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SUB-AQUEOUS CONSTRUCTION METHODS ADOPTED DURING THE EXECUTION OF THE LAHORE SEWERAGE SCHEME.

BY

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Introduction

The Lahore Sewerage Scheme, a part of which has been executed during the past decade, was designed by D. A. Howell in 1937, and was estimated to cost Rs. 2,44,44,160. The scheme provided for a complete sewerage system to the areas within the municipal limits which were likely to be developed in the coming 50 years, a total acreage of 9,124. Starting from Ramgarh and Shalimar on the East, the area extended to Qila Lachman Singh and Krishan Nagar on the West. The Northern boundary of the area was Khui Miran and Tajpura entending up to Chauburji on the South.

The author of the Scheme did foresee the difficulties of construction and the higher cost of sub-aqueous construction of sewers and pumping station chambers. He, therefore, made a special effort to shorten the length of the sewers and to keep the gradients as flat as possible in order to avoid going deep below the spring level. Although one central pumping station is the ideal thing to have, yet he had to split this extensive area into 5 different zones of sewers each leading to its respective outfall. By doing this, he shortened the lengths of sewers.

In order to avoid the sewers going deep under the ground, another important method adopted was to provide a subsidiary pumping station at a point along a sewer where it dipped down too deep under the ground. A balance was kept between the cost of constructing the pumping station and the cost of the sub aqueous sewer. If the cost of the latter worked out to be higher than former, a subsidiary pumping station was provided to lift the sewage into another sewer running at a higher elevation. One such typical example is the Chota Ravi Pumping Station.

Current Methods of Sub-Acqueous Construction

In the past years the technique of doing construction work below the spring level has developed a great deal. Caissons have been sunk under the most difficult conditions to depths in the range of 120'. In the treacherous sands, caissons have been lowered with the help of compressed air. The positive pressure of compressed air from inside the caisson balances the hydro-static head and keeps the water from entering the excavation. Properly designed sheet pilings with extensive dredging operations have made possible the construction of engineering structures. Under water concrete has been laid by drop-bottom buckets or by hopper shaped long pipes delivering the concrete mix to the floor

of the excavation. Concrete has also been deposited by means of bags filled with wet-mixed concrete or with dry-mixed materials. The bags are partly torn and the cement paste welds together the various bags into one solid mass. In cases where the structure had to be placed on the bed of a body of water, subway tunnels, water pipes, and outfall sewers have been cast dry on land, bulk headed, towed to destination and sunk into position with the aid of divers.

Sub-Aqueous Construction Methods at Lahore

The object of this paper is to present to the practical engineer some of the problems encountered in connection with the Lahore Sewerage Scheme for under-water construction and the methods with which they were tackled. Due to absence of elaborate machinery, special tools had to be improvised and ways devised to suit the local conditions. The experience gained in solving these problems will cetainly prove helpful to an engineer doing any construction work on structures under the spring level.

The methods adopted can be classified as follows :—

(1) Pouring concrete under water like the construction carried out at Main Outfall Works, Lahore.

(2) Lowering the spring level by well points and laying concrete in air, as was done for plugging the suction sump at Rajgarh and the laying of 42″ internal diameter sewer at Tajpura under 8′ head of water.

(3) Laying the coarse aggregate under water and injecting the grout in it by the method termed as "Colcreting." The example of this method being the plugging of pump chamber well at Tajpura.

Each of the above methods are being described in detail in the sequence enumerated above.

1. POURING CONCRETE UNDER WATER

Construction at Main Out Works

An example of pouring concrete under water is the extensive sub-aqueous construction carried out at the Main Outfall Works of Part I of the Lahore Sewerage Scheme at Sant Nagar. The Inverts of the two 57″ internal diameter outfall sewers approached the works near the spring level which was normally 675.50. City Outfall Sewer had an invert level. of 674.38 being almost at the same level as the spring level. Central Civil Station Area Sewer had an invert level of 671.05 being 3.45 lower than the normal spring level. Therefore, the work of construction of various units of the Works had to be carried out at levels even lower than the invert levels of the Outfall Sewers.

As the Works are located at a distance of $\frac{3}{4}$ mile only from the Ravi River, any change in the level of water in the river had an effect on the water level of the Works. A fluctuation of up to 10′ has been noticed during the extreme dry periods and the time when the river is in flood. Therefore, the construction work had to be carried out during the dry periods of the year so as to minimize the working depth of water.

Wells had to be sunk on reinforced concrete curbs and plugged. Units completed like this were the detritus chamber, the fine screen chamber, suction sumps and the pump chambers. The diameter and the depths of cement concrete plugs are shown in Table No. 1.

