Paper No. 339

Dewatering of Foundations

By

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Synopsis :—

Dewatering of a formation to lay a structure, is an important problem of engineering construction.

In this note the advantages of dewatering by tube wells or by well points method are discussed and compared with open sump well pumping.

Method to estimate infiltration into an excavation and to plan dewatering arrangement by tube wells are given. Results of seven different sites are discussed where dewatering has been accomplished by tube wells proposed according to the laboratory studies.

In the end relative working of well point system is compared with tube wells with regard to their performance, cost of machinery and operation etc.

Introduction :

There is no important construction where an Engineer is not faced with the problem of dewatering of an area to lay the foundation. The construction may be a barrage or a dam in a river, harbour near a sea or a multiple story building, sub surface is to be dewatered to lay the foundation on a dry bed. This is a common and an essential engineering problem.

In this country dewatering has often been accomplished by constructing square brick caissons at selected points and sinking them into the formation to a few feet below the deepest level to be excavated and its bottom is plugged in with cement concrete. Side holes are kept in the walls through which water seeping from the formation enters into the caisson. This water is pumped out. (1) Water oozing out of the formation flows at a steep gradient to a near by cunette or a drain which leads into the caisson. Very often sand also flows along with the water into the caisson and it has to be removed off and on, to keep the caisson functioning. This method is called the open or sump system of dewatering.

There is another method not very common in this country. This is called the well point system. In this paper a third system of dewatering is

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discussed. It is called dewatering by tube wells. This method has been successfully used at several sites. Full details about this methods and its advantages compared with the above mentioned two methods are discussed.

Elementary conceptions about weight of a submerged soil :—

Alluvial deposits consists of gravel, sand, silt and clay. The specific or unit weight of these deposits depends upon the nature of the materials of which these are the fragments. The unit weight or the specific gravity is the ratio of the density of the substance to the density of water which is taken equal to 1 in C. G. S. system for all practical purposes and is equal to 62.4 when expressed in F.P.S. system. The density of gravel, sand, and silt very often lies between 2.6 to 2.7 gm. per c.c.

Porosity is another physical constant for granular materials and is expressed as :

$$n = \frac{V_v}{V} \times 100$$

where n = the porosity or the volume of voids as percentage of total volume.

V_v = volume of voids.

V = total volume.

The porosity of a material varies with the size of the grains, so that finer particles have higher order of porosity. This factor for sands of the former Punjab has been found to lie between 35 to 45 percent, so that its average is taken as 40 percent of the total volume. The porosity of clay can be as high as 60 percent and even higher. While considering the weight of a given formation, it is convenient to express it in terms of void ratio, *e*, which is stated as:

$$e = \frac{V_v}{V_s} = \frac{n}{100 - n}$$

$$\text{or} \quad n = \frac{e}{1+e} \times 100$$

where V_s = volume of the solid.

If a soil is dry, its unit weight γ_{dry} is equal to $\frac{e}{1+e}\gamma_w$ and submerged weight $\gamma_{sub.}$ is equal to $\frac{G + Se}{1 + e}\gamma_w$ and at complete saturation, when the degree of saturation S, is zero, the unit submerged weight which is called the buoyant unit weight, $\gamma_{buy.}$, is equal to

$$\gamma_{buy} = \frac{G - 1}{1 + e} \times \gamma_w$$

In this relation G is the specific gravity of the materials.

S = is the degree of saturation and

r_w = the specific weight of water.

In a problem of dewatering when water-table is at a high elevation and seepage takes place to the lower excavated level, the seepage force per unit volume is equal to :

$$J = \frac{A\,h}{L} \times \gamma_w = \frac{A\,h}{L} \times 62.4$$

In case of upward flow, the seepage force is resisted by the weight of buoyed sand which is equal to $\frac{G-1}{1+e_{10}} \times 62.4$, so that at the critical hydraulic gradient $\frac{Ah}{L}$ is equal

$$\frac{G-1}{1+e} = 1.$$

Thus at a certain order of the gradient, the sand becomes 'quick'. A fine sand due to its low order of permeability (2) becomes 'quick' very easily. It is thus concluded that an upward flow of water causes a decrease in the bearing value of the formation.

Lifting of particles :—

The velocity of a particle to fall through water is expressed by

$$V = \frac{\gamma_s\ \gamma_w}{18\mu} D^2$$

where V is called the terminal velocity or that constant fall velocity at which a particle of a given diameter D, and of density, γs falls through a liquid of density γw at a given temperature having viscosity equal to μ As an example, a particle equal to 0·06 mm in diameter with $r_s = 2{\cdot}7$ gm. per cc. will fall through water at 20°C with a constant velocity of 0.33 cm. per second. Theoretically any upward velocity more than the terminal fall velocity of a particle, will keep it in suspension. Thus velocity of water particularly with hydraulic gradient above the critical order will cause lifting of soil particles and at a particular point the formation will start 'boiling' which will be particularly intense where there is concentration of flow lines. Finer particles have greater chances to be lifted up even with low order of velocity. Once a particle is brought in the flow stream it will be carried away by the tractive force of the flowing water.

The limiting velocity to move particles of different grades by flowing water may be as under(3) :

Materials	Silt.	Fine Sand.	Medium sand.	Coarse sand.	Fine gravel	Medium gravel	Coarse gravel
Diameter in mm.	0·005 to 0·05	0·05 to 0·25	0·25 to 1.0	1·0 to 2·5	2·5 to 5	5 to 10	10 to 15
Mean velocity in ft/sec.	0·49 to 0·66	0·66 to 0·98	0·98 to 1·80	1·8 to 2·13	2·13 to 22·62	2·6 to 3·28	2·28 to 3·94

This shows that particles of sand as they occur in this part of the country can be rolled away by water moving with a velocity of ½ to 1 ft. per second.

Recently some experiments were conducted in the Research Institute to study the limiting velocity required to move particles when kept in vertical position which is a case similar to tube well where the formation is held vertical by a screen or its shrouding and the flow is horizontal. The limiting velocity, at which movement of particles took place was as under :

limiting velocity to move particles of various grades in a formation kept vertical.

Mean diameter of the particles in mm.	Classification of sand according to this country field conception	Velocity in ft sec. at 20°C at which motion starts.	Reynolds number, $R_y = \frac{Vd}{\gamma}$ at that velocity.	(11) Friction factor. $F = \frac{d\triangle p}{2L\gamma V^2}$
0·545	Very coarse sand	·017	2·78	·27
0·400	Coarse sand	·012	1·4	·43
0·326	Coarse sand	·0092	0.98	·58
0·252	Medium sand	·075	0·56	·72
0·216	50% medium sand 50% fine sand	·006	0.36	1·26
0·18	Fine sand	·0032	0·17	1·8
0·146	Very fine sand	·002	·096	6·0
0·111	Very fine dirty sand	·0069	·023	10·2

Where d = mean diameter of sand grades
L = length of colume i.e. 20 Ft.
$\triangle$P = Suction Head in existence in Ft.
V = mean Velocity corresponding to a suction head
r = Fluid density

It was found that under the above stated conditions of the formation, particles equal to 0·1 mm were moved with velocity of the order of 0·0007 ft.second. The fine particles of silt and clay with diameter equal to 0·05 to 0·005mm and still finer can be moved with still lower velocity. Thus it is concluded that with an upward gradient there is a chance for finer particles to be lifted up and carried away by the current of water, leaving the formation less compact and spongy.

Difficulty of compaction of a bulked sand :

Sand particles envelope a thin moisture film around their grains. The mass of moist sand having water films join together enveloping air bubbles in between and the mass under this condition resists compaction, so that the particles do not come closer together. A fine sand with 5 to

(5)

15 percent moisture shows bulking upto 30% of its compacted volume,

A sand mass can be compacted only on complete saturation or on submergence under water and shaking to drive out the air. If a sand mass is dropped in water, it does not completely loose the entrapped air. This is driven out only after vigorous shaking. It is very difficult to compact a disturbed moist sand, on the other hand if water is drained out of a compacted sand mass and it becomes dry, it does not loose its compaction as the particles of sand are unlike clay colloids which hold the moisture with quite different types of forces.

A sand mass once disturbed is very difficult to be brought to its original compaction and bearing pressure of such a mass decreases. A structure built on a bulked sand is liable to develope hallows after the sand gets compacted by complete saturation.

Movement of fine particles through sand pores :

Sand deposits of the Indus Plains have high order of uniformity, so that majority of particles of a given deposit are of one grade. Sieve analysis of a few samples is shown in Table I. About 60 to 80 % of the particles in a specimen lie within a narrow range of the two sizes. Uniformity coefficient has been found to lie between 1 and 3, so that it is concluded that the sand deposite of Indus plains are usually of uniform grades. This property through of immense advantage for yielding water, is not so good from the point of view of bearing pressure because a well graded sand is more compact and can have greater bearing value. The uniformity of grains has a disadvantage of big size of pores, so that finer particles can easily pass through. Graton & Fraser (6)tried to work out theoritically the size of voids and porosity assuming round grains of equal size arranged either in a square or rhombic layer. His calculations of the volume of unit cell and of unit void in terms of radius, R of the grains for six different types of packing are shown below :

Porosities of various packings

Square layers	Case I.	Case II.	Case III.
Vol. of unit cell.	$8{\cdot}0R^3$	$6{\cdot}93R^3$	$5{\cdot}66R^3$
Vol. unit void.	$3{\cdot}81R^3$	$2{\cdot}74R^3$	$1{\cdot}47R^3$
Porosity %.	47·64	39·54	25·95
Rhombic layers.	**Case IV.**	**Case V.**	**Case VI.**
Vol. of unit cell.	$6{\cdot}93\ R^3$	$6{\cdot}0R^3$	$5{\cdot}66R^3$
Vol. of unit void.	$2{\cdot}74\ R^3$	$1{\cdot}81R^3$	$1{\cdot}47R^3$
Porosity %.	39·54	30·19	25·95

The cross section of the pores varies with each type of packing.

Fraser coined a term ' critical ratio of occupancy' for the ratio of the diameter of the largest spheres that can occupy the pore without disturbing the packing to the diameter of the sphere of the aggregate. He worked out the critical ratio of entrance for the tightest packing equal to 0·154D. and for most loose packing as 0·414D. The critical ratio of occupancy for the tightest packing according to Fraser is 0·414D to 0·225D and for the most loose packing, it is 0·732D. On this basis a uniform round sand of 0·2mm can have pores between 0·1164 and 0·045mm. Although this type of condition is not actually possible in natural deposits as the particles are angular in shape with many smaller ranges yet it does give some idea of the size of pores possible in a given sand packing. This also shows that some silt and clay particles equal to 0·02 to 0·002mm and of smaller sizes may pass out of the pores with oozing water without disturbing the packing and the formation will loose its compactness.

Permeability of a formation :—

Velocity of flow through a unit cross section of a medium under a unit head of water is called permeability coefficient of the medium. This is expressed as :

$$\frac{Q}{A} \times \frac{L}{h} = K$$

Where the symbols have usual meaning.

