so controlled that the rise in water level did not exceed 6 inches per day, and a 36-inch scour valve, which had been added during construction to increase facilities for discharge in case it should prove necessary to commence filling the reservoir before the dam had been completed to its full height, was disconnected when the reservoir had filled to overflow level to forestall too rapid lowering of the reservoir at any future time.

An important question arose as to whether or not the greatly accelerated rate of forming the embankment had a bearing on the movement that developed. Hitherto, it has been customary to form embankments at a much slower rate than is now the practice with muck-shifting vehicles of large capacity. By former methods considerable consolidation took place in the prolonged period of construction, whereas with modern methods the earth work is possibly in a less settled state as successive layers are added. Tests proved the upper Muirhead fill to be better compacted and of more uniform compressive strength than in the lower fill deposited at a slower rate, and, while the evidence is not conclusive, it suggests that the immediate stability procured by modern methods need be no less favourable than has pertained in the past.

ACKNOWLEDGEMENTS.

The Author desires to record his appreciation of the valuable assistance rendered by Engineers of H.M. Ministry of Works, by Messrs. Binnie, Deacon & Gourley, C.C.E., London, who were called into consultation when movement of the embankment was first observed, and to the Building Research Station of the Department of Scientific and Industrial Research who collaborated with the Engineers in the study of the site conditions. Site and laboratory tests and the relative figures and diagrams included in this paper are extracted from or are based on a report submitted by the Building Research Station to whom due acknowledgement is made. Messrs. Casey & Darragh, Ltd., Stirling, carried operations to the first stage and the work was completed by Messrs. George Wimpey & Co. Ltd., London.

REFERENCE.

1) "A Portable Apparatus for Compression Tests on Clay Soils" by L.F. Cooling and H.Q.Golder, Engineering 1940, Jan. 19th.

-o-o-o-o-o-o-

SUB-SECTION IV c

EXCAVATIONS AND SLOPES

IV c 1

DESCRIPTION OF A FLOW SLIDE IN LOOSE SAND

R.B. PECK

Research Professor of Soil Mechanics, Univ. of Illinois

W.V. KAUN

Plant Engineer, Cities Service Oil Co., Chicago

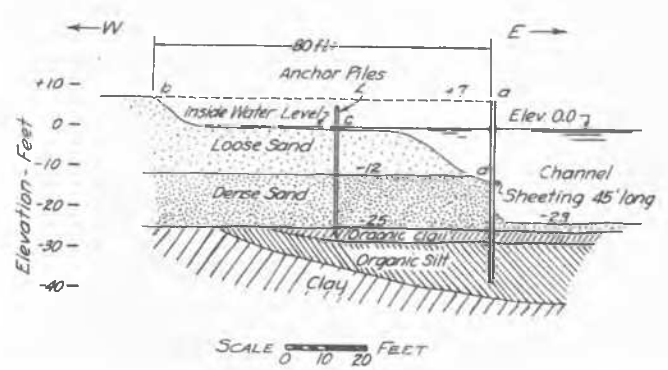
SUMMARY

This paper describes a flow slide that occurred in fine loose sand during reconstruction of a dock wall in East Chicago, Indiana in 1946. The flow occurred through a narrow opening made by the removal of a small portion of a sheet pile wall. Since no seepage pressures were involved, the primary cause of the occurrence appears to be the collapse of the extremely loose structure of the fine sand.

DESCRIPTION OF SLIDE.

Conditions prior to the slide are shown in Figure 1 which represents a cross-section through the dock wall. The outer face of the dock consisted of sheet piles 45 feet long. To the east of the sheet-pile wall was a canal with its water level at El. 0.0. The channel was maintained by dredging to El. -23. On the west side of the sheet piling the surface of the ground had a constant level at El. +7. A row of anchor piles 30 feet long was driven vertically at a distance of 40 feet from the sheet piling and was tied to it by means of steel rods at water level.

The material between El. +7 and El. -12 consisted principally of loose sand deposited by means of a hydraulic dredge. Most of this fill was pumped out of the channel during the construction of the dock. Between El. -12 and El. -25 was a natural deposit of beach sand



Conditions before slide

FIG.1

of the same grain size but of much greater relative density. At El. -25, the sand throughout this general area rests upon a bed of medium clay. However, at the location of the dock, part of the original surface of the clay had been once lowered by erosion and a fill of organic material had accumulated before the beach sand was deposited. On account of the presence of the organic deposits as well as the inadequacy of the anchor piles, the dock wall bulged toward the channel during the spring of 1945 and showed signs of failure. As a consequence it was decided to reconstruct several hundred feet of the dock. In the reconstruction, longer piling was to be substituted for the original sheet piles and a new anchorage was to be built at a distance of about 80 feet west of the dock line.

