observed that, lateral load capacity was increased significantly from 3 to 16% at a displacement of 0.05D and from 6 to 17% at a displacement of 0.1D.

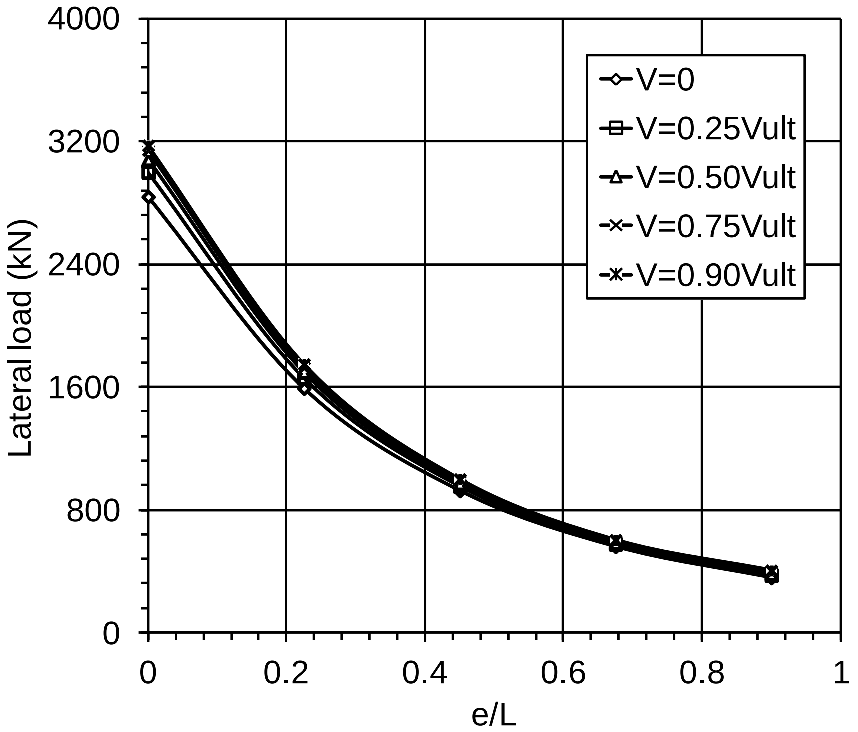


Fig. 3 Effect of axial load on lateral load response of piles in dense sand with various e/L ratios for pile displacement of 0.1D