The flow of water through a medium under a given head depends upon its order of K. Seepage from a formation can be estimated only if the value of K is known. If an undisturbed sample of a formation can be extracted, it is possible to determine its K by a laboratory permeameter. If the permeability coefficient is low, it is advantageous to use a variable head permeameter. The main difficulty is about the collection of undisturbed sand samples. These can however be collected in a disturbed state and thus it is difficult to repack them according to the actual ones. The sand of our formations are uniform, with small percentage of clay and silt particles, so that if these are excluded then the rest of the samples if satuarted before and poured in water in small bits and shaken by moderate blows, can to a greater probability attain the same type of packing as the original ones and thus can give repeatedly same coefficient of permeablity. This procedure has been followed in the laboratory and permeability coefficient so determined for innumerable specimen are plotted against mean diameter or effective size as shown in Fig. 1. The variations of laboratory permeabiliy for the three different ranges of particles (?) occuring in our formation is as under :

Medium.	Diameter in mm	Permeability coefficient
Coarse sand	0·5 to 0·35	$20-6\cdot0\times10^{-4}$ ft/sec.
Medium sand	0·35 to 0·25	$8\cdot0-3\cdot0\times10^{-4}$,,
Fine sand.	0·25 to 0·2	$3\cdot5-1\cdot6\times10^{-4}$,,

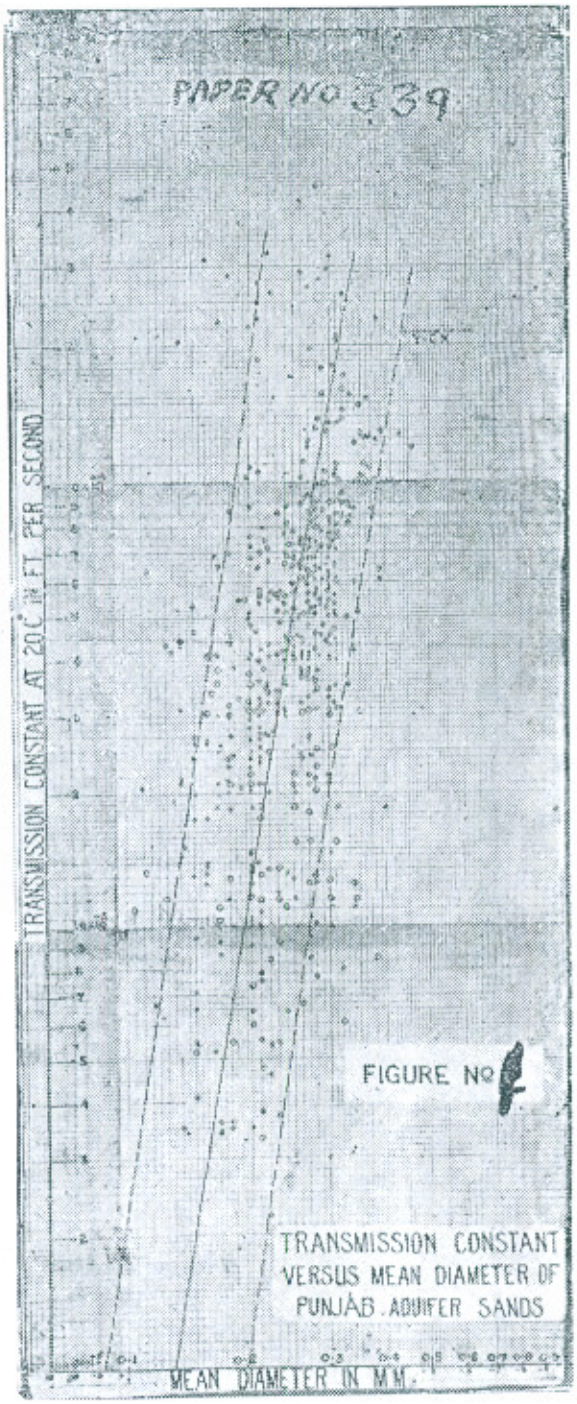


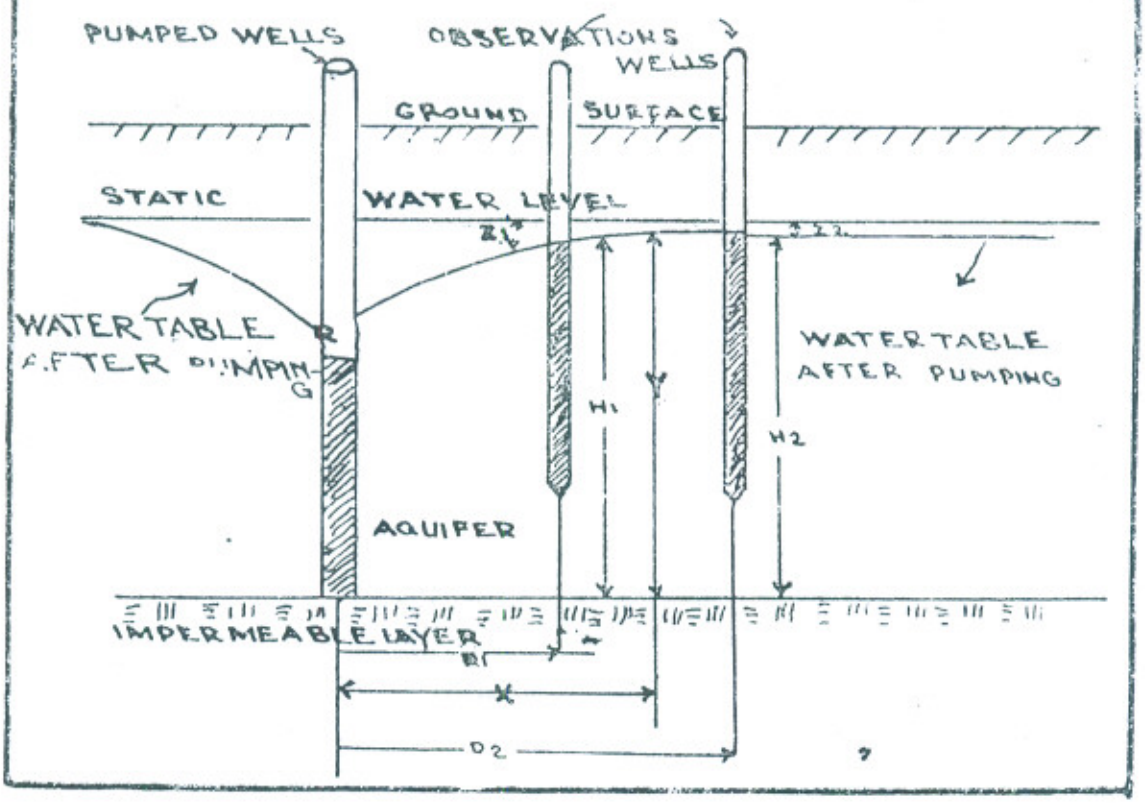
FIGURE NO 1

TRANSMISSION CONSTANT VERSUS MEAN DIAMETER OF PUNJAB AQUIFER SANDS

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FIG NO: 2 169.58.

LOWERING OF S.S.W.L AROUND A PUMPED WELL



The laboratory permeability coefficient is determined for a sample collected from a particular depth. In practice, alluvial deposits are in layers and during pumping, different layers yield water, depending upon their permeability coeffici ent. Thus it is advantageous to know the mean permeability coefficient of the formation to be dewatered 'in situ'. There are two common field methods for such a test. The older one is salled Theim Methed (8) after its originator 'Cunter Theim' in which a tube well is installed at a site and two or more observation wells are installed at 100 ft. or farther from the pumping well. The well is worked to attain nearly steady cone of depression which under favourable conditions takes three to seven days in this country. The lowering of water-table is noted in observation wells and the permeability coefficient is evaluated from the relation :

$$K = \frac{Q \log_e \frac{R_1}{R_2}}{2\pi m(H_2 - H_1)}$$

The symbols are explained in Fig. 2.

This methods is based upon many assumptions all of which do not hold in the actual. In 1933 Theis(9) suggested another method by which observation of the rate of fall of water in a single pipe at some distance from a pumping well could give the permeability coefficient. The details of the method are now too well known, here only the formulas modified by Jacob is reproduced.

$$T = \frac{2{\cdot}3\,Q}{2\pi \frac{ds}{d \log r_{10}}} \quad \text{or } T = \frac{2{\cdot}3Q}{4\pi \frac{ds}{d \log t_{10}}} \quad \text{or } T = \frac{2{\cdot}3Q}{4\pi \frac{ds}{d \log_{10}\left(\frac{r}{t}\right)^2}}$$

Where T is the Co-efficient of Transmissibility and is equal to m times the permeability Coeff. K, m is the same as in Theim's formulae representing the length of the strainer completetly penetrating the homogeneous aquifer. The other factors are :—

t = time interval in seconds :—

S = the lowering of water table as observed :—

Q = the steady discharge pumped out :—

r = the distance of observation wells —

Results of some of the field tests carried out in Sheikhupura area were :—

TABLE

S.No.	Site.	Tube well No.	K is ft/sec.
1.	R.D.110 U.C.C.	29E 1000 ft. from canal.	3×10^{-4}
2.	R.D. 133 ,,	33A	$5{\cdot}5 \times 10^{-4}$
3.	R.D 110 Sheikhupura Drain.	$18R_1$	7×10^{-4}
4.	Chuharkana Reclamation Project.	No·8	$31{\cdot}5 \times 10^{-4}$

For a successful dewatering arrangement a knowledge of the permeability coefficient is very essential and for this reason both the laboratory and field methods for its determination are given in this note. For emergent cases, when K cannot be actually determined, its value can be estimated from Fig. 1, provided the mean diameter of the formation is known.

Estimation of the infiltration from the formation :

The order of seepage from the formation can be estimated by several methods. If the site to be dewatered is such that it is beyond the influence of a line source, the full area can be assumed as enclosed by a single well of that diameter and using a tube well formula the discharge Q is determined such as :

$$Q = \frac{2\pi mkdp}{\log_e \frac{R}{\gamma w}}$$

in which dp = the maximum lowering of water-table to be attained.

m = the thickness of water yielding formation. This will be counted from water-table to the end of clay layer for complete penetration and for partial penetration upto the end of strainer adding about 15% of the length from the water table to the end of the strainer, due to the curvature of the flow lines.

γ_w = the radius of the excavation assumed circular in shape.

R = an assumed distance from the centre line of the excavated area from which the water is being fed. It can be assumed equal to a 500 or 1000 ft. and in special cases upto 2000 ft. depending upon the size of the excavation.

If a site is very long as compared to its width and it is to be dewatered at a time, the full zone can be separated into circular wells equal to the width of the area and with proper consideration of the fall in discharge of wells due to interference, seepage is estimated.

(11)

If there exists only a line source, the tube well discharge formula is changed to,

$$Q = \frac{2\pi mkdp}{\log_e \frac{2d}{r_w}}$$

in which $2d$ is the distance of a line source from the well.

This type of simple cases seldom occur in nature. Usually iu addition to a high level line source, a low level watertable, exists around the well and in the estimation of infiltration due weight is given to the feeding sources and their levels etc.

