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Influence of Mooring Chain Position on Displacement of Suction Pile Anchor

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Abstract— ***Now a days suction pile anchors have gained popularity due to development of offshore wind mill projects. In the locations where wind mills are to be constructed in offshore areas, the water depths can vary from 15 to 60m and soil modulus values also vary in the order of 10 MPa to 100 MPa. Suction pile anchor can be installed with the aid of suction and it is a sustainable foundation system which resists the hydrodynamic wave forces. In this paper, the influence of load position on the displacement of pile anchor for different aspect ratios of anchor and different soil modulus values is presented and discussed. The anchor is modelled in cohesionless soil using PLAXIS finite element software. The load position influenced the displacement of anchor. Deeper level load position (Z=load position form top of anchor = L/2) showed lesser displacement due to higher passive resistance mobilization. The increased soil modulus is resulted less displacement as it may be attributed to mobilization of more frictional resistance. For the anchor aspect ratio, L/D = 1, the upward displacement is higher compared to horizontal displacement. Further as the L/D of anchor increases, the horizontal displacement is more as compared to the vertical displacement.***

Keywords— ***Soil modulus, pile anchor embedment depth, mooring chain location, anchor aspect ratio.***

I. INTRODUCTION

Offshore areas are rich in resources in order to cater the needs of the society. Offshore construction needs technically feasible foundations for the structures installed in the offshore area. Suction anchors are the technically feasible foundation systems for offshore wind mill projects. Sufficient depth of embedment of anchor foundation is required to be considered for design of structures to sustain the extreme climatic conditions. Several investigators have carried out studies on suction anchors in different soil types. Installation of the suction anchors is difficult in certain soil types especially coarse, dense and stiff soil deposits. In these situations, jetting of water at the top of soil plug results in installation of anchor into seabed to its design depth (Tjelta, 2001). Felipe Villalobos (2007) presented installation of suction anchor in seabed to a design depth. First, the suction anchors are allowed to settle on the seabed and penetrate under self-weight to a possible depth. The excess water flows to top from inside the anchor. Further penetration of anchor is made possible by applying active suction and pumping out water from the space between the anchor cap and top of the soil plug.

Studies were carried out on suction caisson foundation to find out the linear-elastic and nonlinear stiffness response of suction anchor foundations. The study developed various models for soils in case of suction caissons operated at low working stresses. Analytical formulae were also created and verified during the investigation. For nonlinear foundation response, it suggested a simpler equivalent linear iterative method to represent the effective stiffness of the foundation in terms of deformation amplitude. The study used finite element approach and the results were presented by using non-dimensional charts for perfectly rigid to flexible caissons with different embedment ratios [1]. Suction caisson foundation behaviour under both static and dynamic loads were studied by considering soil nonlinearity. In order to express non-linear hysteretic soil resistance in finite element analysis, multiple spring connectors were used in the model tests [2]. Standard formulation for installing suction caissons in the sand bed were developed [3] by considering various installation depths of the caissons. The analytical formulation can be applied independently of caisson dimensions such as diameter, height and wall thickness.

Analytical investigations were performed utilizing a conventional bearing capacity theory considering various loading considerations for evaluating the ultimate capacity of suction caissons in the sand [4]. Critical suction pressure which is defined as the suction pressure beneath the lid bottom at the precise moment when the lid separates from the soil surface owing to tension contributes to the bucket uplift capacity [5]. An important option for offshore structures built in silt and sand sea beds is the mono-caisson foundation. Strict control over the angular rotation of the foundation is necessary for a wind turbines normal operation. Predicting the caisson foundations' bearing capacity at a permissible angular rotation is crucial [6].

Genetic algorithms (GA) can be used in uplift capacity estimation of suction caisson with multiple objectives [7]. Majority of offshore structures are required to be designed with strict serviceability limitations that determine the maximum structural deflections and accumulated rotations that were permitted during their operational lives. Under cyclic loading, the caisson stiffness increases logarithmically

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and depended on the local soil strain [8]. Multi-expression programming (MEP) such as Genetic Programming (GP) can be utilized to analyse uplift capacity of suction caissons formulation. The impact of the caisson's aspect ratio, the clayey soil's shear strength, the loading point and angle of inclination, soil permeability, and the loading rate were all taken into consideration by the derived MEP-based formula [9].