TABLE No. 1

THICKNESS OF 1 : 2 : 4 CEMENT CONCRETE PLUG IN VARIOUS CHAMBERS

Item.	No. of Units	Distance of the bottom from Spring Level = S	Depth of C. C. Plug = P	Ratio S/P.
1. Detritus Chamber with elliptical shape size 44′ × 49′ with 3′ thick walls.	1	16·75′	9′ or	1·96
2. Fine screening chamber circular in shape, size 44′ D, with 3′ thick walls.	1	11·75′	7′	1·68
3. Suction sumps circular in shape. size 24′ D, with 2-3′ thick walls.	3	22·96′	10-25′	2·24
4. Pump chambers circular in shape, size 24′ D, with 2′-3′ thick walls.	3	12·75′	6·25′	2·04

Thickness of the Plug

In determining the thickness of the plug, the principle has been kept in view that all the hydro-static thrust on the base of the plug has to be counter-balanced by the weight of the cement oncrete. If the weight of cement concrete is taken as 140 pounds per cubic foot then each foot of cement concrete will support 140/62.5

=2.24′ of hydro-static column. Therefore, theoretically, the ratio of the distance of the base of the plug from the spring level to the depth of cement concrete plug should be less than 2.24. Last column of Table No. I lists these ratios for various plugs. It will be seen that for the two big chambers the ratio has been kept below two. For the smaller chambers, the ratio is above two with no margin for safety. As no dynamic forces are involved it is not necessary to allow a factor of safety.

Plugging of the Detritus Chamber

As a typical example of the sub-aqueous laying of cement concrete, the plugging of detritus chamber is being described. The chamber was of an elliptical shape with axis of 44′ and 49′ respectively. The thickness of the plug was 9′. The 1 : 2 : 4 cement concrete had to be laid under water at depths of between 7.75 to 16.75′. The details of the plug are shown on Plate No. 1.

Sinking of Well

Sinking a well of such a big size offered a number of complications. Excavation was carried down to spring level and a heavily reinforced concrete curb laid. It was feared that cracks might occur due to stresses brought about on account of uneven sinking of the well sections. In order to bind up the well into a more compact unit, two reinforced divide walls along the axis were built. These walls divided the well into four compartments.

Excavation under the spring level was done by means of mechanical dredgers worked by steam winches. Duplicate set of boilers was kept operating so that each will act as a standby for the other in case of failure. Four dredges worked simultaneously, one in each compartment and the divers were constantly watching the progress of the sinking. Care was exercised to see that equal amounts of sand were excavated out of each compartment allowing balanced settlement of the well. The well was sunk to the desired level and the verticality of the walls carefully checked. In spite of the machinery available, the progress of work was extremely slow and it took almost 6 months to sink the curb to its proper level.

Laying Concrete

The mix of concrete used was 1 : 2 : 4. It was decided to first lay only 3.5′ thick plug out of the total thickness of 9′. The intention was to make sure that the bottom was effectively plugged with concrete laid under water, the rest of the plug being finished by depositing concrete on a dry floor. Concrete was laid by means of a specially constructed box of 1 cubic yard capacity which was filled with concrete and lowered to the bottom of the well. By suitable manipulation of the chains, the box

was opened at the desired depth and the batch of concrete deposited. Each one of the 4 compartments was handled separately. Concrete mix was prepared by hand mixing and was deposited continuously in order to avoid formation of constructional seams. It took 9 hours to finish one compartment.

The plug was allowed to set for 28 days under water. At the end of this period, water over the plug was pumped out to see the effectiveness of the plug. The divide walls were dismantled up to 1′ above the 3½′ plug. It was noticed that numerous leaks still existed on the surface of the plug and water was seeping out. This meant that a weak joint will be formed if additional concrete was poured on the top of the floor without rendering it completely dry. Therefore, a small sump 12″ deep and 12″ in diameter was made in one compartment and water from the leaking seams led into it by means of small drains, one inch deep. The tops of these drains were covered with precast cement concrete slabs joined to the floor with cement mortar in order to avoid the inflow of cement into the drains at the time when cement concrete is poured fromthe top. 1½″ internal diameter pipe with a foot valve was placed vertically in the sump and water constantly pumped out by means of a small hand pump. Thus the top of the floor was rendered dry. Top one inch thickness of the floor was chipped off to remove the weak top and the rest of the 5½′ of the plug laid on dry floor. After the concrete had been laid, the 1½″ pipes were also plugged in by pouring 1 : 2 : 4 cement concrete mix into them.

Draw Back of Sub-Aqueous laying of Concrete

Concrete laid in water has the basic drawback that there are too many uncertainties. The batch of concrete gets washed in the process of laying and weakness is liable to occur. This defect is not serious if the concrete has to bear compressive loads only as in the bridge piers. On the other hand, if it is desired to get an impermeable concrete floor like in this case, then washed concrete offers a definite drawback as a portion of the structure will stay permeable. One of the plugs laid for the temporary pumping station at the Main Outfall, laid in the fashion described above, was ripped open it was found that stratification of the various constituents of the 1 : 2 : 4 mix had taken place. Coarse aggregate had settled to the bottom, the fine aggregate was on the top of it and neat cement had the top-most layer. Besides this defect, the possibility of isolated weaker points in the construction is always there. Concrete poured on a dry base is definitely much more reliable because of its homogeneous deposition in all the space. Although some stratification does occur in the process of "colcreting" under water also, yet the fact that mix is homogeneous in the same horizontal plane makes it more reliable. Also in "colcreting," the coarse aggregate has a uniform distribution in the entire volume and the stratification is limited to the fine aggregate and cement only.

