CHECKING COFFERDAMS FOR BRIDGE PIERS

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SYNOPSIS

Cofferdams are bottomless sheet-piling boxes in which excavation under water and pile driving are to be done, and concrete for the base of a pier placed The problem which is discussed in the paper is the determination of the depth of the sheet piling below the bottom of the excavation to prevent "blow in" of the soft soil material into the cofferdam Simple analytical and graphical solutions are given, and a large scale laboratory experiment is described

THE PROBLEM

In constructing bridges over large rivers flowing into the Atlantic, the piers are sometimes founded on piles driven to a resistance stratum which may be a compacted sand layer, or is more often, the underlying ledge rock (Fig. 1). The sand is generally covered with a thick layer of

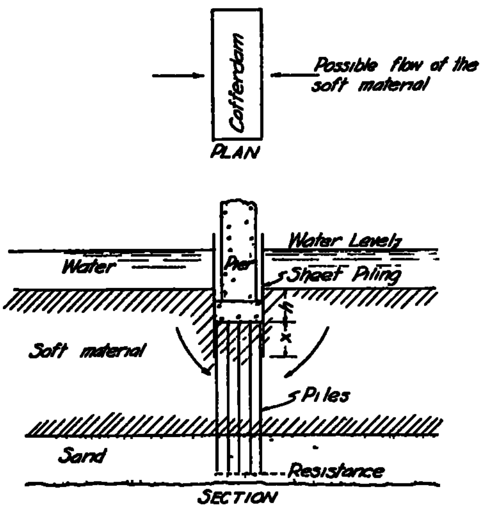

Figure 1. Schematic Sketch of a Cofferdam

soft material which will be described hereafter in some detail. To drive piles, a sheet piling cofferdam may be built, soft material excavated to some depth h (Fig. 1), piles driven, concrete over the piles heads placed and the body of the pier constructed. In excavating soft material from the cofferdam, there is a danger of the "blow in" of the adjacent soft material into the cofferdam. The object of this paper is an approach to a rational determination of the depth of driving x (Fig. 1) below the level of the excavation.

CHARACTERISTICS OF THE SOFT MATERIAL

What is meant in this paper by "soft material" is a material termed in practice "silt," "organic silt," "clayey silt," "silty clay" or "mud" Its mechanical analysis shows that silt and to some extent clay particles prevail. The thickness of a layer of this material may be from a few feet to 100 ft. or more. It is dark in the river and light gray when dry. Its natural moisture content is often close to 100 per cent by dry weight. It smells of methane (marsh gas) due to organic admixtures.

The unit weight of this material as determined from undisturbed samples taken from the Thames River, in New London, Conn., is about 87 lb. per cu ft Deducting about 62 lb. per cu. ft. for buoyancy leaves the net weight of the material in the river about $\gamma = 25$ lb. per cu. ft. The shearing value of this material due to cohesion as determined in the field, is about $c = 100$ lb. per sq. ft. Simple field tests leading to this figure have been described elsewhere (1).[1]

EXPERIMENTAL WORK

Figure 2 shows a heavy wooden box 7 ft. long, 40 in. high and about 18 in. wide (inside dimension). There were five vertical glass panels (windows) at each

[1] Figures in parentheses refer to list of references at end.

long side of the box from top to bottom, each panel being 4½ in. wide. A model of a cofferdam was placed at the middle of the length of the box. It had two walls only (perpendicular to the length of the box) and was made of sheets of galvanized iron, first No. 19 and afterwards No. 12 U. S. Standard gauge. The length of the model was 20 in. The upper part of the model was braced with three light horizontal wooden frames. The lower 6 in. of the model were not braced in order not to interfere with the flow of the material, if any. The bottom of the model duplicated the bottom of the sheet piling in nature, and the bottom of the box duplicated the top of the underlying sand layer which presumably does not participate in the flow, if any.