Simplified limit solutions for suction anchor capacity under undrained conditions were discovered [10]. To find out load carrying capacity of suction anchors in pure cohesive soils, Upper-bound plastic limit analyses (PLA) can be used. Prediction of uplift capacity of suction caissons using a neuro-genetic network is a better option [11]. One crucial factor that must be accurately predicted is the suction caissons uplift capacity. For this, a neuro-genetic model has been used. The multilayer feed-forward neural network (NN) can serve as the host architecture for the neuro-genetic model, which used genetic algorithms to determine its weights. The use of a hybrid model, like the neuro-genetic network, for the uplift capacity prediction problem seems appealing when compared to the application of a traditional NN model.

Number of centrifuges model-based tests on suction anchors in dry and very dense sand are available for models of two representative caisson foundations at a scale of approximately 1:200 and are subjected to 12,000 cycles of cyclic loading. Rotational stiffness of suction anchor logarithmically increased with respect to number of cycles of loading. Investigations were carried out to understand the impact of the suction installation in dense sand on the load-bearing behaviour utilizing a series of centrifuge tests in which model suction caissons were installed in saturated fine silica sand [13].

The suction foundation can preserve soil strength in saturated sand during an earthquake [14]. The greater the aspect ratio of a "Wide-Shallow" bucket, the more resilient it is to liquefaction. The "Narrow-Deep" bucket test yields the lowest settlement value. The strength and stiffness of the soil may be significantly reduced as a result of the liquefaction of the soil brought on by earthquakes in the offshore seismic active area. The experimental results showed that the suction bucket's instability was caused by the occurrence and progression of sand bed liquefaction around it. The study described the importance of the liquefaction process around the foundations and to analyze and summarize the overall stability of suction bucket foundations under severe wave loading in the sand beds [15]. Partial findings from two series of centrifuge tests conducted on suction anchors for soil conditions, anchor geometry, attachment points, and loading angles were presented. The findings offered a way to validate and calibrate the failure mechanisms and design methodologies [16].

Inclined pull-out loading capacity was ascertained for model suction pile embedded in the sand by performing centrifuge tests. The point of mooring line attachment, which varies from the top to the bottom of the suction pile's side surface, and the load inclination angle influences the pull-out load capacity of suction anchor [17]. The load capacity can be increased by connecting a suction bucket to an underlying mat. The hybrid bucket foundations (HBFs) are feasible and perform better. Specifically, HBFs had bearing capacities approximately 1.91 and 1.82 times higher under combined and vertical loads, respectively, than suction bucket foundations within the ranges of testing. The results showed that the bearing capacity is greatly increased by the mat component that is mounted on top of the HBF. The hybrid bucket foundation exhibited greater initial stiffness and rotational stiffness in comparison to the SBF [18]. The behaviour of anchor piles and the soil displacement field under an oblique pullout load can be well observed with transparent sand and the PIV technique using centrifuge models [19].

Effect of soil modulus and load position along the anchor wall surface from top of anchor on the deflection of anchor play a vital role. In this paper the deflection behaviour of anchor with varied load position and for varied soil modulus are analysed using PLAXIS 3D.

II. METHODOLOGY

In order to study the effect of load position and soil modulus effect on deflection of anchor the PLAXIS 3D analysis is carried out by modelling the anchor in cohesionless soil. Fig.1 presents the anchor with geometry and the load action positions, Z = 0, L/4 and L/2.

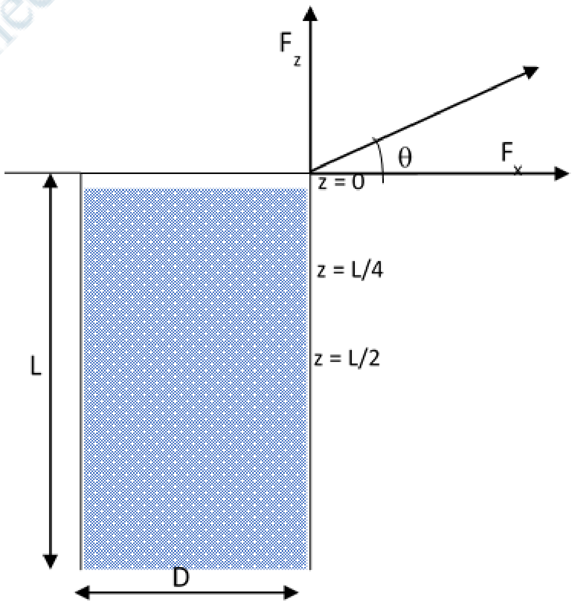

Fig.1. Anchor geometry with load application position

The following input parameters are considered in the modelling of anchor using PLAXIS 3D. Soil Modulus (E) is

