The Effect of Piles and Caissons on Groundwater Flow

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INTRODUCTION

Pile or caisson foundations below groundwater level may impede the flow of groundwater and lead to an increase in groundwater levels. This effect is particularly significant in situations where intense development, involving deep foundations, is taking place on steeply sloping hillsides. This situation occurs in Hong Kong and there is cause for concern that increases in groundwater levels due to the damming effects of foundations could lead to a decrease in stability and possible failures of the slopes.

This paper presents the results from a finite difference numerical model which calculates the increase in groundwater level due to the effects of pile or caisson foundations. The results are used to examine the magnitude of groundwater rises which may be expected and the significance of pile or caisson diameter and spacing is discussed.

SIMPLE MODEL

The ground conditions on the hillsides of Hong Kong often comprise colluvium overlying weathered rock which grades to fresh rock at depth. In some areas there is no colluvium and the thickness of weathered rock varies substantially. Due to the natural topography the hydraulic gradients in the aquifers are often steep, and rapid drainage can take place through groundwater flow. The groundwater behaviour is often complex involving flow in both perched and main water tables.

It has been necessary to consider a simple model of a single sloping aquifer on an impermeable base as shown on Figure 1. It is considered that this simple model is a reasonable approximation to the groundwater flow conditions for many situations. In general permeability decreases with depth and it is probable that a large proportion of the groundwater flow takes place in the upper aquifer which may contain a perched water table. For example, permeability measurements in the Mid-levels area (Geotechnical Control Office, 1982) show that the colluvium is more permeable than the underlying decomposed rocks and it is therefore likely that there is a perching level at the base of the colluvium.

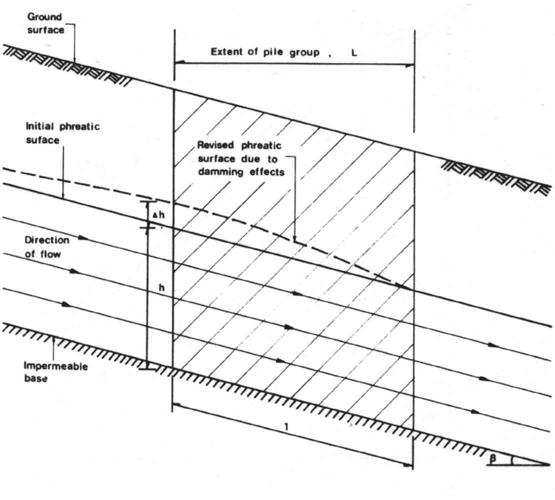

Figure 1. Sloping aquifer on impermeable base

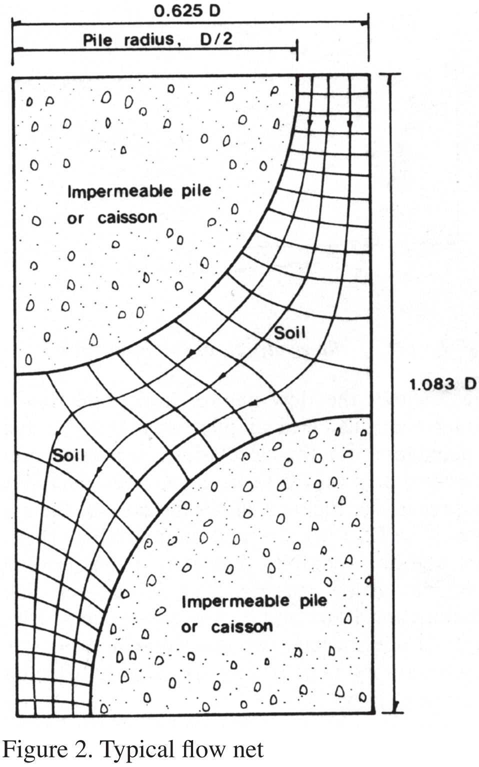

Figure 2. Typical flow net

METHOD OF ANALYSIS

In order to solve the problem shown on Figure 1 it has been necessary to analyse the problem in two steps as follows:

(i) Calculate the equivalent permeability of the soil and pile combination in the direction of groundwater flow.

(ii) Analyse the section shown on Figure 1 using the permeability derived from step (i) to represent the piled area.

For step (i) the equivalent permeability of the soil and pile combination (k_p) is calculated by means of flow nets.

