-shaped Anchor, Geotextile, Uplift Capacity, Elasto-plastic Material.

1 Introduction

Anchor foundation is one of the most important structures for resisting the uplift forces, overturning moments. In case of many off-shore platforms, chimneys, transmission towers where there is an issue of tensile pullout forces, anchor can be used to counter those forces. There have been different types of anchors in the field of geotechnical engineering. Bell-shaped anchor is one of the concerning matter in this field, where an enlarged base (Bell) is attached below the cylindrical shaft. Many authors have worked on anchor foundation with different parameter of foundation material, shape of the anchor etc. Sowa [1] investigated the resisting capacity of cylindrical piles of reinforced concrete cast in situ in bored holes constructed in cohesive soils. Based on an empirical relationship between soil adhesion and the undrained shear strength he evaluated the pulling capacity of the uplift piles. He observed that the active lateral pressure as well as the active skin friction of the soil mass can be improved by rapidly placing the concrete mass and vibrating the same methodically. He also found that the estimation of short time pullout capacity of cast in situ piles within cohesive soil can be accounted based on undrained shear strength and the long-term pile pullout capacity by the creep and effective shear strength parameters. Das [2] performed model tests for determining the uplift capacity of square and rectangular foundations in clay mass. He determined the net uplifting loads experimentally with varying the length-to-width ratio of the anchor plates from one to five. He presented the non-dimensional breakout factors F_c and F_q. He also observed that the value of F_c increases with increase in embedment depth up to a critical depth and after that f_c reached an approximately constant value. Das [3] performed a rigorous study on uplifting capacity of plate anchor with various parametric conditions such as embedded in clayey soil, in sloping ground etc. and gave a general methodology to determine the uplift capacity of plate anchors in clayey soil. He had also considered the suction force, creep in soil etc. factors in the study. He also found that the value of breakout factor F_c increased with embedment ratio up to a certain limit and got constant afterwards. Degenkamp and Dutta [4] developed a technique to estimate the tensile force acting at the anchor point of the chain conformation in the soil mass for an soil-chain- anchor system where a pile is embedded in soil mass with combined anchor pile and the mooring chain. With the help of incremental-integration technique, they have developed the equilibrium equations for the embedded chain. Soil resistance against the chain was modelled as same way used for strip footing in clayey soil. Rao et al. [5] investigated the behaviour of single as well as group of Granular Pile Anchors (GPA) of varying diameter and length embedded in expansive clayey beds. They found that higher surface area of GPA increased the pullout capacity. The increment was about in the range of 33-55%. It was also found from their experiment that the required load for pullout also increased with diameter because of increased surface area. They also found that with increasing length and decreasing length to diameter (L/D) ratio the pullout capacity increased. They also found that in case of group of GPA anchor the uplift capacity increased compared to single pile cause of group action and the increment was about 22%. Merifield and Smith [6] have investigated on multi-plate anchors embedded in clayey soil. They have adopted plane strain numerical model with ABAQUS and executed a numerical limit analysis procedure. They found that ultimate uplift resistance of multi-plate anchor increased up to a limiting value indicating the shift in shallow to deep anchor mechanism. O'kelly et al. [7] investigated the pullout resistance of Granular Anchors (GA) in undrained over consolidated clay. They found that the mode of failure of GAs depended upon the length to diameter (L/D) ratios. For short granular anchors the pullout resistance is offered by shaft and for long GA the same is offered by end-bulging of the granular column. With the help of PLAXIS 2D considering the soil mass as Mohr-Columb material they have performed a numerical investigation and found the range of the bulging zone of about 8 time diameter of pile. Tho et al. [8] investigated the uncertainty of different approaches for determining the uplift capacity of the plate anchors by forming the capacity factors for square plate anchors within a soil of linearly increasing strength using three-dimensional large deformation finite element approach. Liu et al. [9] analyzed the Ultimate Pullout Capacity (UPC) of the anchor and suggested for using the large deformation finite element analysis. Adopting the Coupled Eulerian-Lagrangian (CEL) technique with the help of the ABAQUS they performed the behavioural study and then carried out experimental studies on different types of plate anchors in different types of the soil. Considering the soil mass as elastic-perfectly plastic material with Tresca-Yield criterion they carried out the analysis. They found that for square anchor in uniform clay the value of bearing capacity factor (N_c) increases rapidly with H/B of 4, whereas for square plate anchors in linear type clay the pullout resistance increased linearly up to maximum capacity and reduced to zero at mud line. Banerjee and Mahadevuni [10] investigated the effects of different parameters and uplift capacity of square plate anchors reinforced with geosynthetics buried in cohesive soil with the help of ABAQUS. They incorporated the material non-linearity by considering hypo-elastic model for soil mass and investigated the effect of embedment depth, size and depth of geotextile sheet. They found that the uplift capacity of the plate anchor increased proportionally with embedment depth up to a critical value, which also indicates the transition stage of shallow behaviour to deep anchor criteria. With the application of reinforcement the improvement in uplift capacity was about 52 - 72%. From their study they found that the ultimate capacity as well as breakout factor of the anchor increased with embedment ratio up to 4 but with size of plate had an insignificant effect on breakout factors. From the previous research works it has been found that analysis and experimental works have been done with different types of anchors such as plate anchor, granular pile anchors in clayey soil mass but detail study about bell-shaped anchors with attached tie embedded in soil mass (clayey soil) is still very limited. In the present investigation an attempt has been taken to numerically analyze the bell-shaped anchor with tie embedded in clayey soil mass and also to study its behavior, stress characteristic etc.