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varied from 10 MPa to 1,00 MPa at an increment of 10 MPa. By keeping the diameter of anchor, D = 4m constant, the anchor aspect ratios L/D = 1, 2 and 3 (i.e., L = 4m, 8m and 12m) were modelled. The strength parameters of soil such as angle of internal friction, $\phi = 35^o$ and cohesion, c = 15 kPa were used. The Poisson's ratio of soil was considered as 0.3.

Soil bulk unit weight, $\gamma = 17$ kN/m^3 and saturated unit weight of soil, $\gamma_{satsat} = 20$ kN/m^3 were taken. The lateral and axial forces were estimated using laterally loaded rigid pile concept and the following safe loads were assigned in the horizontal and vertical directions in order to create pullout angle $\theta = 30^o$. The horizontal load, $F_x = 2165$ kN and Vertical load, $F_z = 1250$ kN were inputted as loads to pull out the anchor at pull out angle, $\theta = 30^o$. The coordinates of the applied load positions from top of the anchor along the wall surface and with reference to center of anchor were considered in the following way.^{o}

Case-1 (L/D = 1) : i)2, 0, 0 ii) 2, 0, -1 iii) 2, 0, -2

Case-2 (L/D = 2) : i)2, 0, 0 ii) 2, 0, -2 iii) 2, 0, -4

Case-3 (L/D = 3) : i)2, 0, 0 ii) 2, 0, -3 iii) 2, 0, -6

Fig.2 shows the soil geometry created in PLAXIS.

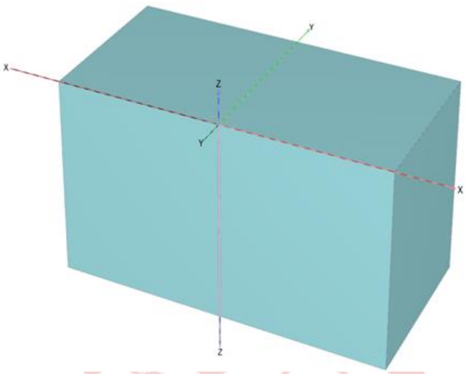

Fig.2 Soil element generated in PLAXIS

Fig.2 shows the anchor model generated using PLAXIS 3D.

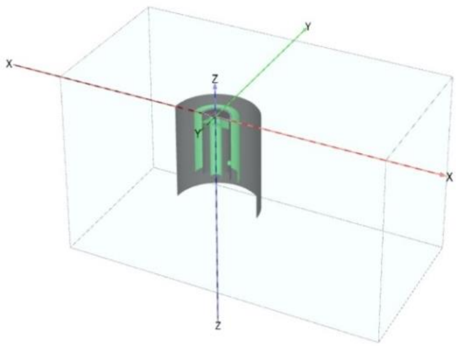

Fig.3 Anchor section generated in PLAXIS

Coulomb soil model was considered for inputting the required parameters and the mesh was generated using 12 nodded elements.

