with the "Hydrauger" equipment for drilling through hard rock. Experimental drilling with this equipment has shown very satisfactory results although the unit cost for core drilling is considerably higher than when auger bits are used, as the tools must be withdrawn each time a 10 ft. core is taken. Therefore, the horizontal holes are usually started using the auger bit and when hard rock is encountered, the diamond bit and core barrel are substituted for the auger bit. After cutting through the rock and pulling the core, the drilling is resumed with the auger bit.

A modified fish-tail type bit has been used occasionally in sandstone and shale strata. Although this type of bit cuts fairly fast, directional control is difficult for any considerable length, and the use of this type bit for the entire length of the hole has not been satisfactory.

As most of the locations where horizontal drains are installed are in active slide areas where the ground is in a saturated, unstable condition, some difficulty has been encountered in casing the holes after they have been drilled. By using a folding-type bit and a double track set-up, it is often possible to drill and case the holes in one operation. The drill rod is run through the 2" perforated casing with a 4" folding bit immediately ahead of the end of the casing. The drill and casing are moved ahead together to the required depth of hole. The drill rod is then backed out, collapsing or folding the bit and drawing it out through the casing.

In some localities, firm material is encountered at the start of the hole with saturated free-running sand or silt layers near the end of the hole. When this condition is met, the practice has been to jack the casing as far as possible and then to jet through the sand layer.

One of the greatest difficulties that we have had installing horizontal drains has been in holes where loose rock or broken shale strata have been intercepted. The loose rock falls into the hole, and due to the action of the bit, the rock is rolled around in the hole, and not drilled. Under such conditions extreme care is necessary to keep the drilled hole straight, and in order to install the perforated casing the loose rock must be removed from the hole. Working in this type of material is difficult and often costly, but it is believed that much of the trouble could be eliminated by circulating a heavy mud under pressure through the hole instead of water, as is normally done.

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IV c 9 UNDERPINNING AND UNDER-DRAINAGE TO CHECK EARTH SLIDING AND SETTLEMENTS AT A LARGE CEMENT PLANT

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When the San Martin Cement plant, in Parana Argentina had reached an advanced stage of construction, serious land movements developed that threatened the safety of many of the key structures. Lateral movements of the soil under several of the structures gave evidence of a slow landslide, or slip; serious tilting of structures gave evidences of rotational slide; and large settlements of structures indicated a deep seated soil consolidation. When the writer of this report first reached the Argentine he found one of the structures, the Kiln Feed building, so seriously damaged by lateral movement and tilting, that after exploratory test pits had shown that supporting concrete piles had suffered shear failure, this building was ordered demolished. He found several other important structures in varying stages of damage and definite evidence of the combined effect of rotational slide.

This large plant was being built for a subsidiary of the United States Lone Star Cement Company. The site, on the south bank of the Parana River, just west of the City of Parana in the State of Entre Rios, had been selected because of the presence of abundant quantities of the raw materials for cement manufacture, in the form of a thick, approximately horizontal stratum of limestone at a reasonable depth, overbedding a good clay; and further because of a location well suited to a port development and well placed for transportation requirements

Prior to the start of construction, a considerable number of sub-soil borings had been made, together with several deep test pits in the quarry area, from which it had been concluded that there was a natural soil formation, continuous inshore from the then existing river bank, and that it would provide an excellent support for the foundations of the various required structures. Although the sub-soil samples all showed soil materials generally considered adequate for the support of spread footings or mat foundations, and although the designers assumed that there were continuous beds of compact sand at the general foundation level, they elected to install long, precast concrete piles; their reports to the owners recommending such piles as "a desirable additional assurance of foundation stability".

But the designers had committed a cardinal error in their failure to plot the soil boring logs into developed geological cross-sections.

When the plotting of such cross-sections was undertaken, it immediately became evident that whereas under the entire quarry area and under a portion of the plant site well back of the river bank, bedding planes and stratification of normal geological deposits could be readily developed, under the majority of the plant site, near the river, bedding planes and stratifications were definitely discontinuous for the full depth of the borings. It was therefore concluded that the majority of the

FIG.1

from the borings in the fill area were prototypes of one of the natural strata found further from the river bank, which explains how the designers had been led into the critical error of assuming the fill to be a natural deposit, an error which became manifest as soon as the effort was made to plot the borings into geological sections by connecting up the bedding planes.

When the old limestone quarrying operations had filled the cove, the deep river bed deposit of organic silt was partially pushed out toward the river channel and partially entrapped and covered over by the fill.

