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Numerical Analysis of Jointed Piles

B. Swathi[1], V. Balakumar[2] and S.S. Chandrasekaran[3]

[1]Graduate Student, MTech Structural Engineering, Vellore Institute of Technology, Vellore, India, swaswathy082@gmail.com
[2]Senior Consultant, Simplex Infrastructures Limited, Chennai, India, vb_kumar2012@yahoo.com
[3]Professor, School of Civil Engineering, Vellore Institute of Technology, Vellore, India, chandrasekaran.ss@vit.ac.in

Abstract. Coastal areas like Kochi, Nellore, Gujarat coasts have deep deposits of highly compressible clay layers. The developments of infrastructures in these areas need deep piles to support the tall and heavily loaded structures involved in the development. Such piles when they pass through such compressible layers are subjected to negative skin friction, which reduces the allowable load on the piles. Under such circumstances the only alternative is precast piles. Precast piles in a single segment have handling problem as well as installation problem. The maximum length that can be handled cannot be more than 15 to 18m. Hence the need for an effective system resulted in the advent of jointed piles. Although jointed piles are used extensively, published data on its performance under various types of loading and joint positions is very limited. This paper discusses the main features of design, performances of precast jointed piles under axial, lateral and combined load conditions. A parametric study was carried out by varying the pile joint location under four typical conditions. Load settlement response and the behavior of stress around the joint have been evaluated. An attempt was made to study the response of the jointed pile subjected to lateral soil movement due to excavation by two-dimensional analysis. ABAQUS 6.14 and PLAXIS 2D have been used for the analysis in this study.

Keywords: Precast Piles, Jointed Piles, ABAQUS 6.14, PLAXIS 2D.

1 Introduction

Presently lot of infrastructure developments take-place in the coastal areas where the strata is dominated by soft compressible clay layers perhaps marine clays, organic in nature in certain cases. The geological history of the site can vary depending upon the location of site. Such compressible deposits might have formed naturally or the site could have been formed by recent hydraulic fills. In general, large diameter bored piles become an automatic choice. The length of the piles becomes more than 50m to 60 m which poses quality problems. Moreover, bentonite solution has to be used to stabilize the boreholes which can form sediments with slush and cleaning the bottom of the pile becomes very difficult. Also, the installation process by drilling can disturb the consistency of the soil, which can change the properties, affecting the capacity of the pile. Hence the option becomes precast pile which is devoid of such quality issues. Further such piles are subjected to negative skin friction and accounting for it can make the design very uneconomical. The length of precast pile becomes high which leads to handling problems. The precast piles can be coated with a slip layer (hot blown bitumen which will reduce the negative skin friction to considerable extent. The practical issue had given rises to precast jointed piles. The behaviors of piles installed through such layers is influenced by the installation methods, (Debeer, 1988[4]; Van Impe, 1991; Viggiani, 1989, 1993[10] which is seldom consider in the design.

Segmental driven precast piles often recommend solutions, Evan Causer et al., 2012[5]; Yuns up Shin, 2014[12]. Precast jointed piles have number of segments in which are jointed by patented joints to achieve the desired length so that the pile can be terminated in a hard stratum governed by the set to generate the desired capacity. There are several types of splices joints available which are patented. The overall effectiveness of splices was examined and investigated, by many researchers Robert N Bruce et al., 1990; Petr Gran, 2012; Paul Doherty etal., 2014[8]; Abou-Jaoude and Zhang et al., 2015[1]. In the cases of hollow spun piles Candra Irawan et al**.,** 2014[3] which belong to the jointed pile family extensively used where ever possible depending upon the soil condition a feasibility.

In the case of jointed segmental piles, the negative skin friction can get Mohamed S. Morsy etal.,2013; Gandhi et al.,2017[11] considerably reduce by apply the slip layer. Therefore, in order to overcome the difficulties, the institutions in Sweden developed pile joints so that the length need not be a constraint, Breden berg and Broms, 1979[2]. Another important issue is axial pile deformation due to lateral soil movement as studied by Poulos & Chen, 1997[8]; Mandy Kroff et al., 2016[7] soil displacement resulting from deep excavation. An important issue is the location of the joint below the cut-off level namely the bottom of the pile cap. Further pile section being smaller, unplanned excavations particularly in soft soils can cause large displacements in the pile and the joint can get overstressed. This paper discusses the main features of design, the significance of joint and its location below the raft and pile cap bottom. Studies on such issues appear to be very scarce.