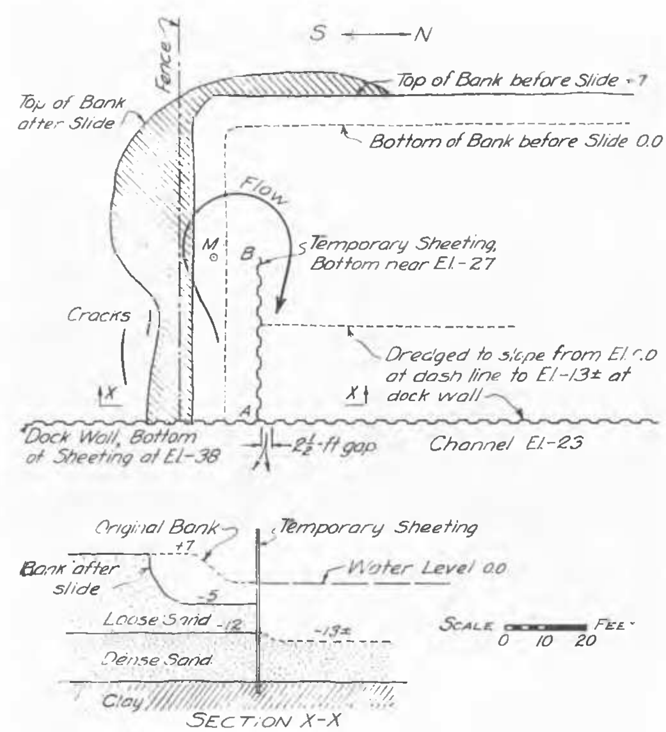
In preparation for the repairs, all of the material between El. +7 and El. 0.0. was removed to the west of the dock line for a distance of about 80 feet. In addition, a deeper pocket with a slope rising toward the west was excavated in the loose sand immediately behind the sheeting so that soil pressure did not act against the sheeting above about El. -14. Upon completion of these operations, conditions were as shown in Figure 1.

Inasmuch as the reconstruction operations were to extend to within a few feet of the south property line indicated by the fence in Figure 2, the contractor took additional measures to protect the adjacent property from possible damage by sloughing of the slopes. At a distance of about 20 feet north of the fence, a row of sheet piles AB was driven at right angles to the dock wall. This temporary piling extended to approximately El. -27. Hence it barely penetrated the clay and organic material beneath the sand. A cross-section through the temporary sheet pile wall just west of the dock wall is also shown in Figure 2. It indicates the manner in which the original bank near the property line was sloped from El. +7 to water level. At M, Figure 2, was located a mooring post that also extended to approximately El. -27.

By virtue of these preliminary operations, the contractor expected to be able to pull the sheet pile dock wall starting just north of point A with little difficulty and without the loss of much sand behind the dock line. However, upon removal of the first two piles, having a total width of 2½ feet, sand began to flow through the narrow opening and continued to flow for about 30 minutes before the gap could be closed. During this time between 500 and 800 cubic yards of sand flowed through the gap.

The principal manifestation of the flow was the dropping of large chunks of sand into the water at the edge of the southern bank. These pieces first cracked away from the bank and then slumped into the water and disappeared. After the slide, the outline of the bank was as shown in Figure 2. Near the east end of the bank several cracks remained. The position of the ground surface just west of the bulkhead line is shown in Section XX. In corner A, the surface of the sand had descended from El. 0 to El. -5. At point B near the end of the temporary sheeting the depth was only slightly greater. At the place where the sheeting was removed, the surface of the sand was at about El. -11. Since the total distance from A to B around the end of the temporary sheeting and back to the gap was 80 feet, the final average slope was approximately 1 on 13.

The photograph, Figure 3, shows conditions after the slide. At the rear of the view the fence can be seen in its original position.