Sometimes it is easier to plot flow lines from the source to the sink and thus to estimate the seepage. This is particularly helpful when there exists more than one free water source at different levels. The flow lines can be quickly plotted from the geometry of the case. In such a case an Electrical Analogy method or a sand model test is of considerable help to trace the potentials contours or flow lines.

Infiltration is worked out by using Darcy's relation in which 'h' is taken as the water-head from source to the sink and L is determined for a particular flow line. Area of cross section of the flow lines is determined and on the basis of known value of K, the seepage from a single stream tube is worked out by using.

$$Q_1 = KA \frac{h}{L}$$

Summing up the seepage from each stream tubes, the total seepage is estimated.

Types of pumps for dewatering :—

While devising dewatering by tube well system, consideration is to be given to the type of pumps available. If deep turbine or submersible pumps are available these are ideal for dewatering arrangement as once their bowls or pumps are fixed at the proper position they can be worked continuously through-out the construction period. An important consideration is their heavy initial cost and limited availability in this country.

Another type of pumping arrangement is that by centrifugal pumps with depression head limited to 15 to 20 ft. For deep dewatering, these have to be lowered as the dewatering proceeds.This is a headache but it can conveniently be done by fixing the pumps and the motor temporarily on sleepers and pumping through a rubber hoze attached to a foot-valve and

both lowercd into the well after unscrewing the blind pipe pieces from the top.

Order of effective lowering by a well ;

When a pump creates a depression in a well, the water starts percolating towards this sink due to gravity and the top most flow line behaves, like a free surface through an embankment so that its point of emergence is not at the level of the depression, but a considerable distance above this point.

It is difficult to determine the exact point of emergence of the free surface into a strainer as besides hydraulic flow characteristics the head loss due to flow from a formation suddenly into a coarser, medium and the loss due to friction in the strainer are a few causes which do not allow the top most flow line to open out at the depression inside the well.

Roughly this position below the watertable may be taken as more (12)
than 1/3 the depression head in a well, so that pump working with a depression of 15 ft. can lower the watertable close to a well by 5 to 8 ft. only and the lowering at 100 ft. away will be 1/4 to 1/5 of this depression (13)
head. This order of lowering is not uniform for all values of depression. It was observed at a place that with a depression of 40 ft. in a well, the lowering of watertable two feet away from the strainer was not more than 8·0 ft. If the depression in a well becomes stable say at 15 ft. it means that infiltration, and the extraction has attained a balance and under this condition continued pumping will not be effective to lower the watertable. Further lowering will now be possible when the depression level is taken down by lowering the position of the pump.

Thus in case of centrifugal pumps lowering has to be done by stages and this is sometimes inconvient as compared to working with a deep turbine or submersible pumps.

Where to start the strainer:

A strainer of a well should start below the deepest dewatering level. If this is not done to avoid air suction, it will be necessary to use rubber hoze with a foot-valve to pump from the inside of a strainer.

The end of the strainer also needs consideration. Usually in the Punjab Doabs in a depth of about 100 ft. one or more clay layers do appear.

If a clay layers exists within the economical depth below the foundation level it will be preferable to end the strainer on it. If the clay formation is 5 to 10 ft. thick then a ring of tube wells kept around the foundation area will shield the infiltration from the sides and the bottom. such a case of dewatering will be a simple one.

In case the wells end in the formation, dewatering may be planned after plotting flow lines and the position of wells and the length of the strainers may be decided to intercept the infiltration.

Length of a strainer :—

The discharge of a tube well is directly related to the length of a strainer. A long strainer brings in the problem of large amount of water to be pumped out. It is thus advantageous to keep the length of the strainer short in keeping with the condition at a site. If the area to be dowatered is small just as in the case of canal structures, a twin strainer system each twenty five feet long fixed to two separate blind pipes and worked by a single large capacity pump can be used, though it is more convenient to have one pump for each strainer separately. While calculating the discharge, consideration to fully and partially penetrating tube wells and the curvature of flow lines at the bottom has to be kept in mind as already mentioned.

Type of a strainer :—

In view of the temporary nature of dewatering arrangement, it is suggested that it will always be advantageous to install a cheap type of strainer either made of 'Munj' string wound round iron strips or those made of clay. The third type suggested is that made of iron sheet. A brass strainer due to its cost should not be used at any site. Baked clay strainer will be the cheapest and if wood is available it is suggested that wooden strips or bamboo pieces fixed on iron and having coir or 'Munj' string wound round it can do the job. For shallower depth of dewatering when the strainer can be extracted, punched iron sheet strainer will be preferable.

Over Pumping :—

For all dewatering problems over pumping to create maximum depression head is essential. So long the pumps do not pump out sand of the formation, it is safe to pump to the full capacity of the pumping set. Intermittent pumping disturbs the formation and sand is sucked out. In dewatering problem this type of pumping may be avoided. Continous day and night pumping without any closure is essential. High lift may also be avoided as this results in reduction in pumping capacity. Pumped water may be discharged into a drain or a tank from where it may be thrown out. If the formation is such that it cannot yield as much as the capacity of the pump, it can be sluiced down to create the maximum possible depression in the well or the pump may be replaced by one of a smaller capacity.

Interference of wells :—

In a dewatering project, interference of well is desirable so as to quickly lower the water-table. Although interference and fall in discharge depend upon the closeness of the pumps, their orientation and the nature of the

formation, yet the under mentioned table gives a rough idea of the interference of two wells working at various distances apart.

Distance between wells in ft.	Percentage Interference observed by		
	Jacob	Sanwal.	Lacey quoted by Montague.
5	—	38.33	—
10	—	34.53	—
56	14·2	—	—
73	8·7	—	—
92	7·5	—	—
100	—	20.0	65·8
148	5,3	—	—
200	—	15·35	45·0
221	0.0	—	—
400	—	10·5	24·0
600	—	—	1·40
1000	—	6·23	6·4

Jacob worked on wells of 24 inchs diameter (15) and 33 to 38 ft. deep Sanwal has given date for 6·0″ diameter well. Lacey's data quoted by Montague was also for 6·0″ diamater of wells. These wells which are shielded on both sides have still greater interference.

After this brief information about the planning of a dewatering system we now give results of some of the actual dewatering systems installed during the last three years. Only those examples are given which were based upon laboratory suggestions, so that it could be possible to compare the field and laboratory results. Those cases which have not yet been started in the field are omitted.

Field dewatering cases and their results ;

Recently dewatering arrangements have been suggested for the following projects:

1. Chichoki Hydel project.
2. Shadiwal Hydel Project.
3. Gujranwala Hydel Project.
4. Ravi Syphon.
5. Panjnad Head - works.
6. Chichoki Hydel Project out-fall at R.D. 225,508.
7. Dewatering of right embankment of Guddu Barrage.

1. Dewatering of Chichoki Hydel Site :

Tnis site is situated about 800 ft. away from the right side of Upper Chenab Canal and about 2000 ft. down-stream of the Joyanwala 10·25 ft. high fall. The full supply depth in canal in summer is about 10 ft. at an elevation of 691·0 and the bed of the canal below the fall has thin soil crust.

The area before dewatering was water-logged with water-table at R.L. 688, hardly 3 ft. below the natural surface. The bottom of raft was to be located at R.L.650 and the proposed dewatering level was fixed at R.L. 648 i.e. 40 ft. below the existing water-table.

The preliminary exploration of site was conducted by Swiss Boring Co. who found the nature of sub-surface mainly consisting of medium to fine sand with 5 to 10 ft. thick clay layer at R.L.600 nearly 50 ft. below the raft level. The order of permeability coefficient was found equal to 0·002 ft. per second. The raft area to be dewatered was 200×300 sq. ft., keeping 50 ft. working space alround. The infiltration was worked out on the basis of tubewell formulae. The various factors used for this estimation were:

m = the thickness of water bearing medium = 80 ft.

d P = the dewetering level = 50 ft from the canal side and 40 ft. S·S. side.

K = the permeability coefficient = 0.002 ft. per aec.

R = 1000 ft. assumed.

r_w = the radius of the area to be dewatered = 150 ft.

so that the seepage:

$$Q = \frac{2\pi k m \, d_p}{2{\cdot}3 \log \frac{R}{r_w}}$$

= 28 and 15 cusecs for the two cases with dp = 50 and 40 ft. respectively and the mean seepage was supposed equal to 20 cusecs and to deal with this a system of 12 wells was proposed around the area.

The strainers were proposed to start at R.L 650 and to end at R.L.600 on the clay layer.

As submersible pumps were available, these were installed and their pumps were kept at R.L. 625 to 630·0. Energising these wells, it was found that it was possible to lower down the water-table to the desired level after pumping for about two weeks. For maintaining the watertable at the desired level only 10 pumps were found sufficient. This method has proved helpful and pumping is in progress for the last four years withont the least trouble. The points of interest are :

(*i*) The discharge being pumped out is nearly the same as worked out by formula under the assumed conditions of the feeding sources, permeability coeffieient and thickness of the formation etc.

(*ii*) The lowering of water-table is similar to as shown in Fig. 3 It is quite flat in the area of the raft.

(*iii*) The wells once installed have been workiug without any trouble and without the necessity of lowering their position with fall of water-table. With one setting these have taken down the water-table to the desired level.

(*iv*) In these regions,clay layers are not extensive. These exist in the form of lenses. It was expected that the clay layer at R.L.600 will be subjected to an uplift pressure and might give way at some week places. As a safe guard it was suggested to take down the strainers of four wells below this layer. It was not done at site and at the maximum lowering of water-table one of the pumps failed due to puncturing of the clay layer under-neath. This well strainer has since worked as a pressure release throughout these years. The head in this well was found equal to the full supply level of the canal.

(*v*) During canal closure working all the ten wells, the discharge pumped out was 16·5 cusecs as against 19·5 cusecs with canal in operation. The dewatering level was kept the same in the two cases. Thus the canal closure caused 20% reduction of discharge to be pumped out as was determined by laboratory model experiments.

(*vi*) The pumping level in the wells was on the average at R.L. 624 and the watertable stood at R.L.645, so that there was 20 ft. of difference between the pumping level and the lowered water-table. This important point is worth noting. In all cases of pumping water.table cannot be lowerd down to the level of water in the well.

(*vi*) Discharge of individual wells was determined and it was found that the maximum interference was of the order of 25% and the lowest being 13·5 % It was found that the presence of the canal was contributing about 33% more to the total discharge coming from the formation.

(*viii*) It will be of interest to note that three years of pumping from thirty feet length of strainer has continued to yield the same discharge without deterioration. The lowering has also stabilized, so that on the opposite side of the canal there is not much effect of this pumping.

