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The Fluid Loss and Sealing Mechanisms in Slurry Trench Conditions (I) : A Large Scale Test and Design Procedure

Slurry wall 공법에서 안정액의 역할 (I) : 대형모형실험과 설계절차

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요 지

안정액(bentonite slurry)을 이용한 지하연속벽의 건설은 굴착된 trench 내에서 안정액이 침투케익과 표면케익을 포함한 불투수막을 형성함으로서 trench 의 안정성을 유지할 수가 있다. 그러므로 구조용 지하연속벽 건설이나 폐기물 매립장의 차수용 연속벽 건설시 지반조건 및 주변여건의 변화에 의하여 여러 가지 문제가 발생 될 수 있다. 본 논문은 안정액 유출과 불투수케익 형성과정을 대형실험으로 모델링하여 그 결과가 slurry trench 안정성에 미치는 영향을 평가하고, 현장조건에 적합한 설계절차를 제시하였다.

Abstract

Bentonite slurries in a slurry wall construction must fulfill a stabilizing function by forming impermeable membrane (surface cake and penetrated cake) on the excavated soil faces. Thus problems are occurring in practice for the construction of diaphram walls and cut-off walls with a low permeability for wastes disposal areas in some deep excavations or different grounds. In this paper, the fundamental mechanics of fluid loss and filter cake formation in various soil beds are investigated using large scale laboratory apparatus. The sealing efficiency of filter cake from the large scale tests and the significance of fluid loss in a slurry trench are utilized for practical situation as a recommended design procedure.

Keywords : Design procedure, Filter cake, Large scale test, Slurry trench

1. Introduction

The supporting action and the stabilizing effect of slurries are widely understood with introduction of bentonite and its measurement tool of the stormer viscometer in 1930.

The application of slurry trench system may be divided into two main fields. The most extensive area would be the construction of diaphragm walls providing the permanent basement structures for building substructure, subways, sewage works, bridge foundations parking, shafts, and waterfront facilities.

Also the other application of stabilizing slurries have been used for the construction of cut-off walls for the improper land disposal of wastes.

The low permeability cut-off or slurry wall, has been used as part of the remedial effects at both hazardous and solid waste disposal sites (EPA).

The control techniques for the slurry properties in civil and environmental engineering have been adapted

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from the standard specification employed in the oil well drilling industry, although certain requirements are not relevant. Therefore, the standard test procedure and the standard equipment for the measurement of fluid loss of a slurry would be examined.

Elson(1968) carried out model tests in sand and suggested that the hydrostatic pressure of slurry on the filter cake, an impervious membrane, accounts for 75% to 90% of total stabilizing force which is required for the stability of trench walls.

Therefore, the properties of the filter cake and the fluid loss mechanism of slurries must be understood before a complete analysis of trench wall stability and cut-off assessment can be made.

Effects of fluid loss and change of pore water pressure to various ground conditions were examined by means of the finite element technique.

The large scale fluid loss test to simulate slurry trench conditions provided a considerable insight into the formation mechanism of surface and penetrated cakes in various soil conditions.

The permeability (K_{tc}) and the thickness (X_{tc}) of filter cake have been presented by introducing the total cake transmissivity (T_{tc}) which can easily interpret the sealing mechanism of slurries by means of the time dependent parameters (i.e. $T_{tc}=K_{tc}/X_{tc}$).

The "T" values of filter cake obtained from laboratory test may be incorporated into a finite element computer program in order to provide design procedure of fluid losses and sealing performance in the slurry trench system.

2. Theoretical Studies on the Formation of Filter Cakes in Slurry Trench

The results of experimental work in sand have shown that the formation mechanism for filter cakes consists of two different stages. The first stage is by deep filtration to form a penetrated cake, as the viscous slurry flows through the soil pores or capillaries. The second stage is the formation of a surface cake controlled by the filtration mechanism, once further penetration of the slurry has been stopped by the gel (or shear) strength. In a cohesive soil, there will be no penetrated cake and the surface cake will begin to form almost immediately on the soil/slurry interface (though at very slow rate).