Position of Detritus Chambers in Sewerage Pumping Stations

At the time of the design of the Main Outfall Pumping Station, the question as to whether the Detritus Chamber should be placed before the pumping chamber or after it was thoroughly gone into. Placing the detritus chamber after the pumping chamber would avoid the tedious sub-aqueous work involved in the construction of the detritus chamber. As seen in plate No. 1, it was finally decided that it should be placed before the pumping chamber. This was done in order to avoid the wear and tear inside the pump casings and the impellers due to the abrasive effect of grit. Although some of the pump manufacturers did specify their pumps as being able to handle the normal grit particles, yet it was deemed desirable to protect the expensive pumping machinery from the ill effects of grit. As a bulk of the sewage coming to the pumping station was to be contributed by the surface drains in the Lahore area through gulley gratings having a screen opening of about $\frac{1}{2}$", there was the possibility of excessive grit particles entering the sewers and reaching the pumping station. Therefore, the detritus chamber was provided before the pumping chamber. This arrangement insured that the sewage pumped by the pumps will be free from grit. This involved the construction of a big structure described above, below the Spring Level and its construction was not only a tedious job but a very expensive one too.

The modern pumps are designed with special wearing surfaces to pass the grit without any injurious effects. The nature of the grit which has been handled at the Main Outfall Works during the past 2 years shows that most of the grit particles settling in the detritus channels are of size less than $\frac{3}{8}$ of an inch and these could be very easily pumped through by the pumps installed. The high velocities maintained on the suction, delivery and within the body of the pump are more than enough to keep these particles in suspension and eject them on the delivery side.

Therefore, for future constructions, it will be advisable to keep the detritus chambers after the pumping chambers. By so doing the detritus chamber could be constructed on the ground level which will be very cheap in cost due to the sub-aqeuous construction being avoided. Also in these ground level Detritus Chambers it will not be necessary to raise the grit through a height as is the case with the low detritus chambers. This will decrease the cost of operation of the detritus chamber machinery.

2. CONSTRUCTION OF 42" i/d CIRCULAR SEWER AT TAJPURA LAHORE UNDER 8' HEAD OF WATER. (WELL POINTING)

At the time of inception of the Lahore Sewerege Scheme it was expected that no sewers will be constructed under more than 2½' head of

water. By experience it was found that upto a depth of 4' of water, circular sewers could be constructed without removing water from the trench in which excavation below the sub-soil water level was done by means of a "Jham". Vertical shuttering by the sides of the trench with circular shuttering made out of M.S. plates were put in place, (Plate No. 3 fig. B). Between these, 1 : 2 : 4 concrete was poured which formed the cradle for the sewer. The cradle excluded water completely and sewer could be constructed within it.

In Tajpura area the 42" i/d re-inforced concrete sewer had to be built under about 8' head of water. The increased depth of water had been caused due to the increase in the spring level after the floods of 1950. The spring level receded on the average at a rate of 9" per month. Waiting for the spring level to fall would have meant long waiting and wastage of time. Works had to be pushed through under the adverse conditions. Working under such a depth was impossible by the method described above. Also to ensure that no leakage was present in the re-inforced concrete cradle at the bottom, it was necessary to adopt special methods to lay the cradle accurately and without any structural flaw in it. Therefore, it was found necessary to depress the water level by well points.

Up to spring level closed timbering had to be done in order to hold back the sand. Below the spring level excavation had to be done by means of 'Jham' operated by divers.

Two alternate construction methods were tried :—

(i) Without Sheet Piling.

First it was decided that the spring level be lowered to the base of the cradle and excavation done dry. In order to accomplish this dotted pipes with strainers underneath them were placed in the trench within the closed timbering.

The strainers consisted of 4" i/d cast iron pipes 18' long with one inch diameter holes drilled in them along their length.

Coconut fibre string was tied around the pipes which kept the sand out of the strainer. 16 strainer pipes of this type were lowered at 5' distance along both sides of the trench to cover the total length of 35' at a time.

Pumping was done at 24,000 gallons per hour or at higher rates by means of self priming pumps. The spring level went down. When the excavation was done in sand thus dried up, the side walls of the excavation did not stand vertical and started to crumble down. Trial was made to continue closed shuttering in the strata where the water level had been depressed, *i.e.* below the normal spring level down to the base of the cradle. The closed timbering proved in-effective because sand would

flow through the slots in the timbering. Also when failure occured in the pumps the bouyancy lift on the wooden struts forced them out. Therefore, it was concluded that is will not be convenient to excavate below the spring level just by lowering the spring level, high rate pumping and doing closed timbering in vertically excavated trenches.