1.1 Need for Study

In the case of the marine deposits there can be variation in the consistency at different locations which is unavoidable. Isolated very stiff to hard pockets are very common in the marine deposits and driving may become impossible. In such cases the last joint can come closer to the raft bottom. Therefore, it becomes necessary to study the stress around the joint. When the pile is subjected to peak loading such as test load and the load settlement of the jointed portion. In this present study undergoes an excavation is assumed to be sufficient as two-dimensional analysis applicable and to determine the response of pile due to lateral soil movement.

2 Parametric Study

Parametric studies were conducted by varying the joint locations as L/2, L/4, L/6, L/8 was carried out where L is the length of the pile. Figure 1 represent the layout of jointed pile. A series of 3-d finite element analyses were performed on a single free head jointed pile in both homogeneous stiff clay and medium dense sand separately. The response of the jointed piles under pure axial and lateral load was analyzed initially. Further, the study carried out the corresponding load increment on the combined effect of both axial and lateral load. The ultimate vertical load capacity was considering an appropriate N value, adopting Meyerhof's expression the capacity was calculated as 1000KN and the corresponding lateral load was considered as 5% of axial load.

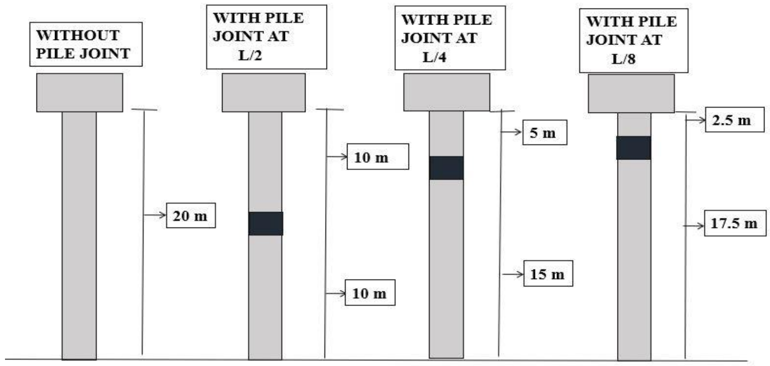

Fig. 1. Pile Joint Layout

3 Finite Element Analysis

3.1 Introduction

All numerical analyses in this investigation were performed by using 3-d finite element program ABAQUS 6.14. The program is supported by a preprocessor to develop three dimensional meshes consisting of bar and beam type prismatic elements, 8-node or 20-node continuum brick elements with zero thickness type interface elements as well as a post-processing tool that is capable of plotting the original mesh, deformed mesh, displacement vectors, extracting nodal displacements and element stresses etc.

3.2 Finite Element Modelling

Three-dimensional modelling of the jointed pile-soil system has been carried out in finite element analysis by using "ABAQUS 6.14". Figure 3.1 presents the finite element model of soil mass and jointed piles. The soil and pile were modeled using eight-node brick element soil strata having three degree of freedom of translations in the respective co-ordinate direction at each node. Out of these, the linear elastic and the Mohr-Coulomb model are used to simulate the behaviors of the soil respectively, whereas piles have been idealized to behave as linearly elastic. Table 1 and Table 2 present the physical and material properties of jointed pile and soil respectively. The depth of soil block is 2 times of the length of the pile was chosen since it is the optimum limit beyond that additional bearing capacity doesn't appreciable.

Table 1. Numerical details of the FEM model

Property	Pile	Steel	Soil
Material	M40 Concrete (Square piles)	Mild steel (High Durability)	Medium sand/Stiff clay
Width	400mm	400mm	12m
Depth	20m	600mm	40m

Table 2. Material Properties of the FEM model

Property	Pile	Steel	Sand	Clay
Material	Concrete	Mild steel	Medium Dense	Stiff clay
Elastic Modulus (MPa)	3.1e4	210e3	100	80
Density (kg/m3)	2400	7850	1500	1330
Poisson ratio	0.2	0.3	0.3	0.25
Friction angle	-	-	37^0	-
Cohesion (kPa)	-	-	-	200

The interaction between the sand and pile was modeled by defining tangential and normal contact behavior in the FE model. The normal force is transferred only when pile and soil are contacts tightly; otherwise, it becomes zero thickness. This type of normal contact behavior can be modeled by the “hard” contact option was provided. Perfect contact is provided between pile-steel-pile and pile-soil.

