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

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This article is a continuation of the author's contribution published in the preceding issue of JURUTERA. It forms the final portion of three parts that constitutes the full article.

(I) BACK-ANALYSIS ATTEMPT #1: USING PRE-EXCAVATION C_U

As a first attempt, the pre-excavation c_u profile (see Figure 1) at the pile location of 3m behind the wall is used as the input soil strength parameters in the back-analyses. The normalised limiting soil pressure coefficient P_n is defined as the ratio of limiting soil pressure p_y and c_u to differentiate it from the case of a laterally-loaded pile where K is used. The following P_n values (Poulos and Davis 1980) are adopted in the back-analysis:

$$P_n = p_y/c_u = 2(1 + z/d) \leq 9 \qquad (1)$$

where z is the depth below the ground and d is the pile diameter. As P_n is analogous to K, the symbols P_n and K may be used interchangeably in this paper.

If Eq. (1) is used directly with pre-excavation c_u, the corresponding soil limiting pressure envelope is as shown in Figure 2. The measured soil pressure acting on the pile is also shown on a similar plot using dashed lines. One can see that if the soil pressure envelope is not properly specified to consider soil failure, large over-prediction can be expected as the measured soil pressure is only a small fraction of that calculated had the pre-excavation c_u is used to specify the limiting soil pressure envelope.

Subsequently, when the back-analysed and measured pile responses are plotted in Figure 3 after being extracted from the numerical method performed on a beta version of the software package as shown in Figure 4, it is clear that the back-analysed pile bending moments are much larger than the measured values, as expected from the observations made from Figure 2. This confirms that the use of pre-excavation c_u profiles in the numerical model by adopting conventional limit soil pressures for laterally loaded piles would over-predict the induced pile bending moments especially when the magnitude of lateral soil movement is large.

