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The Fluid Loss and Sealing Mechanisms in Slurry Trench Conditions (II) : Finite Elememt Models of Fluid Loss for a Slurry Trench

Slurry wall 공법에서 안정액의 역할 (II) : 유한요소해석법 적용

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요 지

Slurry trench의 안정성은 안정액의 유압이 filter cake 막을 통하여 trench 벽에 전달됨으로서 확보될 수가 있다. 지반조건의 영향에 따른 slurry trench 공법에서 주변 공극수압의 변화를 수치해석(FEM)으로 추적하였다. 이러한 주변 공극수압의 변화 요인으로는 안정액의 밀도, filter cake의 상태, 토질조건, 시간, trench 심도, 주변지하수위로 조사되었으며, 가장 큰 영향력을 보인 요인으로는 토질조건과 filter cake 상태로 나타났다.

Abstract

The stability of slurry trench system is closely associated with the characteristics of the filter cake (assumed impervious membrane) transferring the hydrostatic force of slurry to the trench walls. The effectiveness of this assumption in a wide range of trench systems has been examined with the aid of a Finite Element program. Build up of excess porewater pressure in the soil mass behind the filter cake is a function of the slurry density, the properties of filter cake, the ground conditions, time, the geometry of trench and the original ground water level. These factors were all investigated by the Finite Element Method. The most significant factors were found to be the ground conditions and the properties of filter cake.

Keywords : Filter cake, Finite element method, Fluid loss, Porewater pressure, Slurry trench, Trench geometry

1. Introduction

One of the essential functions of a slurry is to form a low permeable membrane on the side of trench so that the hydrostatic pressure of the slurry can act upon the membrane and so counteract the ground water and lateral earth pressures.

As the formation of the filter cake is directly related to the total fluid loss through the ground, it follows that there is hardly any filter cake formed in highly impervious soils.

In granular soils a substantial amount of cake may form.

Therefore, the main aim of this paper is to investigate the potential build up of pore water pressures adjacent to the slurry trench related to the fluid loss through the filter cake in various ground conditions.

The variation of permeability and thickness of filter cake is rather complex and time dependent, and is influenced by the slurry properties, ground water level, ground soil conditions, trench geometry and filtration time.

This produces an extremely complex relationship of

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pore pressure with time.

Therefore, for the analysis, a constant fluid loss flow rate was assumed.

The finite element technique was employed in this work in order to investigate the build up of pore water pressure in the soil mass.

The computer program enabled to evaluate the effectiveness of the supporting forces (i.e. hydrostatic pressure of slurry) and the change in the disturbing forces (i.e. possible increase in pore water pressure) in various ground conditions.

The program was written in the Fortran IV language and was enhanced by many subprograms such as an automatic data generating subroutine and a contour plotting (Tektronix) system. Simple triangular elements were chosen for the finite element mesh.

A two-dimensional flow system was used to represent the trench (i.e. effects of the trench ends were ignored.)

2. The Basic Governing Equation

$$\frac{\partial^2\phi}{\partial X^2} + \frac{\partial^2\phi}{\partial Z^2} = 0 = \nabla^2\phi \qquad (1)$$

where, ϕ = Velocity potential

X = Horizontal direction

Z = Vertical direction

The validity of Eqn. (1) depends on:

i) Steady flow conditions where the medium and ground water are incompressible.

ii) The kinetic energy term ($v^2/2g$) is negligible.

iii) The void diameter in the formation ground does not exceed 10mm and the hydraulic gradient is less than 5. (i.e. otherwise, flow may be turbulent.)