2. Dewatering of Ravi syphon :

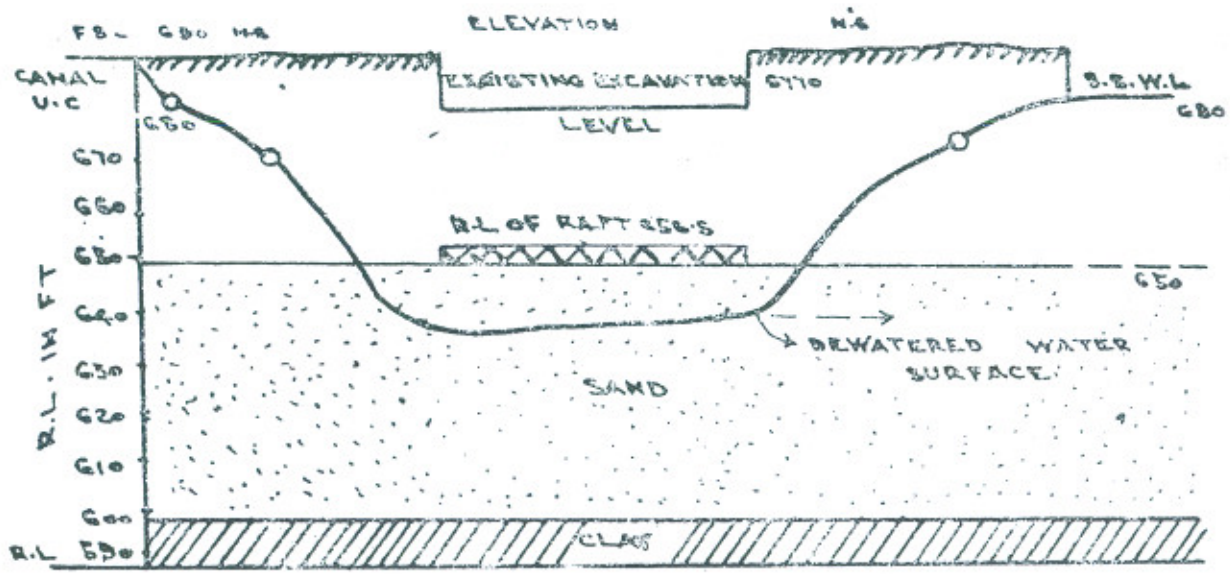
This is another site where dewatering of the foundation was accomplished by tube wells. The syphon which consists of five barrels each of 10·25 ft. in diameter was damaged during floods of October 1955. For repairs it was proposed to dewater the whole 1800 ft. length of the syphon to a width of 350 ft. The water-table was to be taken down to

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FIG NO 3

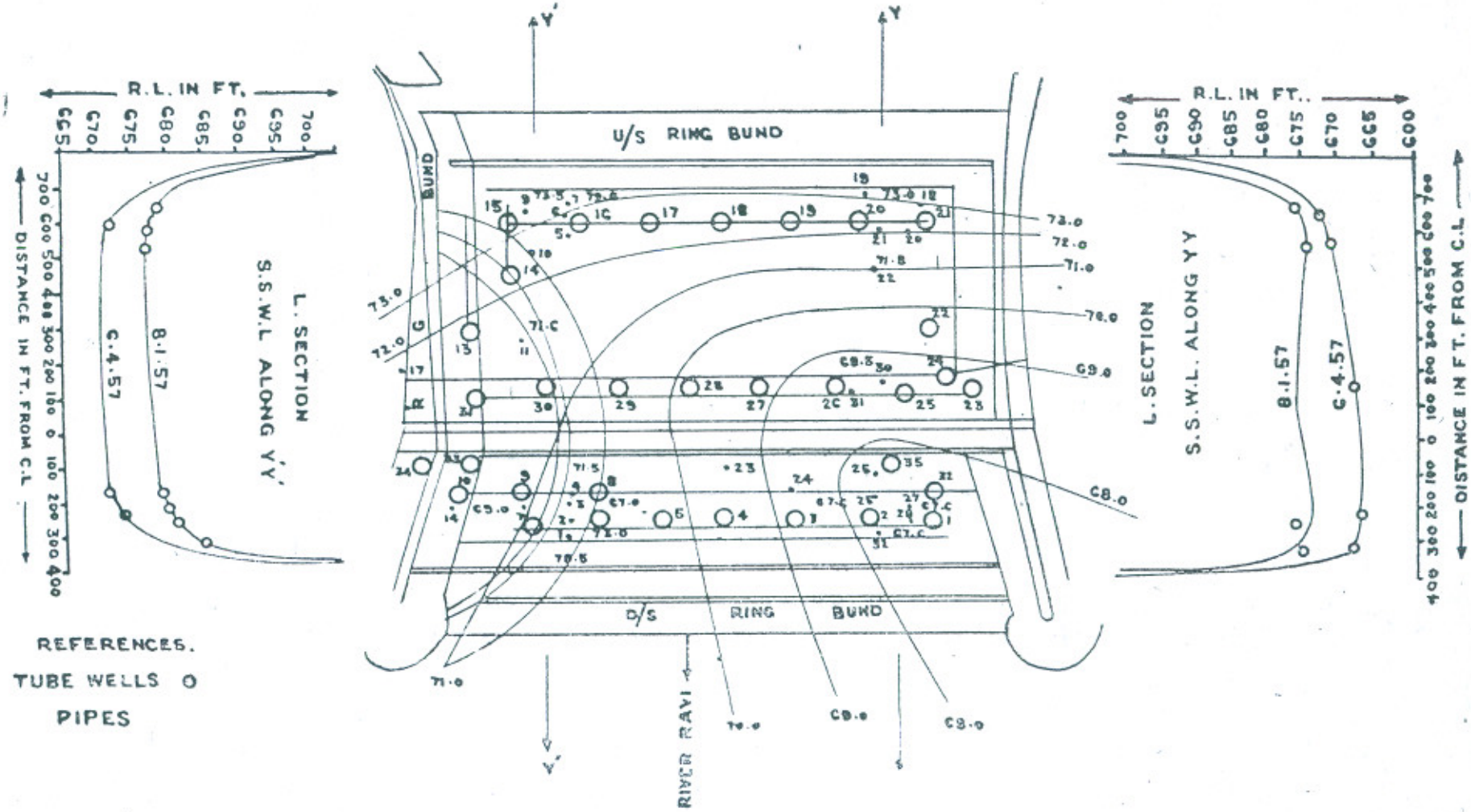
S.S.W.L IN CHICHOKI MALLIAN HYEIL SITE AFTER PUMPING FOR ONE MONTH



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FIG. 4

PLAN OF RAVI SYPHON
SUB-SOIL WATER LEVEL CONTOURS ON
6.4.1957



REFERENCES.

TUBE WELLS O

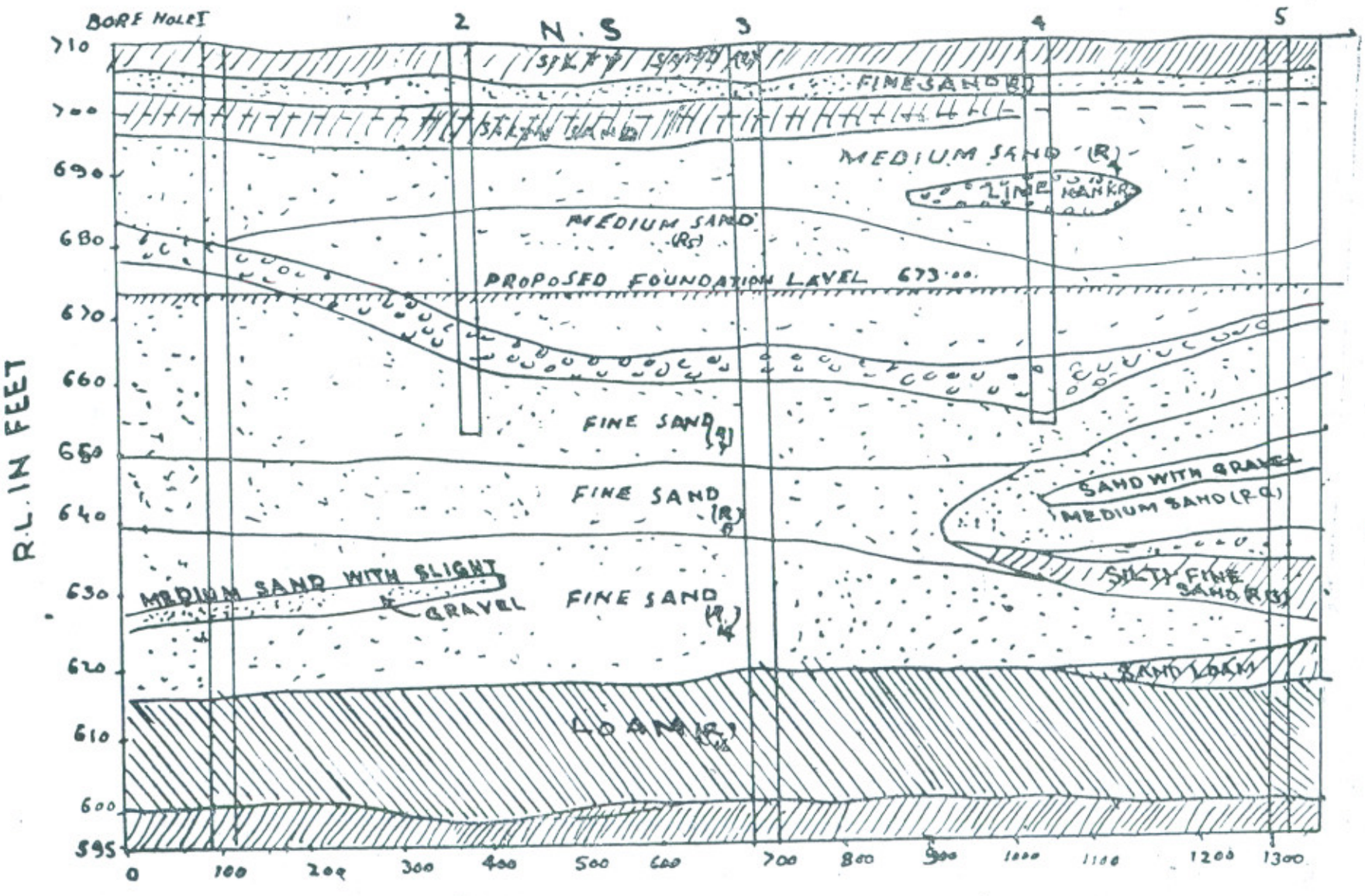
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FIG 5

165-58-1

SUBSOIL PROFILE OF RAVI AQUADUCT FOUNDATION IN APRIL 1950



R.L.670 being 18 ft. below the top level of the barrels. The working area was protected by embankments, one on the upstream side and the second on the down-stream at 769 and 425 ft. respectively from the centre line of the barrels. The arrangement of embankment is shown in Fig. 4 Embankment protection was also made on the right damaged portion. Another bank was constructed on the upstream side at 1325 ft. from the centre line of the barrels. The free sources of water were assumed to exist on all the there sides and the maximum level was taken equal to R.L. 710 on the upstream and R.L. 706 on the down-stream side.

As to the geological formation no boring was done, nor a pumping test was carried out and thus the permeability of the medium was unknown. The dewatering arrangement had to be suggested early, so that the data of soil exploration conducted during 1950 at the time of its construction was collected and the nature of the formation was assumed to be the same as existed at that time. The formation explored at that time is shown in Figs. 5 in which the top 18 ft. below the barrels consisted of medium sand and the rest being fine sand. At R.L. 620 i.e. 68 ft. below the top of the barrels existed a thick impervious clay layer.

