Steel Sheet Piling Studies

Recherches sur les palplanches en acier

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Summary

Studies were conducted to estimate the effectiveness of steel sheet piling as a cut-off wall placed through a pervious foundation of an earth dam. Equations derived for the flow of water through the interlocks of various types of piling embedded in river sand were used to estimate the seepage under the dam. Based on the conditions of the tests and on those assumed in the field, it was estimated that a steel sheet pile wall would be initially equivalent to 30 ft. (9 m) of upstream impervious blanket, for all interlocks loose, and to 300 ft. (90 m) of blanket for all interlocks slightly tight and compacted with sand. It was also assumed that the interlocks would be intact and not rusted, and that the ends of the piling would be sealed into impervious material. In time, rusting of the piling would increase its effectiveness as a seepage barrier, but it is not known if sufficient rusting would occur to warrant the cost of a steel sheet pile wall as compared to the cost of an upstream impervious blanket.

Sommaire

Des études ont été faites pour évaluer l'efficacité approximative d'un écran parafouille de palplanches exécuté à travers l'assise perméable d'un barrage en terre. Pour établir l'infiltration d'eau à travers les joints des palplanches les auteurs ont eu recours aux équations permettant de calculer l'écoulement total sous le barrage-réservoir. Se basant sur les essais et les conditions sur place, il semble que, au début, un rideau de palplanches est équivalent à un tapis imperméable d'environ 30 pieds (9 m) en amont du barrage, si les joints sont relâchés, et d'environ 300 pieds (90 m) si les joints sont serrés et bien bourrés de sable, à condition que les joints ne soient ni endommagés ni rouillés, et que les extrémités des palplanches soient scellées dans un matériau imperméable. Il est probable que les joints se rouilleraient à la longue, ce qui contribuerait à réduire l'écoulement. Cependant on ignore s'ils se rouilleraient au point de justifier le coût d'un écran de palplanches plutôt qu'un tapis imperméable en amont du barrage.

General

An investigation (x) was carried out to (see references) estimate the effectiveness of steel sheet piling as a cut-off wall placed through the pervious foundation of a proposed earth dam on a river in Saskatchewan, Canada. Experiments were conducted from which relationships were derived for flow through the interlocks of various types of piling. The experiments were conducted in tanks ranging from 10 inches in diameter and 15 inches in height, to 48 inches in diameter and 48 inches in height. The tanks were constructed such that various sections of piling could be sealed along their sides and ends, so that the flow occurred entirely through the interlocks. The tanks were filled with representative river sand having the following characteristics:

$$D_{10} = 0.15 \text{ mm}$$
$$D_{60} = 0.40 \text{ mm}$$
$$C_u = \text{Coefficient of uniformity} = \frac{D_{60}}{D_{10}} = 2.7$$

Dry Density = 95 lbs./cu.ft.

Tap water was used for the tests, and the desired pressures were obtained by the regulation of valves which controlled the flow of the water from a pressure tank.

The relationships derived were used in conjunction with *Darcy*'s equation for flow through a soil, to estimate the seepage under the proposed dam. It was also possible to compute the length of upstream impervious blanket which, when substituted for the sheet pile wall, would yield the same seepage as that obtained with the use of the piling.

It must be emphasized that the calculations which follow were based on the results obtained from the experiments and therefore apply only to the conditions assumed. For the tests, such factors as the stress in the piling, the area of the flow path through the interlocks, and the amount and permeability of the sand in the interlocks, could be approximated with some degree of reliability. For a sheet pile wall under a dam, these factors among others would be indeterminate. Therefore, the assumptions of field conditions which are presented contain a great degree of speculation. Unfortunately, very few measurements have been recorded to date on sheet piling in place under dams. It would appear, based on the tests that were conducted and on a few field measurements known to the writers, that a sheet pile wall, placed through a pervious foundation of a relatively high dam would not be as effective a seepage barrier as one would desire.

Equations

Darcy's equation for flow through a soil is:

$$q = kia \quad (1)$$

where:

q = flow through the soil
k = coefficient of permeability of the soil
i = hydraulic gradient through the soil
a = area of soil across which flow occurs.