3. The Boundary Condition

The solution of Laplace's equation, (1), may be done graphically as a flow net system for a steady state seepage flow. In order to solve a 2-dimensional 2nd order partial differential equation, four boundary conditions are required.

i) Impervious boundary

No flow is allowed to pass through this boundary. This boundary is also defined as a streamline where equipotential lines meet it at right angles. Generally for a trench in this case, a clay with very low permeability or bed rock could represent such a boundary.

ii) Boundary of slurry trench

Boundary of slurry trench, against which the hydrostatic slurry pressure will be distributed, is also considered as an equipotential line.

iii) Seepage face

The surface of seepage (assumed outlet in this case) occurs when the flow enters to a zone of infinite permeability. The pressure at this boundary is constant and equal to atmospheric.

$$\phi + k_z = constant$$

where ϕ : velocity potential

k_z: permeability of the medium

iv) Free surface (Phreatic surface)

The upper streamline of the flow domain (i.e. atmospheric pressure) forms a boundary between the saturated zone of the soil (due to capillary action) and the flow domain. One of the major tasks of this investigation was to monitor the free surface so as to assess the build up of the fluid loss through the filter cake in a slurry trench system.

4. Flow Chart of Computer Program

(i) Call title

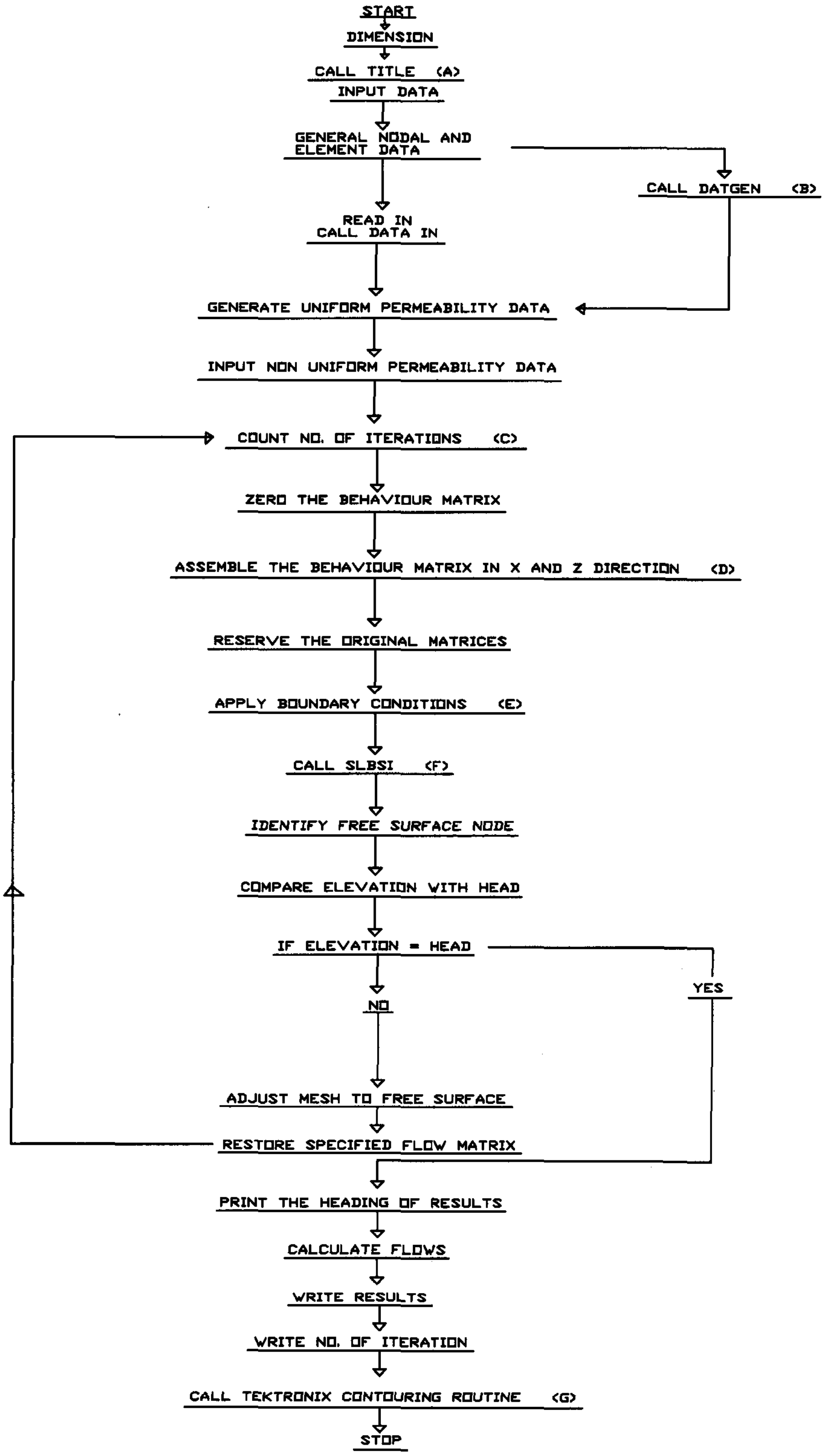
Title writing subroutine

(ii) Call datgen

This automatic data generating subprogram consists of basic algorithms which generate coordinates of the nodes and nodal connection numbers.

(iii) Count no of iteration