III. RESULTS AND DISCUSSION

Fig.4 shows the typical displacement pattern for anchor aspect ratio (L/D) = 1 and load position (Z) = 0m, for pullout angle (θ) 30^o and soil modulus (E) of 10 MPa. From this figure, for the above input, the maximum displacement in the horizontal direction observed is 0.138 mm. Similarly, the maximum displacements obtained through PLAXIS analysis for L/D = 1, 2 and 3, $\theta = 30^o$, load positions, Z = 0m, L/4 and L/2 from top of anchor along the wall surface and for varied E values from 10 MPa to 100 MPa at an increment of 10 MPa are presented in Figs. 5 to 13. The u_x, u_y and u_z are the anchor displacements in the x, y and z directions. Fig.5 shows the maximum displacement variation with soil modulus for anchor L/D=1, $\theta = 30^o$, Z = 0 m. It is observed that the maximum displacement is decreasing as the E value increases from 10 MPa to 100 MPa. In this case, the maximum displacement obtained is 0.14 mm and is treated negligible. It means that at smaller displacement itself the anchor is getting failed. It may be attributed to L/D = 1 and E = 10 MPa are unable to provide sufficient grip and strength mobilization to anchor. Whereas Fig.6 and 7 present the variation of maximum displacement of anchor for the load positions, Z = L/4 = 1m and Z = L/2 = 2m. From these figures, it is observed that the displacement is increasing as the load positions changes from top of anchor towards bottom. It may be attributed that the soil is offering more resistance due to more soil projection around the anchor.

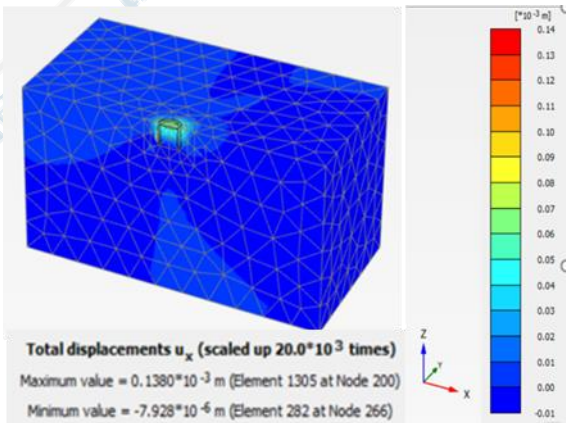

Fig.4 PLAXIS model showing displacement pattern of anchor in soil

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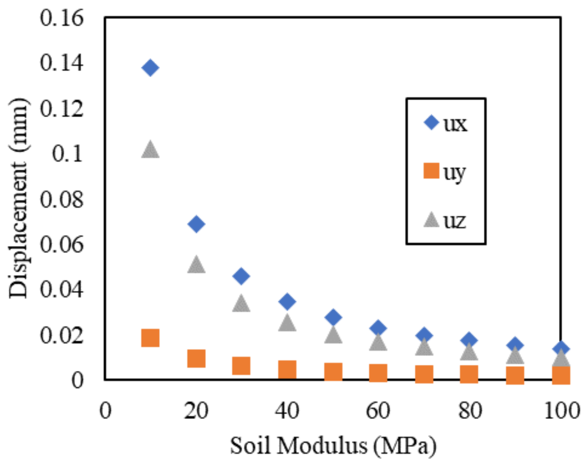