In no case did the precast concrete piles, installed under the various plant structures, penetrate through or even to the underlying soft silt deposit, which was at an average depth of about 75 feet below grade. Therefore the effect of the pile installations was to transmit structural loads to a support in soils closely overlying the silt deposit and thus materially increase the total load on the

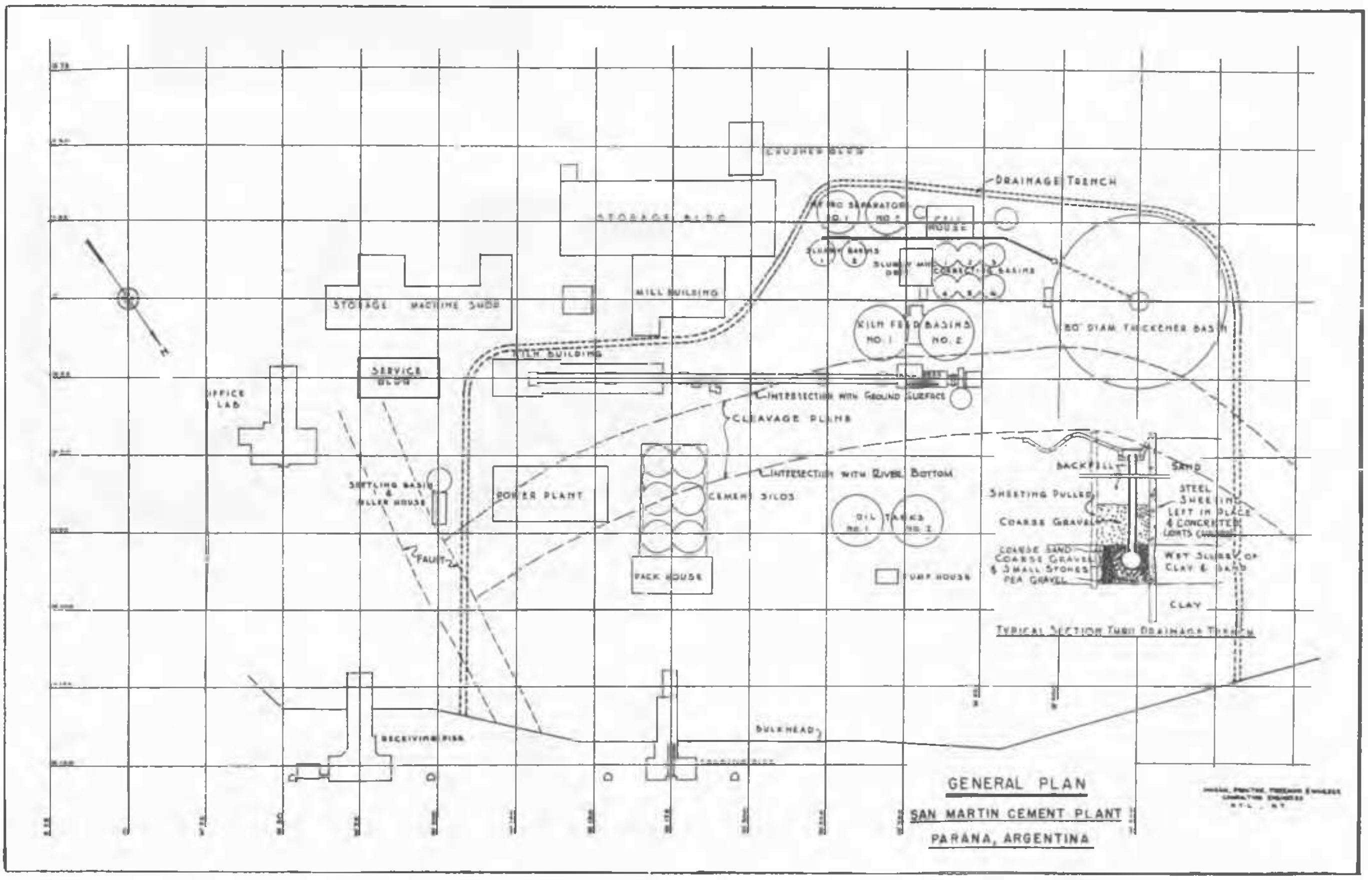


FIG.2

site for the plant structures must constitute an old filled area, notwithstanding design assumptions to the contrary.

Hence, careful investigation of Parana City records were made, and many of the oldest residents were interviewed, and it was discovered that about a hundred years before, when the river bank at the plant site had outlined a semi-circular cove, limestone had been quarried from the side hill by a stoping or undercutting method that had caused the overlying sandstones and clays to shear off and to fill in the cove.