Applying *Darcy*'s law to flow through a sheet pile interlock:

$$q = \frac{k_i (H_1 - H_2) a_i}{l_i} \quad (2)$$

where:

q = flow through interlock, cu.ft./sec.
k_i = coefficient of permeability of sand in interlock, ft./sec.
$(H_1 - H_2)$ = drop in head across interlock, ft.
a_i = wd (area of flow path through interlock) sq.ft.
  w = effective width of flow path through interlock, ft.
  d = depth (amount) of interlock considered, ft.
l_i = length of flow path through interlock, ft.

Equation (2) was rewritten in a more convenient form:

$$q = \frac{(H_1 - H_2) a}{y} \quad (3)$$

where:

a = Sd (area of piling represented by "d" amount of interlock), sq.ft.
  S = spacing of interlocks, ft.
  d = amount of interlock considered, ft.
y = coefficient (in seconds).

Note:

$$q = \frac{k_i (H_1 - H_2) wd}{l_i} = \frac{(H_1 - H_2) Sd}{y}$$

from which:

$$y = \frac{S}{w} \cdot \frac{l_i}{k_i}, \text{ seconds} \quad (4)$$

To determine the length of upstream impervious blanket that would be equivalent to the sheet pile wall, that is, the amount by which the average flow path through the sand must be lengthened to dissipate the same amount of pressure as the drop across the piling $(H_1 - H_2)$, without altering the flow, let:

$$Q = \frac{K(H_1 - H_2) A}{L_b} = \frac{(H_1 - H_2) A}{y}$$

from which:

Equivalent length of blanket, $L_b = ky$, ft. .. .. (5)

The flow through the sand foundation of a dam with sheet pile wall, can be determined by solving the following three equations simultaneously (see Fig. 1).

Equation for flow from upstream toe of dam to sheet piling:

$$Q = \frac{K(H - H_1) A}{L_1} \quad (6)$$

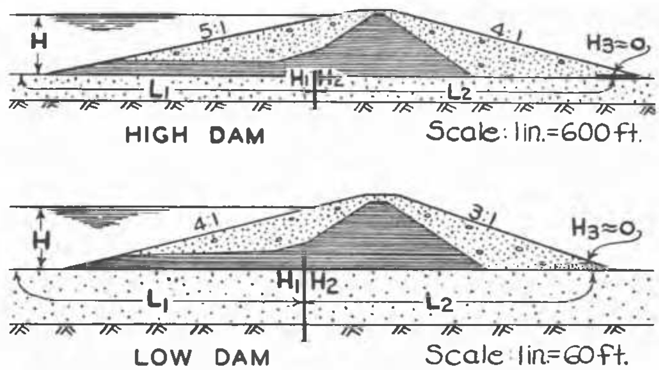

Fig. 1 Sketch of Dams
Diagramme des barrages

Equation for flow through piling:

$$Q = \frac{(H_1 - H_2) A}{y} \quad (7)$$

Equation for flow from sheet piling to downstream filter of dam:

$$Q = \frac{K(H_2 - H_3) A}{L_2} \quad (8)$$

The flow without the sheet pile wall would be:

$$Q = \frac{K(H - H_3) A}{L_1 + L_2} \quad (9)$$

where:

Q = flow, cu.ft./sec.
K = coefficient of permeability of sand in situ, ft./sec.
H = head of water in reservoir, ft.
H_1 = head at upstream face of piling, ft.
H_2 = head at downstream face of piling, ft.
H_3 = head at downstream filter, ft. (H_3 assumed approximately atmospheric and equal to zero)
A = cross-sectional area of foundation through which flow occurs, sq.ft.
L_1 = average length of flow paths from upstream toe of dam to piling, ft.
L_2 = average length of flow paths from piling to downstream filter, ft.