One method to avoid these difficulties would be to make the sides of the trenches sloping, say at an angle of 30°, and then depressing the water level by well points. This meant a much bigger strip of area to be acquired for the sewer construction and additional earth work. Any earth work done under spring level would necessitate the constant use of pumps and any added earth work below the spring level would thus materially add to the construction costs. Therefore, this method also was not resorted to either.

(ii) By Sheet Piling.

As the method described above did not work well, it was decided to use sheet piling for going under the spring level. It served the dual purpose of holding back the sand without any leakage at the joints and acting as shuttering for pouring concrete. Sheet piles consisted of 4′ × 8′ × ½″ thick M.S. plates with grooves made on the sides. The two sheet pile lines in the trench were kept a fixed distance apart by means of struts. The new position of the well points was established outside the trench as shown by the full line strainer pipes.

In order to give support to the toe of the vertical shuttering above the spring level and to avoid its pressing against the top of the sheet piling, 4″ internal diameter 18′ long cast iron pipes were sunk. Between the top of the pipes and toe of the shuttering suitable wedges were placed. As spring level was approached, the sheet piling was put in position and hammered down as far as possible. Then by means of "Jham" the sand was excavated and the sheet piling lowered further by application of pressure or hammering. Water was pumped from the well points to keep the water low enough to facilitate the lowering of sheet piling. When the sheet piling had been lowered to the desired level, the sand surface was levelled up and brick pitching laid under water by divers in order to give a good base to the cement concrete cradle.

Pumping was started from the net-work of well points at the rate of 48,000 gallons per hour which depressed the spring level in the trench by 5′ in 3 hours. At this time water level was one foot below the top of the sheet piling. In the remaining 3′ of water, concrete cradle could be laid in a controlled condition. 35′ of cradle was completed in a day. Once the cradle had been laid, it was easy to put in the inner cement concrete ring and the radiated brick work ring.

Utility of the Method.

The method of sewer construction by well points is not only very

useful but indispensable at times. The strainers, pipes, couplings, hoses and other accessories have to be so arranged that the system can be assembled and dismantled easily. The ease of lowering and with-drawing the well points is an important feature in making the method attractive. The pumping machinery should preferably be in duplicate and reliable. Any failure ot the pumps will give rise to discouraging results. Once the staff gets trained in handling the equipment, rapid progress is possible.

Plugging of Suction Sump at Rajgarh Pumping Station by Lowering Spring Level with well Points.

Well pointing technique with slight modifications was also tried for sub-aqueous construction at Rajgarh Sewage Pumping Station. 22′ deep suction sump of 20′ internal diameter with 22½″ thick walls had to be plugged with an average thickness of 5′ of 1 : 2 : 4 cement concrete mix. The depth of water to be lowered was 6′ (plate No. 3).

Equipment used.

At the time when the work was carried out neither high capacity pumps nor 4″ internal diameter or smaller strainers were in the stores. Two pumps of 6,000 gallons per hour capacity were available for use. It was decided to lower the strainers within the sump well below the base of the plug, rather than lowering them around the outside wall of the well. This was done to minimize the area from which water will have to be pumped.

It was kept in view that the strainers were not to be removed after plugging and were to be left buried under the cement concrete plug after the completion of the work. A cheap strainer was improvised as shown on Plate No. 3. It consisted of 8 Nos. 5/8″ diameter 5′ long mild steel bars connected at the ends by flanges forming an octagonal pipe with longitudinal slots. A coconut fibre rope was wrapped all around the pipe to form the strainer. The strainers were lowered in place by first doing a 10″ i/d size boring lowering the strainer in, and then withdrawing the boring pipe.

The strata consisted of sand mixed with excessive quantities of clay and, therefore, it was expected that even with low rates of pumping spring level could be lowered to the bottom of the excavation of the sump well.

To start with, 5 Nos. strainers were placed at equal distances apart in the well each at a distance of 2′ from the curb. The tops of the strainers were connected to a common header.

Pumping was done with a 5,000 gallons per hour capacity pump which only yielded 4,000 gallons per hour of water. This low yield was due to the fact that sand contained excessive clay which reduced the permeability of the starta. Although practically the whole of water was

drained out of the well still water kept seeping in along the periphery of the well. In order to intercept water as it passed by the curb of the well, it was decided to place the strainer under the curb along the full perimeter of the well, and the above system of horizontal strainers was connected to a separate self-priming pump of 6,000 gallons per hour capacity. This stopped the seepage of water in the well completely and the base became dry for laying concrete.

Concrete was deposited within 8 hours and pumping was continued 36 hours after that to allow partial setting of cement. The common headers of the two strainer systems were plugged up with 1 : 2 : 4 cement concrete mix poured into them.