Free surface water line (pheratic surface) is required to be identified by several trials. The trials are carried out by means of finding the identical points where



z-coordinates and the head (i.e. constant pressure $\varphi + k_z$) are equal. Normally, five to seven trials were sufficient to find a compatible location of the phreatic surface in the mesh system of the program.

(iv) Assembling the behaviour matrix

The behaviour matrix is assembled by satisfying the equilibrium and compatibility conditions along the interconnecting boundaries in X and Z-directions.

(v) Applying boundary conditions

See Chapter3 for the boundary conditions.

(vi) Call slbsi

This subprogram is to solve the matrix equations by applying the Gauss elimination method for symmetric bounded matrixes. This program was adopted from the program written by Brebia and Ferrante (1978). The original matrix has to be reserved in order to avoid destruction during the calculation process of the Gauss elimination.

(vii) Call tektronix contouring

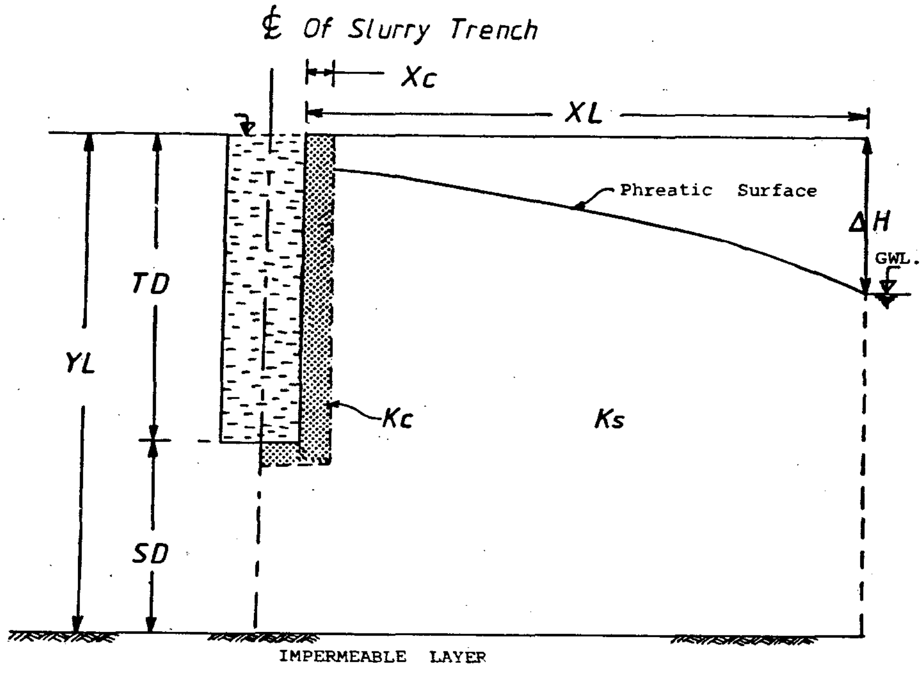
The contouring routine in this program was successfully carried out by the GINO and DIMFILM graphic accessories. Equipotential contours are drawn in the filter cake and the ground so as to identify the phreatic surface (free surface flow line) in the slurry trench system. The contouring map in the filter cake zone was designed to magnify the actual thickness of the cake a hundred times in order to be able to visualise the pressure drop through the cake medium.

5. Results and Discussion

The finite element program to obtain a phreatic surface was based on the following input data. Description of symbols for a slurry trench system is shown in Fig. 1.