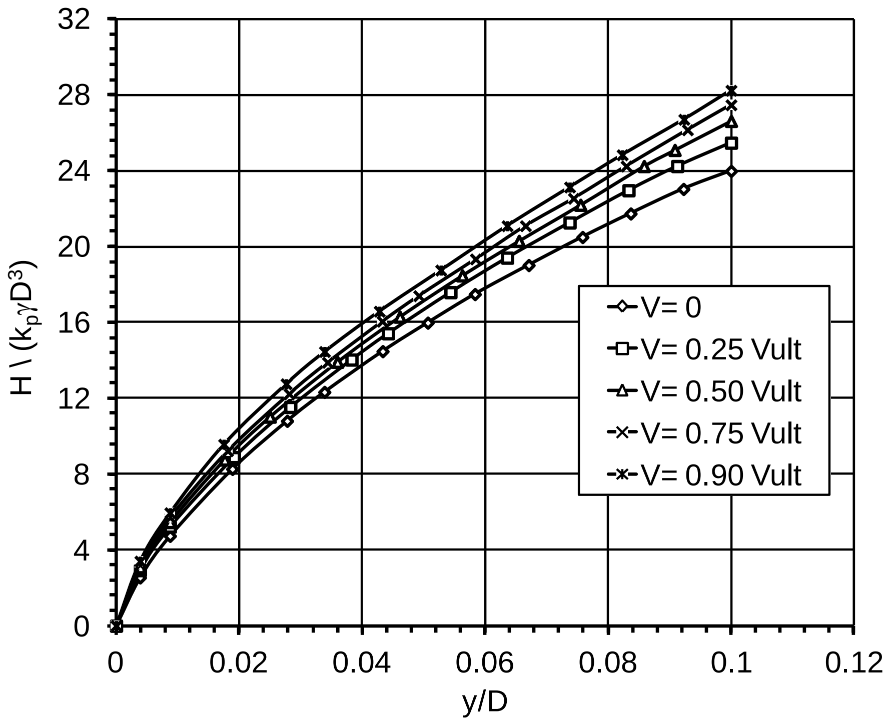
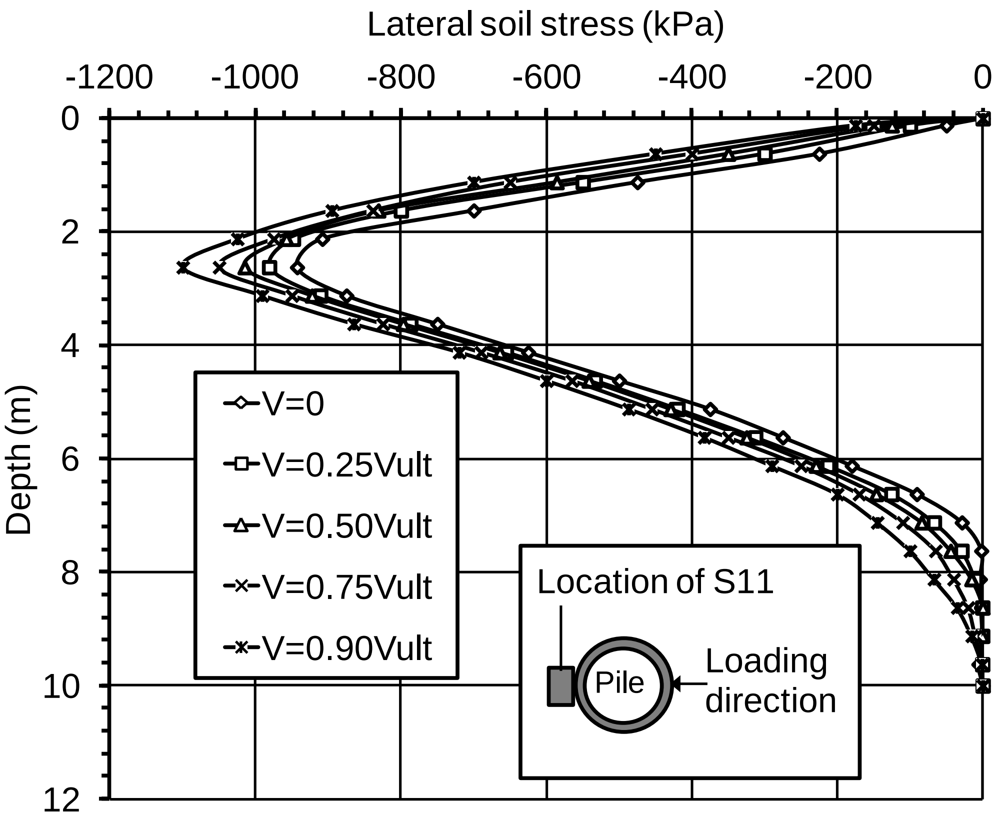


Fig. 4 Normalized lateral load deflection curves in dense sand

The main reason for the increase in lateral load capacity was investigated by closely observing the variation of lateral stresses along the pile depth.

Figure 5 shows the variation of lateral soil stresses (S11) along piles depth in dense sand for e/L = 0. Lateral soil stresses in front of the pile along the loading direction were shown in Fig. 5. Soil stresses were shown in the figure corresponds to pile deflection of 0.1D of the pile. As shown in Fig. 5, increase in vertical load level is influencing the increase in lateral confining stresses along the pile depth. Location of maximum lateral stress is independent of vertical load level. Point of maximum lateral stress location is approximately 2.6D vertically from soil surface.



e

Fig. 5 Lateral soil stresses (S11) along piles depth in dense sand

5. INFLUENCE OF *e*/L RATIO IN STIFF CLAY

It was seen in the previous section that vertical load is a having considerable influence on the lateral load response of piles in dense sand. In this section, influence of vertical load on lateral load response of piles in stiff clay for various eccentricities was investigated. Total 25 simulations were performed in stiff clay for pile embedment depth of 10 m and a diameter of 1.2 m for various vertical load levels and results are plotted in Fig. 6. Figure 6 shows the variation of lateral load for various e/L ratios at various vertical load levels corresponds to pile deflection of 0.1D. As seen in Fig. 6, vertical load influence is insignificant at all e/L ratios. However, lateral load carrying capacity of piles is more at lower e/L ratios compared to higher ratios, irrespective of its vertical load levels. Lateral load carrying capacity of piles decreases significantly when e/L ratio is more than 0.4. This type of trend was found to be identical to dense sand.