For lack of permeability tests, the value of the coefficient was assumed equal to 0·002 ft. per second and the infiltration expected was worked out with the following conditions of flow.

Dewatering level dp = 710—670 = 40 Ft. with reference to up-stream water level.

Dewatering level dp = 700—670 = 30 Ft. with reference to down stream water level.

Thickness of the formation yielding water, m = 70 Ft.

Width of dewatering strip as assumed = 300 Ft.

Well diameter assumed $2\,r_w$ = 300 Ft.

Distrance of feeding source on up-stream & down—stream side, d = 800 Ft. & 400 Ft. away respectively.

Permeability coefficient, K = 0·002 ft. second.

The infiltration, $$Q = \frac{2\pi\ Km\ dp}{2{\cdot}303\ \log_{10}\frac{2d}{r_w}} = \frac{2\pi \times 0{\cdot}002 \times 70 \times 40}{2{\cdot}303\ \log\frac{2\times 800}{150}}$$

= 18·92 cusecs if the source is assumed at 800 ft. away.

= 15 cusecs if the source is assumed at 400 ft. away.

A mean seepage expected was thus equal to 17 cusecs.

As the full length of 1800 ft. was to be dewatred and assuming 25% interference particularly in the internal wells, the seepage was expected equal to about 75 cusecs. It was suggested to be dealt-with by 40 wells 22, of which were to be installed on both sides of the syphon and extending down to the clay formation, and the rest 18 wells were to be installed in between these wells and the barrels. As neither the permeability coefficient nor the type of the formation after the floods was known it was suggested to install one well and see its performance as well as have an idea about the change in the formation. As for the installation of the wells, in order to avoid rip rap, the distance from the centre line of the barrels was suggested, to be kept equal to 175 ft. and the distance apart between two wells was to be 200 ft. It was further suggested to use coir strainers and the pumping was to be done by centrifugal pumps and their position was to be lowered as the dewatering was to proceed. In case of brass strainer, these were to be 7½ inches in diameter and were to start at R.L. 670 and end at R.L. 620 on the clay layer. The free water was to be pumped upto the top of the barrels at R. L. 628 after which the tube wells were to start functioning. The first setting of the pumps was to be at R,L. 628 and with the proceed of the water level these were to be lowered, 5 to 6 ft. at a time.

The constructional authorities decided against the laboratory suggestion and installed the wells 900 ft. apart on both sides of the barrels instead of at 350 ft. The number and spacing of wells was however fixed as suggested by the laboratory. The position of wells so installed is shown in Fig. 4 When the boring was completed and strata was examined it was found to have a thick deposit of impervious black clay extending to R.L. 684 and 680 and it extended on both sides of the barrels even beyond the protective bunds. This impervious clay layer was very helpful in cutting down the infiltration from the free water surface of the river.

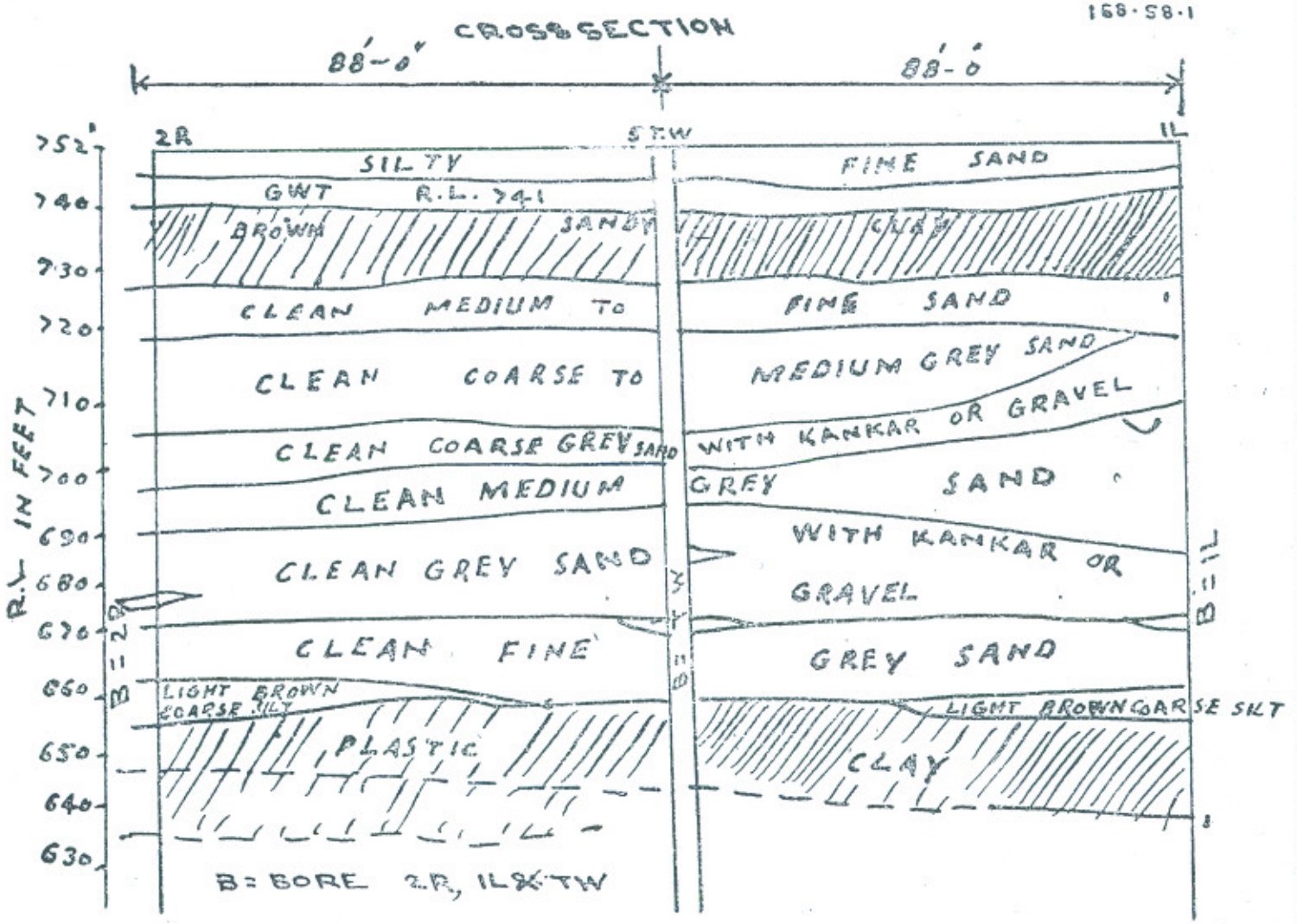
This arrangement of wells brought down the water-table to R.L. 678·0 nearly ten feet below the top level of the barrels at R.L. 688

The data of the tube wells observed in February is shown in table (2a). There were 23 tube wells in operation at an average depression head of 14·0 ft. pumping 13 cusecs. In order to bring down the water-table to R. L. 670, the wells had to be brought closer so that another row of wells was installed close to barrels on the upstream side at the position suggested by the laboratory. Eleven new tube wells were installed and some of the old ones were extracted, so that in March and April, the number of wells working was 26 with average depression head at 14·0 ft. pumping 16·0 cusecs against a lift of 35 ft. (table 2b). The location of the wells together with the lowering of water-table attained by them is shown in Fig. 4.

This study again showed that it was possible to dewater the formation by a system of tube wells. This time centrifugal pumps were successfully used and the whole big area of 1800×350 ft. was dewatered to an average level of R.L. 670 i. e. 18 ft. below the top of the barrels. The general water level was at R.L. 672. The pumps had to lift the water 35 ft. and were sited at an average level of R.L. 676 working with an average depression-head of

PAPER NO 339 FIG: 6

SOIL FORMATION AT SHADIWAL HYDEL SCHEME.



I5 ft. The pumping level inside the well was at R. L. 661, so that it was about 11 ft. lower than the watertable around the well. Here it may be noted that clay deposits were considerably helpful in reducing the infiltration and the dewatering was accomplished with a few wells. Usually a river bed is a source of considerable infiltration and the efficiency of pumps is also reduced when they have to lift the discharge to a great height as was the case in Ravi Syphon.

3. Dewatering arrangement for Shadiwal Hydel Site :—

(18)

Shadiwal Hydel Station is to be located down-stream of fall at R. D. 426 on Upper Jhelum canal. On its right side, 550 ft. away, the full supply level in canal is at R.L. 749 with its bed at R.L. 741.74. The general water-table was at the bed level of the canal being at R.L. 741·7. The raft was to be laid at R.L. 707 and the proposed dewatering level was to be at R. L. 701 0, so that watertable was to be lowered by 40 ft. in a raft area of 250 × 150 ft. keeping a working space of 25 ft. alround.

Exploration of site :—

The site was also explored by Swiss Boring Company who found the formation upto R.L. 560 i.e. 50 ft. below the raft to consist of sand and out of this 30 to 40 ft. was coarse sand. The distribution of various sands according to this investigation was :

Type of sand.	Bore number	R1	R2	L1	L2
	Thickness	in ft.	in ft.	in ft.	in ft.
Coarse		30	—	28	42
Medium		19	71	28	—
Fine		22	—	17	31

In Fig. 6 is shown the strata of the formation as determined by the firm. At R.L. 650, there existed I0 to 17 ft. thick clay layer which can be taken as impervious. The company had determined the permeability coefficient equal to 0·0063 ft. per second and thus they warned about the difficulties of dewatering of the foundation due to this high permeability coefficient unless the infiltration from sides was cheeked by clay piling.

The problem was referred to the laboratory and starta samples of a few bores were examined and it was concluded that laboratory permeability was of the order of 0.0008 to 0.0016 ft. per second. On the examination of report of Swiss Boring Co., it was found that the company had carried out improper pumping tests and has thus arrived at incorrect order of permeability coefficient. The infiltration expected at this site was worked out in the Institute and was found to be 13.5 cusecs. It was based upon the following data ;

d_p = 40 ft.
r_w = 150 ft.
K = 0.002 ft. per second.
R = 600 ft.
m = 80 ft.

This mean seepage by considering infiltration due to high level canal was supposed te go up to 16 cusecs. It was further checked that the canal bed contained soil and its contribution will not be much. Based on this information a system of 12 wells was suggested for dewatering of the site.

The strainer of coir string were suggested and were to be shrouded to increase their effective diameter. These were to start at R.L. 710 and to end at R.L. 650. The dewatering was proposed by submersible pumps located at R.L. 685. The dewatering was expected to be completed within two or three weeks.

Arrangement at site :—

As the construction of the project was entrusted to Canadians, the authorities preferred to import well point equipments, the dewatering was carried out by four setting of well points. At present it is not proposed to compare the working of the system but the point of interest is that at the desired lowering, the water being pumped out is 17·6 cusecs which is quite close to that estimated by the Institute. The fear of the Swiss Boring Company has been disproved.