Fig.5 Displacement vs Soil modulus for L/D=1, θ = 30º, Z = 0 m

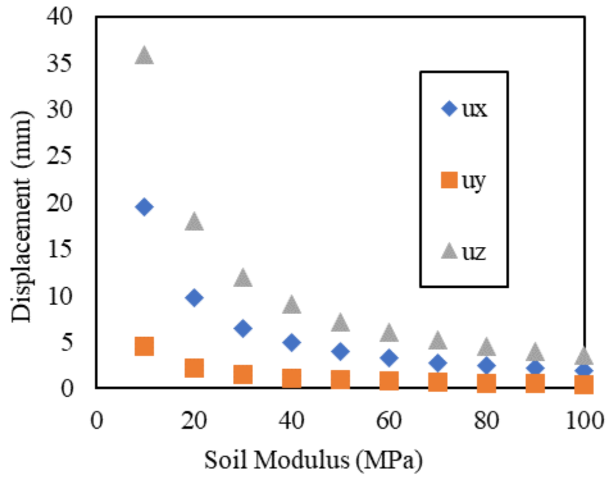

Fig.6 Displacement vs Soil modulus for L/D=1, θ = 30º, Z = 1 m

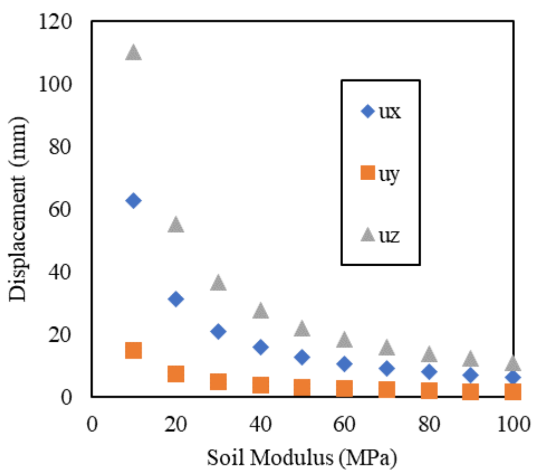

Fig.7 Displacement vs Soil modulus for L/D=1, θ = 30º, Z = 2 m

Figs. 8, 9 and 10 present the maximum displacement variation with E for L/D =2 (L = 8m) for Z = 0m, 2m and 4m respectively. From these figures, it is observed that the force applied is causing higher displacements for the load positions Z = L/2 = 4m as anchor is resisted by the surrounding soil. Similar such trend is observed even in Figs. 11, 12 and 13 for anchor of L/D =3 (L = 12m) and for Z = 0m, 3m and 6m respectively. From Figs.11 to 13, typically it is observed that the displacement is lower compared L/D = 2, because the force applied is same in both cases and further the anchor embedment is more for L/D =3 as compared to L/D = 2. Higher is the anchor embedment depth, the more is the soil resistance and hence, the displacements are less compared to lower embedment depths of anchor.