The fluid loss (or sealing) property of slurries in practice is measured and controlled by the standard API test which is based on the formation of cake on a filter paper under a pressure of 10 psi. The relevance of the test to slurry trench systems will be critically examined in the following sections.

The following theoretical studies were carried out to analyze the penetration (deep filtration) mechanism and surface cake formation (filtration of slurries subjected to applied pressures).

2.1 The Formation of Penetrated Cake

The rheological properties of clay slurries can be modelled by the laminar flow of Bingham plastics (Fig. 1). Under static conditions, the clay particles in the suspension form a card house structure by electro-chemical bonding forces. Thus slurries possess yield strength and thixotropic characteristic as the card house structure may be broken down by shear but reform when the slurry is left quiescent.

Jefferis (1972) developed the eqn.(1) by using carman's approach to calculate the critical hydraulic gradient required to displace a slurry from a gravel. The derivation takes into account the tortuosity of the interconnected pores as an extra length of equivalent straight tubes. Thus, the actual length becomes l/cos θ for an inclined pore tube of angle θ.

$$i=\frac{6}{\cos\theta}\frac{\tau}{D\cdot\gamma}\frac{(1-n)}{n}+\frac{\gamma'}{\gamma} \quad (1)$$

where, τ = gel strength of slurry
γ = slurry density
$\gamma' = \gamma - \gamma_w$, effective weight of slurry
D = spheres of diameter, D_{20} size
n = porosity

In the gravel ground, the gel strength (τ) was assumed to be a constant multiple (m) of the 10 min. gel strength.

$$i=\frac{6}{\cos\theta}m\frac{\tau}{D\cdot\gamma}\frac{(1-n)}{n}+\frac{\gamma'}{\gamma} \quad (2)$$

The penetrated depth of slurry ($\triangle l$) in sand also can be evaluated from eqn. (1) (assuming the horizontal movement only, $\gamma'/\gamma = 0$), $\triangle P$ is pressure difference.

$$\Delta l = \frac{\cos\theta}{6}\frac{\Delta P\cdot D\cdot r}{\tau}\frac{n}{(1-n)} = \frac{\Delta P\cdot D\cdot r}{9\tau}\frac{n}{(1-n)} \quad (3)$$

Typical values of θ in granular medium are in the range of 48° to 50° (Carman, 1938), thus cos θ /6 = 1/9. τ is now the gel strength during penetration.

2.2 The Formation of Surface Cake

The formation of a surface cake occurs on the slurry soil interface only when the rheological penetration of the slurry into the soil pores has ceased (save for any coarse material in the slurry which is too large to penetrate the soil). In soils of low permeability such as silty or clayey soils, surface cake formation will start immediately without any deep filtration.

Therefore, surface cake formation is analogous to general filtration in that the sealing performance of the filter cake depends on the initial permeability of the filter medium (soil permeability), the quality of slurry (concentration and shear strength) and the filtration pressure.

There are many theories representing the filtration mechanism of clay suspension. The most important of all in slurry trench construction was the following equation derived from the filter-loss tests using the standard Baroid filter press (API).

$$Q = C\cdot A\cdot\sqrt{t} \quad (4)$$

where, Q : fluid loss
A : area
C : constant
t : time

This equation indicates that the filter loss (Q/A) is proportional to square root of time (t). The constant (C) can be found from the slope of Q versus $\sqrt{t}$ graph.

Thus, the filter loss (Q_2) at time (t_2) can be estimated.

$$Q_2 = Q_1\frac{\sqrt{t_2}}{\sqrt{t_1}} \quad (\text{ if "C" = Constant })$$

Differentiating eqn. (4),

$$\frac{dQ}{dt} = \text{q (rate of flow)} = \frac{1}{2}\cdot C\cdot A\cdot t^{-1/2} \quad (5)$$

From Darcy's law,

$$q = K\cdot\frac{\Delta P}{X_c}\cdot A \text{ or } Q = K\cdot\frac{\Delta P}{X_c}\cdot A\cdot t \quad (6)$$

where X_C = thickness of surface cake.