2 Statement of the Problem

A 2-D axisymmetric bell-shaped anchor embedded in clayey soil mass with geotextile ties is analyzed with the help of FEM software (ABAQUS). The numerical analysis has been performed by varying different parameters of soil, geotextile ties and anchor. One typical anchor with attached geotextile ties has been used for the analysis. Fig 1. presents the illustrative diagram of the numerical model.

3 Materials used for the analysis

One typical model bell-shaped anchor, diameter (D) of 0.125 m has been chosen for the present analysis. Three types of soils (Type I, Type II, and Type III) have been collected for the present work. Type I soil is Kaolinite, which has been procured from local market Kolkata, West Bengal, India. Type II and Type III soils are also locally collected soils from different places around Howrah District, West Bengal. The engineering properties of the above three soils have been presented in the Table1. In accordance with ASTM 2487 [11] the soil Type I, Soil Type II, and Soil Type III may be classified as CH, CL, and CL respectively. Woven geotextile made of Polypropylene ties has been used for analysis purposes. Tensile strength for the geotextile has been found as 41kN/m and 37kN/m in machine direction and cross-machine direction respectively.

Table 1. Properties of Soil Mass

Soil Designation	Type I	Type II	Type III
Dry Density (DD) kN/m^3	17.85	14.32	16.28
Optimum Moisture Content (OMC) %	12.1	26.56	21.63
LL	51.40	35.00	33.54
PL	29.84	21.60	17.34
Type of Soil	CH	CL	CL
ϕ,Angle of friction (degree)	4.4	3.5	3.0
c,Cohesion (kN/m^2)	21.15	15.50	12.00
Specific Gravity	2.597	2.685	2.587

4 Analysis procedure

In the present numerical simulation the anchor, soil mass and the ties have been modelled as elastic material, elasto-plastic and homogeneous element respectively. The properties of the Anchor have been taken as follows: Density of the anchor as 2.5 kg/m^3, modulus of elasticity 25MPa, poison's ratio 0.15. As for geotextile ties material has been chosen as woven polypropylene, whose mass per unit area, modulus of elasticity and poison's ratio has been taken as 0.250 kg/m^2, 193 MPa and 0.25 respectively for numerical study purpose. Detailed properties of the geotextile sheet have been described elsewhere (Das and Bera[12]). Breakaway condition has been considered after the failure occurs. From symmetric consideration half model has been accounted for numerical analysis and performing sensitivity study the boundary of the soil mass has assigned as 6D as width and 10D as height. Detail procedure of analysis has been discussed in Das and Bera [13]. In the current study cohesive interaction has been chosen between soil and anchor. In the numerical simulation the model of anchor, tie and soil have been modelled as solid homogeneous plane strain element. Friction as well as cohesion has been applied between geotextile and soil mass due to direct non-applicability of adhesion.