This created a condition where the samples silt. Hence, as structural loads came on to the piles, there was a deep seated flow of silt towards the river channel as evidenced by a mud wave, with resulting severe settlements.

The new plant grades had required up to 30 feet of fill above the top of old fill. The boundary between the original fill and the natural soil followed the approximate shape of a spheroidal surface. Therefore a condition obtained that was conducive to a rotational slide, and such a slide did occur over the entire filled area.

Fig. 1 is a general view of the plant.
Fig. 2 is a plan of the plant site.

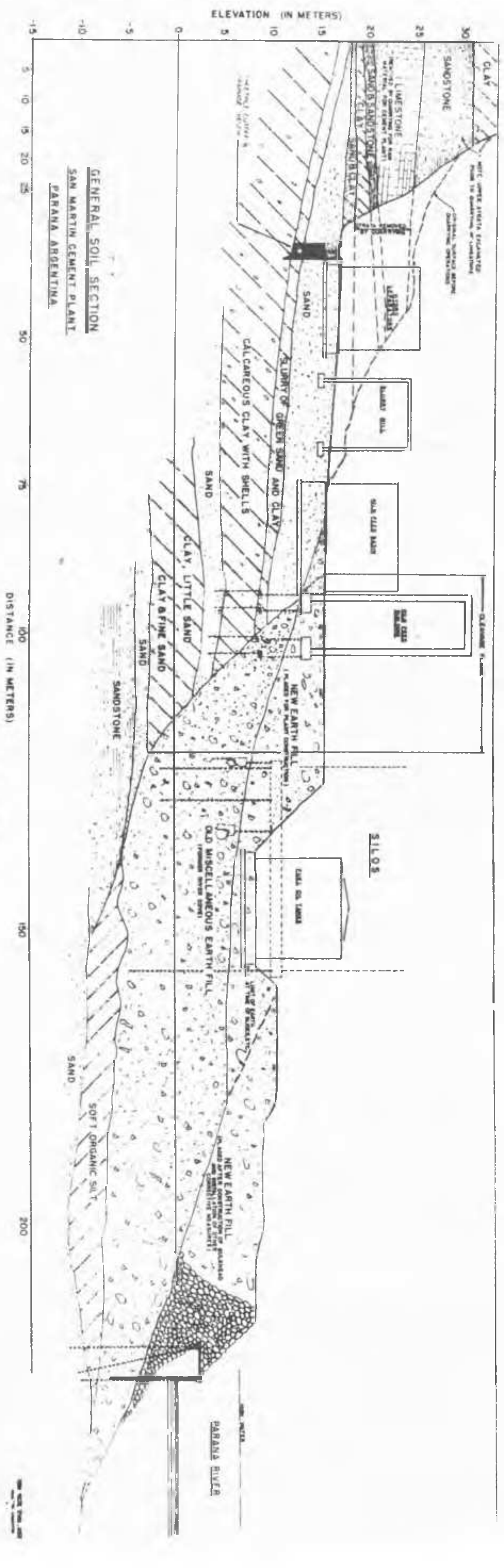


FIG.3

Excavation for power house underpinning.

General view of excavation on west side for underpinning of silos.

Fig. 3 is a typical soil profile.
Fig. 4 shows the silo underpinning.
Fig. 5 shows underpinning of the stack and typical kiln pier underpinning.

On Fig . 3 it will be noted that in situ the limestone and upper clay deposits overlie a bed of sand, which is in turn underlain by a thick bed of clay, the top surface of which dips sharply towards the river. Coincident with the start of boring operations and other preliminary construction work, the stripping of the overburden from the limestone was started and the limestone and its underlying clay deposit were quarried and stock piled.

Immediately under the quarried clay bed lay a deposit of compact coarse sand, which was underlain by a highly calcareous clay, the top surface of which dipped sharply towards the river. Whereas the coarse sand deposit and its underlying calcareous clay had been insulated from the elements by its natural overburden of limestone, sandstone and a superficial clay bed, after removal of such overburden through quarrying operations, storm water from a water shed of considerable area in the back