By combining eqn. (5) with Darcy's Law,

$$t^{1/2} = \frac{1}{2}\frac{C\cdot X_C}{K\cdot\Delta P} \quad (7)$$

where, K : permeability

Thus, substituting $t^{1/2}$ from (7), (6) becomes,

$$Q = \frac{A\cdot C^2}{4}\frac{X_C}{K\cdot\Delta P} \quad (8)$$

Eqn. (8) expresses the following relationships.

(1) The thickness of surface cake (X_C) is directly proportional to the fluid loss (Q). This implies that the more impermeable the soil medium, the thinner the surface cake since the fluid loss in impermeable soil will be small.

(2) The sealing coefficient (i.e. cake transmissivity = T, K/X_C, flow rate per unit area per unit pressure) is a function of time independent coefficients, C, Q and P.

$$\frac{K}{X_C} = \frac{A\cdot C^2}{4Q\cdot\Delta P} \quad (9)$$

Eqn. (9) has practical importance in relating the results from the standard Baroid filter press tests to the sealing behaviour of a slurry under trench conditions since the filtration mechanism in both cases should be identical for the same K/X_C values.

Eqn. (8) shows that the thickness of surface cake (X_C) is proportional to the fluid loss (Q).

If X_C is substituted in eqn. (4),

$$X_C \propto C \cdot A \cdot \sqrt{t} \qquad (10)$$

Eqn. (10) implies that the thickness of surface cake (X_C) is proportional to the square root of the time (t).

3. The Apparatus for the Large Scale Fluid Loss Test

The large scale fluid loss apparatus was designed to meet the following requirements.

(1) The slurry chamber and the soil chamber should be water tight under the applied pressure.

(2) It is possible to compact the soil medium in order to avoid any large deformations during a test.

(3) It is possible to de-air the soil medium and the pressure measuring system.

(4) No initial penetration of slurry into the soil bed should be permitted when the slurry is introduced into the chamber prior to application of the pressure.

(5) Constant pressure is applied to the slurry chamber by compressed air. This has considerable advantages in transmitting the pressure compared with compressed water or compressed slurry. Water may produce dilution effects at the slurry boundaries. Slurry could block the pipes due to its shear strength (or at least cause significant pressure losses).

(6) The apparatus should be equipped with measuring and recording devices for the following properties.
   i) Fluid loss (rate of penetration and rate of filtration)
   ii) Porewater pressures in the soil medium.
   iii) Thickness and permeability of filter cakes.

3.1 The Perspex Cell

The cell was made of 230mm dia x 820mm length x 7mm wall thickness perspex tube which was designed to incorporate the slurry chamber, the soil chamber and a filter layer at the bottom of the tube. The top perspex plate which was 18mm thick has two holes in it: one was used to supply the constant air pressure to the slurry chamber, and the other was to release the air at the end of the test.

Seven holes were drilled through the bottom plate, six holes for piezometers and a central hole for the fluid loss outlet.

3.2 Application of Pressure and Filtrate Measurement

The constant air pressure supply to the slurry chamber was provided by an air compressor via an air reglator. A metal grid plate with a 30mm thick filter layer was placed at the fluid loss outlet to prevent the soil particles from blocking the outlet tube. The outlet tube was connected to the fluid loss measuring cylinders.

3.3 Porewater Pressure Measuring and Recording Unit

Six 6mm diameter copper tubes fitted with sintered brass end plugs were installed at various depths in the slurry and soil chambers. The excess porewater pressure was transmitted through these copper tubes to the pressure tansducer.

The "T" shape plastic tube at the end of each of the copper tubes was designed to release any trapped air in the system and to accommodate the pressure transducers. The electrical outputs from the pressure transducers were connected to the chart recorders.

The pressure transducers employed in the experimental work were of a silicon chip with integral sensing diaphragm type. Two different pressure ranges of transducers supplied by the RS Component Ltd. were used, 0-15 psi (105 KN/m^2) and 0-30 psi (210 KN/m^2) with an over pressure capacity of 45 psi and 60 psi, respectively.