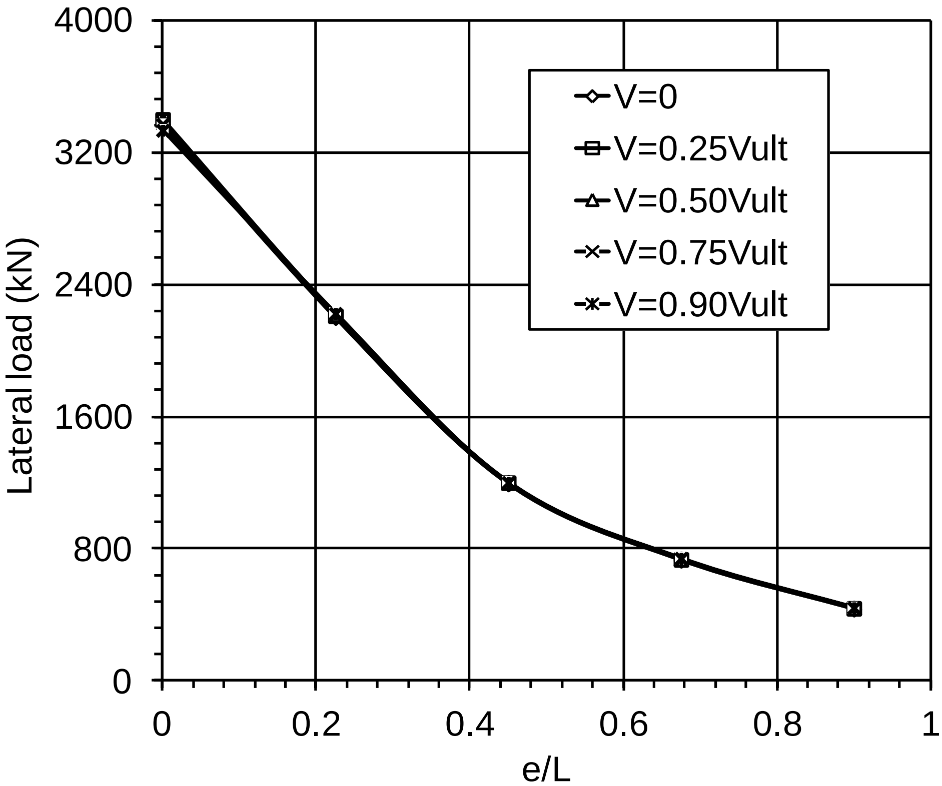


Fig. 6 Effect of axial load on lateral load response of piles in stiff clay with various e/L ratios for pile displacement of 0.1D

Normalized lateral load deflection curves for stiff clay at various vertical load levels were shown in Fig. 7 for e/L=0. Deflection of the piles was normalized with diameter and lateral load was normalized with cohesion and diameter of pile. Unlike in dense sand, for stiff clay different trend was observed in relation to vertical load levels. It was noticed that vertical load has an unfavorable effect on lateral load response of piles. There was a marginal decrease in lateral load carrying capacity of piles at higher vertical load levels. The reason for reduction in lateral soil stresses are further examined through the variation of lateral soil stress along piles depth. Soil stresses in front of the pile at deflection of 0.1D is shown in Fig. 8 for e/L=0. It is noticed that, vertical load is not influencing to enhance the improvement in lateral soil stresses like the case of dense sand. Maximum lateral soil stress was located at a distance of 1.5D from the soil surface. It was noticed that in case of stiff clay location of maximum stress occurs at shallow depths compared to dense sand.