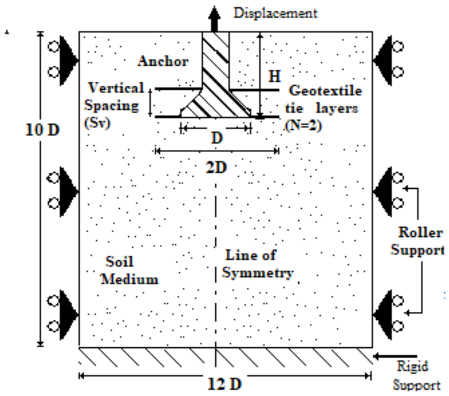

Fig. 1. Schematic diagram of soil-tie- anchor system used for analysis.

Table 2. Plan of analysis

Series	Anchor	H/D	Soil Type	Ties
F1	1	0.5-3	Soil Type I, Soil Type II, Soil Type III	-
F2		0.5-3		L_g/D- 2
F3		3		L_g/D- 2,3,4,5
F4		3		N- 1,2,3,4

5. Plan for the numerical analysis

In the present numerical simulation analysis has been done in four different series (Series F1, Series F2, Series F3, and Series F4). In series F1, H/D ratio (H- Depth of embedment, D- Diameter of the Anchor) of the anchor has been varied from 0.5 – 3.0 for three types of soil without any ties. F2 represents the variation of H/D ratio for L_g/D =2 (L_g = Length of Geotextile) for three types of soil. F3 represents the variation of L_g/D ratios for H/D = 3 in all three types of soil and F4 represents the variation of number of layers (1 to 4) for H/D= 3 in three types of soils. Series F1 has been performed to know the effect of H/D ratio with varying types of soil on uplift capacity of anchor without tie. Whereas, series F2, F3, and F4 have been performed to study the effect of application of geotextile ties on uplift capacity of the tie attached anchor. In the present paper one particular anchor (diameter 0.125 m) has been chosen for the entire analysis. The detail of the plan for analysis has been presented in Table.2.

6. Convergence Study

For improving the accuracy of the numerical analysis a convergence study have been performed. A model anchor of diameter 0.125, L_g/D = 2, N= 1, and H/D = 3 has been selected for the analysis purpose. The results of the convergence study have been presented in Fig 2. From the figure it has been found that 2170 no. of CAX4R of 2D elements are sufficient to analyze the model accurately.

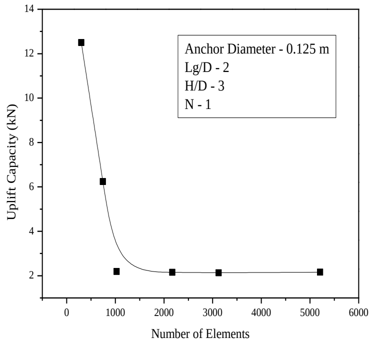

Fig.2 convergence study for the analysis.

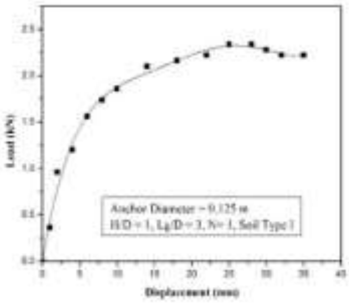

Fig. 3. Uplift displacement versus uplift capacity in Type I soil

7. Validation of the numerical study

For the purpose of validating of the present work a series of model tests with the model anchor (diameter 0.125m) with geotextile tie have been carried out in the laboratory for soil Type I with varying H / D ratio, L_g/D ratio. The model tests have been carried out in Type I soil at MDD and OMC. Typical uplift capacity versus displacement curve for H/D = 1.0, L_g/D=3(within soil sample 1) is shown in Fig.3. Fig 4 shows the comparison between the result obtained from experiment and numerical investigation. From the curve it is observed that the experimental results are very close to results obtained from ABAQUS analysis. From the curve it is also found that the maximum deviation is around 9% only.