The main features of these transducers were low null shift (zero at normal range), high sensitivity (6.67 mv/psi for 0-15 psi type and 2.63 mv/psi for 0-30 psi type), linear output proportional to pressure(maximum error ± 0.65% of 100 mv, full scale output), and good temperature compensation.

To confirm the performance of the transducers they were recalibrated at the beginning of each test.

3.4 General Layout and Assembly of the Apparatus

The general layout of the experimental work for the large scale fluid loss tests is shown in Fig. 1. Measurements were started when the air pressure was applied to the slurry chamber. The pressurized slurry creates a pressure gradient which becomes increasingly non-linear and dynamic throughout the soil bed with time in accordance with the penetration and filtration behaviour of the slurry. The pressure gradient across the sample is measured and recorded by means of the pressure transducers and the chart recorders. The fluid loss from the slurry (sealing performance)is measured with the measuring cylinders.

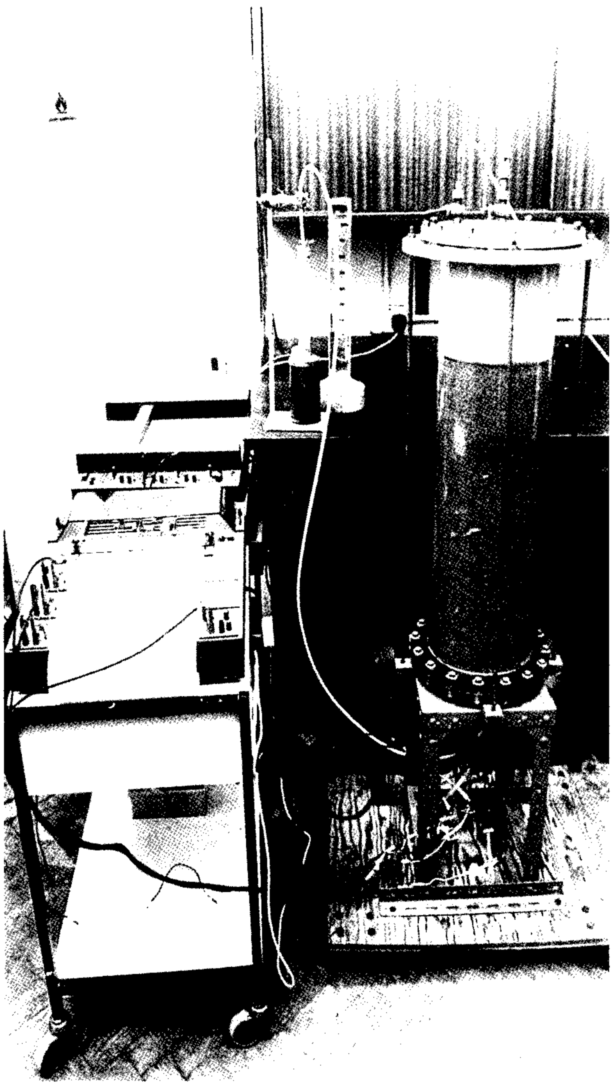


Fig. 1. Configuration of the large scale fluid loss test

Table 1. Properties of the sands

Descriptions	Medium Sand	Coarse Sand
Specific Gravity	2.65	2.65
Specific Surface Area	5.04(m^2/kg)	2.81(m^2/kg)
Size Range in mm	0.3−0.5	0.6−1.0
Void Ratio after Compaction	0.65	0.59
Porosity after Compaction	0.39	0.37
Permeability after Compaction	1.8×10^{-2} ($cm/$ sec)	4×10^{-2} ($cm/$ sec)

4. The Test Programme and Procedure

4.1 The Test Programme

The main purpose of the experimental work was to investigate the physical mechanisms involved in the formation of surface cake and penetrated cake under simulated slurry trench conditions where the slurries could be subjected to a variety of pressures and soil conditions.