4. *Gujranwala Hydel Site* :—

(19)

This site is also proposed to be dewatered by tube wells pumping. It was also explored by Swiss Boring Company, and they did not carry out pumping tests, Some infiltration tests were conducted and the mean order of seepege was given equal to $1{\cdot}3 \times 10^{-3}$ ft. per second.

Data of this site.

The starta profile of the area is shown in Fig. 7. Majority of the formation is build up of medium to fine sand. The formation is inter-laid with small lenses of silt and dirty sand at R.L. 700 to 710. At R.L. 665 about 95to 100 ft. below the natural surface exists a thick clay layer of 10 to 17 ft. in thickness. This was also a case in which infiltration from bottom could be sealed.

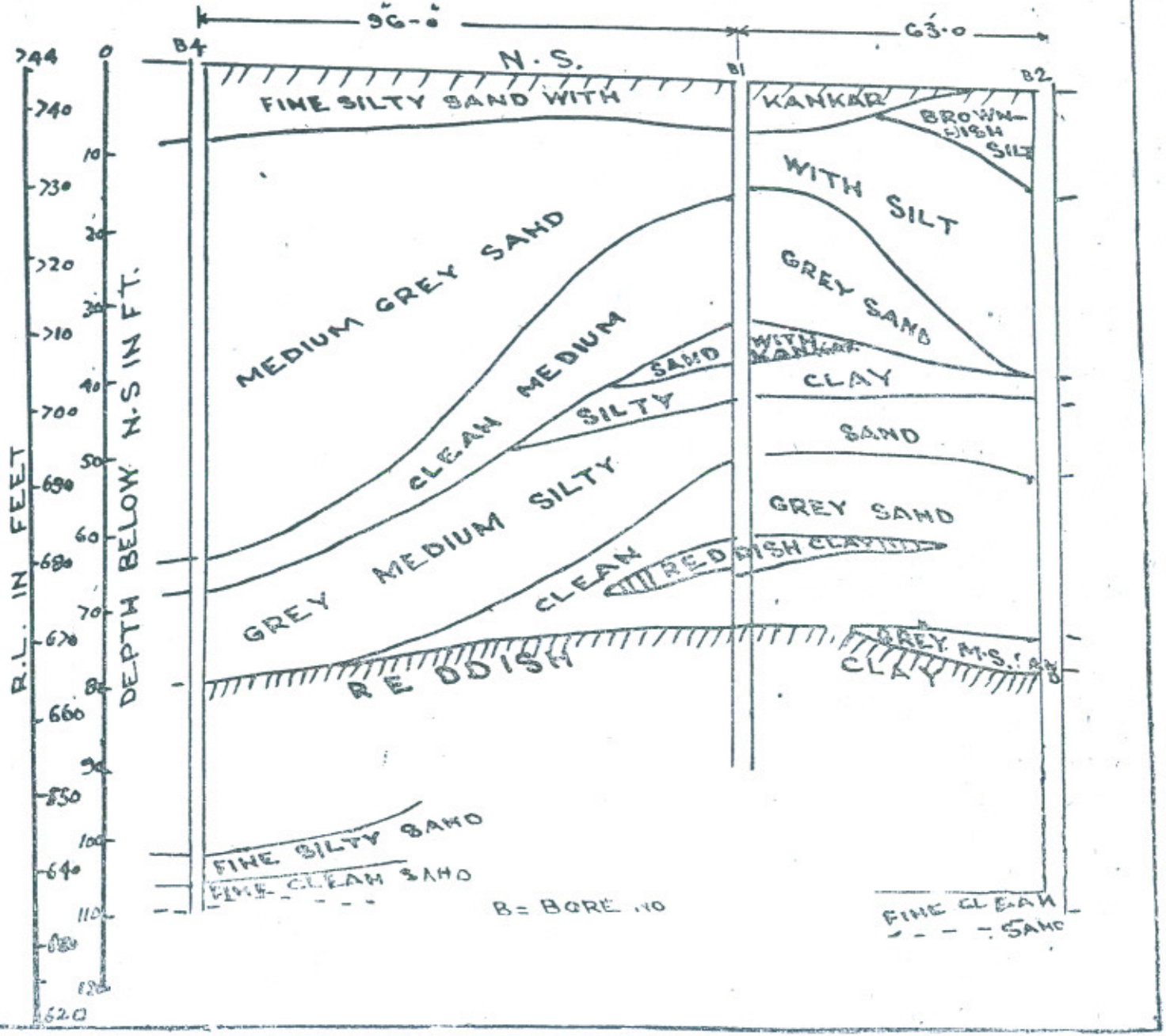
The other conditions of the site were :—

The raft is to be laid in the bed of the existing Upper Chenab canal which has been diverted and now flows about 1000 ft. away from the proposed site. The full supply level in the canal is at R.L. 755 and the general

PAPER NO339 FIG:7

GEOLOGICAL CROSS-SECTION OF POWER HOUSE GUJRANWALA HYDEL SCHEME

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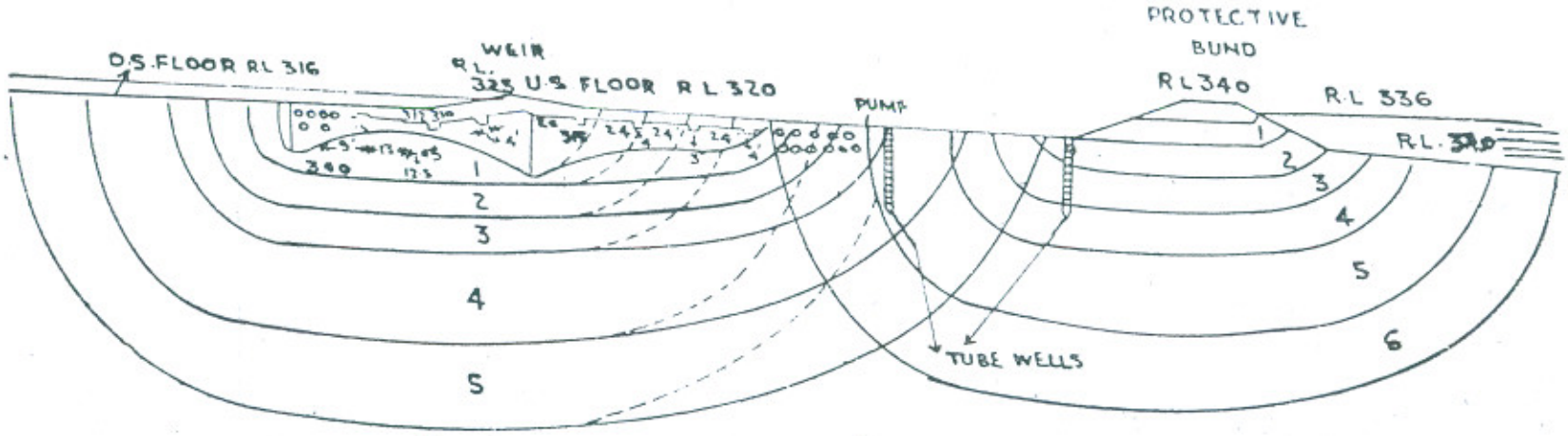


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170·58.1

FIG:8

DEWATERING OF DAMAGED FLOOR
OF PANJNAD HEAD WORKS



FLOW LINES WITH FLOOR INTACT

" " " " DAMAGED

watertable in the area lies at R.L. 745.0. The Nandipur fall being 2000 ft. upstream and having a thick clay bed may not be a source of the trouble as in that area a thick impervious clay layer exists under the bed of the canal. The water-table is to be lowered to R.L. 710, so that it was to be taken down to 35 ft. below water-table and 45 ft. below canal full supply level. The water yielding formation was 85 ft. and thus this case was also similar to Chichoki Hydel and if the permeability coefficient was assumed the same at that site, the percolation expected was 21 cusecs and for such a case the usual system of ten wells was suggested for the dewatering of the site. The strainers were to be made of coir, starting at R.L. 710 and ending at R.L. 660 on the clay layer, If deep turbine submersible pumps are to be used, these shall have to be located at R.L. 690 to 687.

This site has not as yet started to operate. Wells have been installed and it is hoped that this year it might be possible to collected the data of their performance.

5. Dewatering of Panjnad Headworks :—

About 14 days constituting 840 ft. length of the Panjnad weir on the up-stream side between the Groyne and weir were demaged. During repairs it was proposed to dewater the site by tube well pumping.

The data of this site was :

Length to be dewatered	= 1000 ft.
Length of the floor upstream of the central sheet pile	= 175.0 ft.
River level on the upstream side of the embankment	= R.L. 336
River level on the down-stream side of the weir.	= R.L. 325.
Proposed dewatering level.	= R.L. 316.
Water head on the upstream side.	= 20.0 ft.
Water head on the down-stream side.	= 9.0 ft.
Floor level etc.	= R.L. 320.
Mean diameter of sand formation of river.	= 0·18 mm
Laboratory permeability coefficient for the sand specimen.	= 0.0005 ft. per sec.

In case flow was expected from both the upstream and the down-stream sides and plotting the flow lines as shown in Fig. 8, the probable order of infiltration was worked out.

In case of flow from the upstream side about six stream tubes were

assumed effective and discharge was worked out from Darcy's relation so that :—

$$Q = \frac{h}{h/L} . K.A.$$

where A = 1000 × 20 sq. ft.
K = 0·0005 ft. per sec.
h = 20 ft.
L = is the length of flow path and its value is given below along with the order of seepage worked out from the flow lines.

Stream tube No.	L in ft.	Q in cusecs.
1.	110	1.845
2.	150	1.335
3.	220	0.950
4.	280	0.950
5.	370	1.050
6.	490	0.455
	Total :	6·350

Similarly the infiltration due to the head on the down-stream side of the weir, was found out to be equal to 1·815 cusecs as per detail below.