The soft material brought to the laboratory in moist lumps was kneaded mostly by hand and placed in horizontal layers into the box in which the model of the cofferdam was already hanging. Efforts were made to keep the top of the soft material under water at all times. Thin horizontal layers of white sand were placed close to the windows in order to determine the direction of the flow from the deformations of those layers.

When the material was in the box, an excavation 6 in. deep was made inside the model, thus leaving 4 in. of galvanized iron at the bottom in cantilever. To facilitate the flow of the soft material, the inside of the model was unwatered, and a surcharge reaching 150 lb. per sq. ft. was placed on the silt level on both sides of the model. It consisted of metallic loads placed on transverse wooden boards resting on earth. Each of these boards including the surcharge on it, could move down independently of the others.

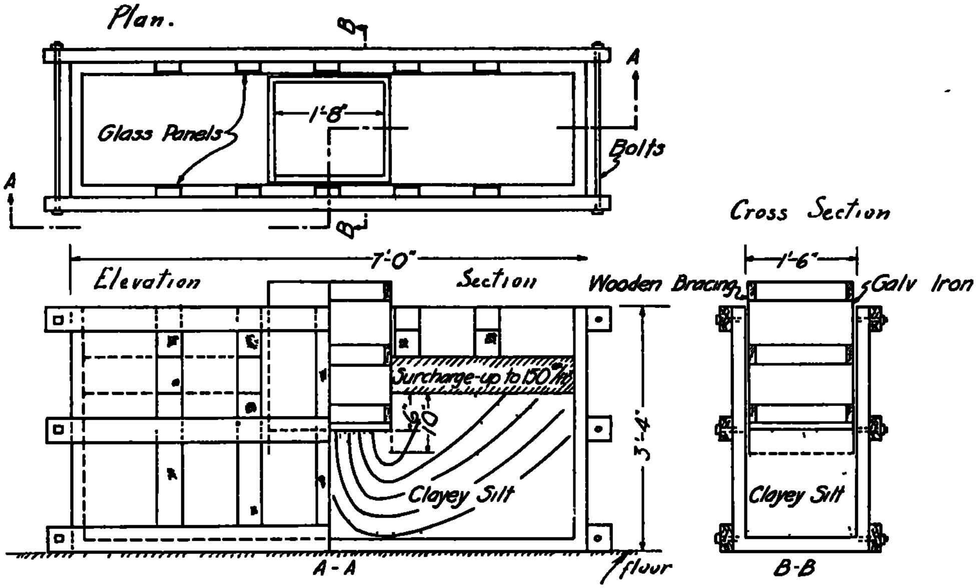

Figure 2. Experimental Box Showing Approximate Flow Lines of the Clayey Silt

The bottom of the excavation went up about 1½ in. No disintegration of the mass along a definite failure line (shearing surface) has been observed. Under the action of the surcharge the soft material moved towards the model, but this movement discontinued very soon. Flow lines as determined from the deformations of the white sand layers are shown in Figure 2. They extend through the whole mass of the material in the experimental box.

It should be noticed that the experiment described was of a purely qualitative nature, therefore no efforts were made to determine what part of the surcharge was carried by the walls of the experimental box due to friction. The only conclusions drawn from this experiment were: (a) the lowest point of a flow curve should be under the tip of the sheet piling where the flow enters the cofferdam; and (b) disturbance of the material far away from the cofferdam is not an impossibility.

PICTURE OF A POSSIBLE FAILURE

Figure 3 represents the picture of a possible failure as the writer visualizes it.