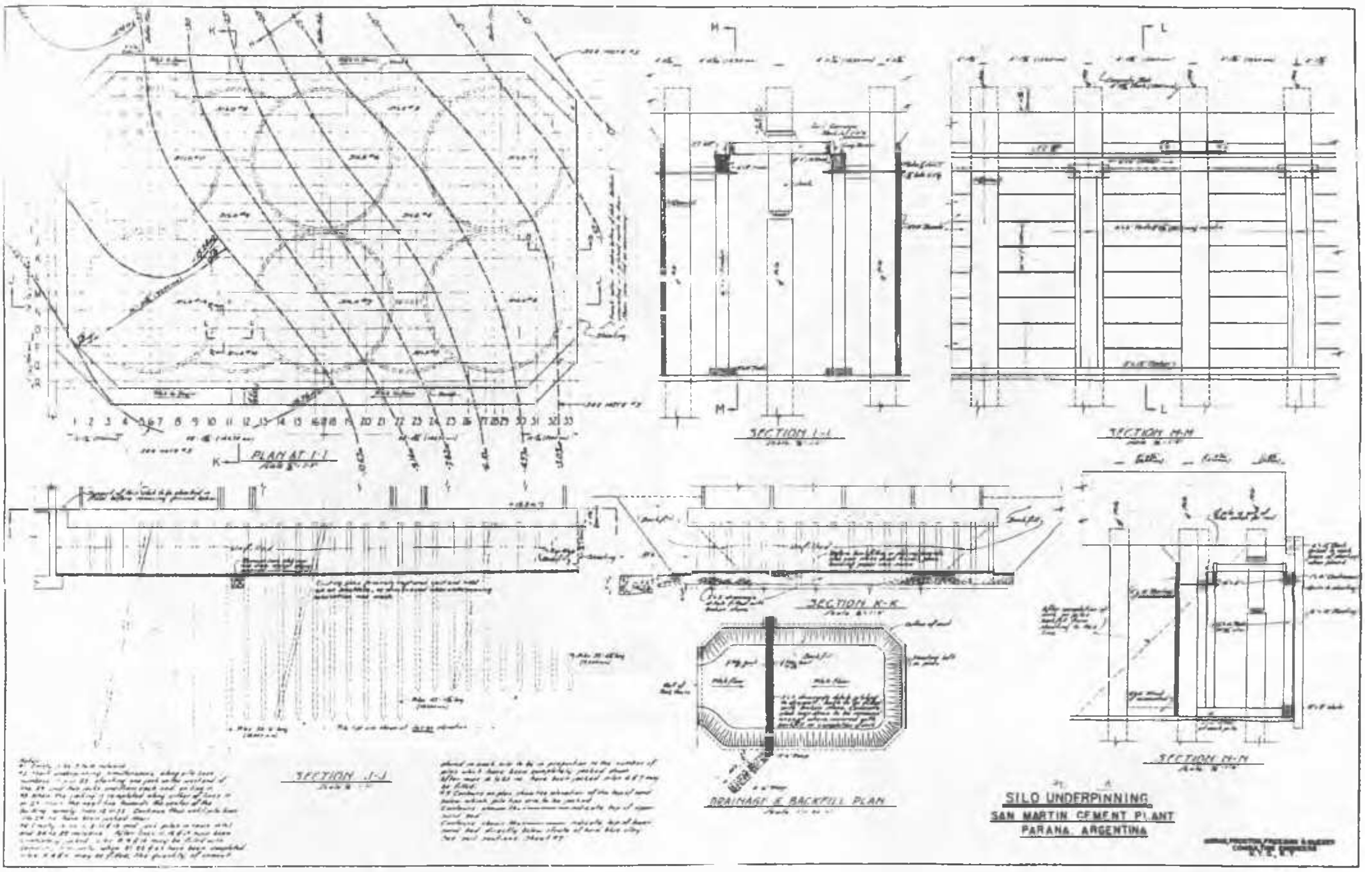

PLAN AT I-I
SECTION I-I
SECTION M-M
SECTION K-K
SECTION J-J
SECTION H-H
DRAINAGE & BACKFILL PLAN
SILO UNDERPINNING
SAN MARTIN CEMENT PLANT
PARANA, ARGENTINA