The needed mesh refinement was carried out keeping in mind the economics of computational time, efforts and the needed level of accuracy in the results. The fixed boundary condition is provided at the bottom surface and along the four edges of the soil block. All nodes on bottom surface were restrained in all three directions provided rigidly then the loads are imposed on the jointed pile and the load settlement and shaft stress around the pile values are obtained on each node of piles near edges to the soil surface are used in plotting the graphs.

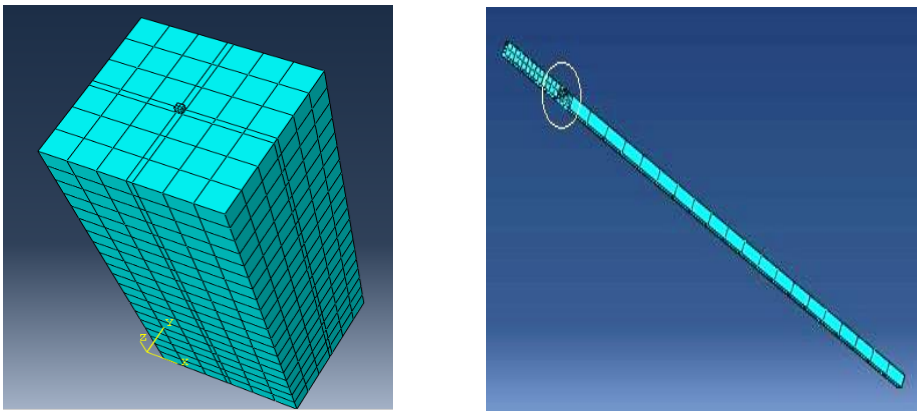

Fig. 2. Finite Element Mesh for Soil Mass and Jointed Piles

3.3 2D Analysis of Excavation

A two-dimensional finite element program was used to simulate the excavation using PLAXIS 2D. In the program 15–node plane strain model of jointed portion is assumed to be linearly elastic and the soil is treated as an elasto-plastic material, obeying a Mohr-Coulomb failure criterion. The interface thickness between the soil and pile is kept as rigid, (Karthikeyan et al, 2011) i.e., no-slip occurred. In mesh, vertical and bottom boundaries are fixed in all three directions. In the second phase, while the soil layers were excavated from top to bottom in various steps with each step involve the removal of consecutive 2m until the desired depth of excavation was achieved in both cases.

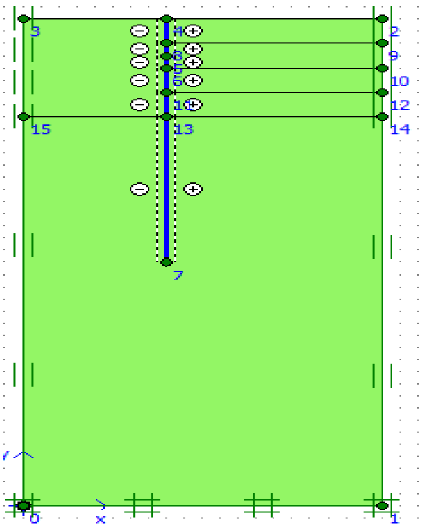

Fig. 3. (a) Model Excavation of Jointed Pile

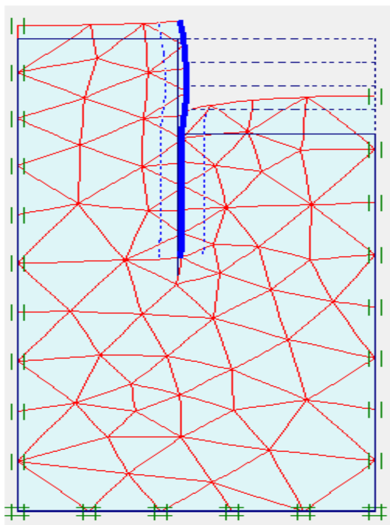

Fig. 3. (b) Deformed Mesh PLAXIS 2D

4 Result and Discussion

The present work is intended to study the effect of joint position. The results of the numerical analyses were found to be a quick and reliable mode to get the desired results compared to model tests or observational studies under the present conditions of requirement. Fig 4 shows displacement contour for jointed pile. The shaft stress around pile, settlement criteria, deflection pattern of the jointed pile system was analyzed.