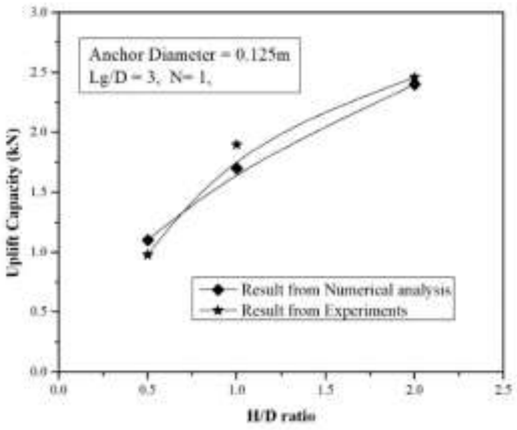

Fig.4. Comparison between experimental and numerical result

8. Results and Discussion

The data obtained from the ABAQUS analysis have been presented in the graphical form. Fig 5 displays the displacement contours of the anchor-tie-soil system after application of the load. Fig 6 presents the typical load versus displacement curve for anchor without and with geotextile ties of L_g/D -2 (Soil Type II, H / D = 3). Fig 7 presents the variation of ultimate uplift capacity with H/D for a particular L_g/D (=2) for soil Type II. Fig 8 displays the variation of uplift capacity versus L_g/D for single layer ties in soil Type II. Fig 9 represents the variation of the ultimate uplift capacity with number of layers for $L_g/D = 2$ in soil Type II. The improvement in ultimate uplift capacity for a typical H/D (=3) with increasing the L_g/D for all three types of soil has been shown in Fig. 10. Fig. 11 represents the variation of maximum tensile stresses in geotextile with increasing the L_g/D for soil Type II. Based on the results acquired in the present analysis discussions are made as follows:

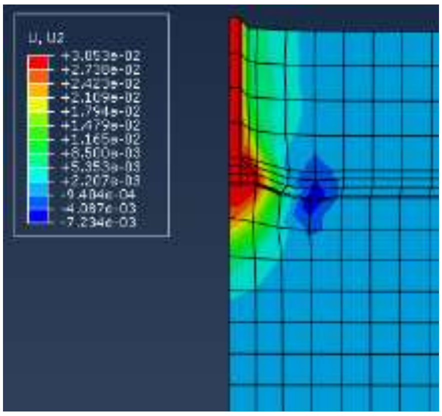

Fig. 5. Displacement contour obtained from numerical simulation

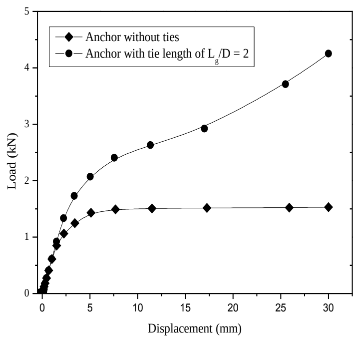

Fig. 6 .Typical uplift load versus displacement curve for anchor without and with ties (H/D = 3, soil Type II)