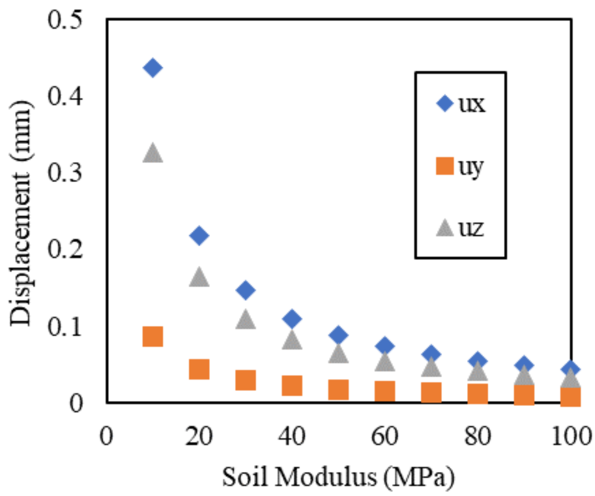

Fig.8 Displacement vs Soil modulus for L/D=2, θ = 30º, Z = 0 m

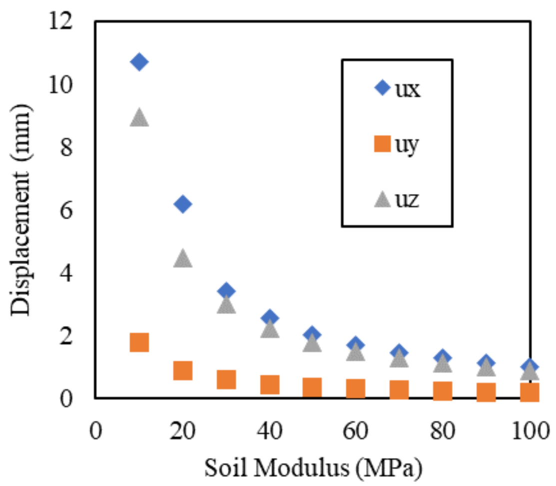

Fig.9 Displacement vs Soil modulus for L/D=2, θ = 30º, Z = 2 m

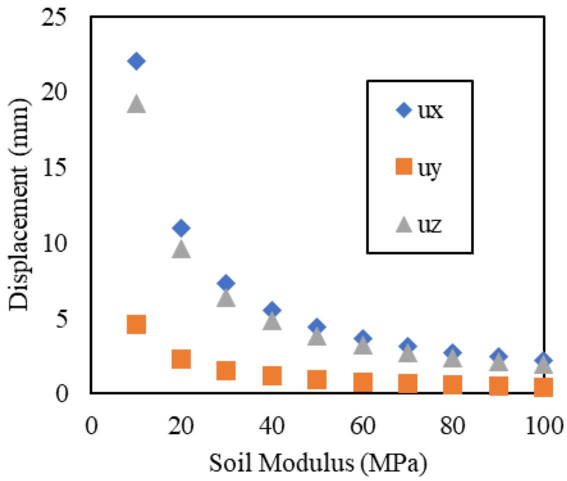

Fig.10 Displacement vs Soil modulus for L/D=2, θ = 30º, Z = 4 m

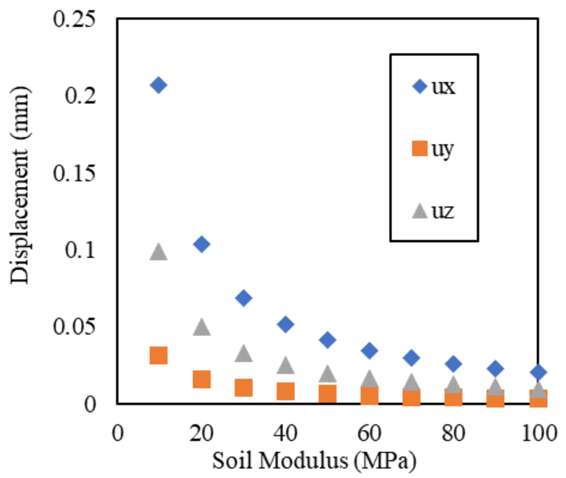

Fig.11 Displacement vs Soil modulus for L/D=3, θ = 30º, Z = 0 m

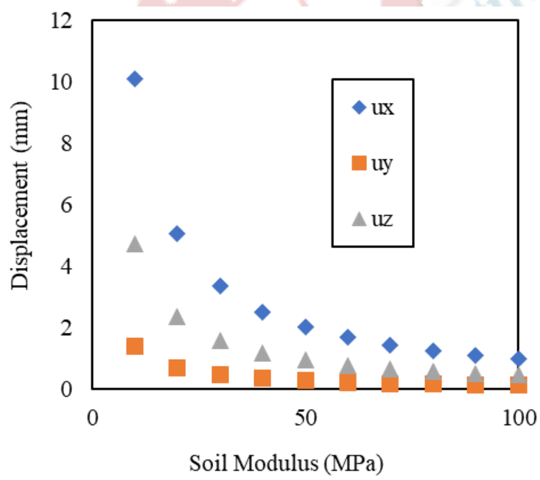

Fig.12 Displacement vs Soil modulus for L/D=3, θ = 30º, Z = 3 m

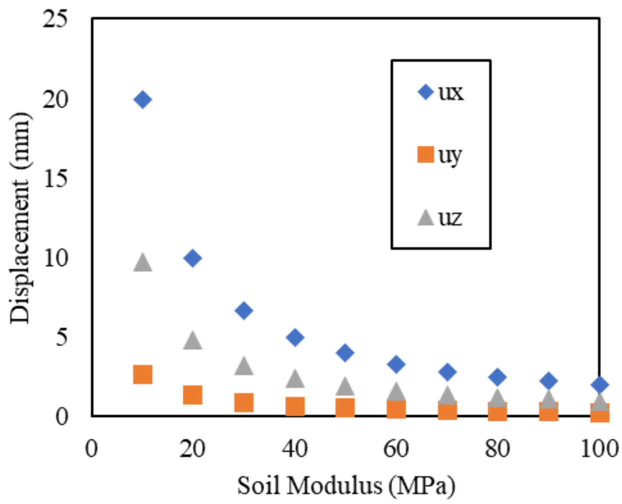

Fig.13 Displacement vs Soil modulus for L/D=3, θ = 30º, Z = 6 m

IV. CONCLUSIONS

From the results presented in this paper, some interesting conclusions are drawn.

1. Irrespective of load position (Z) on anchor, the displacements of anchor increased with the increased soil modulus, E.
2. In case of anchor L/D = 1, the displacements are seen higher compared to the anchor L/D = 2 and 3. It is due to the force applied is constant and anchor embedment depth is less.
3. In case of anchor L/D = 1, the displacements are higher in the vertical (z - direction) direction compared to the x and y horizontal directions.
4. In case of anchor L/D = 2 and 3, the displacements are higher in the horizontal direction (x - direction).

The displacements are lower in L/D = 2 and 3 as compared to the L/D =1. It is because, the force applied is unable to mobilize displacements in anchors due to higher embedment depths are deriving more soil resistance.

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