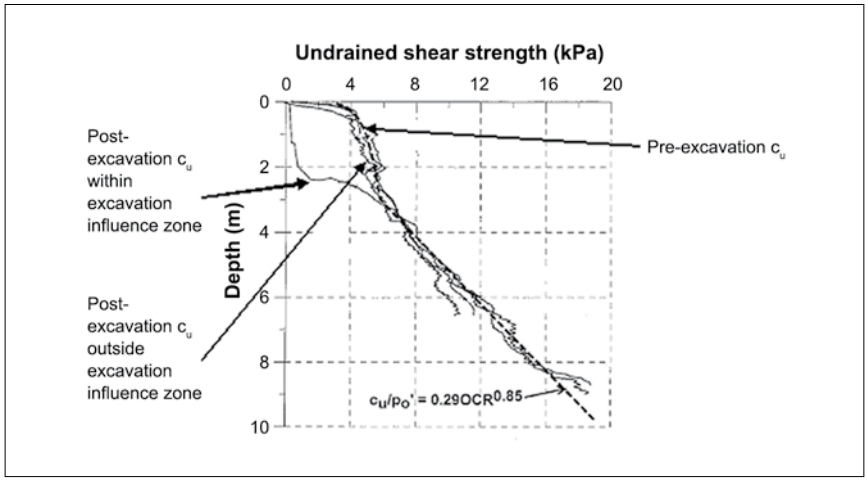


Figure 1: Clay undrained shear strength

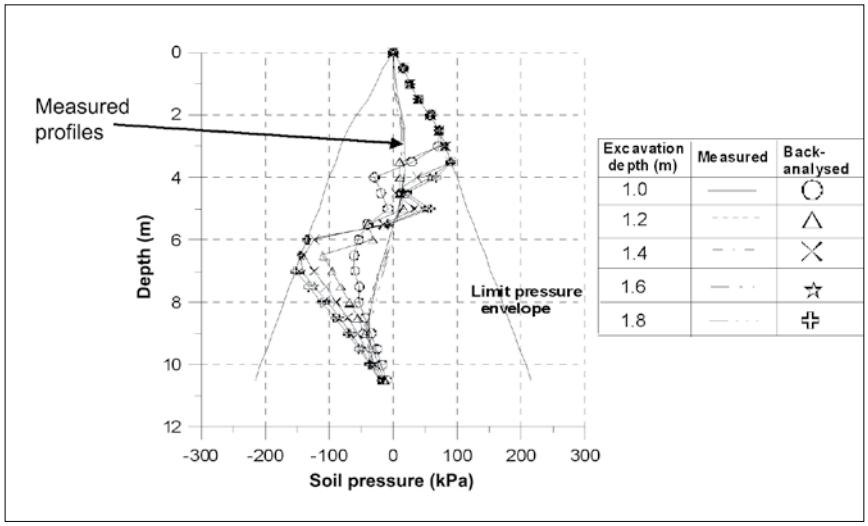


Figure 2: Measured soil pressure in relation to the calculated and specified limit pressure envelope based on pre-excavation undrained shear strength

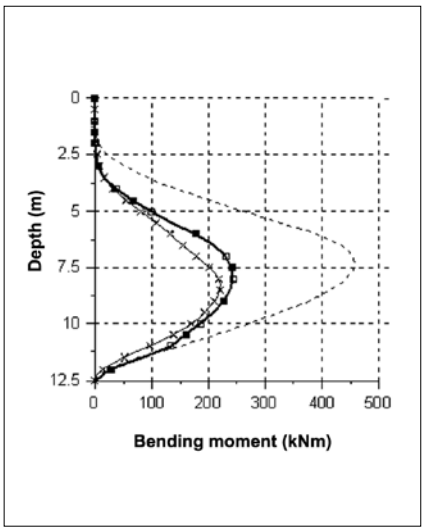


Figure 3: Comparison of measured and back-analysed pile bending moment

(II) BACK-ANALYSIS ATTEMPT #2: USING POST-EXCAVATION C_U

The second attempt in the back-analyses is to employ the post-excavation c_u as the input soil strength values as measured in Figure 1. The back-analysed pile bending moment profile using the post-excavation strength profile is shown in Figure 3. It is evident that the agreement between the back-analysed and measured pile bending moment profiles are considerably better.

The maximum soil pressure acting on the pile is likely to be reached upon large soil movements. At this juncture, it is worthwhile to evaluate the actual magnitudes of soil pressure acting on the pile. As an example, Figure 5 shows the soil pressure profiles (enlarged from Figure 2) that are deduced from the corresponding bending moment pro-files. It is evident that the limiting soil pressures along the upper portion of the pile have been reached at an excavation depth of 1.2m. Thereafter, the soil pressures do not increase further with increasing excavation depth. This may be attributed to the formation of tension cracks that prevents the full transmission of soil pressure onto the pile. It is also probable that the soil would flow past the pile and could not exert full pressure on the pile.

As the current numerical model facilitates the input of limiting soil pressure, the third attempt is useful in studying the effect of pile behaviour subject to large strain soil deformation. It involves employing the pre-excavation c_u profiles but adopting the envelope of P_n values deduced from Figure 6(b).

The back-analysed and measured pile bending moment profiles are compared and shown in Figure 3.