Utility of the Method.

The method is much more reliable than laying concrete under water. Batches of concrete can be laid with greater degree of surety wihot any danger of their being washed up. The drawback in the method is that pumping has to be carried on long after the work is completed so as to allow the concrete to develop some strength. Of course, filling up the well to the spring level after the cement has attained the initial set would minimise the period of pumping. This method is not nearly as convenient as the method of plugging with grout to be described in the following pages.

3. USE OF GROUTING POR SUB-AQUEOUS CONSTRUCTION

Work of plugging the suction sumps of the sewage pumping station at Sharaqpur had to be carried out. Mr. Azam, Chief Engineer, P.W.D., B & R visited the works in May, 1952 and proposed the use of "Colcrete" process for plugging the wells which were being sunk on site. In order to study the effectiveness cf grout injected under water, a few preliminary experiments were made and found to be successful. Actual plugging of a well was first done in Tajpura at Lahore. The method proved successful and is recommended for sub-aqueous construction.

"Colcrete" Process.

It is the trade name of the patent process for grouting of Colcrete Limited, England, in which coarse aggregate is placed in position and its interstices are filled with a grout of cement, sand and water. Cement is churned vigorously with water for 15 seconds in a centrifugal mixer. This breaks the air film sticking to surface of cement particles and water coming so closely in contact with it causes complete physical hydration, thereby forming a colloidal solution. A colloid will stay in suspension indefinitely. The chemical hydration of cement takes place when it sets after the grout has been laid. After the cement has been mixed, requisite quantity of sand is added and thoroughly churned by centrifugal action, and the mix is termed "Colgrout". Colgrout is lead to the previously laid coarse aggregate by a rubber hose.

The fact that cement is in colloidal suspension and the colloidal mix formed has a specific gravity of more than 2, it will displace water and

not mix with it. As the colgrout is repugnant to water, there will be a sharp line of separation if the two are put together in a vessel without any turbulence. Colgrout being higher in specific gravity will sink to the bottom and displace an equal volume of water out of the vessel.

Tests Carried Out.

In order to study the relative dispersal of sand and cement through a mass of coarse aggregate, experiments were carried out. The grout was prepared in "Colcrete Mixer Mark III" obtained from Colcrete Ltd. England.

A 45 gallon tar drum was filled with brick ballast of size $\frac{3}{4}$" to $1\frac{1}{2}$" as indicated in plate No. 1 fig. B. It was completely filled with water. 1 : 3 grout was prepared using 12 gallons of water per cwt. of cement. 3 batches using $\frac{1}{3}$ cu. ft. of cement in each were injected within 10 minutes period. It was noticed that as grout entered at the top of the coarse aggregate it neatly displaced the water in the drum without causing even mild turbidity. The concrete was allowed to set for 24 hours and the next day a 3" wide strip was cut along the length of the drum for inspection. 5 different samples were taken as indicated on the diagram and analysed chemically for the cement sand ratio. The results are tabulated in table No. 2 and plotted on plate No.1:—

Sample No.	*Depth of sample.*	*Percentage of cement to sand by volume.*	*Ratio Cement : Sand.*
1.	0"	51	1 : 0.95
2.	7.5"	38.5	1 : 6.6
3.	15"	14.5	1 : 5.9
4.	22.5"	14	1 : 6.1
5.	30"	14	1 : 6.1

Table No. 2. Dispersion of cement and sand with grout injected from the top of the coarse aggregate.

It will be seen that a big percentage of cement stayed at the top while the mix at the bottom was very lean being 1 : 6. The curve in diagram No. 1 on plate No. 1 shows that upto about 1 foot depth good penetration of cement took place, the content of cement being 25 per cent. Tests were carried out in the soil research Laboratory of the P. W. D., B & R Branch to find the crushing strength of concrete prepared by grouting $\frac{3}{4}$"—$1\frac{1}{2}$" brick ballast with 1 : 6 grout. The crushing strength came to an average of 350 lbs. per sq. inch. This value is on a very low

side as compared to 1 : 2 : 4 cement concrete which has a crushing strength of 2,000 lbs. per sq. inch under similar conditions of tests and 28 days curing. As there is no possibility of any tensile stresses being created in the plug of a sump well even 1 : 6 mortar to fill interstices of the coarse aggregate will be quite alright.

As the dispersion of cement obtained by injecting the grout from the top was very non-homogeneous giving higher cement percentage on the top, it was decided to see the dispersion by injecting the grout at the bottom of the course aggregate. Therefore, grout as described in the last test was injected from the bottom of the coarse aggregate, as indicated in plate No. 2. The results are tabulated in table No. 3 and plotted on plate No. 1 : -

Sample No.	*Depth of sample.*	*Percentage of cement to sand by volume.*	*Ratio Cement: Sand*
1.	0"	50	1 : 1
2.	6"	17.5	1 : 4.7
3.	12"	14.1	1 : 6.1
4.	18"	14.7	1 : 5.8
5.	24"	14.3	1 : 6
6.	30"	14.1	1 : 6.1

Table No. 3. Dispersion of cement and sand, with grout injected from the bottom of the coarse aggregate.

