Importance of Limiting Soil Pressure on Pile Responses (Part 1 of 3)

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PILES embedded in soils undergoing increasing lateral movements would experience increasing horizontal soil pressure which in turn causes additional induced pile bending moment and deflection. Horizontal limiting soil pressure is an important consideration in such an event because it defines the maximum magnitude of soil pressure that can effectively act on a pile to cause an increase in the pile responses. Beyond this magnitude, no further soil pressure could be mobilised to act on the pile, which in turn would not result in further pile responses. Such scenario is particularly prevalent in piles embedded in soft soils. Piles which are acted on by soil movements are called passive piles (De Beer, 1977), whereas active piles as known as conventionally laterally loaded piles.

The first of this 3-part article describes real-life issues associated with civil engineering structures when subjected to lateral soil movemment and the different limiting soil pressure to undrained shear strength ratio (p_y/c_u) commonly used.

Examples where piles could be subjected to lateral soil movements include those installed within the influence zones of excavation, tunnelling, embankment/abutment construction, landslide or riverbank slope movement. If these piles are not designed to withstand the additional forces induced, then the integrity of the structure may be threatened. Structural distress due to the imposition of lateral soil movement have been reported, for instance, (i) Ong *et al.* (2004) highlighted the failure of a 4-pile group consisting large 900mm diameter bored piles due to a nearby slope excavation as shown in Figure 1, (ii) Ting *et al.* (1994) presented the failure of piles supporting an embankment due to landslip, (iii) Poulos (1994) reported on the foundation failure of an office tower due to a nearby excavation and (iv) Ting *et al.* (1997) described the failure of a pile-supported wharf structure due to riverbank soil movement as shown in Figure 2.

Figure 1: Slope excavation-induced lateral soil movement

Figure 2: Detrimental effect of riverbank soil movement on structure

One major design concern is that the behaviour and mechanism of such complex soil-structure interaction problems are still not well understood. It is evident from the examples given that the limiting soil pressure acting on a pile is crucial and, as such, the author believes that it deserves greater attention.

Many authors have proposed single, average values or lumped p_y/c_u ratios for estimating limiting soil pressure on piles due to moving soils. The limiting soil pressure adopted by various authors is listed in Table 1. It is evident that a wide range of p_y/c_u ratios for laterally loaded piles (active piles) and piles subjected to lateral soil movement (passive piles) have been proposed. Careful study of the proposed p_y/c_u ratios in Table 1 reveals some contradictions by several authors.

Poulos and Davies (1980) proposed that for the case of a laterally loaded pile in a purely cohesive soil, the ultimate lateral resistance or limiting pressure, p_y, increases from $2c_u$ at the surface to $8c_u$ to $12c_u$ at a depth of about three pile diameters and remains constant for greater depth. On the other hand, Broms (1964) proposed that this ultimate soil resistance or limiting soil pressure, p_y, for a cohesive soil can be further simplified and to account for the near ground effect for design purposes. The result is a limiting soil pressure distribution of zero from the ground surface to a depth, z of 1.5 pile diameters and a constant value of $9c_u$ below this depth.

Table 1: Values of $K=p_y/c_u$ for single passive piles

Reference	K value	Method of analysis	Situation
Chen and Poulos (1994)	11.4 for piles near a cut	2-D FEM	Similar to piles used for landslide stabilisation
Viggiani (1981)	2.8-4 (sliding soil) 8 (stable soil)	Empirical	Piles used for landslide stabilisation
Maugeri *et al.* (1994)	3.33 (sliding soil) 6.26 (stable soil)	Empirical, field data	Piles used for landslide stabilisation
Chow (1996)	3-4 (sliding soil) 8-12 (stable soil)	Empirical, numerical	Piles used for landslide stabilisation
Poulos and Chen (1997)	9	Empirical	Piles adjacent to an excavation
Goh *et al.* (1997)	9	Empirical	Single pile adjacent to embankment

However, the limiting soil pressure of $9c_u$ has also been adopted by some authors in their analyses of piles subject to lateral soil movement caused by embankment loading (Goh *et al.*, 1997) and excavation (Poulos and Chen, 1997), even though the former is a construction loading process while the latter is an unloading process. However, other authors like Viggiani (1981), Maugeri *et al.* (1994) and Chow (1996) proposed that the limiting soil pressure on a passive pile is much lower than that of an active pile. Therefore, in view of such contrasting p_y/c_u ratios adopted for a passive pile, one of the aims of this article is to evaluate the p_y/c_u ratio for passive piles.

It is acknowledged that very few design methods are currently available to evaluate these problems in practice because real-life structures are not normally built and then tested to failure as tremendous amount of money and time is involved. Therefore, full-scale testing of a structure to failure is generally deemed to be uneconomical and undesirable. Physical modelling, on the other hand, can offer an attractive alternative to further understand the behaviour and mechanisms behind complex soil-structure interaction problem. For example, centrifuge model tests can be carried out under a controlled environment where the soil strength profiles, soil deformation and elapsed time can be measured with reasonable accuracy resulting in reliable test results. Besides that, the consistent repeatability of centrifuge experiments also renders the centrifuge model study attractive and relatively economical.

Part 2 of this article describes the effects of pile behaviour when imposed with lateral soil movements resulting from an excavation in very soft soil in a centrifuge experiment. ■

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