FIG.4

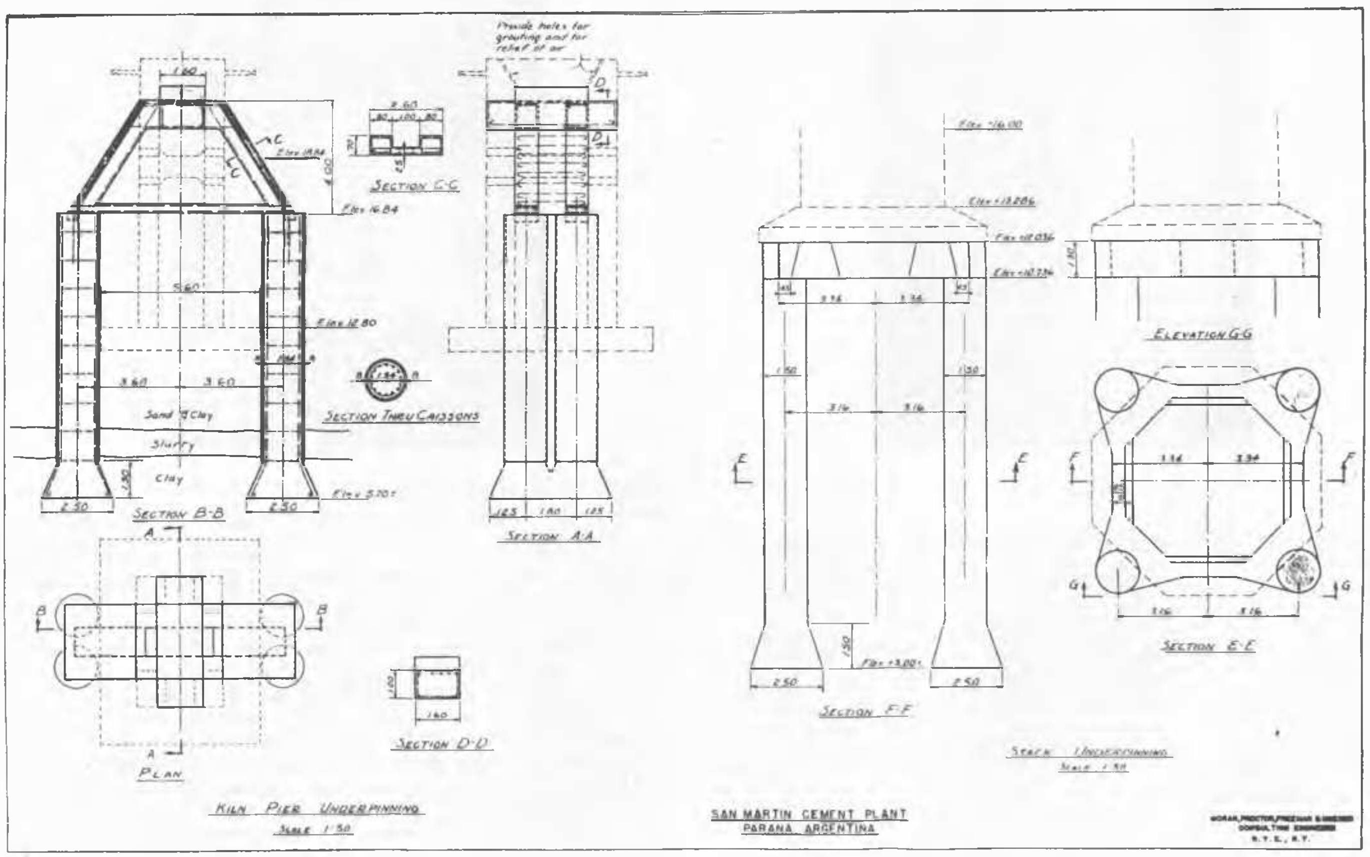
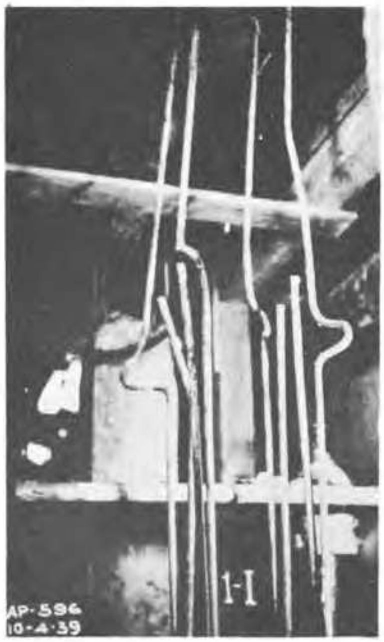

Provide holes for grouting and for relief of air
SECTION C-C
SECTION B-B
SECTION A-A
SECTION THRU CAISSONS
SECTION D-D
PLAN
Sand & Clay
Slurry
Clay
ELEVATION G-G
SECTION E-E
SECTION F-F
KILN PIER UNDERPINNING
SCALE 1:50
SAN MARTIN CEMENT PLANT
PARANA, ARGENTINA
STACK UNDERPINNING
SCALE 1:50

FIG.5

Excavation for underpinning of silos.