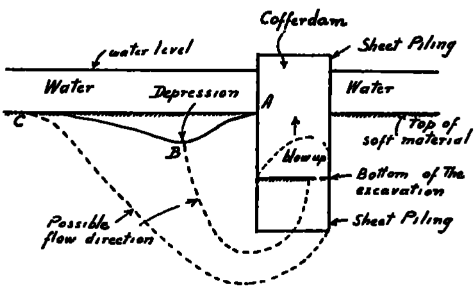

Figure 3. Possible Slump Motion of the Soft Material

Due to the overcoming of the shearing resistance, silt material rushes into the cofferdam, and a depression B at the top of the silt should be formed. Probably, point A close to the sheet piling is held in place due to adhesion, and at a certain point C there should be an end of the depression. Figure 3 should not be interpreted too literally, however. The "blow in" may occur not only at the outside wall of the cofferdam as shown in that figure, but the soft material may start to "blow in" at any point of the bottom. In particular, cases when the failure starts close to the inside wall, are very frequent.

With Figures 2 and 3 in mind, two methods of analysis may be proposed, one of them being based on the idea of a remote boundary of the disturbance (Fig. 4) and the other one on that of a restricted disturbance (Fig 5).

ANALYSIS OF THE COFFERDAM FROM THE ORIGINAL CONDITIONS OF EQUILIBRIUM

Before the excavation OMNP is made (Fig. 4), the semi-circle ADBC is in equilibrium. Point B of this semi-circle corresponds to the assumed location of the tip of the sheet-piling After the excavation is made, the semi-circle in question tends to rotate due to the action of an

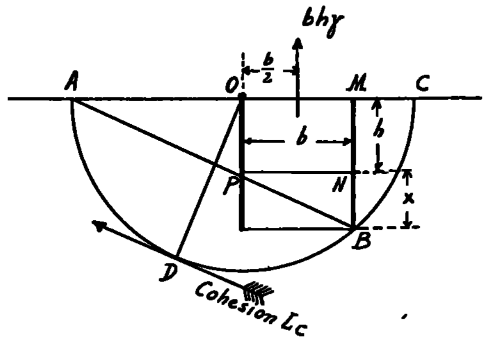

Figure 4. Depth of Driving Determined (Semi-Circular Shearing Surface Assumed)

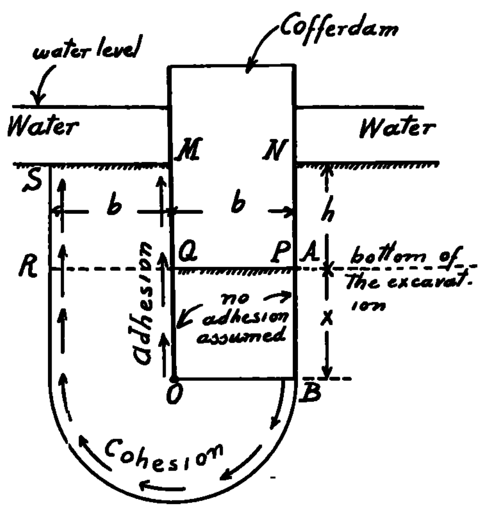

Figure 5. Rotational Flow of the Soft Material (an Assumption)

overturning moment which is caused by the non-symmetrical loss of weight $bh\gamma$.

The designations are:

b—width of the excavation, in ft.
h—depth of the excavation, in ft.
γ—unit weight of the soft material in lb. per cu. ft (buoyancy deducted).

This overturning action is resisted by the cohesion along the arc ADB. The value of the total resistance equals the length of chord AB=L (in ft.) times unit cohesion, c (in lb. per sq. ft.). In an actual problem this length may be scaled. The point of application of the force Lc lies somewhere on the continuation of the radius OD which is perpendicular to chord AB. A proof of this statement may be found in ref (2) and (3). For the sake of safety, the arm of force Lc will be taken equal to the length of the radius OD=R (in ft). Thus the value of the resisting moment is:

$$M_r = LRc \ldots\ldots\ldots\ldots (1)$$

and that of the overturning moment

$$M_o = (bh\gamma) \times \frac{b}{2} \ldots\ldots\ldots (2)$$

The ratio $\frac{M_r}{M_o}$ is the safety factor.

It has been assumed in this construction that forces other than cohesion Lc and loss in weight $bh\gamma$ pass through the center of rotation O and hence do not influence the values of the moments M_r and M_o.