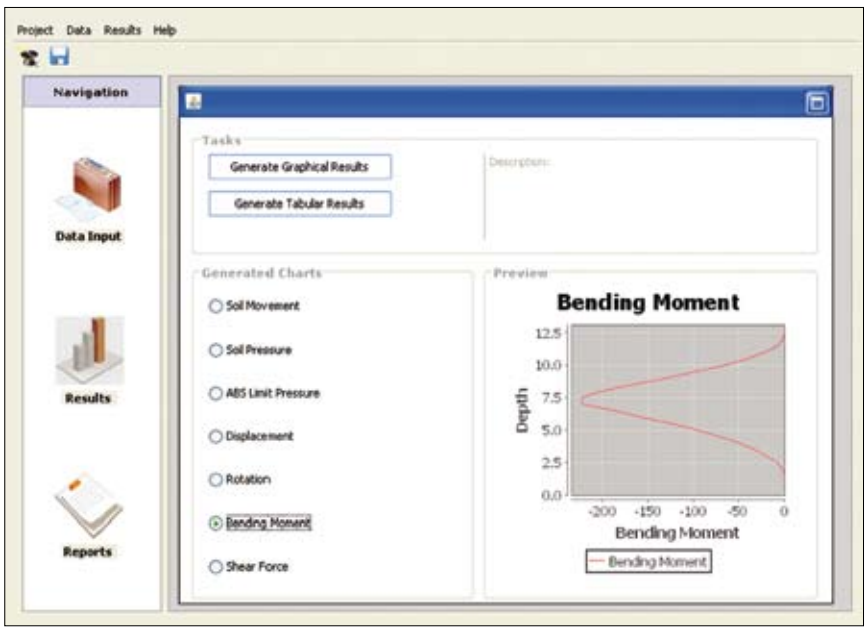
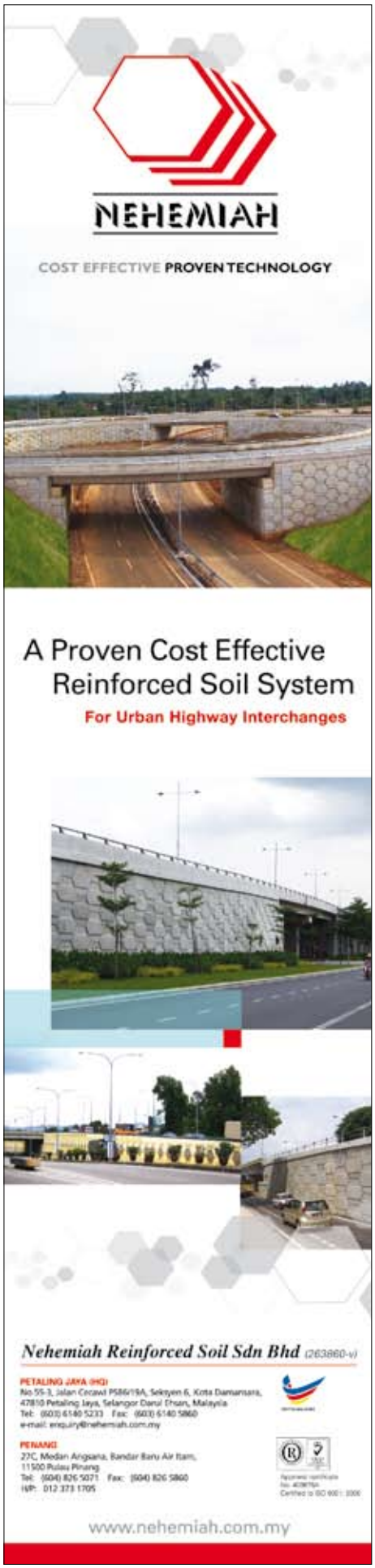


Figure 4: Snapshot showing output of software being developed to analyse limiting soil pressure on pile for Windows-based application