The fluid loss of the slurries and variation of porewater pressure along the length of the main cell were measured and recorded with time during the test. It was expected that the fluid loss characteristics of slurries (i.e. sealing behaviour) would be functions of the initial concentration of the slurries, the type of soil, the applied pressure and time. Therefore, the following variables were chosen after considering the practicality and accuracy of the experimental work.

4.1.1 Initial Concentration of Slurries
3%, 5% and 7% bentonite slurries

4.1.2 Soil Type
Two types of sand were used in the test: Leighton

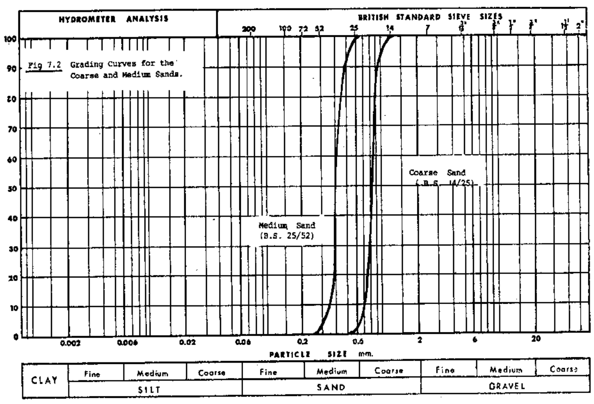
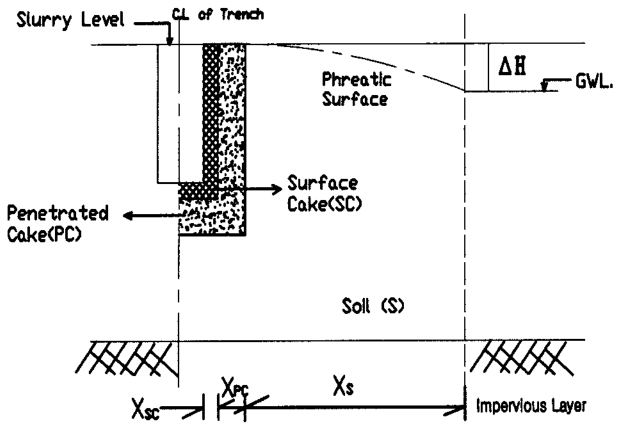


Fig. 2. The grading curves for these sands



	Total cake (TC)		
	Surface cake (SC)	Penetrated cake(PC)	Soil (S)
K (Permeability)	K_{SC}	K_{PC}	K_S
X (Thickness)	X_{SC}	X_{PC}	X_S
⊿H (Head Loss)	h_{SC}	h_{PC}	h_S
T= K/X	$T_{SC}=K_{SC}/X_{SC}$	$T_{PC}=K_{PC}/X_{PC}$	$T_S=K_S/X_S$
	$T_{tc}=K_{tc}/X_{tcS}$		

Fig. 3. Simplified fluid loss model

Bussard rounded medium and coarse sands. The grading curves for these sands are shown in Fig. 2.

Both sands were fairly uniformly graded, between 0.3mm -0.5mm BS sieve size for the medium sand, and between 0.6mm -1.0mm size for the coarse sand.

The equivalent of silty sand soils were produced by penetration of slurries into the sand bed. The permeabilities of these "silty" soils varied from 2.0 x $10^{-5} cm/\sec$ to 5.0 x $10^{-6} cm/\sec$ depending on the properties of slurry and the applied pressure.

4.1.3 Applied Pressure

The pressures employed in the tests were 2 psi (14 KN/m^2), 5 psi (35 KN/m^2) and 10 psi (70 KN/m^2). Although in practice, the applied pressure may exceed 10 psi in dry grounds, the stability of trench walls in such grounds is unlikely to suffer from the fluid loss problems, once the theological blocking of soil pores has been achieved.

4.1.4 Time (Duration of the Test)

The construction period for slurry trench walls excavated with bentonite or other types of clay slurries is relatively short, perhaps one or a few days. Thus, test periods of a minimum 30 mins. to a maximum of 7 days were chosen though the experimental work reveals that the most significant amount of fluid loss occurs at the initial stage which could last 30 mins to 2 hrs until filter cakes have formed.