(i) Length of-direction boundary (XL) = 20m

Depth of trench (TD) = 10m



TD = Trench Depth .
SD = Soil Depth from the bottom of Trench to the Impermeable Layer.
YL = Depth from Ground Surface to Impermeable Layer.
XL = Distance between Filter Cake/Soil Interface and a point where the Phreatic Surface meet Ground Water Level.
Xc = Thickness of Filter Cake.
Kc = Permeability of Filter Cake.
Ks = Permeability of Soil.
GWL. = Ground Water Level.
ΔH = Hydraulic Head Difference between Slurry Level and Ground Water Level.
γ_{SL} = Slurry Density.

Fig. 1. Description of symbols for a slurry trench system

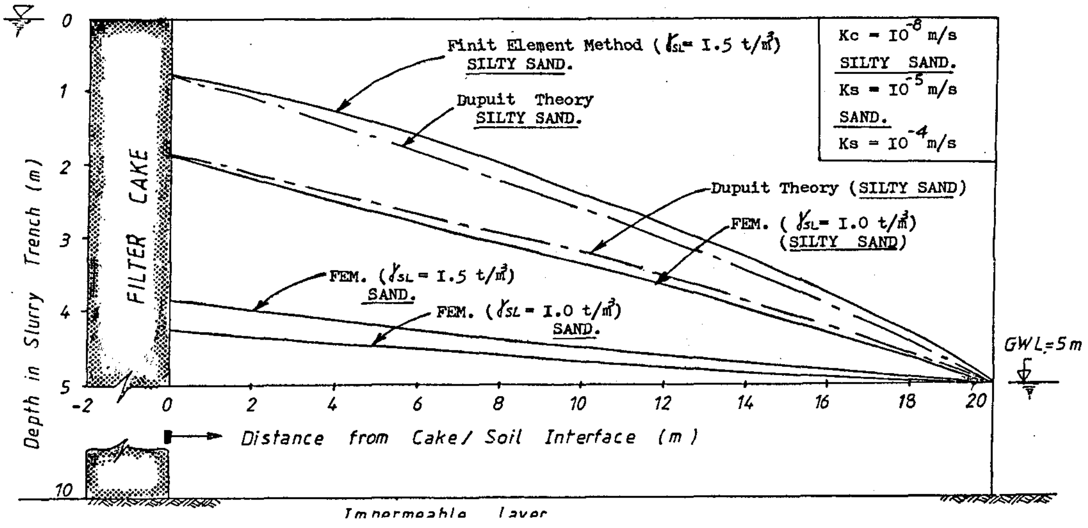


Fig. 2. Comparision of phreatic surface profile by finite element method with dupuit theory

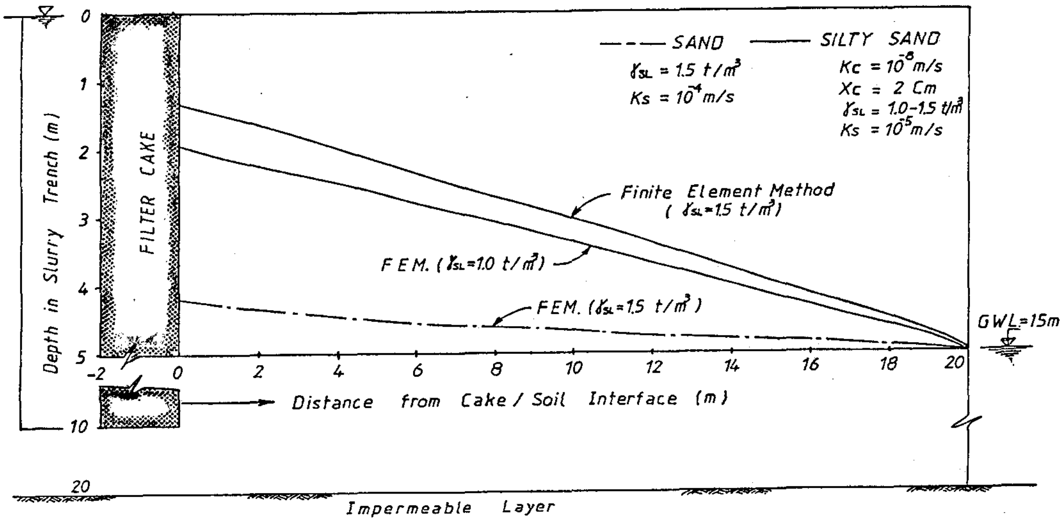


Fig. 3. Phreatic surface profiles by finite element method for various ground conditions