Stream tube No	L. with floor intact.	L. with floor non existing	Seepage with damaged floor.	Seepage with floor intact.
1.	320	240	0·315	0·415
2.	370	300	0·270	0·335
3.	420	350	0·240	0·285
4.	520	480	0·385	0·435
5.	640	580	0·315	0·345
		Total:	1·525	1·815

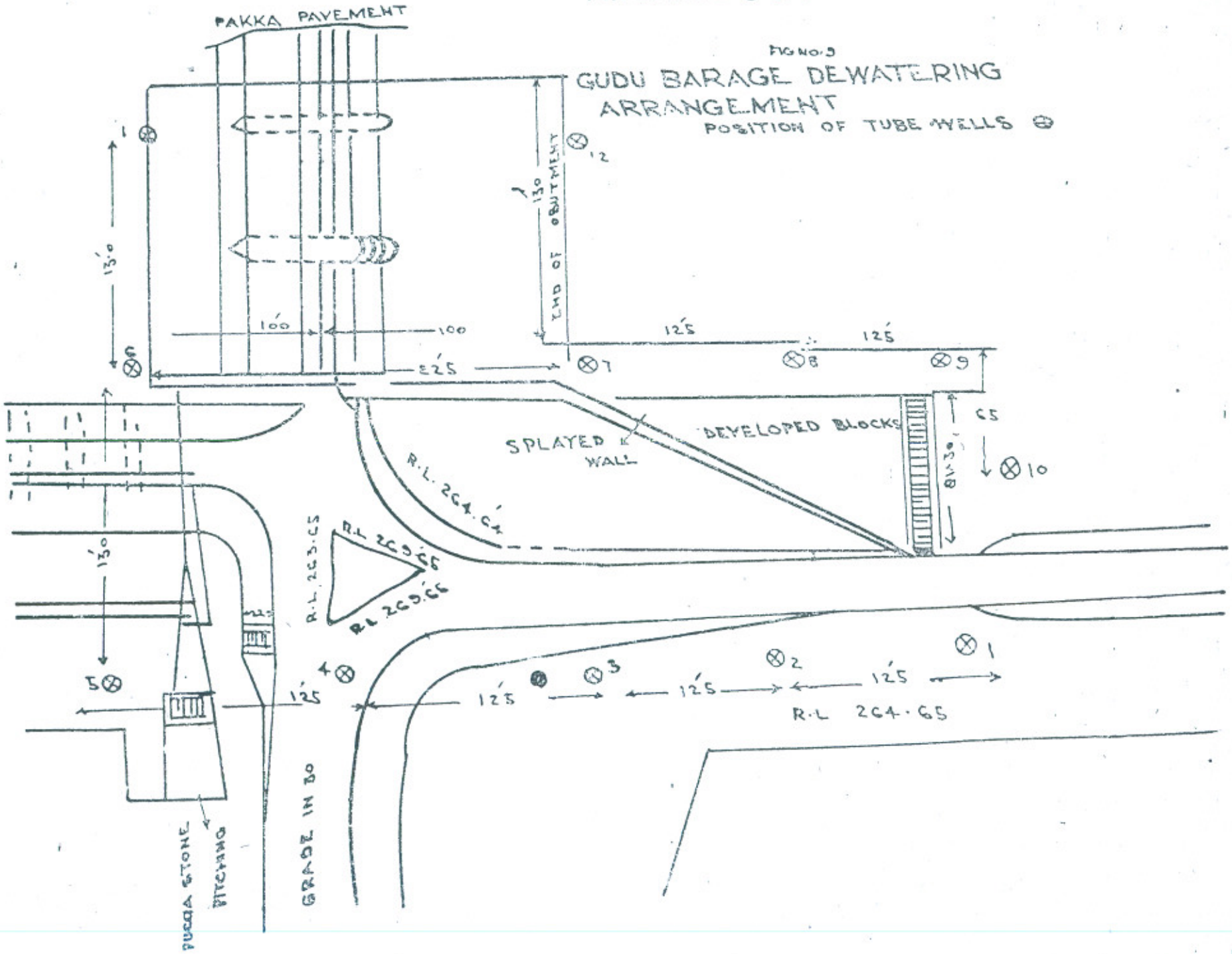
Thus the expected infiltration was to be 8·2 cusecs and to deal with this the method suggested is given below. :

Install nine tube wells each with two strainers. The strainers are to be of 7½ inches in diameter with slits, equal to 10/1000 or 12/1000 of an inch. Each well is to have 15 ft. of blind pipe and 25 ft. of strainer. The pumps are to be located at R.L. 320 and each one is to work with

FIG NO. 3

GUDU BARAGE DEWATERING ARRANGEMENT

POSITION OF TUBE WELLS ⊗



at least 15 ft. of depression head, so that the pumping level inside the well shall be maintained at R.L. 305 and at this condition they will dewater to a level of R.L. 316. As for the installation of blind pipe it was to be started at R.L. 320 and end at R.L. 305 beyond which 25 ft. long strainer was to be installed ending at R.L. 280".

The distance apart for the wells was to be 200 ft. apart and 100 ft. across. The twin well strainer were to be installed 25 to 30 ft apart. Pumps of one cusec capacity were suggested. The tube well authorities did not stick to the laboratory suggestions and installed well without consideration of the position of pumps, depression head in the well, length of blind pipe or the position of strainer. Practically in all cases pumps were installed at R.L.325 and the blind pipe had 6 to12 ft. of length only, and no consideration was given to the pumping level inside the well. In some of the wells, the strainer length started at R.L.320 which was the level of the up-stream floor. Naturally tube well installed without any consideration to their hydraulics were bound to be in-effeetive. Working of the wells did lower down the water-table to R.L.320 and in some cases to R.L. 319 but several of the wells could not be worked due to the position of their strainers and the other were effective only when their position was lowered below R.L.326. The discharge pumped out was lower than the ealculated one.

6. Dewatering arrangement for right embankment of Guddu Barrage:

A dewatering arrangement for the right embankment of the Guddu (21)
Barrage was suggested at the instance of the Chief Engineer, Guddu. The area to be dewatered is shown in Fig. 9 The Indus river being a free source of supply was said to exist at 7000 ft. away. Its maximum and minimum water level varicd between R.L.256 and 248 with sub soil water-table lying between 3 to 5 ft. below the natural surface.

The dewatering was to be done in an area equal to 500 × 100 ft. which included about 225 ft. wide pucca floor of the weir and 100 ft. wide canal. The water-table was proposed to be lowered to R.L. 220 or 218 i.e. nearly 30 ft. below the existing water-table.

As to the nature of formation, Swiss Boring Co., had carried out an investigation for crossing of Sui Gas across the Indus river at a site close to Guddu Barrage. They had reported that the formation of the river was fine to medium sand up to 100 ft. below the bed and its permeability was very low. A sample of the river sand from the site was sent to the laboratory and its analysis showed that the sand had a mean diameter of 3·17 mm. effective size equal to 0·088mm. and uniformity coefficient equal to 2.16. It had about 5% of particles below 200 mesh. For this type of sand formation the laboratory permeability coefficient is between 0·001 to 0·0001 ft. per second which is much higher than that found by Swiss Boring Co., and hence this order was used for calculation of discharge with the following conditions :

d P = 250-230 = 30 ft,

K = 0.0005 ft. per second.

m = 70 ft.

r_w = 50 ft.

R = 500

$$Q = \frac{2\pi \times 70 \times 0{\cdot}0005 \times 30}{2{\cdot}3 \log \frac{500}{50}} = 2{\cdot}87 \text{ cusecs.}$$

and for the full area the expected seepage was 14·4 cusecs, excluding interference of wells.

Based upon these calculations the dewatering was proposed with 12 tube wells, nine to be installed in the first instance followed by well No. 10,11 and 12 if found necessary. Their proposed position is shown in Fig 9. Each well was to have 45 ft. of blind pipe starting at R.L.230 and ending at R.L. 205. The blind pipe is to consist of pieces equal to 4 or 5 ft., so that in case, centrifugal pumps are used; their position could be lowered with the proceedings of the pumping. strainers equal to 25 ft. in length are to start at R.L.205 and to end at R.L. 180. Each of the the pump is to work with a maximum depression head, in no case less than 15 ft. and it will be preferable to use high capacity pumps of about two cusecs discharge out put. In case submersible or deep turbine pumps are available, the suitable position for their lowls will be at R.L. 205. This suggestion was adopted at site and the wing well area was successfully dewatered and the construction has since been completed.

7. Dewatering arrangement for out-fall at R.D. 225. 508 Chichoki Hydel Project:

An out-fall at R.D. 225, 508 was to be constructed. This was in connection with Chichoki Hydel Project. (22) A suggestion for dewatering was invited.

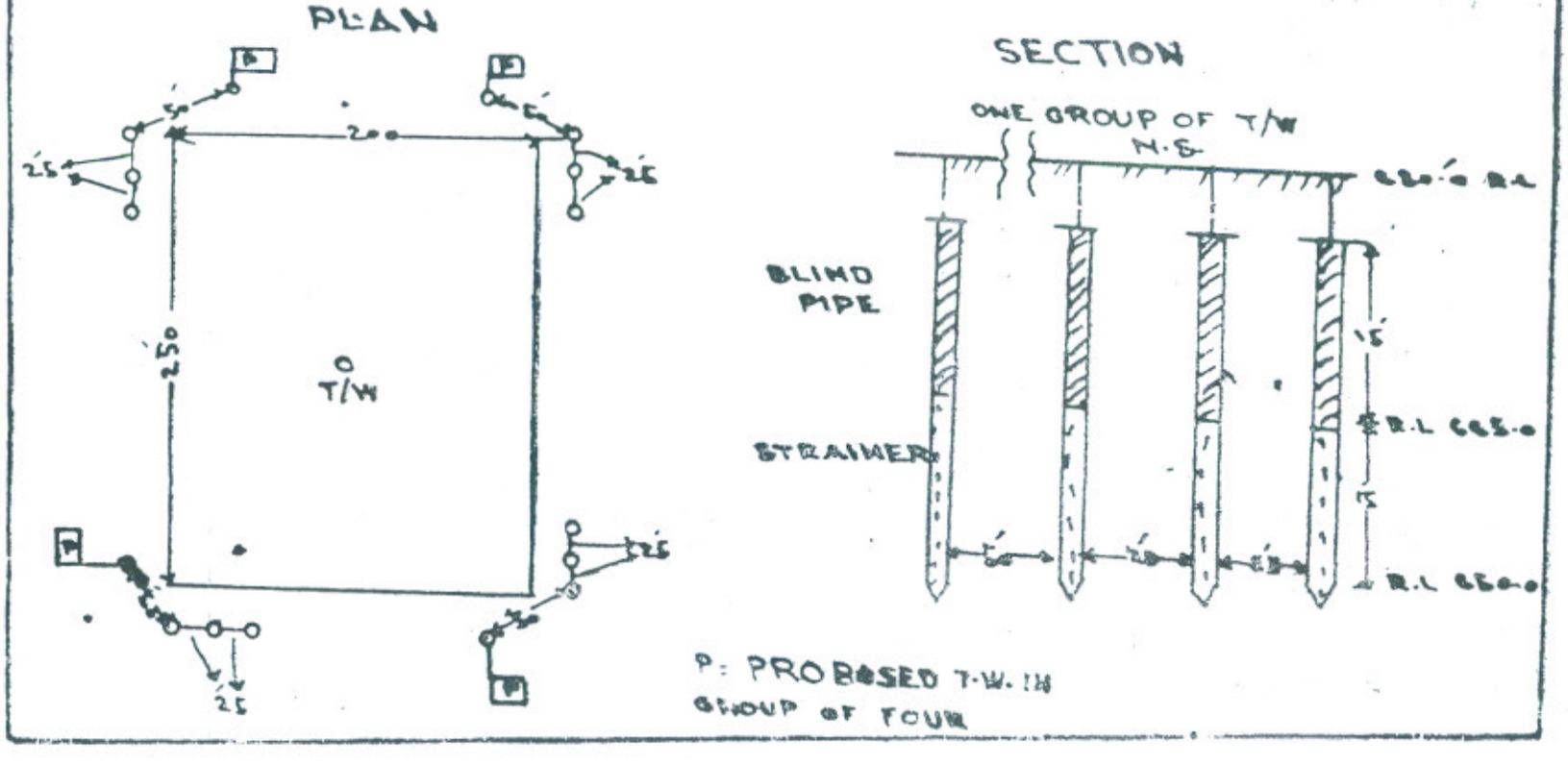
The site was very close to the Upper Chenab Canal which had been diverted to one side. The fall was to be constructed in an area of 250 × 200 ft. and was to be dewatered to R.L. 682 and both on the left and the upstream side of the fall, the Upper Chenab Canal with F.S.L., equal to R.L. 692·0 would be in operation during the construction.