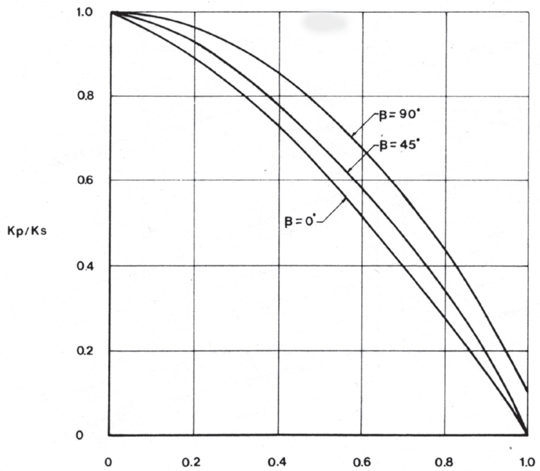

Figure 3. Equivalent permeability, K_p

Figure 2 shows the flow net for horizontal flow through a regular triangular grid of piles arranged at a spacing of 1.25 diameters. For the calculations, it is assumed that the soil permeability (k_s) is isotropic and the piles or caissons are impermeable. Figure 3 shows the ratio of the equivalent permeability (k_p) to the soil permeability (k_s) plotted against the ratio of pile diameter to pile spacing for a regular pile group spacing. The results for three flow inclinations are shown and it can be seen from Figure 3 that for normal pile spacing, two diameters or more, the equivalent permeability (k_p) is not significantly affected by the inclination of flow.

For (ii) the increase in groundwater level (Δ_h) at the upstream edge of the pile group has been calculated using a numerical model and a computer. The numerical model adopted is a forward difference explicit finite difference technique (Rushton K.R, and Redshaw S.C., 1979).

RESULTS

The Building (Construction) Regulations restrict the spacing of circular piles to twice the diameter measured centre to centre. However, grouting is often carried out during the construction of hand-dug caissons which increases the effective diameter of the caissons with respect to their damming effects on groundwater flow. It is also probable that new piles or caissons will be installed on sites which contain disused piles or caissons thus increasing the density of the foundation works. It is therefore necessary to consider the effects of piles or caissons at less than two diameter spacing as well as greater spacings.