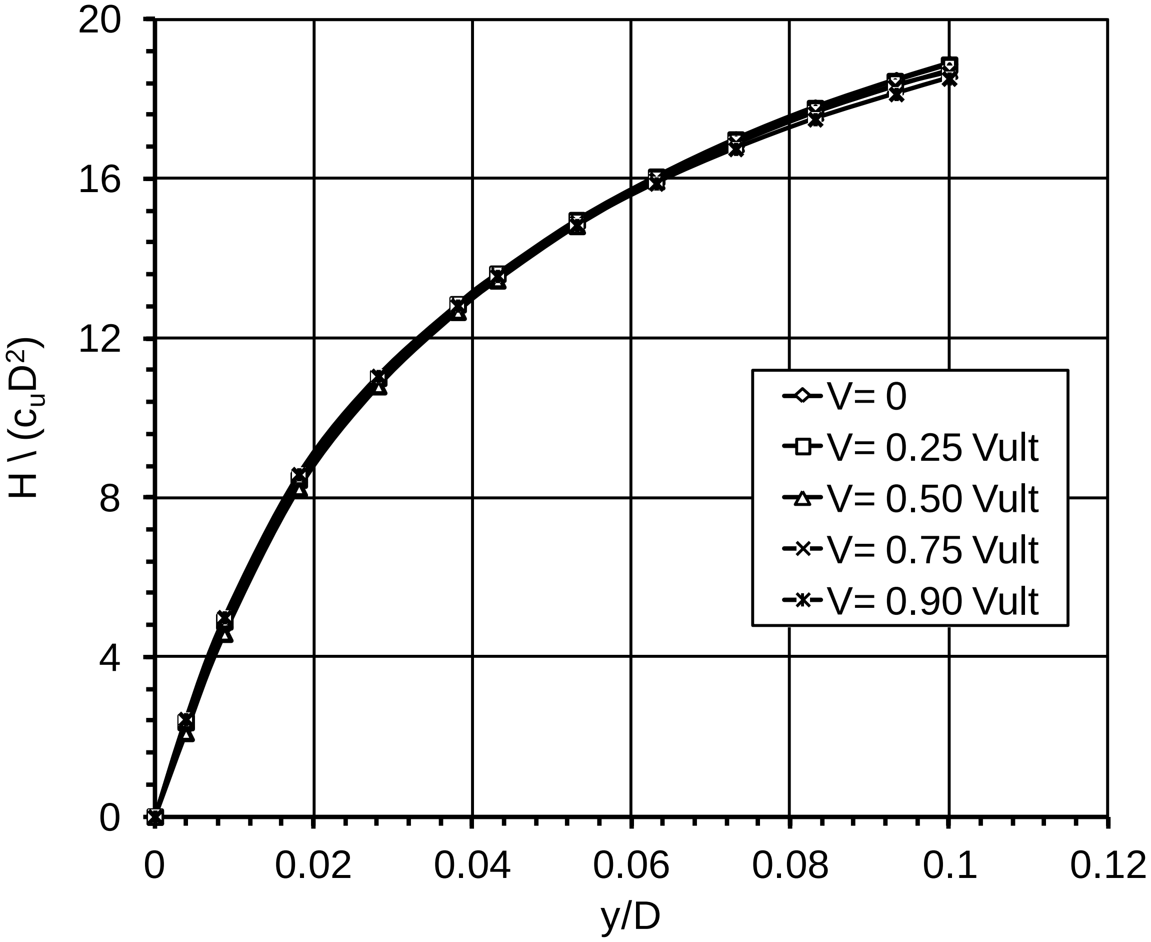


Fig. 7 Normalized lateral load deflection curves in stiff clay

The lateral soil stresses variation in front of the pile along the loading direction is further examined through the stress contours. Lateral soil stress contours are shown in Figures 9-10 are corresponding to 0.1D of the pile deflection. Increase in lateral soil was observed for two load cases, one corresponds V = 0 (lateral load case) and the other is V = 0.75V_{ult} cases in both dense sand and stiff clay. It can be seen from the Fig. 9a-b that location of maximum stress is independent of the vertical load level. However, it is noticed that vertical load significantly influences the increases in lateral soil stresses (Fig 9 b) compared to pure lateral loading condition (Fig. 9a) in dense sand. Increase in lateral soil stresses helps to mobilize more shear stress and thus in turn it will help to improve the lateral load carrying capacity of piles in dense sand. On the other hand, in case of stiff clay, as shown in Figure 10a-b, lateral soil stresses for the case of V = 0.75V_{ult} is less compared to lateral load case (V = 0). Decrease in soil stress leads to early loss of interface shear strength between pile and soil in case of vertical loading compared to pure lateral load case. And it was noticed that maximum stress occurs at 1.8 m from soil surface. Confining stresses due to overburden soil is also less due to occurrence of maximum lateral stresses at shallow depths in stiff clay.