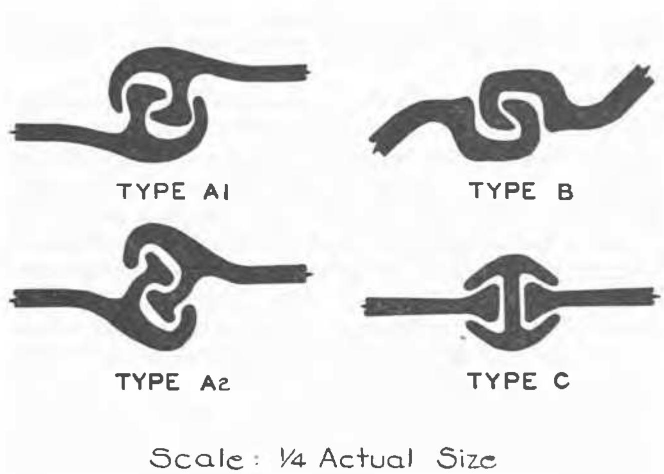

Fig. 2 Sketch of Interlocks
Diagramme des joints

Experimental Results

Eight tests were conducted on four types of sheet piling interlocks, illustrated in Fig. 2, to obtain Pressure-Flow relationships, from which were derived the coefficients "y", in the equation:

$$q = \frac{(H_1 - H_2)a}{y}$$

Table 1 Values of "y" for Initial Flow through Interlocks

Test	*Type of Piling*	"y" (*sec*)	*Remarks*
1	A_1	18.5×10^4	Interlocks tight[1]), manually compacted with sand
2	B	14.5×10^4	Interlocks tight, manually compacted with sand
3	C	8.0×10^4	Interlocks tight, manually compacted with sand
4	C	1.8×10^4	Interlocks loose, not manually filled with sand
5	C	1.4×10^4	Interlocks max. loose, not manually filled with sand
6	C	6.2×10^4	Interlocks hand-tight[2]), manually compacted with sand
7	C	3.6×10^4	Interlocks hand-tight, manually compacted with sand
8	A_2	4.4×10^4	Interlocks hand-tight, manually compacted with sand

Note: The degree of tightness of the interlocks could not be determined accurately. The *probable* tensile stress in the interlocks was:
[1]) "tight"—greater than 100 lbs./in. and less than 500 lbs./in.
[2]) "hand-tight"—less than 20 lbs./in.

Application to Field Conditions

Three points should be discussed before applying the equations to estimate seepage under a dam. These are the "tightness" of the interlocks, the amount of sand in the interlocks, and rusting of the interlocks.

Tightness of interlocks. The tests were carried out for interlocks ranging from a maximum loose condition to a state of tension probably not exceeding 500 lbs./in. of interlock. In actual practice, a sheet pile wall under a dam could be, in parts, under a tensile stress many times this amount. It conceivably could also be in compression in parts, while other parts may be in a loose state. The average overall condition is indeterminate.

Amount of sand in interlocks. As noted in Table I, some interlocks were manually filled with sand and compacted with a length of wire. Other interlocks were not specially filled or compacted. For the latter, the piling was placed in the tank, and the tank filled with sand and water. The amount of sand in the interlocks was the amount that washed in from the sides.

In actual practice, the amount of sand in the interlocks cannot be determined. If piling is driven into place, there likely would be sand in the interlocks. If piling is jetted into place, there is the possibility that a smaller amount of sand would enter or remain in the interlocks.

For some of the tests, the average permeability of the sand in the interlocks was estimated by measuring the interlocks and by applying *Darcy*'s equation. The average coefficients obtained were 0.02 to 0.03 ft./min. for the compacted interlocks, and 0.08 ft./min. for an interlock not specially filled. For an interlock with no sand at all, the permeability, assuming *Darcy*'s law to apply, was calculated to be in the neighbourhood of 1 to 3 ft./min. As a matter of interest, the horizontal permeability of this particular sand in situ, determined from field pumping tests, ranged from 0.10 to 0.14 ft./min., while its remolded permeability varied from 0.02 to 0.03 ft./min.

(Note: 1 cm/sec. is approximately equal to 2 ft./min.)

Rusting of the interlocks. Table I indicates flow coefficients that pertain to interlocks which were not rusted. In practice, rusting of the piling would increase its effectiveness as a seepage barrier, but the rate and amount of rusting that could occur under a dam is indeterminate, and would depend on various factors.