ASSUMPTION OF A ROTATIONAL FLOW

Assuming that the soft material rushing into the cofferdam rotates about the tip O of the sheet piling at the entrance to the cofferdam, the picture shown in Figure 5 may be obtained.

As soon as the excavation MNPQ is made, the equivalent volume SMQR pushes soft material along the channel SRBA. This action is resisted by the cohesion of the soft material (c lb per sq. ft.) and its adhesion to the sheet piling. If a reasonable time between the sheet pile driving and the excavation has passed, this adhesion may be relied on, otherwise not. For the sake of simplicity, the value of this adhesion will be taken equal to cohesion c. The condition of equilibrium is then:

$$Fbh\gamma = (2h + 2x + \pi b) \times c \ldots\ldots (3)$$

Assuming a value of the safety factor F in Equation (3) the depth of driving x=AB may be found.

The construction shown in Figure 4 furnishes somewhat high values of the safety factor due to the fact that cohesion is assumed to act on a relatively large surface. The construction shown in Fig 5 furnishes rather small values of the safety factor since in this case the surface in question is somewhat underestimated. The real value of the safety factor lies perhaps somewhere between. The writer believes that for structures like cofferdams, the value of the safety factor F=1.2 should be considered satisfactory. Unwatering a cofferdam before placing concrete considerably decreases the value of the safety factor and may cause a collapse of the structure.

WIDE COFFERDAMS

It has been assumed in the preceding discussion that the flow of the soft material into the cofferdam is influenced by the width of the latter. This is possibly not so in the case of wide cofferdams for which other methods of analysis should be used (4).

ACKNOWLEDGMENTS

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DISCUSSION ON COFFERDAMS

DR. JACOB FELD, *Consulting Engineer, New York:* Foundation conditions along the shores of tidal streams filled with silt and broken rock overlying steeply sloping and irregular surfaced bed-rock often require unusual design and construction procedures. At a creek emptying into Long Island Sound, an overhead industrial bridge was planned to be supported on piles. After steel pipe piles were driven, apparently to rock, a scow tied up to one cluster and, as the tide went out, showed that a pile foundation had no lateral strength. The writer was then consulted and upon his recommendation that a steel sheetpile cofferdam be used, was ordered to design and supervise the construction of such a foundation.

The cofferdam 18 ft -9 in. by 28 ft.-3 in. was made up of a single flat sheetpile skin braced by a pre-fabricated steel frame, first used as a driving frame. The tidal range varied from the normal 7½ ft. to a low of 5 ft. and a high of almost 12 ft., depending upon wind conditions. Rock levels over the area of the foundation varied rapidly. The pipe piles had stopped at from 5 to 9 ft below low tide. The rock exposed after excavation varied from 5 to 15 ft. below low tide. In spite of the 6-ft. extra unexpected depth, the cofferdam was safely put down and the sheeting seated into the rock.

The material overlying the rock was a silt mud in which had been dumped over a period of many years, large and small broken rock and concrete, topped with massive cast concrete blocks to protect the shore. Preparation for the work consisted of removing the blocks, building a timber decking to support a crane just shoreward of the proposed cofferdam and removing all material to a depth 2 ft. above low tide, leaving a fairly level berm.

The cofferdam design (see Fig. 1) consisted of a flat 16-in. steel sheetpile weighing 23 lb. per sq. ft. (type FW 23 J & L); this being the only material immediately available. A steel frame, consisting of two layers of braced beam tied with posts, spaced 7½ ft. vertically, was designed and detailed completely for bolted connections.

At low tide, this frame was completely erected in approximate position and set on wood mud sills, clear of the sheeting lines. Exact positioning was performed at high tide, the crane picking up the frame and setting it to instrumental precision. To level up the frame, loads at the high corners were placed to cause a settlement into the mud and stone fill (see Fig. 2).