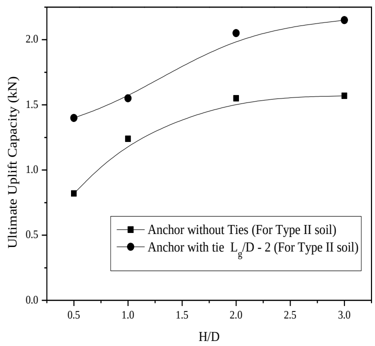

Fig.7. Uplift Capacity versus H/D for $L_g/D= 2$ for Soil Type II

8.1 Effect of tie on uplift capacity of anchor

The uplift loads versus displacement curve with and without ties are shown in Fig 6. From the curve it is observed that the inclusion of geotextile ties increases the ultimate uplift capacity. From the curves (Fig.6) it is also found that the improvement of uplift capacity starts after the measurable displacement (1.15 mm). Fig 7. displays the ultimate uplift capacity versus H/D ratio curve for anchor with ties and without ties. From the curve it is found that with increase in H/D ratio the values of ultimate uplift capacity of both the anchor (anchor with ties and anchor without ties) increases. Also from Fig 7 it can be found that with respect to H/D the inclusion of geotextile ties to the anchor definitely improves the uplift capacity. Fig 8. Shows the improvement for uplift capacity of anchor with tie versus H/D ratio curve. From the curve it is found that the maximum improvement achieved at $L_g/D = 0.5$ after that it is decreases with increase in H/D ratio for all three types of soil (soil Type I, soil Type II, and Soil Type III). Reason behind this can be stated that with increment of the embedment ratio (H/D) as more shaft-soil adhesion force comes into play the effect of geotextile tie reduces. From the present analysis it is found that the respective percentage improvement for inclusion of geotextile ties ($L_g/D = 2$) for H/D= 0.5 is 70% and for H/D = 3 is about 37% for Type II soil. Also for H/D=0.5 the percentage improvement in uplift capacity is about 22% and 17% for Type I soil whereas for H/D= 3 the percentage improvement is about 5% and 2%.

8.2 Effect of L_g /D on ultimate uplift capacity

L_g/D is one of the important factors for evaluating the ultimate uplift capacity of anchor with ties. Fig 9 explains that the increment of L_g/D increases the ultimate uplift capacity up to a critical value. For this particular case in soil Type II the critical value of L_g/D is found to be 3

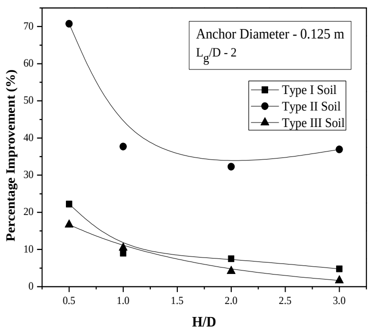

Fig.8. Improvement for Uplift Capacity with H/D for L_g/D =2

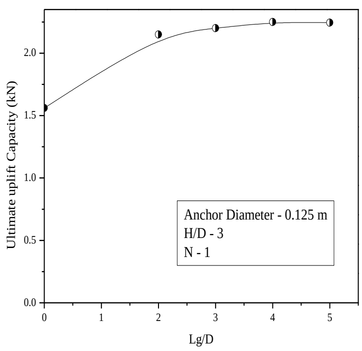

Fig.9. Uplift capacity versus L_g/D for N=1 for Soil Type-II

8.3 Effect of number of layers of ties on uplift capacity of anchor

Fig 10 represents that increment of the number of layers of the geotextile ties increases the ultimate uplift capacity of the anchor and after a certain number of layer it achieves a constant value. In the present investigation for this particular case in soil Type II the critical value of number of ties is found to be 3. The percentage increments in uplift capacity for inclusion three layers of geotextile ties is about 73% compare to the anchor without ties for soil Type II whereas for soil Type I and III the maximum percentage increment is about 11% and 44% for three layers of geotextile with H/D =3.

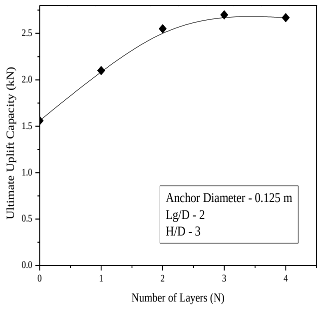

Fig.10. Uplift Capacity versus N for $L_g/D = 2$, H/D=3 for Soil Type II

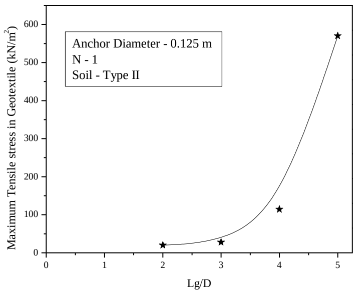

Fig.11. Maximum Tensile stress variation with L_g/D for N- 1 Soil Type II

8.4 Tensile Stress in geotextile ties.

From the present study it can be found that increasing the number of geotextile ties layers improves the ultimate uplift capacity of the bell-shaped anchor and simultaneously tensile stresses have been generated in the geotextile ties. Fig11 represents the tensile stress variation with increasing the L_g/D ratio curve for soil Type II, N=1. The maximum tensile stress is found to be generated at the junction point of anchor and geotextile ties. Also for the particular case in soil Type II for $L_g/D = 5$ the maximum tensile stress is found to be 570 kN/m^2. For a typical case of $L_g/D = 5$, H/D=3, it has been found that tensile stress takes place at displacement of 1.15 mm, we can say after 1.15 mm of displacement, the geotextile ties start to take tensile stresses.