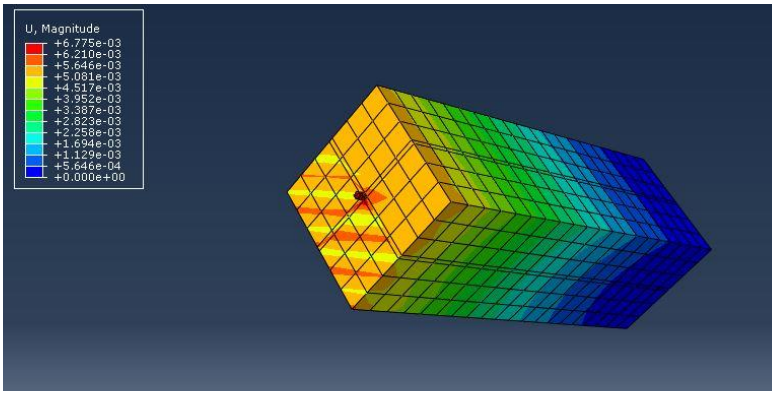

Fig.4. Displacement Contour for Jointed Pile

4.1 Load Settlement Response due to Vertical load

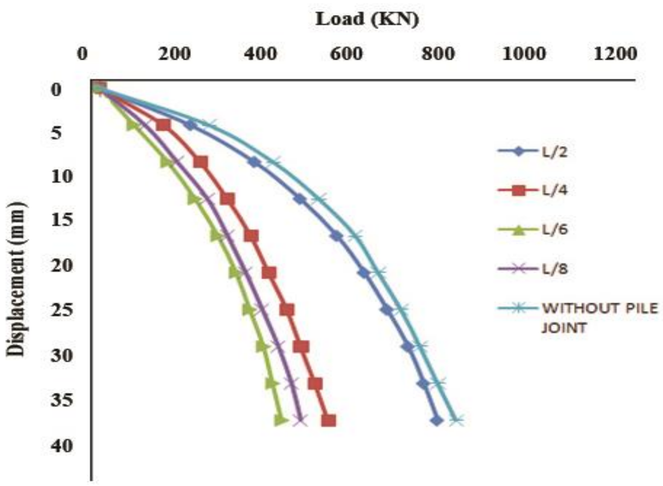

Fig. 5. Load Settlement Response for various Joint Position in Medium sand

Fig 5and 6 presents comparison the load settlement response of jointed pile with joint at various locations. The performance of jointed pile is compared with a full-length pile without considering the joint. In the present study the length of the pile is taken as 20m (two segments of 10m) long elements with one joint mainly because the performance is very critical only in the top portion, most specifically the first joint from the ground level.

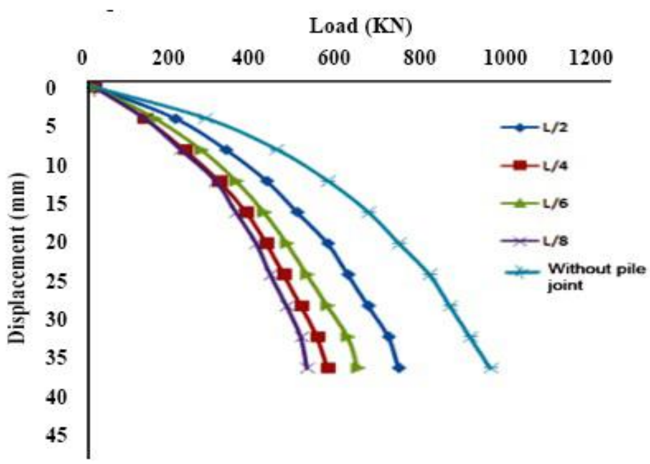

Fig.6. Load Settlement Response for various Joint Position in Stiff Clay

These graphs indicate that joints at middle portion of the pile the load settlement response shows a very small variation from that of the pile without joint in case of medium dense sand but in case of stiff clay variation was higher. This may be perhaps be that in case of stiff clay the installation method generates excess pore water pressure and remolding effects leading to the temporary loss in shear strength. The capacity of a single pile did numerical analysis compared to the jointed pile in medium sand shows that the percentage variation of 25mm of L/2, L/4, and L/8 is 25%, 15.7% and 5.2% whereas the single pile value of 23%. As the joint position moves towards ground level the load settlement response become more or less identical and indicate a much lesser stiffness. Under the identical settlement the reduction of load taken in order of 40%, the joint moves to L/4. This behavior indicates that as the joints move closes to the ground the capacity of the pile reduces that at 25mm settlement the percentage variation is much higher than 12mm. This may be because of loss of friction at higher settlement.