Conditions after slide

FIG.2

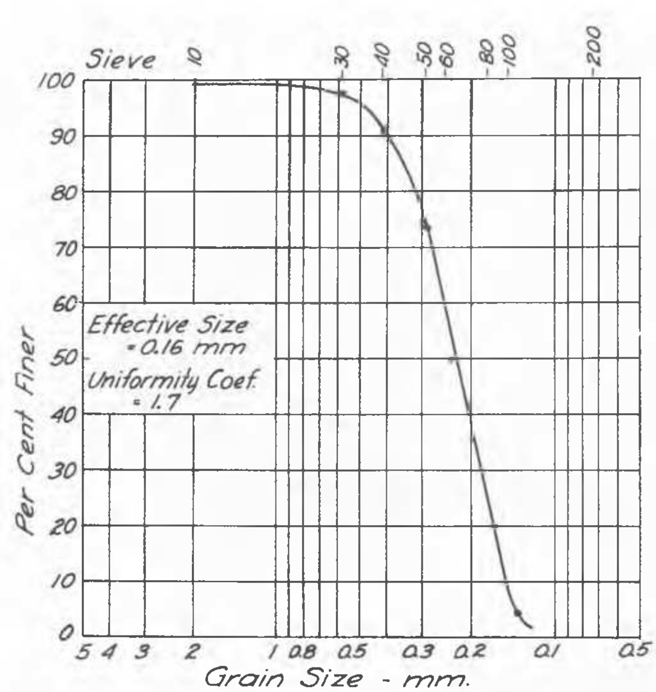
FIG.3

Closer to the dock, it is seen that the fence has collapsed in the area involved in the slide. At the extreme right of the photograph can be seen the temporary sheet pile wall. It was still in position in spite of the fact that after the flow it had an embedment of only 12 to 15 feet. In the center of the photograph is the mooring post still in position and not tilted.

It is obvious from the drawings and the photograph that the slide was not a deep-seated phenomenon and that only the material above El. -12 was involved. Had the underlying sand layer been disturbed, the mooring post and the temporary sheeting would almost certainly have collapsed or moved. Inasmuch as the dock wall was provided with holes at water level to maintain the elevation of the water at the same level inside and outside the sheeting, no hydraulic head could have existed across the gap at the time the sheeting was removed. The relatively small disturbance caused by removing the support from a few feet of submerged sand at the gap set into motion a flow that continued even when an extremely flat slope was attained. The movement stopped only when the gap was closed.

The excessively loose nature of the overlying part of the sand deposit was indicated by a number of test borings made at the site before reconstruction operations were begun. Each of these borings was made within a 2½-inch casing. Samples were taken at intervals of 2½ feet in the vertical direction by means of a split spoon having an internal diameter of 1 3/8 inches and an external diameter of 2 inches. The spoon was driven into the ground by a drop hammer weighing 140 pounds and allowed to fall 30 inches. The number of blows per foot of penetration was recorded as a measure of the relative density of the sand. This procedure is widely used in the United States for preliminary exploration of sand deposits. In general, resistances of less than 5 blows correspond to very loose sand, from 5 to 10 to loose sand, from 10 to 30 to sand of medium density, and over 30 to dense sand.

Within the upper 12 feet, a single blow of the drop hammer was sufficient to advance the sampler as much as 22 inches. In many parts of the deposit the resistance to penetration was only one blow per foot. On the other hand, below El. -12 the penetration resistance varied between 10 and 15 blows. Hence, the lower sand appears to have been relatively loose but stable whereas the upper sand involved in the flow was abnormally loose and unstable. The grain size curve of the sample of one of the finer lenses in the hydraulically deposited soil is shown in Figure 4. It indicates that the individual lenses are extremely uniform. The fraction passing the 100-mesh sieve and retained on the 200 and that passing the 200 were examined under the microscope. Both consisted almost exclusively of angular quartz grains; very few rounded or sub-rounded grains were present. Grains passing the 200-mesh sieve were slightly more angular than those in the coarser fraction.



Grain size curve

FIG.4

CONCLUSIONS.

This paper describes the general features of a flow slide that occurred in very loose sand due to a relatively minor disturbance. The flow was confined exclusively to a uniform excessively loose hydraulic deposit having a penetration resistance, according to the procedure described in the text, of as little as one blow for 22 inches. On the other hand, the underlying sand which had a relative density somewhat greater (about 10 blows per foot), did not participate in the movement. Inasmuch as no seepage pressures were involved, it may be concluded that the flow was due to the spontaneous liquification of the excessively loose sand.

-o-o-o-o-o-o-o-

IV c 2

A COASTAL LANDSLIP

W.H. WARD, B.Sc. (Eng.), A.C.G.I., A.M.I.C.E.
Department of Scientific and Industrial
Research-Building Research Station

The landslip occurred along the seaward side of Castle Hill, Newhaven, Sussex, see plan and section Figure 1. The recent movements are restricted to the upper part of the hill above the chalk cliff, where a small outlier of Woolwich and Reading beds overlies the Thanet sand (Lower Tertiary) and the chalk (Upper Cretaceous).

EARLY HISTORY AND GEOLOGY.

Hawkes (1939) considers that Castle Hill was more or less continuously occupied from the late Bronze Age (circa 750 B.C.) until about 250 A.D. There was an early hill fort, which like others in Sussex, occupied the whole of the summit (Fox 1859). These earthworks have been slowly destroyed by the loss of land and by the construction of forts from time to time. There is no record of occupation between 250 A.D. and Elizabethan times, and since then according to Field (1939), the site has been in constant use and adapted for successive fortifications. Forts were constructed in the early 19th century and the present fort, built in 1864, practically obliterated all traces of more primitive encampments.

There are enough maps and references to the geology of the Hill, dated back to 1783, to enable the history of earlier movements to