(ii) Filter cake permeability (K_C) = 10^{-8} m/sec

Filter cake thickness (X_C) = 20mm

(iii) Ground soil permeability (K_S) = 10^{-4} m/sec (for sand)

Ground soil permeability = 10^{-5} m/sec (for silty sand)

(iv) Slurry density (K_{SL}) = 1.0 t/m^3 to 1.5 t/m^3

The comparison of the phesatic surface was made only in the ground soil zone as the Dupuit theory can not predict head drop in the filter zone and the ground soil zone together.

Dupuit theory : $hx^2 = (H^2 - h^2)\ X/L + H^2$

This theory gives a paraboilc shape for the phreatic surface.

5.1 Deep Trench to Depth of Impermeable Layer (YL=TD)

Fig. 2. shows the phreatic surface drawn by the computer method for slurry densities of 1.0 t/m^3 and 1.5 t/m^3 in sand ground. Both methods are in good agreement in sandy soil, although the surface profile by the Finite Element Method (FEM) shows some sag which may be due to the rapid dissipation of pore water pressure in the sand ground and the slurry density which is greater than 1.0 t/m^3.

The phreatic surface obtained by the FEM in silty sand, in Fig. 3. has slightly greater curvature than that of Dupuit theory for a slurry density of 1.5 t/m^3.

A considerable build up of porewater pressure in the soil mass may occur as can be seen in Fig. 4 for various stages of the trench excavation. This raised water table, or porewater pressure, behind the filter cake may reduce the effective hydrostatic pressure of slurry which is exerted against the wall, and could lead to a reduction in the stability of the slurry trench system.

In the contour plotting subprogram, the actual thickness of filter cake was multiplied by 100 times for clarity in the plot.

Fig. 5. demonstrates the relationship between head loss through the filter cake and ground conditions. The graph shows that the head loss through the cake in sand was always above 80% regardless of the trench geometry and cake permeability (in the rang of 10^{-8} to 10^{-9} m/s). In silty sand and silty soil, the head loss varied widely from 35% to 95% and 2% to 62% respectively depending on the trench geometry and the cake permeability. A non-dimensional design chart was prepared in order to predict