4.2 Shaft Stress Distribution for Axial Load

Fig 7 presents the shaft stress distribution of jointed pile obtained from axial load approach. It is seen that in case of medium sand when the joint at L/2 the rate of fall of shaft stress is gradual. At 5m depth the shaft stress reduces from 85 kPa to 50 kPa and 8m reduce to 30 kPa and forms rapidly. The joints at L/4 the shaft stress remain up to the depth 6m and reduce rapidly. In other two cases analysis of stress around pile in stiff clay condition the trends remain more or less similar. This trend may be due to additional stiffness provided by joints. At the end of the pile portion, the stress value attains zero for all locations of the joint pile section.

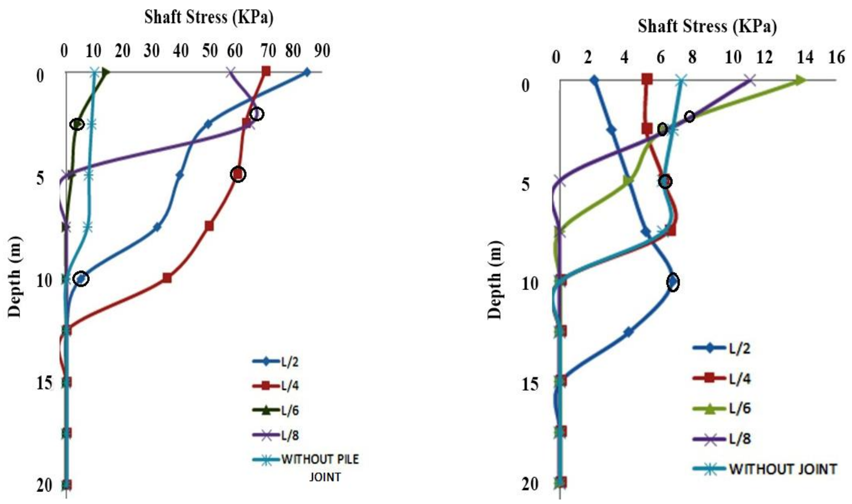

Fig.7. Shaft Stress Distribution Curve in Medium Sand and Stiff Clay

4.3 Lateral Load Deflection Response

The load deflection response of jointed pile under the lateral load needs a separate consideration mainly because the joint position as lots of influences as it comes closes to pile cap. The reaction forces that developed at the nodes used to calculate the lateral load corresponding to the applied lateral deflection.

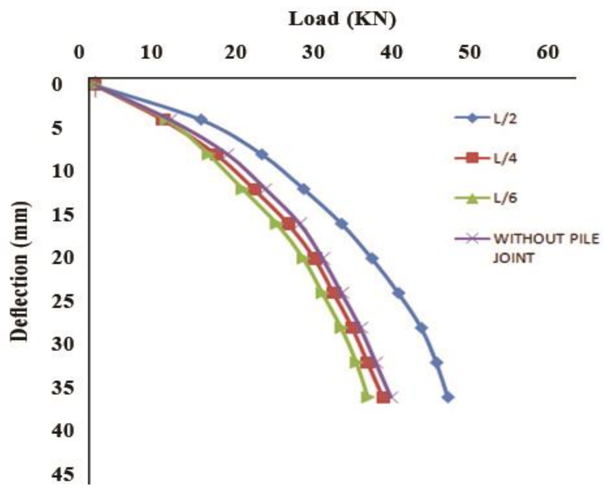

Fig.8. Lateral Load Deflection curve in Medium Sand for various joint locations

Fig 8 and 9 present the load deflection response of jointed pile medium sand and stiff clay. As discussed in this section, the percentage of reduction in settlement reduces with a decrease in the loading condition, and the initial loading condition the settlement achieved shallow values. It appears that the joint position at L/8 get failure and reduce stiffness of joint soil system. At any load the deflection when the joint comes closes is far higher than the deflection with joint at the center position similar behavior was observed in the case of stiff clay condition. At 5mm deflection, very little change will occur in the load deflection, while the deflection of medium sand L/2, L/4, L/6 and without joint has increased 42%, 39%, 16% and 20% than stiff clay respectively.