5. The Results of Large Scale Test and Their Application

5.1 Filter Cake Transmissivity ($T_{tc}=K_{tc}/X_{tc}$)

Thus, introduction of total filter cake transmissity (T_{tc}) is of special interest in interpreting the sealing mechanisms of slurries as it links the time dependent properties (K_{tc}) and (X_{tc}) together which is shown in the following eq.

$$q = K \cdot A \cdot \frac{\triangle H}{X}$$

$$\therefore \ \frac{K}{X} = \frac{q}{A \cdot \triangle H} = T \qquad (11)$$

The following simplified fluid loss model as shown in Fig. 3. was developed to formulate the overall sealing performance of the filter cakes in slurry trenches constructed in various ground conditions.

From eqn. (11),

$$\triangle H = \frac{q}{A} \ \frac{X}{K}, \text{ But } \triangle H = \triangle h_{sc} + \triangle h_{pc} + \triangle h_{s} \qquad (12)$$

Therefore,

$$\triangle H = \frac{q}{A}\left(\frac{X}{K}\right) = \triangle h_{sc} + \triangle h_{pc} + \triangle h_s$$

$$= \frac{q}{A}\left(\frac{X_{sc}}{K_{sc}} + \frac{X_{pc}}{K_{pc}} + \frac{X_s}{K_s}\right) \qquad (13)$$

It can be seen from eqn. (13) that the total filter cake transmissivity (T_{tc})is directly a function of rate of flow (q) and head loss (△H) for a given area.

Therefore, the individual filter cake transmissivities may be calculated by measuring the rate of flow and the head loss through each medium.

For surface cake : $T_{sc}=(\frac{K_{sc}}{X_{sc}})=\frac{q}{A\cdot\triangle h_{sc}}$ (14)

For penetrated cake : $T_{pc}=(\frac{K_{pc}}{X_{pc}})=\frac{q}{A\cdot\triangle h_{pc}}$ (15)

For soil : $T_{s}=(\frac{K_{s}}{X_{s}})=\frac{q}{A\cdot\triangle h_{s}}$ (16)

Now the overall (filter cake and soil) transmissivity (T) can be evaluated by substituting the individual cake transmissivites into eqn. (13)

$$T=\frac{1}{(\frac{1}{T_{sc}}+\frac{1}{T_{pc}}+\frac{1}{T_{s}})} \quad (17)$$

Also the total filter cake transmissivity (T_{tc}) can be defined.

$$T_{tc}=\frac{1}{(\frac{1}{T_{sc}}+\frac{1}{T_{pc}})} \quad (18)$$

5.2 A new Approach for Penetrated Cake

The experimental measurements of the penetrated depth from the large scale tests were made by direct observation through the perspex cell, by the volume of initial slurry loss and by dismantling the cell.

A comparison between the test results and the various analytical methods including a new approach by author has been provided.

The new equation was derived from the shear resistance between the viscous slurry and the solid surface based on Konzeny's method.

The depth of penetrated cake (△l) becomes,

$$\triangle l = \triangle\frac{P}{\tau}(\frac{Vs}{S})\frac{n}{1-n} \quad (19)$$

But Kozeny's Eqn. gives $d = \frac{4\cdot Vs}{S}\frac{n}{1-n}$.

Eqn. (19) can be simplified by the above Kozeny's Eqn.,

$$\triangle l=\frac{\triangle P\cdot d_p}{4\cdot\tau} \quad (20)$$

where, △l = penetrated depth of slurry,
J = shear (gel) strength of slurry,
△p = applied pressure,
d_p = average pore diameter,
Vs = volume of solid,
n = porosity of the medium,
S = total surface area of the solid.