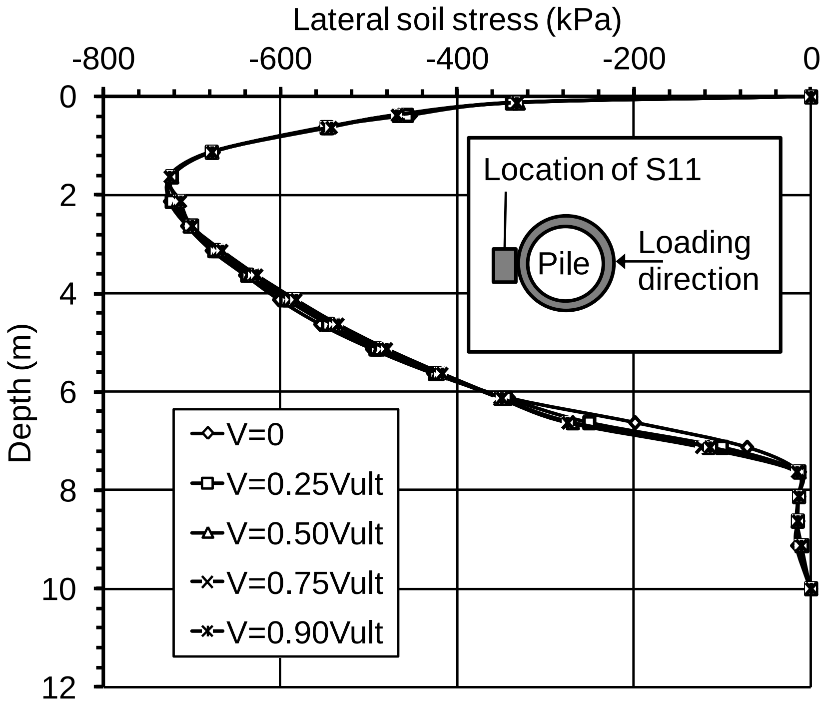
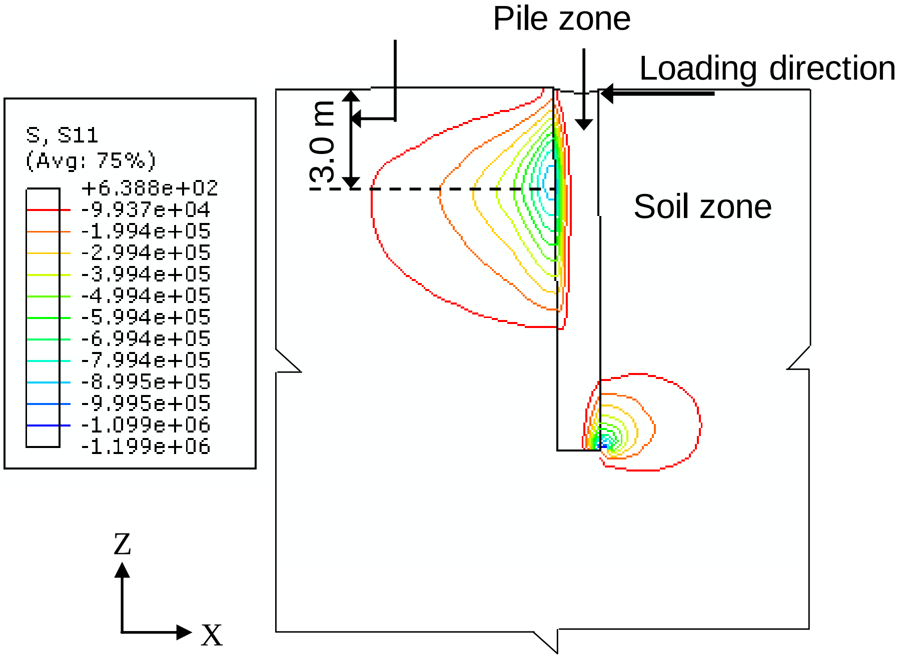
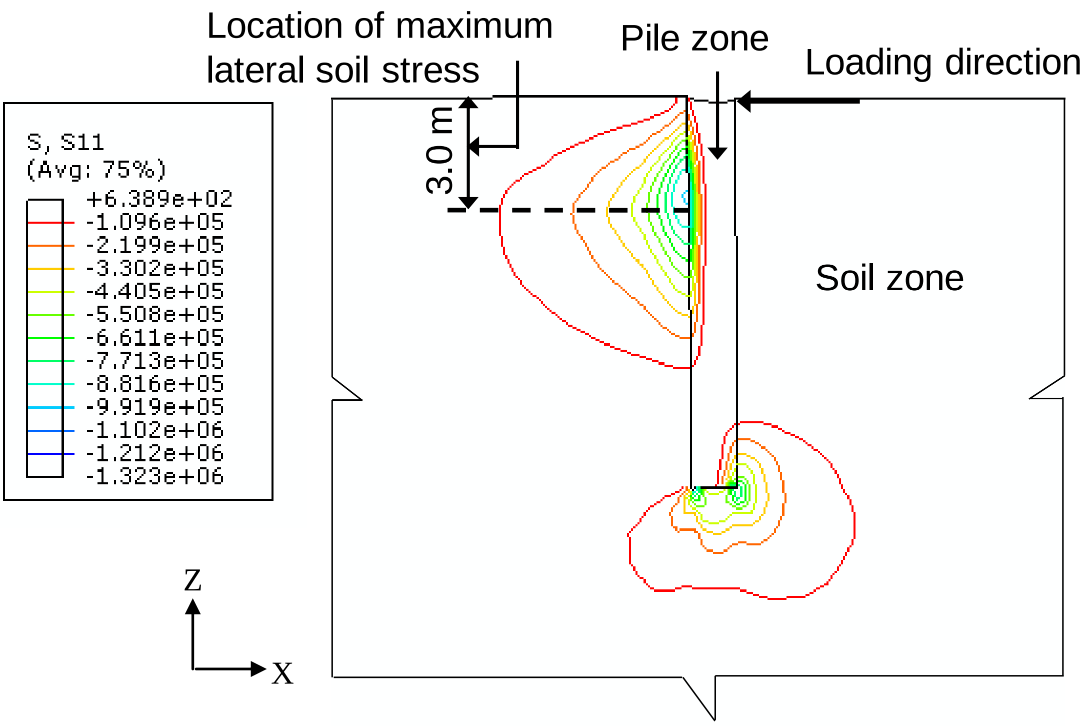