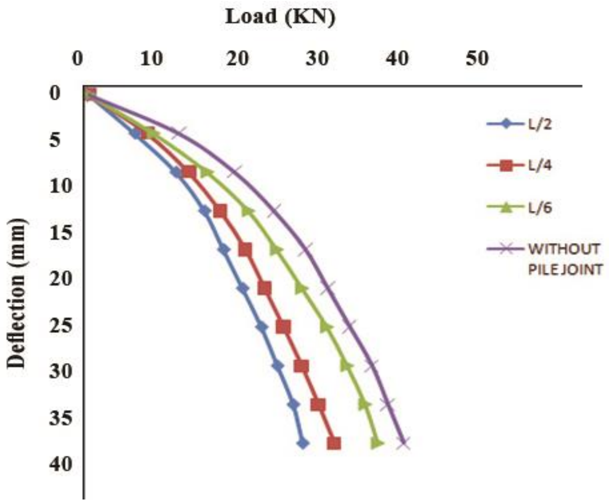

Fig. 9. Lateral Load Deflection Curve in Stiff Clay for various joint locations

4.4 Influences under Combined Loading Condition

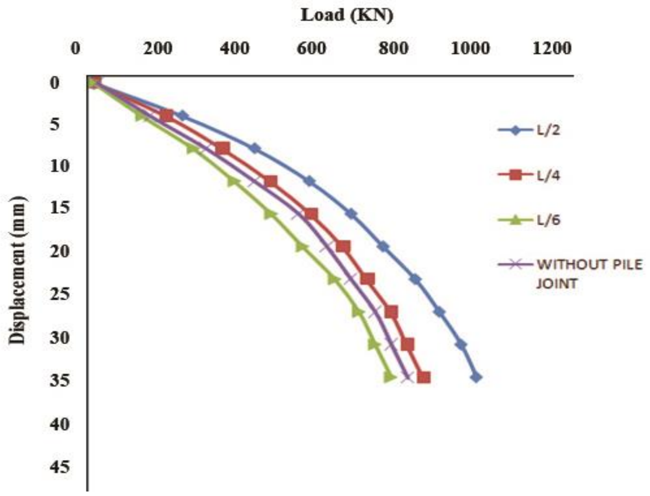

Fig .10. Combined Load Deflection Curve in Medium Sand for various joint locations

From the graph 10 and 11 presented that there is a considerable increase in the lateral load capacity under an increase in vertical load level. Under the lesser load condition, the cohesive layer gets large deformation than cohesionless layer. It can be observed that the combined load in the case of L/8 tends to fail due to the location of the joint near to the cut off level. The axial load is acting on top of the pile, hence it acts as a fixed end condition. The observed variation of 25mm displacement of L/2, L/4, and L/6 is 41%, 34% and 20% more than without pile joint due to application of latera load. Similarly, for jointed pile variation observed in 50%, 42%, 26% above the valve for 12mm of deflection. Increase of lateral load capacity of the pile along with increased earth pressure on side of the pile. It is mainly due to the confinement of soil particles.