The average pore diameter(d_p) in a medium with the average particle diameter (D) was estimated from the average particle size (D_{50}) in the grading curve.

$$Area\ of\ a\ pore = D^2 - \frac{\pi D^2}{4} = 0.25D^2 \quad (21)$$

$$Average\ pore\ dia.\ (d_p) = \frac{0.215\pi D^2}{4} \quad (22)$$

The relationship between the average pore diameter (d_p) and the average particle diameter(D_{50}) in the grading curve becomes,

$$d_p=0.523D$$

If D is considered to be D_{50}, then d_p=0.523 D_{50}.

Therefore, the average pore diameter (d_p) for the two types of sand used in the large scale tests can be evaluated from the above equation.

For medium sand D_{50} = 0.41 mm, thus d_p=0.21mm
For coarse sand D_{50} = 0.81 mm, thus d_p=0.42mm

The depth of slurry penetration would be obtained by substituting the average pore diameter(d_p) into eqn. (20). The comparison of this method and the experimental result is shown in table 1.

Evaluation of the penetrated depth by the fluid loss method was based on an assumption that the initial fluid loss found from Fig. 4. is to fill the soil pores prior to formation of surface cake.

Table 2. Depth of slurry penetration

SOILS	Description	Initial Loss	Approximate Time for Cake Formation (min)	Depth of Slurry Penetration (Cm)				REMARKS
				Fluid Loss Method	Jefferis Eqn	Author's Eqn	Test Results	
COURSE SAND	3% - 5 psi	No Rheological Blocking	-	-	-	-	-	
	5% - 5 psi	5.5/5 Mins	17	15	9	16	20	
	5% - 10 psi	9.8/10 Mins	25	27	18	33	40	
	7% - 10 psi	4.3/5 Mins	20	12	10	18	20	
MEDIUM SAND	3% - 5 psi	6.2/15 Mins	30	16	17	23	18	
	3% - 10 psi	12/20 Mins	60	32	34	46	35	
	5% - 5 psi	2.0/5 Mins	10	5	5.5	8	6	
	5% - 10 psi	4.0/9 Mins	30	10	11	16	12	
	7% - 5 psi	0.7/1 Mins	2	2	2.6	4	2.5	
	7% - 10 psi	1.6/3 Mins	3	4	5.2	8	5.0	

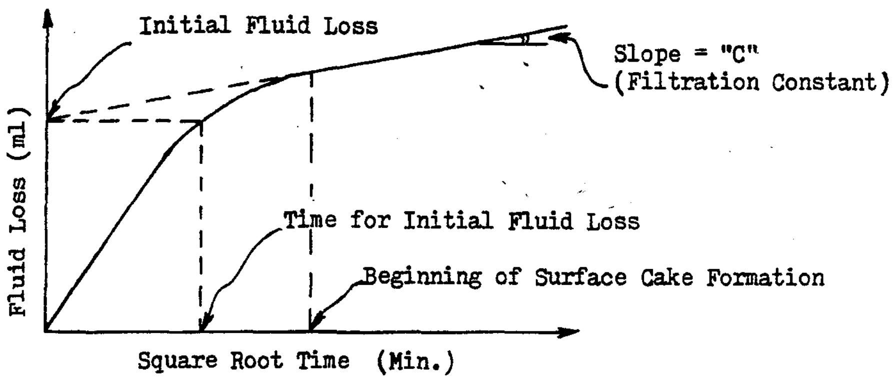


Fig. 4. Fluid loss versus sqare root time

5.3 Comparison of Test Results.

Table 2. shows a comparison of the depth of the slurry penetration between the experimental results and the theoretical prediction in sand.

Jefferis' (1972) equation which is based on Carman's theory gives good results for the medium sand. However, the method underestimates the penetrated depth in coarse sand. The initial fluid loss technique as shown above in Fig. 4 seems to provide reliable results, but the values obtained in coarse sand are still rather low.

The author's approach to evaluating the penetrated depth slightly overestimates in medium sand and underestimates in coarse sand. The overall prediction by this method was quite satisfactory for the particular sands tested.

The inconsistent results of the various methods imply that the shear strength of slurries in both sand medium may require some adjustment as they are subjected to different rate of shear strain when penetrating into the soil pores.