Fig. 8 Variation of lateral soil stresses (S11) along piles depth in stiff clay

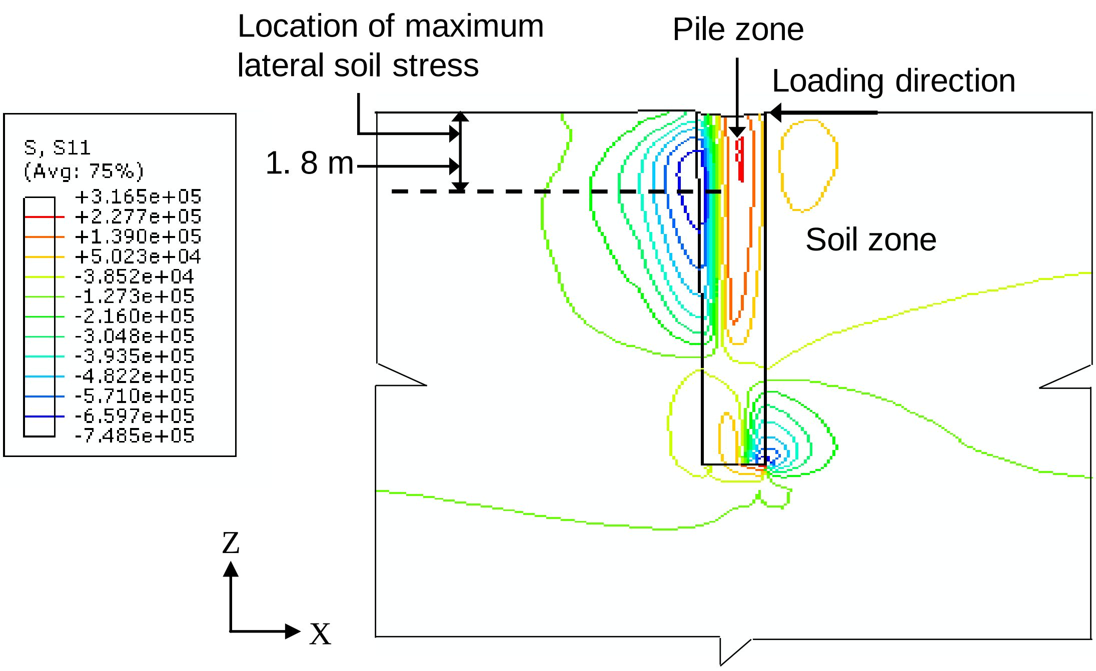


a) V = 0 case

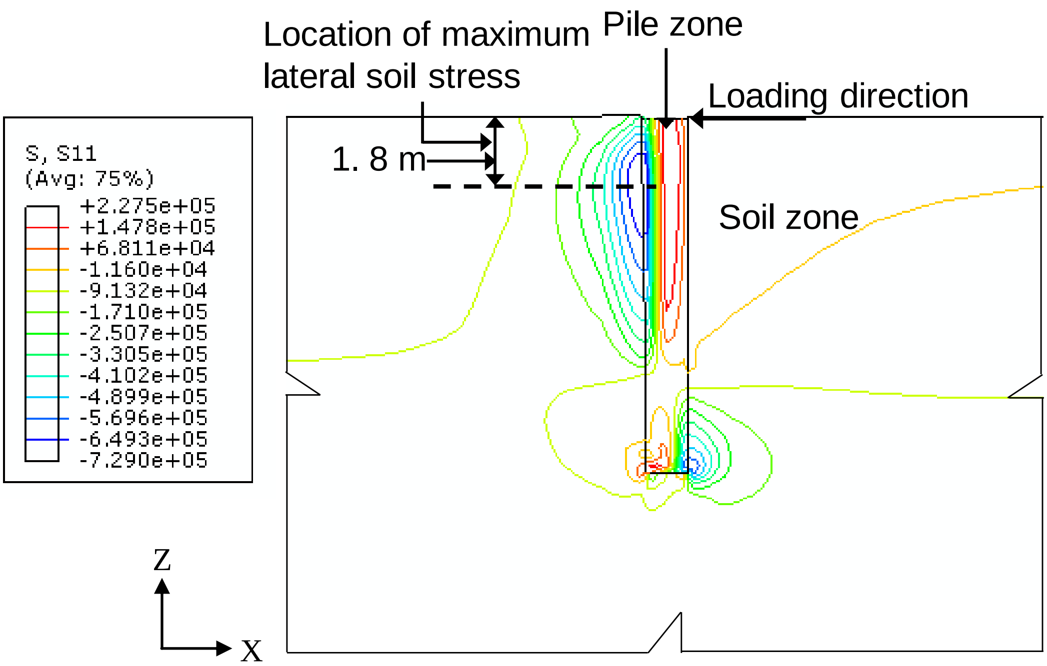


b) $V = 0.75V_{ult}$

Fig. 9 Lateral soil stress (Pa) contours in ZX Plane in dense sand for e/L = 0



a) V = 0 case



b) V = 0.75V_{ult}

Fig. 10 Lateral soil stress (Pa) contours in ZX Plane in stiff clay for e/L = 0

6. CONCLUSIONS

Three dimensional finite element analyses have been performed on a single pile embedded in dense sand and stiff clay. Present study mainly involves in ascertaining the influence of vertical load on the lateral load deflection response of piles with reference to some important parameters, like magnitude of vertical load, e/L ratio and soil type. Based on the present study outcome, the following conclusions can be drawn.

The lateral load response of piles in both dense sand and stiff clay depends on e/L ratios as well as the vertical load level on the piles. Both in dense sand and stiff clay, lateral load carrying capacity of the piles is significantly varies up to e/L ratio = 0.4, beyond this ratio increase in lateral load carrying capacity of the piles becomes marginally negligible. This could be attributed to less mobilization of soil stresses in front of the piles at higher e/L ratios. Vertical load influence is significant on lateral load response of piles in dense sand up to e/L ratio = 0.4, where as in case of clay, vertical load influence is insignificant at all e/L ratios.

In the case of e/L = 0, vertical load has a favorable effect on the lateral load response of piles in dense sand. Presence of vertical load increases the lateral load carrying capacity of piles is in the order of 17%. However, in case of stiff clay, vertical load has an unfavorable effect on lateral load carrying capacity of the piles. At higher vertical loads marginal decrease in lateral load carrying capacity of piles was observed.

Occurrence of maximum lateral soil stresses location was unaffected by vertical load level in case of both dense sand and stiff clay. However, location of maximum lateral stress was at 2.5D of the pile in dense sand and in the case of stiff clay it was 1.5D of the pile from soil surface.

NOMENCLATURE

e = Point of application of lateral load above ground
H = Lateral load
K_p = Passive earth pressure coefficient
V= Vertical load
y = Deflection of pile
z = Depth of pile from ground surface
z = Section modulus

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