9. Conclusion

From the numerical simulation performed in the present work the following conclusions can be drawn.

1. Inclusion of geotextile ties increases the uplift capacity of the bell-shaped anchor. The improvement of uplift capacity starts to take place after a measurable settlement.
2. Increasing the length of geotextile ties increases the ultimate uplift capacity up to a certain limit. From the current study the optimum value for L_g/D is found to be 3 for Type II soil.
3. Increasing the number of geotextile ties layer also increases the ultimate uplift capacity of the anchor up to a certain value. The optimum number of layers of the geotextile ties is found to be 3 for Type II soil.

4. Maximum tensile stress generated at the junction of geotextile ties and anchor. Tensile stresses increase with increment of length of geotextile ties.

References

1. Sowa. V A (1970), "Pulling Capacity of Concrete Cast in situ Bored Piles" *Canadian Geotechnical Journal*. Vol. 7, 482 august 1970

2. Das B. M (1978) "Model tests for Uplift capacity of foundations in clay", *Soils and Foundations*; Volume 18 (1978) Issue 2
3. Das, B.M., (1994), "Uplift Capacity of Plate Anchors in Clay", *Proceedings of the Fourth International Offshore and Polar Engineering Conference (1994)*, Osaka, Japan, April-15, 1994
4. Degenkamp, G., and Dutta, A., (1989) "Soil Resistances to Embedded Anchor Chain in Soft Clay", *Journal of Geotechnical Engineering*, Vol. 115, No. 10, October,1989
5. Rao A, S., Phanikumar B. R., Babu, R D., and Suresh, K., (2007), "Pullout Behavior of Granular Pile-Anchors in Expansive Clay Beds In Situ", *Journal of Geotechnical and GeoenvironmentalEngineering*, Vol. 133, No. 5, May 1, (2007) pp:531-538
6. Merifield , R.S., Smith, C.C., (2010), "The Ultimate Uplift Capacity of Multi-Plate Strip Anchors in Undrained Clay", *Computers and Geotechnics*, volume:37, pp:504–514
7. O'Kelly, B.C., Brinkgreve, R.B.J., and Sivakumar, V., (2014)'Pullout resistance of granular anchors in clay for undrained condition', *Soils and Foundations*; Vol: 54, issue;6: pp: 1145–1158
8. Tho, K.K., Chen, Z., Leung, C. F., and Chow, Y. K., (2014), "Pullout Behaviour of Plate Anchor in Clay with Linearly Increasing Strength", *Can. Geotech. Journal*. Vol. 51, 2014 pp: 92-102
9. Liu, H., Su, F., and Li, Z., (2014), "The Criterion for Determining the Ultimate Pullout Capacity of Plate Anchors in Clay by Numerical Analysis", *American Journal of Engineering and Applied Sciences* 2014, Volume 7 issue;4pp: 374-386
10. Banerjee, S Mahadevuni, N., (2017), "Pull-Out Behaviour of Square Anchor Plates in Reinforced Soft Clay" *International Journal of Geosynthetics and Ground Eng*. (2017) Issue 3, 2017
11. ASTM D2487 – 17, "Standard Practice for Classification of Soils for Engineering Purposes", (Unified Soil Classification System)
12. Das, A. and Bera. A. K., (2019) Study on Effect of Tie Length on Uplift Capacity of Anchor with Geotextile Tie Using Finite Element Software "ABAQUS", *Indian Geotechnical Conference*,IGC-2018, Bangalore,India.
13. Das, A. and Bera. A. K., (2019) "Ultimate Uplift Capacity of Bell-Shaped Anchor in River Sand Using Finite Element Software "ABAQUS" ', *Geotechnical and Geological Engineering*, April 2019