The results that follow pertain to two dams, each with a sheet pile wall with (i) interlocks loose, containing an amount of sand that is thought to be fairly representative of field conditions, and (ii) interlocks at a tightness in the neighbourhood of, say, 400 lbs./in., compacted with sand; the latter is probably representative of an interlock at a greater degree of tightness and containing a smaller amount of sand. All results represent non-rusted conditions. However, it was assumed in all cases that the entire flow would take place through undamaged interlocks, and that the ends of the piling would be sealed into impervious material.

Assume, for computation purposes, two earth dams, of the dimensions indicated in Fig. 1. Table 2 indicates the values assumed, and the corresponding results obtained by substituting in Equations (5) to (9).

Table 2 Field Assumptions and Results

	High Dam		*Low Dam*	
H (head of water), ft.	200		20	
L_1 (upstream toe to piling), ft.	1,000		100	
L_2 (piling to filter), ft.	1,000		100	
A (seepage area), sq.ft.	100,000		10,000	
K (coeff. of perm. of sand), ft./min.	0.12		0.12	
	Interlocks Loose	*Interlocks Tight*	*Interlocks Loose*	*Interlocks Tight*
"y" (piling coeff.), sec. $\times 10^{-4}$	1.5	15.0	1.5	15.0
$(H_1 - H_2)$, drop in head across piling, ft.	2.96	26.0	2.6	12.0
Total flow with piling, cu.ft./sec.	19.7	17.4	1.74	0.8
Total flow without piling, cu.ft./sec.	20.0	20.0	2.0	2.0
Reduction in flow using piling, %	1.5	13	13	60
Length of Blanket, equivalent to piling, ft.	30	300	30	300

Discussion

Based on the conditions under which the tests were conducted and on field conditions that were assumed, it was estimated that a sheet pile wall under a dam would be initially equivalent to some 30 feet of impervious blanket for *all* interlocks loose, and to some 300 feet for *all* interlocks slightly tight and well compacted with sand. It was also assumed that all interlocks would be intact and not rusted, and that the ends of the piling would be sealed into impervious material.

The actual field conditions under a dam are indeterminate. Unknown are such factors as tightness of the interlocks, amount of sand in the interlocks, airlocking of the sand and interlocks, rate and extent of rusting of the piling, extent of damaged or ruptured interlocks, and effectiveness of seal of piling into impervious material.

The design of the sheet piling interlocks is also a factor affecting its effectiveness. Piling with the tighter interlocks, longer length of path through the interlocks, and greater spacing of interlocks will be more effective as a seepage barrier.

Very few measurements have been taken on existing dams to estimate the effectiveness of steel sheet piling. Quite likely some have been conducted which are unknown to the writers. For one dam in the United States, an attempt was made to grout the bottom of the piling to the rock contact. It was found that the mortar rose rather freely through the interlocks, indicating that there was very little resistance in the interlocks. This was one specific case and it may not be representative of all sheet pile walls under dams. A point unknown to the writers is whether the piling was driven or jetted. For another dam in the United States, the piling was estimated, from piezometer readings, to be equivalent to some 500 to 600 feet of blanket, after being in place for over 15 years. For a comparatively low dam in Canada, built by P.F.R.A. about 10 years ago, the piling is estimated to be equivalent to some 600 feet also.

This report is not intended to appear prejudiced against the use of steel sheet piling under dams. It is based on the experiments conducted and on the limited data known to the writers. Actual conditions of piling under dams are so indeterminate that any estimate contains a great degree of speculation. The installation of numerous piezometers both immediately upstream and downstream of piling in place would yield valuable information regarding the drop in head across the piling. Additional piezometers in the pervious foundations would aid in determining the average hydraulic gradient through the foundation. With the above, one could estimate the effectiveness of the piling, in terms of equivalent length of blanket.

Reference

Steel Sheet Piling Studies (1951): P.F.R.A., Soil Mechanics and Materials Division, Saskatoon, Saskatchewan, Canada, December.