Pile 1-I



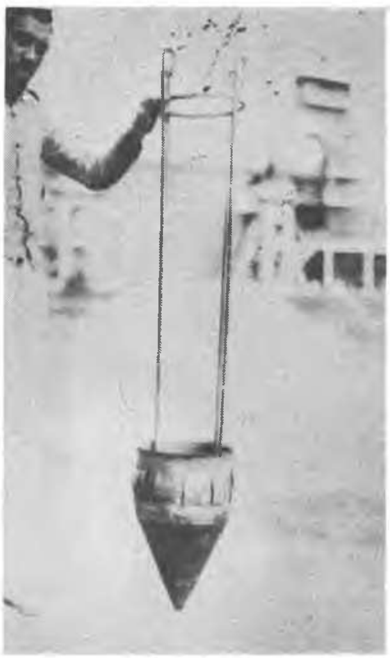
Vertical reinforcement 8 - 18 mm. bars except last 4 Ft. against slab which has 4 - 18 mm. bars.

country hills readily permeated the uncovered areas of coarse sand, saturated the surface of the underlying clay bed and produced a lubricated plane along which slippage occurred. On the writer's first visit to the site a lateral slippage averaging some three feet had sheared off the tops of piles supporting the kiln feed building and had caused serious lateral movements of varying amounts in the structures and kiln supporting piers, that were located near the juncture of natural soil and old fill. The occurrence of a lateral movement, or land slide, was demonstrated through test pits sunk along the fissure that developed at the plane of juncture between fill and natural soil. Most of these test pits gave access for an examination of foundation piles, the shear failure condition of which gave further evidence of the extent of the slide failures. Into each such test pit there was a flow of water along the surface of the calcareous clay bed.

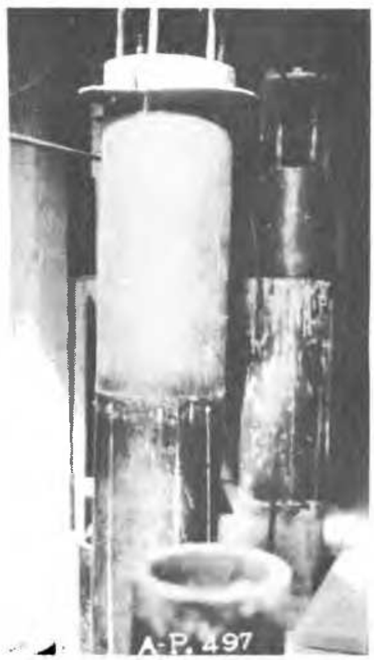
Several operations were carried out to correct these conditions. An intercepting trench was excavated, in a generally semi-circular plan location, to surround and enclose the affected structures. This trench was excavated within a double row of braced steel sheet piling, the excavation being carried into the calcareous clay underlying the coarse

Two small jacks operating jointly.

Typical bell reinforcing at top of jacked piles.



Showing a pipe point.



Steel forms in place for pile extension.

sand bed, and the line of sheeting nearest to the river was driven a minimum of one meter into the clay. In the bottom of this trench, pitching uniformly towards the river each way from a high point near its mid-length, there was laid a porous tile drain. The entire trench was then filled with gravel, with a graduated filter bed against the outer sheeted face, installed by the use of temporary forms. This vertical filter bed provided a 12 inch vertical layer of coarse sand, then 18 inches of pea gravel against the trench fill of coarse gravel. The uphill line of sheeting was pulled to facilitate complete uphill drainage and the joints of the permanent line of sheeting on the river side were caulked with lead wool and oakum to prevent leakage into the enclosed plant area. The trench fill was surfaced by a concrete gutter to intercept surface flow of storm water.

Further precautionary measures included the paving of all ground surfaces between the sheet pile cut-off drainage trench and a semicircular line well to the river side of the juncture between fill and natural soil. All joints between this paving and the various building walls were grouted and suitable fillets were provided, also a system of curbs and gutters, to prevent the penetration of surface water into the soil.

A reduction in the rate of lateral movements became evident soon after completion of

Large jack in inclined position over batter pile.

General view of Bulkhead extension also showing dumping of rip-rap on the outside of the Bulkhead.

Pile 5-P

Pile 24-M.