In this case also a higher concentration stayed at the top while throughout the rest of the mass the mix stayed on the average in the range 1:6

The above two experiments gave the surety that even at such high rates of grouting with 1:3 mix at least 1:6 mortar could be obtained. With low rate of grouting better dispersal of cement and sand is to expected because the lower layers will be deposited first and before the upper layers are injected the lower layer will have get. This will prevent the settling of sand particles in the grout which causes accumulation of cement in the top layers. When the dimensions of the actual job to be grouted are big, better dispersal is expected because the rate at which the mass of the coarse aggregate is filled with grout will be very low.

Plugging of well at Tajpura, Lahore.

16 feet diameter well of the pump chamber had to be plugged with concrete under 8′ water. The total thickness of the plug was 5′ (Plate

No. 3). First it was decided to lay concrete in the lower two feet thickness and after having ascertained the effectiveness of the plug to finish the rest of the three feet.

Arrangement for Grouting.

The well was sunk to the proper depth and the sand at the bottom levelled up. On this 3" thickness brick-pitching laid without mortar in order to provide a solid base on which the concrete will rest. In order to inject grout from underneath first a 9" layer of 1" to 2" size brick ballast was laid. On this seven pipes of 3" diameter were placed vertically. These pipes were provided with 8 holes of $\frac{3}{4}$" diameter in the lower 6" of the base in order to deliver the grout horizontally. Having placed the pipes in position, remaining 1'—3" thickness of brick ballast was laid. The pipes were anchored on the top such that they could be easily withdrawn and refixed higher up. Therefore, grout could be delivered at any desired level.

The pipes were spread so that no point in the surface to be grouted was at more than 3' distance from the source of grout. This distance was fixed in the light of past experience. Further experience in sub-aqueous grouting may show that pipes spaced further apart would serve the purpose just as well. It will be an interesting subject for further investigation.

Ratio of the Grout mix.

Although in conducting the experiment mix of 1 : 3 was used, yet for the actual work the mix used was 1 : 1. This was done due to the uncertainties involved when the grout goes under water. Also in a richer mix, there is lesser tendency for the sand particles to settle in the delivery hose and clog the system, due to the higher density of the colloidal solution.

Ordinary slow setting cement and local Ravi sand was used. Each batch of grout was prepared with 1 cwt. cement, 1 cwt. sand and 6.75 Imperial Gallons of water. This was the minimun quantity of water which gave a workable mix.

In order that the supply of grout be continuous, a 45 gallon tar drum was connected to the outlet of the "Colcrete" machine pump and the rubber delivery hose pipe connected to this drum. Continuous flow of grout prevented the tendency of sand to settle in the hose pipe or the choking of the voids of the coarse aggregate due to sand settling in, and, thereby, hampering the flow of grout to the farther off points.

In order to determine more economical ratio of mix and the amout of water to be added, further investigations are required. Experiments in the laboratory and in the field will throw more light on the subject.

Injecting Grout

To start with, four batches of grout were injected into each pipe turn by turn. This filled up the voids of the lower 9" layers. Then the pipes were raised by another 9", and 6 batches of grout further poured into each pipe. This meant that lower 18" had been grouted. Without raising the pipes any further, additional grout was poured in each pipe. A diver was sent in the well and by touch he could exactly state the height to which the grout had risen. The diver was constantly checking the level of the grout and the process continued until the whole surface of the coarse aggregate was completely covered.

Special care was taken to maintain the level of water in the well constant at the spring level. This was necessary because the volume of grout poured in displaces an equal volume of water which if not pumped out, will cause an increase in water level inside the well. This will cause the flow of water from the well to the subsoil strata causing washing of the grout. A self priming small capacity pump was used for this purpose. The foot valve of the pump was placed flush with the spring level. As soon as the water level rose above the foot valve, it was pumped out. When water level fell after pumping, air went into the suction pipe and broke the suction. It may be noted that after a certain thickness of grout has been poured, the hydrostatic pressure inside the well is more than the pressure outside although the water level inside and outside is the same. This is due to the higher specific gravity of the grout. What this means is that due to higher pressure inside some grout may be forced into the sand surface immediately below the coarse aggregate and the brick-pitching. This will be a beneficial factor as it will further stabilise the foundation on which the plug has to rest.

Inspection of Plug.

After 14 days of curing, water inside the well was pumped out and inspection made. The surface had about 2 inches of scum and below that the mortar had beautifully set. The interstices were completely filled and the grout had spread evenly over the whole surface. A small pit made showed that the dispersal of cement and sand was more or less uniform through-out the depth. Scum was removed in order to allow the remainder of the 3 feet plug to be laid dry.

Utility of the Method.