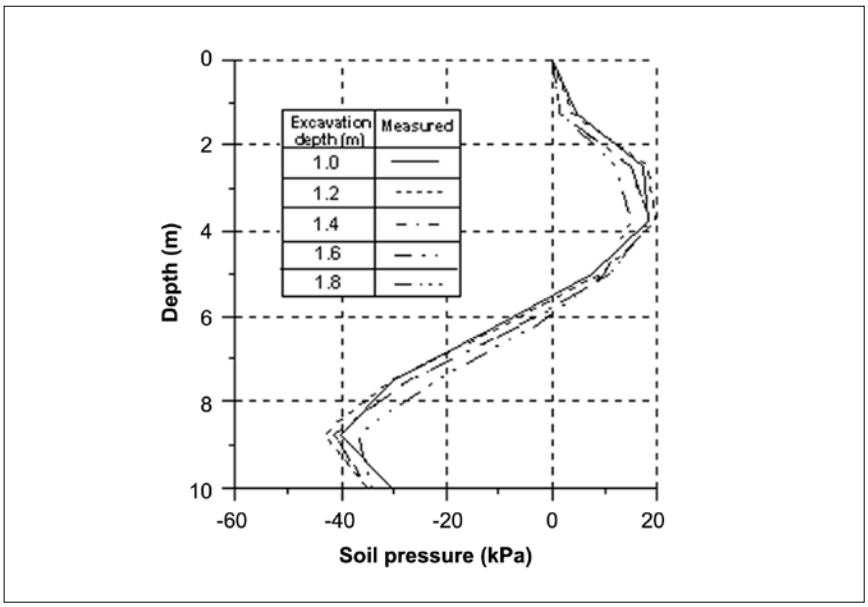


Figure 5: Limiting soil pressure deduced from pile bending moments

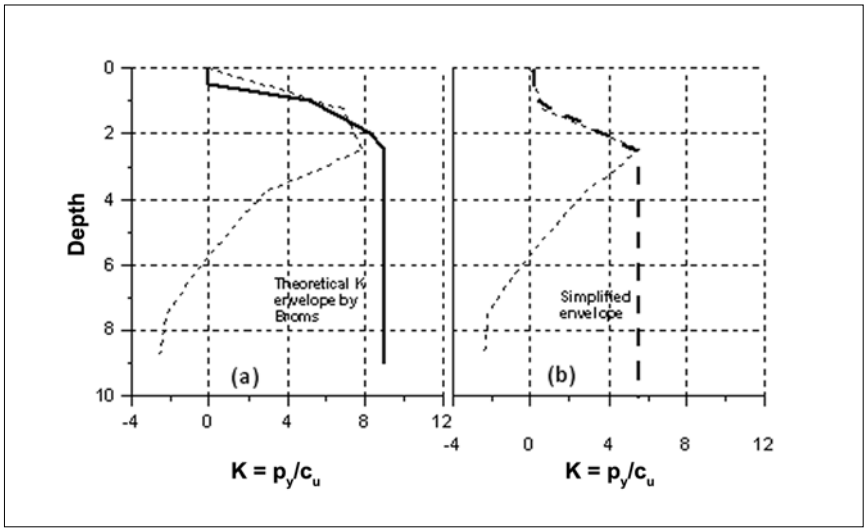


Figure 6: Variation of K or Pn value with depth using (a) post-excavation and (b) pre-excavation undrained shear strength

The fairly close agreement between the back-analysed and measured pile responses reveal that the use of pre-excavation c_u with reduced limiting soil pressures would provide a reasonably good prediction of pile bending moment. The limiting soil pressures on the pile are reached upon large soil movements.

(III) BACK-ANALYSIS ATTEMPT #3: PRE-EXCAVATION C_U WITH BACK-ANALYSED LIMITING SOIL PRESSURE

In most practical situations or in design, the post-excavation cu profiles are not available. In view of this, the back-analysed P_n (or K) values with respect to the pre-excavation cu profile is also determined and shown in Figure 6(b). As expected, the back-analysed P_n values are much lower than the theoretical P_n values shown in Figure 6(a). An envelope of limiting P_n values is hence plotted and indicated by the bold dash line in Figure 6(b). The maximum back-analysed P_n value is about 6.

It should also be noted that the calculations obtained using the post-excavation c_u profile and pre-excavation c_u profile with reduced P_n values are identical. This is as expected as the two approaches essentially use the same back-analysed limiting soil pressures.

It can be concluded from the above back-analyses that the commonly adopted P_n value of 9 is applicable when post-excavation c_u profile is used. However, if only pre-excavation c_u profiles are available, an appropriate reduction in the P_n value should be adopted in order to obtain a more accurate prediction of pile bending moment when subjected to large soil movements. In the present study, the maximum normalised limiting soil pressure/undrained shear strength ratio is established to be about 6.

The importance of this work is to highlight the existence of limiting soil pressure, if unaware, can result in the gross overdesign of piles resisting large strain deformations in soft soils. As post-excavation c_u is not usually determined in practice due to cost and practicality, this study has successfully demonstrated the importance of physical modelling via the centrifuge to carry out investigative studies such as this. This centrifuge study has also successfully demonstrated that post-excavation c_u within the zone of influence actually led to stress relief and tension cracks, which otherwise may be not be easily proven and understood.

The knowledge gained can be used to develop the design concept of landslide stabilising piles and piles to withstand riverbank soil movement. The underlying principle is to design pile with small projected width to limit the solicited pile area in contact with soil movement so as to minimise the development of soil pressure and additional bending moment on the pile. Thus, a software that permits the input of limiting soil pressure such as the aforesaid can greatly help the computation of such pile responses. ■

REFERENCE

[1] Poulos, H. G. and Davis, E. H. (1980). Pile foundation analysis and design. John Wiley & Sons, New York.