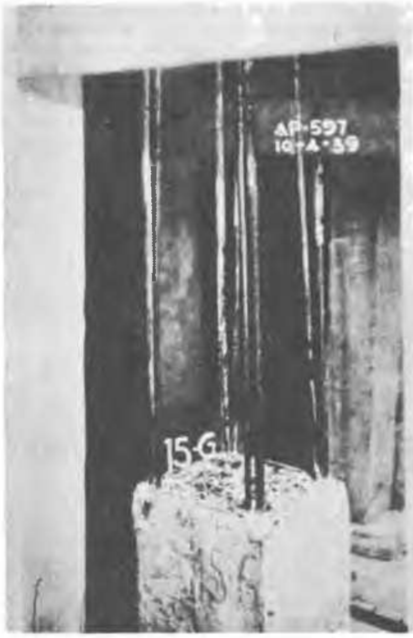
the major portion of these remedial measures and as long as movements continued, it was necessary to refill and re-caulk joints in the paving and between paving and buildings. At the end of approximately two years, observations showed that the site had become thoroughly stabilized against lateral movement.

Since the installation of the sheet pile cut-off drainage trench, there has been a steady flow of water into the river at both of its outlets.

When the first exploration pits were sunk over the slippage plane, a "slurry" was found at the surface of the calcareous clay bed; this consisted of a super-saturated, soft, slippery intermixture of limy-clay and sand. Later, when water had been eliminated from the slippage plane inside the cut-off drainage trench, underpinning operations encountering this slurry bed showed that it had dried out and taken on the characteristics of an artificial sandstone.

The kiln feed building had moved laterally and downward to such an extent, that in consideration also of the failure of its supporting concrete piles, (determined through exploratory test pits) its complete demolition was required. New foundations were installed, consisting of concrete shell caissons, sunk excavated, and concreted to the sand stratum underlying the calcareous clay deposit and a new kiln feed building was erected. The stack, kiln supporting piers and the various other disturbed structures along the juncture plane of natural soil and fill were all underpinned by the installation, through jacking operations, of concrete shell caissons, to depths necessary to penetrate all fills and the calcareous clay deposit, and support the loads on the underlying consolidate sand stratum.

The juncture plane between natural ground and old fill intersected the floor of the 180ft.



Vertical reinforcement 4 - 12 mm. and 4 - 18 mm. bars in piles 15-E,F and G. These piles were not broken.

Pile 19-M.

diameter thickener basin, so that the northerly quadrant of the basin's outer wall subsided seriously when the slippage and rotational slide took place, resulting in cracking of walls and floor. Through approach pits the wall was underpinned by a continuous concrete wall provided with a spread footing resting on the compact sand stratum and the floor was rebuilt and re-waterproofed.

The power house and the cement silos were relatively close to the river, and were the only structures supported on long precast piles that penetrated deeply into the old fill. Here the depth to natural soil beneath the underlying river bed silt deposit was beyond the limits of caisson underpinning practicability. At these two structures access trenches were excavated alongside of each building and carried ten feet below the underside of the heavy concrete mats that capped the foundation piles. From these access trenches, cross trenches were excavated, using poling-boards, to permit the hereinafter described under pinning operations. These trenches were carried under the structure so as to expose the upper ten feet of a line of piles at right angles to the approach trench. The first two of these cross trenches were installed near the center of the silo and at its south end. After completion of underpinning operations in these trenches, the center trench was progressively expanded in both directions, by the use of poling boards, to include one row of piles at a time, and the southerly trench was expanded in the northerly direction in a similar manner. Thus, on completion of underpinning, the underside of the pile capping concrete mat remained ten feet above the new ground surface and this space under the silo was not backfilled but was concrete paved and drained, so as to keep to a minimum the fill load on the river bed silt.

In the underpinning operation, piles that were found in good condition were cut off and their vertical reinforcement was left projecting above the cut. By the use of inverted 150 ton hydraulic jacks these piles were forced down until their tops were flush with the floor of the trench and each pile was then built up to the level of the underside of the jack(while the jack was in operation on other piles) and the jacking operation was repeated on the built up pile. By successive build-up and jacking, such piles were sunk to refusal in the compact sand beneath the river-bed silt.

But the majority of the piles, particularly under the silo, had hit sandstone boulders during their installation and many of them had been destroyed as pile supports through overdriving. Many had not penetrated below the level to which excavation was carried for the underpinning operations and many were found to be badly shattered, split and twisted when exposed. Where such piles could be removed, open ended 12" diameter steel piles, sleeve connected, were jacked down to replace them, and where they could not be removed, steel-pipe piles were installed between the old piles. Originally it was intended to jack and blow out these steel piles, always leaving a small plug of soil in the bottom to prevent blow-ins until the desired level had been reached, after which the piles were to be concreted and then seated to refusal resistance under the jack. But the old fill with its large content of sandstone offered such high resistance to the jacking of steel pipe-piles that it was necessary to keep the piles blown out practically to their cutting edge level. Therefore when the pile points reached the water bearing silts and sandy silts, these materials blew up into the pipes. To avoid the serious hazard of such losses of soil under the loaded silos and power house, the pile jacking was held up when each pipe pile was still in the fill and when it had closely approached the top of the silt deposit. The pipe was then blown out below its cutting edge and a pointed steel shoe was lowered into the bottom of the pile and held in place by supporting wires. (See illustration of the pile point shoe) The pile was then concreted, and after the concrete filling had set up, jacking was continued until refusal in the deeper dense sands was obtained.