The steel sheets, all 20 ft. long, were then set around the frame, letting each sheet slide into the mud, guided by the two brace tiers. The entire job was performed from one crane set up. The corner sheets were then driven to refusal with a pneumatic hammer weighing 3,000 lb. hung from the crane boom. All the flat sheets in rotation, starting with those furthest from shore, one each side of each corner, were then driven to resistance. The second run drove each to refusal.

It was known that the rock fill would prevent complete penetration to bed rock, and it was decided to loosen the rock

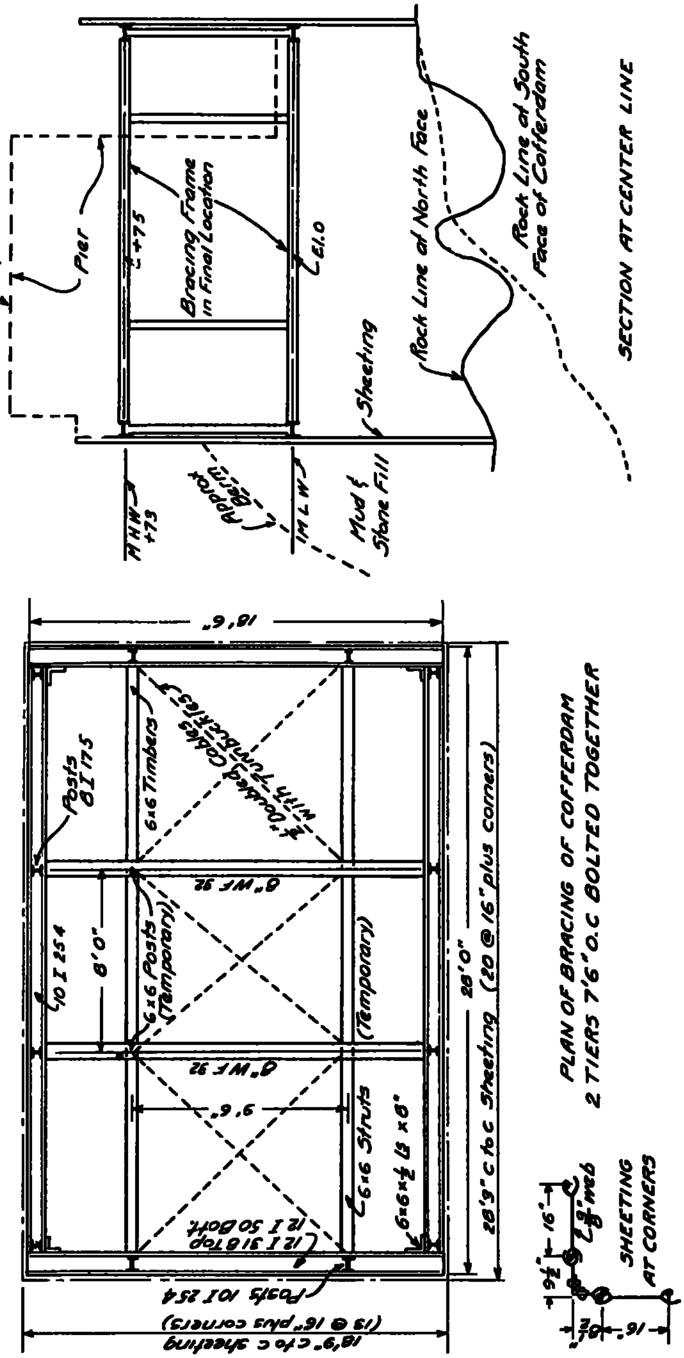

Figure 1. Cofferdam Details

obstructions by "blowing" the cofferdam. The high tide range would then be of some benefit. After mucking the inside of the cofferdam by clam-shell and placing some of the fill as a berm around the sides of the cofferdam—to about mid-tide level, a timber collar was placed around the top of the cofferdam to prevent outward movement of the top sheets from sudden unbalanced pressure. The sheets were then re-driven, some moving only an inch, while others moved a foot or more. The irregular top line, (see Fig. 3) showed definitely the presence of rock obstructions at some locations. Excavation was continued at these places, while the cofferdam was pumped out. A little practice taught the men to localize a "blow" through the bottom and to close off the subterranean gap by driving down the sheets nearest the blow.