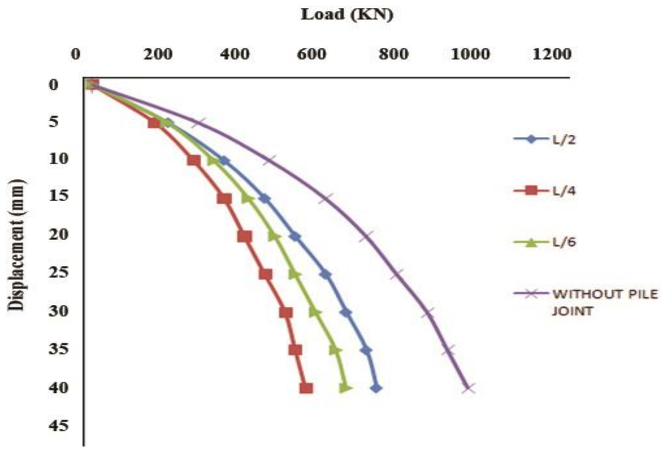

Fig.11. Combined Load Deflection Curve in Stiff Clay for various joint locations

4.5 Shaft Stress Distribution for Combined loading

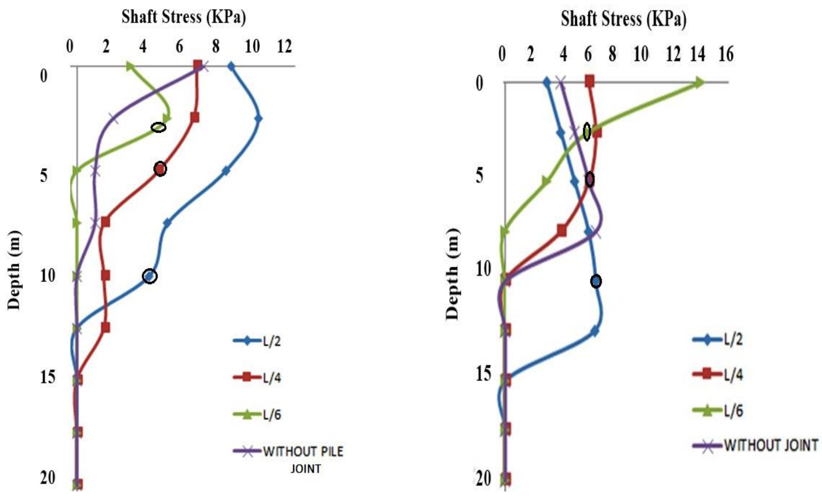

Fig.12.. Shaft Stress Distribution Curve in Medium Sand and Stiff Clay-Various joint

Fig 12 clear that design shaft stress in piles is higher under combined loading. Due to the influence of combined effect the maximum shaft stress occurs in the case of L/6 condition i.e.14kPa in stiff clay, whereas the induced stress will be increase, particularly in the jointed section. Alternatively, the joint portion at L/4 shows nearly equal in both cohesive and cohesion less soil and starts reducing rapidly at depth of 10m. As increase depth of the pile, the induced stress in the pile will decrease.

4.6 Influence in Pile Deflection Due to Excavation

The effect of excavation close to the existing pile is projected in Fig 13. The joint is located at L/6. An excavation of 2m induces a deflection 19.2mm in the top segment, where as in the case of pile without any joint the maximum deflection occurs after an excavation of 8m. Hence the position of joints play an important role during excavation for the pile cap.

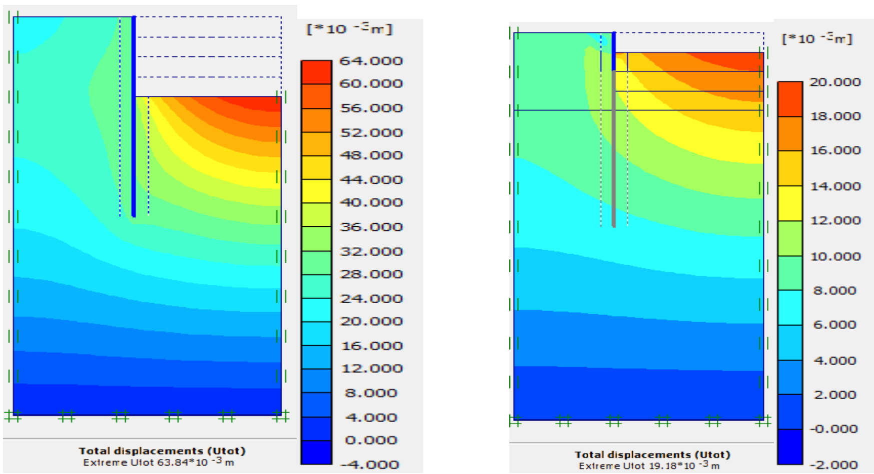

Fig.13. Displacement Contour for Unjointed Pile and Jointed Pile

5 Conclusions

1. While jointed piles provide a safe solution whenever pile length larger, but the joint position plays a very important role. So, the length of the segments has to be carefully optimized. Geotechnical report has to be review carefully for deciding the length of each segment.

2. It is evident that the joint at center location, the displacement for the jointed pile is higher than a single pile. As the displacement reduces and bending moment rises to maximum value and then a particular portion tends to failure, which indicates brittle behavior.

3. The numerical data, shows that the shaft stress resistance increase under lateral load is applied. The pile body tends to rotate around the inflection

point and produces a negative deflection closed to the jointed portion. Hence the joint at L/8 portion fails down due to applied lateral load.

4. It can be concluded that under static loading condition. The location of joint portion should not be above L/6 from the cut off level. The percentage variation around nearly 41% and 39% in combined effects. So that the ideal condition for the location of the joint in L/2 to L/4.

5. It also clear that the maximum pile deflection follows soil movement closely at a distance from the excavation face. The pile deflection is very close to the jointed section, reflecting the fact that the pile is relatively flexible.

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