A relieving platform type bulkhead along the shore property line permitted the placement of fill and roadway and act^ed as a final contribution to the stabilization of the plant area.

The plant has now been in full operation for seven years, during which time careful level and transit recirds have shown that there have been no further movements of soil or structures. A small maintenance crew is charged with the responsibility of keeping all openings in pavements and all joints between pavements and structures, caulked or cement grouted, so as to assure that no storm water will enter the soil in the paved area on the river side of the cut-off drainage trench. The same crew regularly cleans out the drainage pipe and the catch basins provided in the man holes in the drainage line. As noted above, the drainage pipe has been steadily discharging a stream of clear water at each of its river outlets.

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IV c 10

SLOPE STABILITY STUDIES FOR THE DELTA-MENDOTA INTAKE CANAL

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SUMMARY

Because of the complexity of the field conditions, the critical character of the materials involved and the unusual depth of the cut, the slope stability analysis for the Delta-Mendota Intake Canal was performed on the basis of data obtained by a detailed field investigation and laboratory testing program. The stability analysis was based upon the Swedish theory (slip circle) as developed by Petterson, Hultin, Fellenius, and others. Before applying the Swedish method to the study of the proposed slopes, the unit weight, cohesion, and internal friction values were determined on undisturbed soil samples in the Earth Materials Laboratory.

The purpose of this paper is to present the general procedures followed for the systematic use of field investigations, sampling, and laboratory testing with a well-known slope analysis method in obtaining a rational design of earth slopes.

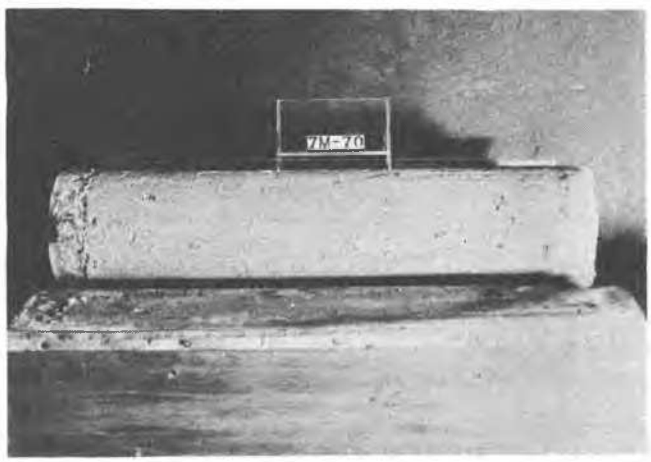
INTRODUCTION.

The intake canal for the Delta-Mendota Pumping Plant is located at the foot of the low-lying hills to the west of Tracy,California. Up to a cut depth of 80 feet at the pumping plant, preliminary estimates indicated that it was more economical to extend the intake canal rather than pressure pipes on the discharge side of the pumping plant. The logs of test holes and samples of the soil indicated a saturated cohesive soil (sandy clay,clayey sand, sand, and clay). For cuts deeper than 80 feet in this type of material, the required slopes would be flattened to such an extent that the cost of excavation plus the cost of additional right-of-way would be higher than the cost of a discharge pipeline. Due to the unusual depth of cut and the type of soil, it was deemed advisable to incorporate field experience and a mathematical analysis supported by laboratory test data in arriving at the final canal sections. The mathematical analyses which were performed on four sections (cuts 50, 65, 80, and 100 feet in depth) were based on the Swedish theory as developed by Petterson, Hultin, Fellenius, and others.

FIELD INVESTIGATIONS. SAMPLING. AND LABORATORY TESTING.

The investigation program consisted of drill-hole exploration, sampling, and laboratory testing to determine the characteristics of the natural materials in the cut area.

The soils throughout the cut area are sedimentary, lenticular clayey sands and sandy clays with some pockets of sand and clay.These sediments are compact and cohesive except for a few sandy beds, up to 7 feet thick, that are moderately friable. The clays are stiff and compact. The groundwater table lies at a depth



Dennison sample after casing was removed.

FIG.2