The constant gradient (C) which represents the formation of surface cake by means of a filtration mechanism depends on the properties of the slurry, the applied pressure and the nature of the soil pores (i.e. filter medium).

The fluid loss at any time can be evaluated from the fluid loss against square root time plot if the constant gradient (i.e. filtration constant; C) is known. The initial slurry loss into soil pores was obtained by extending the constant gradient back to the fluid loss axis.

Table 3. shows the filtration constant (C) obtained from the large scale tests and standard API tests in various soil mediums.

Table 3. Filtration constant "C"

Soil	Large Scale Test		Soil	Large Scale Test		Standard API Test
	Description	"C"(* 10^2) (cm/min$^{1/2}$)		Description	"C"(* 10^2) (cm/Min$^{1/2}$)	"C"(* 10^2) (cm/Min$^{1/2}$)
COARSE SAND	3% − 5 psi	30.0	MEDIUM SAND	3% − 5 psi	5.2	8.2 (100 psi)
	5% − 5 psi	13.0		3% − 10 psi	6.7	3.8 (10 psi)
	5% − 10 psi	15.0		5% − 5 psi	4.0	6.2 (100 psi)
	7% − 10psi	13.0		5% − 10psi	5.9	3.3 (10 psi)
SILTY SOIL	3% − 10psi	8.9		7% − 5 psi	3.1	5.8 (100 psi)
	5% − 10 psi (A)	5.6		7% − 10psi	4.3	2.6 (10 psi)
	5% − 10 psi (B)	5.0				

It should be noted that the silty soil was produced by penetrating bentonite into a sand. A true silt could behave slightly differently. Thus before drawing definitive conclusions for silt, further testing would be necessary.

5.4 Extrapolation of Laboratory Results

The filter cake transmissivity (T_{tc}) provides not only reliable input data to extrapolate the laboratory results to a slurry trench condition in the computer program, but also a way of obtaining the fluid loss design parameters from the simple standard Baroid testing.

The following "T" values obtained for 3%, 5% and 7% slurries indicate a consistent fluid loss behavior after one hour for medium sand and four hours for coarse sand. The initial fluid losses are not considered in evaluating "T" values.

The recommended design procedures which are based on the experimental results and the finite element computer analysis were introduced to assess fluid loss properties of slurries and to establish an analytical method of evaluating the porewater build up behind the filter cake in various slurry trench systems.

To assess the fluid loss properties of slurries involves the filtration constant (C) values from the fluid loss versus square root of time graph and a theoretical equation to calculate initial fluid loss of the depth of penetrated cake.

Estimation of fluid loss and its effect on slurry trench condition is important in developing an understanding about the sealing mechanisms of filter cakes together with the stability of the trench walls in various soil conditions. The properties of filter cakes ("T" values) from the laboratory test may be incorporated into a finite element computer program in order to examine the significance of the fluid losses in the slurry trench systems.

Table 4. The properties of filter cakes from the laboratory test

Apparatus	Filter Medium	Applied Pressure	Equations
Standard Filter Press	Filter Paper	10 psi 100 psi	$T = \mathrm{Exp}(-5.0)/\sqrt{t}$ $T = \mathrm{Exp}(-7.0)/\sqrt{t}$
Large Scale Test Rig	Medium Sand	5 − 10 psi	(After ihr of test) $T = \mathrm{Exp}(-6.0)/\sqrt{t}$
	Coarse sand	5 − 10 psi	(After 4hrs of test) $T = \mathrm{Exp}(-6.0)/\sqrt{t}$
	Silty sand	5 − 10 psi	$T = \mathrm{Exp}(-6.0)/t^{-0.4}$

6. Conclusion

A relatively simple equation to predict the depth of slurry penetration into the trench wall was introduced. The experimental results were found to be in good agreement with this suggested equation for medium and coarse sand.

Formation of surface cake was proportional to the square root of time (or the quantity of fluid loss) which is influenced by the quality of filter medium (soil condition) and applied pressure.

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