The method is by far more convenient as compared to the other methods. It is more reliable than pouring concrete under water as there is no danger of the washing away of cement. Once the method is organised the work can proceed at a much greater speed. The

depth under water where the plug is to be laid is immaterial. This is a very important feature in favour of the process. In the well pointing methed it is impossible to work when the depth of water is excessive and the other methods involve constructional difficulties.

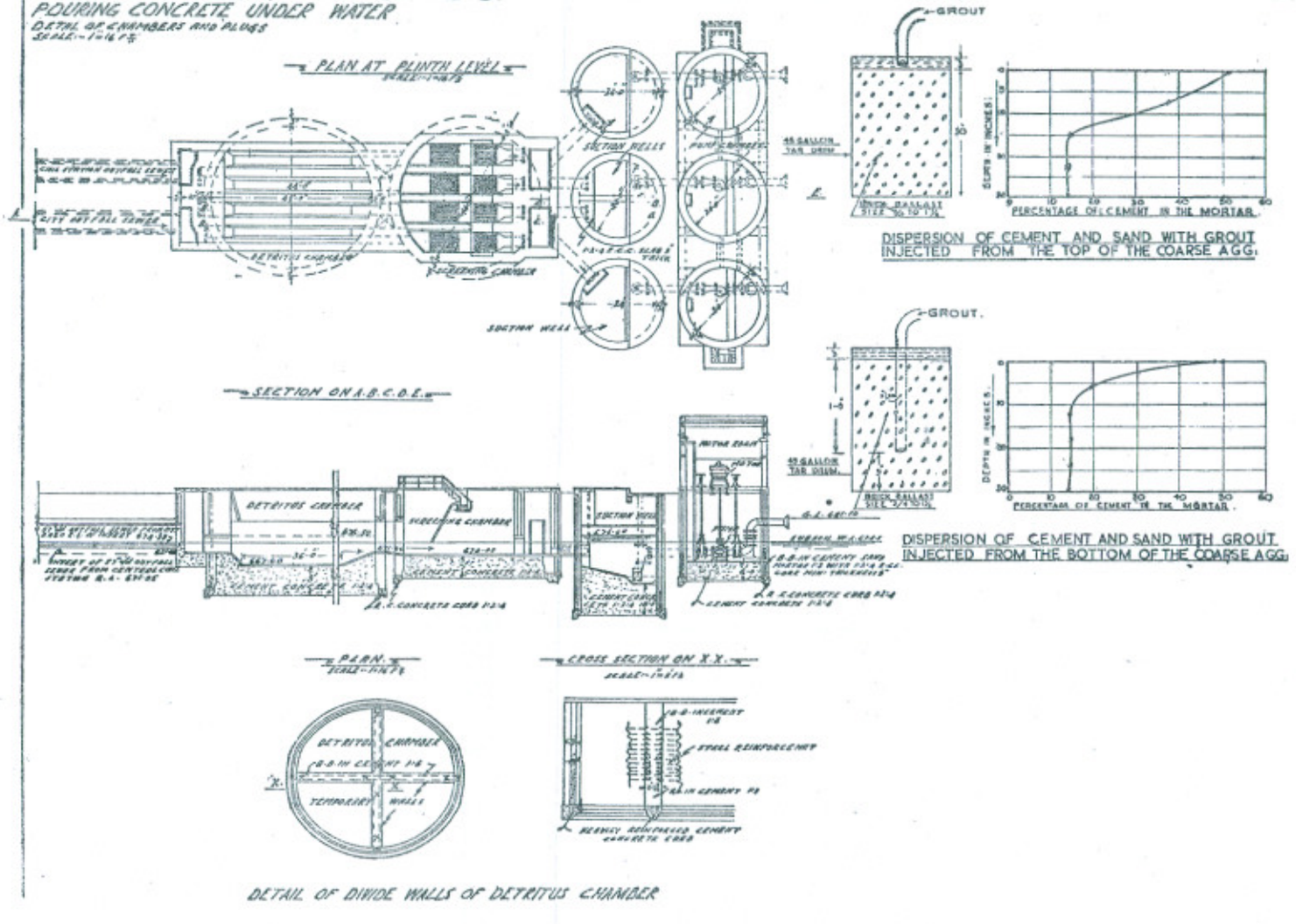
Placing reinforcement in the coarse aggregate prior to injecting the grout will decrease the thickness of the plug as it could be designed to take the hydrostatic thrust acting as a slab.

Acknowledgement.

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PLUGGING OF WELLS AT MAINOUTFALL BY POURING CONCRETE UNDER WATER

DETAIL OF CHAMBERS AND PLUGS
SCALE:- 1/16 F.



DISPERSION OF CEMENT AND SAND WITH GROUT INJECTED FROM THE TOP OF THE COARSE AGG.