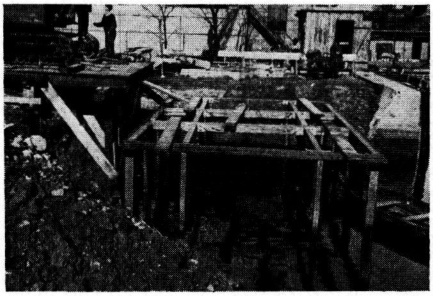

Figure 2. Steel Bracing Frame, Pre-Fabricated and Set in Dredged Area to Proper Grade and Line, to Act as Sheet-piling Driving Frame. Lower Beams ($7\frac{1}{2}$ Ft. Below Top Tier) Just Below Water Level.

In general, the bottom would blow with an unbalanced head of not less than 15 ft. with the outside sloping berm level about 5 ft. below water level.

After the sheets in one area were driven down to stop a blow, unwatering without excavating a new area inside the cofferdam would often cause a series of small blows throughout the bottom, but not of sufficient velocity to displace the rock fill. During a good localized blow, the entire cofferdam filled in 10 minutes, admitting a volume of about 8,000 cu. ft.

The next step was to place the driving frame into the proper depth. This was done by placing the hammer successively at the four corners, on the frame and forcing it down a few inches at a time, until the frame had been lowered about 18 in. There was no difficulty in moving the frame within the sheetpiling; the operation being performed during low tide. To avoid further slip, the frame was then bolted to the sheetpiles.

The amount of leakage through the joints was small, and it was almost entirely eliminated by filling the interlock spaces with a heavy grease pumped in with an automobile grease gun equipped with 10 ft. of small bore tubing. The grease showed through the joints, but sealed off all the water.

Figure 3. Sheetpiling Driven Through Silt, Rock-Fill and Soft Rock, Unwatered with 15 Ft. Head at High Tide Level.

To seal the bottom, the cofferdam was unwatered at low tide and the bottoms of the highest sheets were cleared by hand, and driven into the mica schist rock. Where the rock sloped more than 2 in. in the width of a sheet the bottom of the sheet was flame-cut to match the rock line before re-driving. Where water still came in, a fast setting cement mortar, mixed with some hay, was packed into the crevises. A successive operation of this kind around the full perimeter gave a tight job, even at high tide. At the front, the rock shelved off very rapidly, and some temporary wood struts were placed between the sheet-piling and the higher rock. The bottom dimensions only differed by less than 2-in. from the top dimensions.

The cofferdam was sealed during low tide and all concrete was placed in the dry. Steel dowels were set in drilled holes in the cleaned rock surface to compensate for the 10 ft. of drop in the 19-ft. width of the pier.

After the concrete seal to about low tide level was poured, the sheetpiling was welded to the upper frame and three lines of tie rods were placed across the frames to take the tension from the complete concreting. Where sheets (ordered 20 ft. in length) came below the desired level, 4 ft. above high tide, crops cut from the high sheets were spliced in and tack welded. The face of the completed cofferdam is less than 1-in out of a straight line. The axes of the cofferdam were less than ½ in from the desired center lines The pier was completed in five weeks from the date of the displacement of the piles, over 500 cu. yd of concrete were poured and recessed bases for the three columns of the bridge tower were built.

This description of an actual small cofferdam job is given to show how blowing can be used as a means of sealing; as an example of the principle that if the sheetpiling is kept from moving, the bracing system is sufficient and also that a single sheet coffer can be made watertight and sealed in rock 20 ft below high water level.