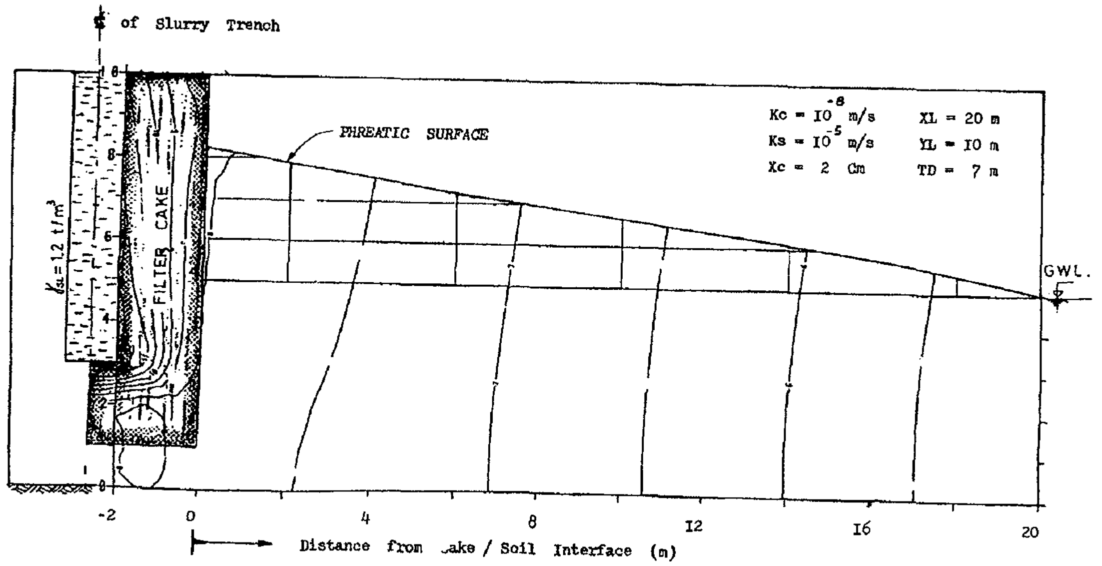


Fig. 4. Fluid loss through filter cake for silty sand

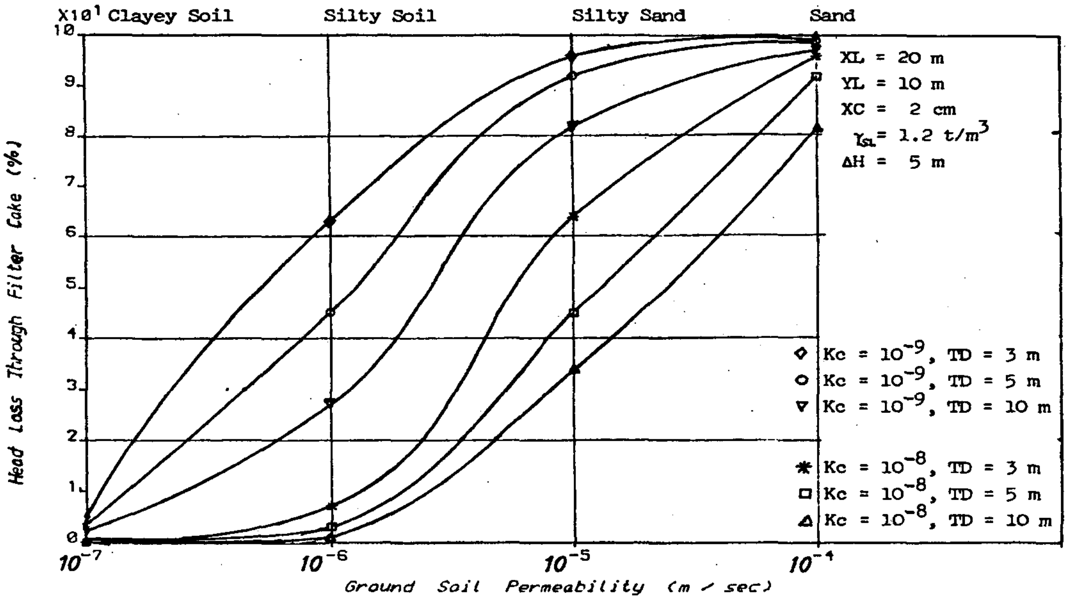


Fig. 5. Relationship between head loss through filter cake and ground soil conditions