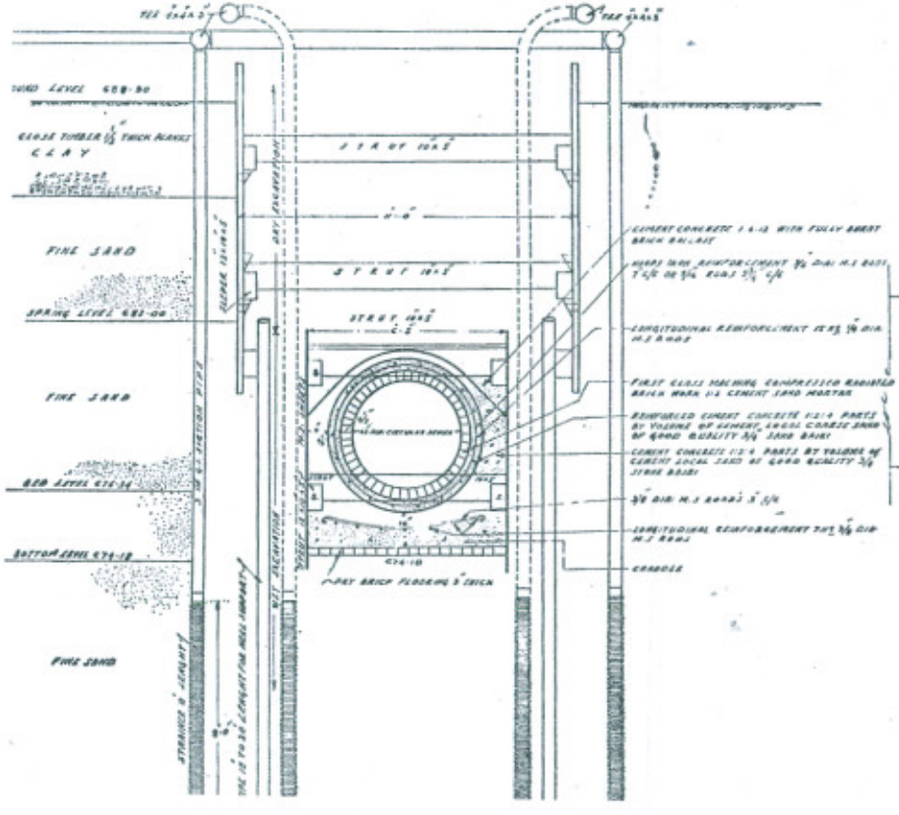
DISPERSION OF CEMENT AND SAND WITH GROUT INJECTED FROM THE BOTTOM OF THE COARSE AGG.

DETAIL OF DIVIDE WALLS OF DETRITUS CHAMBER

EWER CONSTUCTION AT TAJPURA.

ENT OF WELL POINTS FOR LOWERING SPRING LEVEL

FIGURE A.



PLAN SHOWING THE ARRANGEMENT OF BORING AND HEADERS FOR LOWERING SPRING LEVEL IN TRENCH

SCALE 1" = 4'

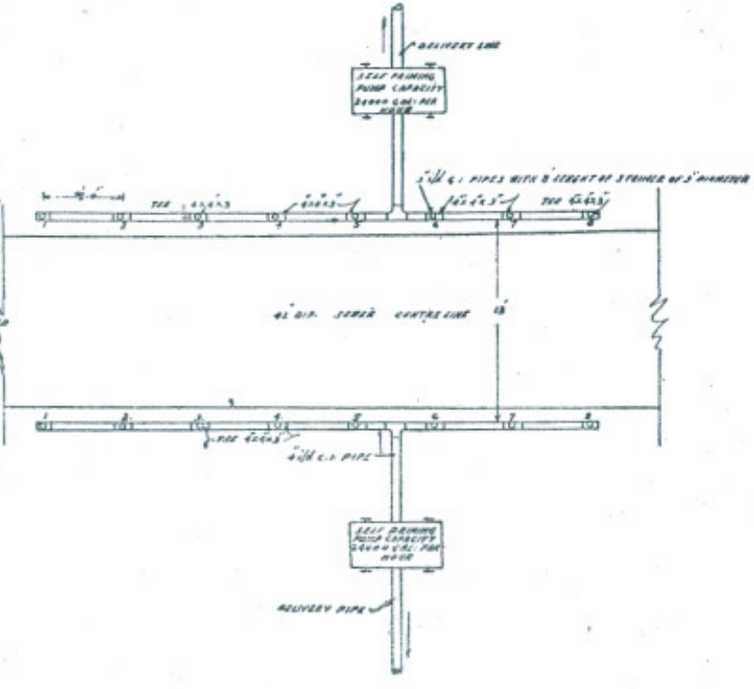


PLATE No 3

PLU..ING OF SUCTION SUMP AT RAJGARH PUMPING STATION BY VERTICAL WELL POINTS AND HORIZONTAL STRAINERS

PLUGGING OF PUMP ROOM WELL AT TAJPURA PUMPING STATION BY CALCRETING