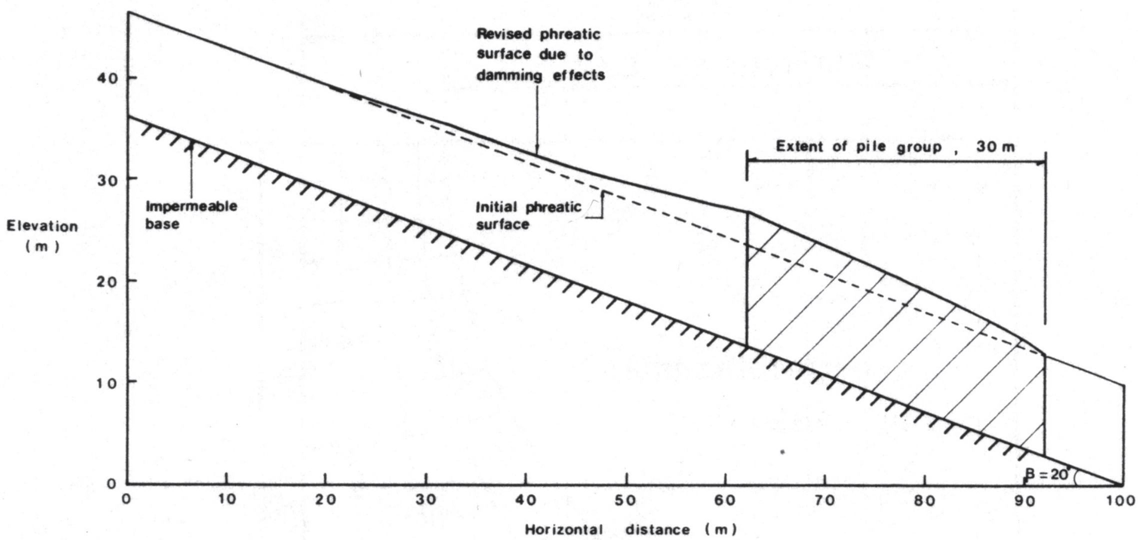

Figure 4. Effect of pile group on phreatic surface

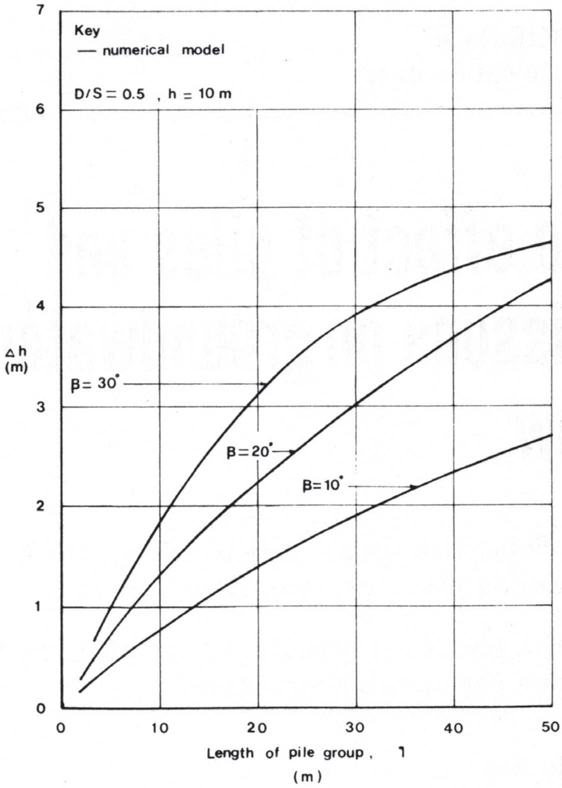

Figure 5. Variation in Δh with length of pile group

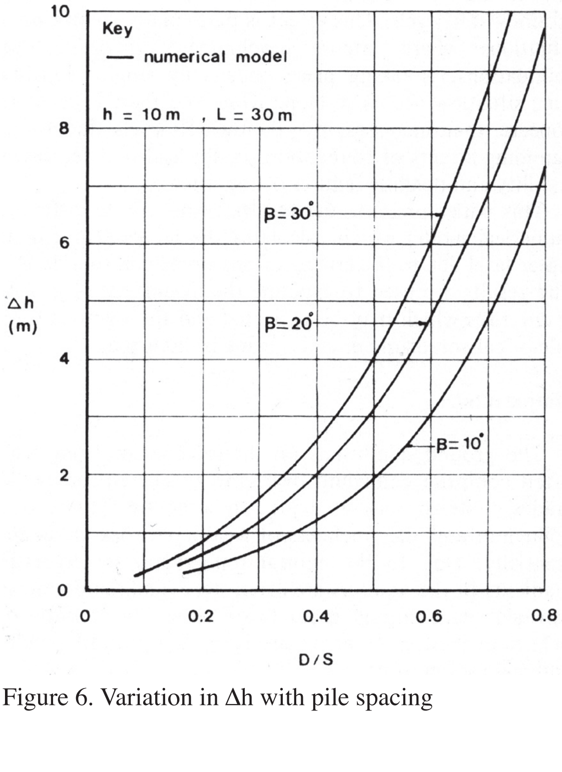

Figure 6. Variation in Δh with pile spacing

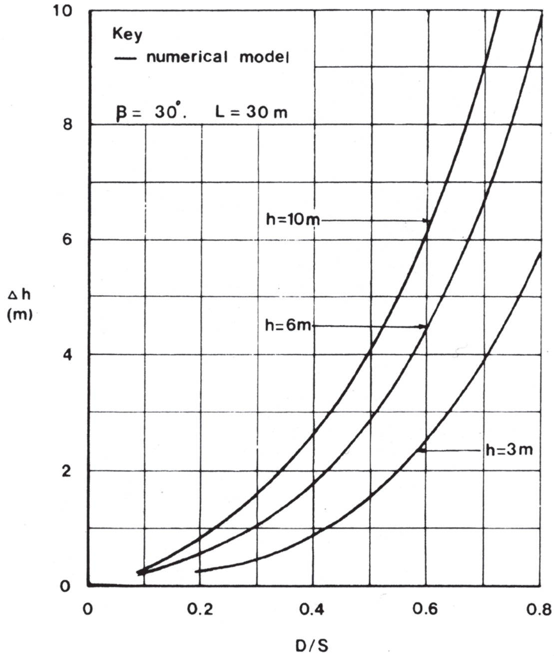

Figure 7. Variation in Δh with height of flow

Figure 4 shows the effect of a pile group on the phreatic surface for an original height of flow of 10 m. The example illustrated is a slope angle of 20 degrees, plan length of pile group 30 m and pile spacing of two diameters. It may be seen from Figure 4 that the greatest increase in groundwater level occurs at the upstream edge of the pile group and there is a significant backwater effect which extends upslope from the pile group. Groundwater levels downslope of the pile group are not affected.

Figure 5 shows the effect of the downslope length of the pile group (1) on the increase in groundwater levels for an initial height of flow of 10 m, a fixed pile spacing of two diameters and slope angles of ten, 20 and 30 degrees. For the lengths of pile group shown on Figure 5 the increase in groundwater level is greatest for the steepest slope angle (30°) .

Figure 6 shows the effect of pile spacing on the increase in groundwater level and Figure 7 shows the effect of the original height of flow. It may be seen from Figures 6 and 7 that pile groups with pile spacing less than two diameters can cause substantial increases in groundwater levels.

ACKNOWLEDGEMENTS

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REFERENCES

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Rushton K.R. and Redshaw S.C. (1979). Seepage and Ground-water Flow, Wiley.

NOTATION

h	vertical height of initial groundwater flow above impermeable base (m)
Δh	increase in vertical height of groundwater flow at upstream edge of piles or caissons (m)
l	length of soil and pile combination measured along impermeable base (m)
L	length of soil and pile combination measured on horizontal plane (m)
β	slope angle of impermeable base (degrees)
k_s	isotropic permeability of soil (m/s)
k_p	equivalent permeability of soil and pile combination (m/s)
D	pile diameter (m)
S	pile spacing (m)