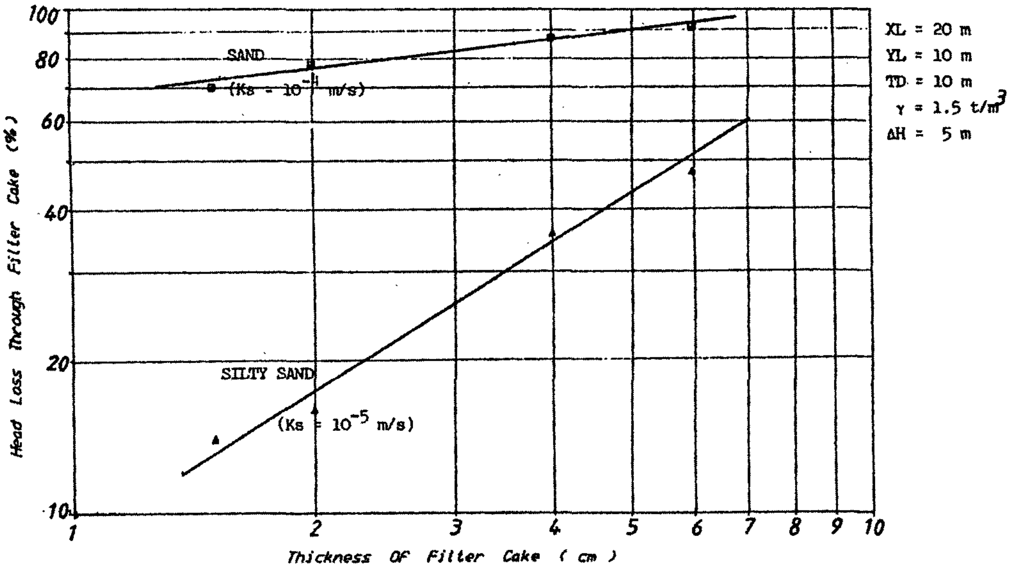


Fig. 6. Head loss across filter cake for various thickness of filter cakes

the efficiency of hydrostatic thrust on the trench wall via the filter cake under various site conditions but this refers to a fixed cake thickness.

The relationship between thickness of filter cake and head loss through the cake in Fig. 6. shows a linearity in log-log scale graph for both sand silty sand grounds. The percentage of head loss through the cake in sand varied from 78% to 92% as the cake thickness increased from 20mm to 100mm, whereas in silty sand ground is influenced more than the sand soil by the thickness of filter cake.

Fig. 7. illustrates the effect of slurry density and ground water level on the porewater pressure in the soil mass behind the filter cake. When trench with depth of 10m was filled with slurry of density 1.03t/m^3, the raised phreatic surface in sand was 1.7m above the original ground water level (0. GWL) for the GWL = 2m case, 0.7m above the 0. GWL for the GWL = 5m and 0.4m above the 0. GWL for the GWL = 7m. In silty sand, the raised porewater level above the original ground water level becomes considerably greater, 5.5m for the GWL = 2m, 3.2m for the GWL = 5m and 1.5m for the GWL = 7m.

Two extreme slurry densities and filter cake thicknesses were also examined in Fig. 7. The head loss through the filter cake in the first model, a slurry of density 1.03 t/m^3 with 20mm thick filter cake, exhibited a very similar result when compared with the second model, a slurry of density 1.5 t/m^3 with 40mm thick filter cake. The most significant factors effecting the slurry level in a trench were found to be the properties of filter cake, slurry density and the ground condition.

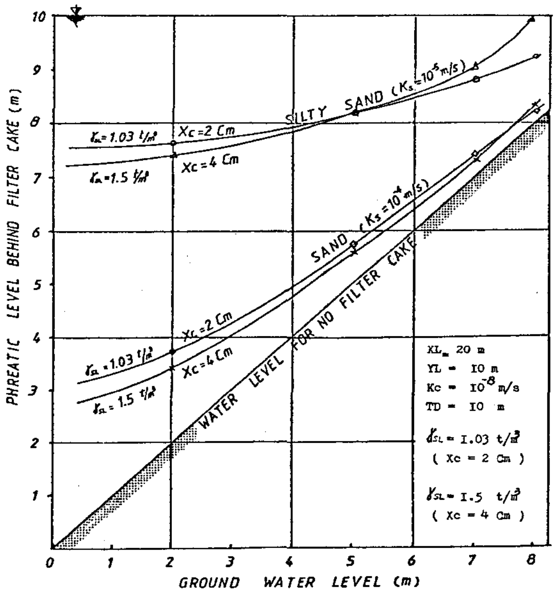


Fig. 7. Effect of slurry density and ground water level on phreatic level behind filter cake

6. Summary and Closure

Effects of fluid loss to the various formation ground were examined by means of the FEM technique. For a given trench geometry, the magnitude of fluid loss and build-up of porewater pressure behind the filter cake were evaluated so as to examine the significance of filter cake under various ground conditions.

In sandy soil, increase in porewater pressure was insignificant due to its rapid dissipation, although the quantity of fluid loss was rather high. The most significant build up of porewater pressure adjacent to the trench was found in the silty sand where the excess porewater pressure might help to mobilize a slip plane or soften the soil along the trench wall.

In computation of fluid loss, no allowance was made for the rapid fluid loss which occurs as filter cakes form.

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