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LATERAL RESISTANCE OF PILES IN COHESIVE SOILS

By Bengt B. Broms,[1] M. ASCE

ULTIMATE LATERAL RESISTANCE

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General.—At low load levels, the deflections of a laterally loaded pile or pole increase approximately linearly with the applied load. As the ultimate capacity is approached, the lateral deflections increase very rapidly with increasing applied load. Failure of free or fixed-headed piles may take place by any of the failure mechanisms shown in Figs. 1 and 2. These failure modes are discussed below.

Unrestrained Piles.—The failure mechanism and the resulting distribution of lateral earth pressures along a laterally loaded free-headed pile driven into a cohesive soil is shown in Fig. 7. The soil located in front of the loaded pile close to the ground surface moves upwards in the direction of least resistance, while the soil located at some depth below the ground surface moves in a lateral direction from the front to the back side of the pile. Furthermore, it has been observed that the soil separates from the pile on its back side down to a certain depth below the ground surface.

J. Brinch-Hansen[47] has shown that the ultimate soil reaction against a laterally loaded pile driven into a cohesive material (based on the assumption that the shape of a circular section can be approximated by that of a square) varies between $8.3c_u$ and $11.4c_u$, where the cohesive strength c_u is equal to half the unconfined compressive strength of the soil. On the other hand, L. C. Reese,[48] M. ASCE has indicated that the ultimate soil reaction increases at failure from approximately $2\ c_u$ at the ground surface to $12c_u$ at a depth of approximately three pile diameters below the ground surface. T. R. McKenzie[49] has found from experiments that the maximum lateral resistance is equal to approximately $8\ c_u$, while A. G. Dastidar[50] used a value of $8.5\ c_u$ when calculating the restraining effects of piles driven into a cohesive soil. The ultimate lateral resistance has been calculated in Appendix III as a function of the shape at the cross-sectional area and the roughness of the pile surface. The calculated ultimate lateral resistances varied between $8.28\ c_u$ and $12.56\ c_u$ as can be seen from Table 5.

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General.—The mode of failure and the resulting distribution of lateral earth pressures are shown in Fig. 4 for a laterally loaded pile driven into a cohesionless soil. At failure, the soil located in front of the pile moves in an upward direction, whereas the soil located at the back side of the pile moves downward and fills the void created by the lateral deflection of the pile. However, at relatively large depths, the soil located in front of the pile will move laterally to the back side of the pile instead of upwards. Approximate calculations have indicated that down to a depth of approximately fifty pile diameters, the lateral resistance with respect to an upward movement of the soil is less than the resistance with respect to a lateral movement. This critical depth of fifty pile diameters corresponds to an angle of internal friction of approximately 30°.

Close to the ground surface, passive lateral earth pressures develop at the front face of the loaded piles while active pressures develop at the back face as soon as the rotation of the pile exceeds approximately 0.002 and 0.006 radians for a dense and loose sand, respectively.[45] (It has been assumed that this rotation is approximately equal to that required to develop the passive pressure against a long wall.) The lateral earth pressures can be calculated by standard earth pressure theories within a depth of approximately one pile diameter below the ground surface assuming that the pile is infinitely wide. If the surface of the pile is assumed frictionless, the lateral earth pressures can be calculated by the Rankine earth pressure theory. Below a depth of approximately one pile diameter, the soil reactions which develop at the front face are larger than the passive lateral resistance corresponding to an infinitely long wall due to lateral stress distribution in the soil. The corresponding active lateral resistance acting on the back face will be less than that calculated by standard earth pressure theories.

In the following analysis, the active earth pressure has been assumed small compared to the passive earth pressure and has been neglected in the calculations. Driving of piles cause an increase of the relative density of the soil surrounding the piles to a distance of approximately one diameter from the pile surface. This increase of the relative density results in a lateral soil reaction larger than that estimated from standard penetration or laboratory triaxial or direct shear tests.

Laboratory tests by Shilts, Graves and Driscoll,[31] by Ramelot and Vandeperre,[23] and by Roscoe[28] with model piles of different shapes have indicated that the shape of the pile section has only a small effect on the ultimate lateral resistance and on the lateral earth pressure distribution. Prakash[21] has observed that the maximum lateral earth pressure is two to three times the passive earth pressure calculated by the Rankine earth pressure theory.

In the following analysis, it will be assumed that the lateral earth pressure which develops at failure is equal to three times the passive Rankine earth pressure and that this lateral earth pressure is independent of the shape of the cross-sectional area of the laterally loaded pile. The accuracy of this assumption can be established only from comparisons with test data. Such comparisons will be made subsequently. It will be shown that this assumption will yield results which are on the safe side.

The assumed distribution of lateral earth pressure at failure is shown in Fig. 4 (b). At the depth z below the ground surface, the assumed soil reaction Q per unit length of the pile will be:

$$Q = 3D \gamma z K_p \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

in which D is the pile diameter, γ is the unit weight of the soil and K_p is the coefficient of passive earth pressure as calculated by the Rankine earth pressure theory. The unit weight γ is equal to the submerged unit weight if the ground water table is located at or above the ground surface and is equal to the wet unit weight if the ground water table is located below the section considered.