Only two bores were made to a depth of 30 ft., and these showed the existance of hard clay upto R.L.668, so that with bed level of canal at R.L.682, there could still be clay layer below the bed of the canal and little contribution was thus expected from the canal though it was at quite close distances. The permeability of the site was not known but for calculation of seepage it was assumed equal to that adopted at Chichoki Hydel i.e. 0·002 ft. per second. The other factors for calculation were as under :

dp, the depression head was taken equal to 692-667 = 25 ft.
m, the thickness of water yielding formation =40 ft.

PAPER NO 339 FIG NO:10 166·58·1

PROPOSED DEWATERING ARRANGEMENT FOR FALL AT R·D 225,508 CHICHOKI HYDEL SCHEME



Keeping in view the partial penetration of the well and the curvature of the flow lines at the bottom and taking R = 1000 ft.

$$r_w = 150 \text{ ft.}$$
$$K = 0{\cdot}002 \text{ ft. per sec.}$$

the seepage was worked out equal to 6·7 cusecs, The sub-soil water-table existed at R.L. 682, so that from the down-stream and the right sides of the fall, the seepage expected was only 4·0 cusecs and mean percolation expected was about 5½ cusecs. This order of percolation was checked by drawing flow lines on and the order worked out to be nearly equal to that calculated by the tube well formulae. A few flow lines appeared to open out in the middle of the excavation. With this back ground of the case, a system of four tube wells each having four strainers of 15 ft. each was suggested. The top blind pipe was to be 15 ft. and the distance apart of the wells was proposed equal to 25 or 30 ft. The arrangement of wells to be installed is shown in Fig 10. Two settings of pumps were proposed, the initial setting being at R.L. 682 and the second at R.L. 675. Strainers of coir were proposed to be used and if flow appeared in the middle another tube well was proposed to deal with this flow.

The persons incharge of construction proposed their own arrangement of 13 tube wells out of these three tube wells had submersible pumps similar to as put in at Chichoki Hydel site. The rest of the wells had 30 to 50 ft. of coir strainer with 16 to 30 ft. of blind pipe at top. On 27th of March discharge and depression of the well was recorded. On that date only nine wells were working under an average depression head of 9 ft. pumping 8·1 cusecs.

The data of each individual well was :—

Tube well no.	App. Discharge in cusecs	Depression head in ft.
1.	0·4	8·0
2.	0·5	12·5
3.	0·75	8·3
4.	0·3	7·3
5.	0·75	6·2
6.	0·3	5·5
11.	1·0	10·6
12.	1·5	11·2
13.	2·6	8·0
Total	8·1 cusecs	9·0 average

It was thus found that although the wells were not put in, according to the laboratory proposals but the discharge necessary to attain the required dewatering was nearly equal to the calculation. The small variation is attributed to longer length of the strainers.

Dewatering by well point :—

The dewatering of the seven sites discussed in the previous pages have been accomplished by tube wells. The system has been developed in this country and has been found to give satisfactory results. The dewatering system often adopted in other parts of the world is called the well point which in brief consists of innumerable small wells made of 1½ inch diameter G.I. Pipe very often 21 ft. long and having a 3·5 ft. long filter at their ends. Each of these well is pushed in the sand formation by water pressure exerted through the same pipe, The distance apart of each well is usually 2·5 ft. but it can be increased by shutting off some wells. All these well points are connected to a common pipe with the help of a system of bends, universal joint and a valve etc. Very often these are laid around the area to be dewatered. This pipe is then connected to a reciprocating pump worked by diesel or by electric power. The pump sucks out air in the beginning and then starts sucking of the water.

Brief details of well point system as used at Shadiwal ;—

The Institute suggested a system of 12 tube wells to dewater the foundation but Canadians whe are financing the project have imported a well point system and are using at the it site. In this note brief information about their working is given.

The detail of site, its location and position of water-table is already given. The design being executed has some difference. The raft is now to consist of 175×160 ft. and was to be founded at R.L. 701·5. The proposed level of dewatering was upto R.L. 698. The excavation and dewatering by open pumping was taken down to R. I. 734 after which the well points were started to be installed.

The operation with well points was started on 6th May 1957 and the first stage dewatered the area within two to three weeks. The second stage was installed on 18th June 1957 and the third on 16th August 1957 and the last on the 19th Octcber 1957. At the last stage five pumps with their maximum pumping capacity of each pump equal to 2000 gallons per min. or 4·4 cu. ft. per second were working. Their distribution was such that four were connected to the 3rd and 4th stage and one to the 2nd stage. The first stage was dry. Assuming each pump working to full capacity the at the lowest, point of dewatering, the discharge being pumped out was 20 cusecs. Brief information about the lowering and pumping capacity with number of well points in operation etc., is given below in a tabular form.

Serial No.	Well point stage.	Top R.L. of W. P.	R.L. of W.T. before starting.	R.L. of W.T. after working of a stage.	Lowering attained by W.P. in ft.	No. of W.P. in a stage in the beginning.	No. of W.P. is Final setting.	Sides of W.P. ring in ft.	Distance of W.P. from edge of raft in ft.	Pumping operation
1.	1st	734·0	732·0	729	13·0	528	538	363x343	94·0	4
2.	2nd	722	729	697·6 or 706	21·4 or 13·0	430	330	317x302	71·0	5
3.	3rd	709	697·6 or 706·0	696·3	1·3 or 9·7	400	416	297x222	31·0	6
4.	4th	701·5	696·3	695·8	0·5	—	82	206x191	15·5	

The second stage was also much effective and the third stage lowered the water-table by 9·7 ft. and in the final 4th stage, only half a foot of lowering took place.

Cost of well point against tube well pumping :—

In case of dewatering by tube wells, the strainer is made of brass, or coir string or is of baked clay. The pump can either be centrifugal or deep turbine or submersible. All these articles can be locally made from the local material. Even deep turbines and submersible pumps are being made in this country. The power to work these wells is also produced locally and labour is quite well experienced to install the equipment. On the other hand a well point equipment has to be obtained from foreign countries particularly the pump which usually work on diesel. Thus all this equipment has to be imported. More-over the labour is not yet experienced in these installations.

Relative cost of the two equipments :—

A eomparative cost of dewatering at Chichoki and Shadiwal is both informative and interesting. This is given below in the form of a statement.

Type of equipment.	*Well point.*	*Tube Well.*
Machinery, such as pumps and well point strainers etc.	Original cost $107000, shipping insurance, import duty at $53500 Total $160500 or Rs. 802500/:	12 Nos. submersible pump each Rs. 8100/- including carriage. Total Rs. 97200/

Installation of the system.	Four stage well point installation at Rs. 250,000.	Cost of well screen blind pipe etc., excluding, boring of wells for installation is Rs. 7652/- each and for 12 wells it is equal to Rs. 91824/
Total for machinery and installation.	Rs. 10,52,500	Rs. 189,024
Pumping cost per month.	Oil, Rs. 23,000	Current for I2 pumps Rs. 23620.
	Establishment, Rs. 5000-/	Driver Rs. 3400.
	Other charges, Rs. 2090-/	Other charges Rs. 6912.
	Total Rs. 30,000/-	Total Rs. 32,932

The cost of a tube well can further be cut down if coir strainers or clay strainers are used. The cost in that case will be reduced to Rs. 3600. It can further be reduced to Rs. 100 by installing a clay strainer, so that for 12 wells, saving in strainer alone will come to Rs. 36,000/-. Similarly if centrifugal pumps are used, the cost of which is Rs. 3500/- per pump against 8100/- of submersible pump and their life is also considerably longer than the former pumps. The saving on this account can also be about Rs. 55200/-

Recovery and resuse :—

The well point equipment is such that it can be re-used at any other place without any repair. The pumps are the only item to be given care and which will have considerable life if properly attended.

As for tube well equipment, salvage of strainer may not be completely possible, usually these are damaged after extraction. If however cheap type of strainers are used, these can be written off for a particular project. The pumps can however be re-used at any other place.

Performance :—

Both methods are quite easy to work. The well points have to be installed in stages after every 12 to 15 ft. of lowering. Sometimes they are installed in the form of a rectangle, very close to the work, and interfere with other operations at the construction site.

Tube well pumping if done by submersible or turbine pumps, is care free and also the pumps can easily be located as not to interfere with the other operations. Centrifugal pumps, however, do cause a bit of inconvenience of lowering after every five to six feet when the pumping proceeds.

Conclusions :—

1. Dewatering for foundation is an important and essential engineering problem. In this country sump system of open pumping has commonly been used. It is defective as it results in reduction in weight of the formation due to the upward flow gradient. The oozing water carries with it fine praticles causing a loss of compactness and bearing pressure of the formation. A well point or a tube well system of dewatering is free from the defects mentioned above.

2. For planning a dewatering system, exploration of the site is very essential to know the type of formantion upto a reasonable depth below the foundation. The determination of permeability coefficient of the site is essential to estimate the infiltration and the means to deal with this. Both the Theim and Theis methods of determination of permeability coefficient are given in this note together with the order of permeability coefficient found out for the various types of formation occuring in this part of the country. A curve showing the permeability coeffiicient and the mean diameter of sand or its effective size is given from which this factor can be estimated.

3. In the Ex-Punjab regions, the formation is uaually of fine or medium grade and within a depth of 100 ft. one or two clay layers' appear, so that for small area to be dewatered a certain number of wells taken down to the clay layer shields the area lying within the wells and the site is dewatered.

4. If the area to be dewatered is small, it is assumed equal to a single well of that much diameter and ordinary tube well formula is used for estimation of infilteration. The maximum lowering to be attained below the water-table is assumed equal to the depression head and the length of the water bearing formation is considered equal to the depth below the water-table up to the clay layer. This is the positions for a case of complete penetration when the strainers end on the clay layer. If the penetration is partial and the strainers end in sand formation, the depth of water bearing formation is taken equal to the length of the strainer below the water-table and to it is added 10% of this length due to curvature of the flow lines at the bottom. The other factors, are the permeability coefficient either actually determined for this site or worked out from the relation given in the text ,the distance of effective feeding source usually taken being 1000 ft.

If the site is close to a high level line source, increase in the infiltration has to be based upon the nature of the soil under the bed of this source and its width, together with its closeness to the excavation etc. The predominance of this source to that of the formation is given due consideration.

It has been found that infiltration worked out by these methods have been found to hold in the field conditions.

5. In certain cases when it is not possible to apply tube well formulae

drawing of flow lines and the use of Darcy's formulae has been successfully used to estimate the infiltration.

6. If the site to be dewatered is fairly long, it can be split up into small circular wells and giving due consideration to interferences, infiltration can be worked out.

7. For the tube well pumping to be effective to the desired level, the pumping level inside the well must always be 10 to 20 ft. below the maximum dewatered level depending upon the order of lowering being attempted.

It will be preferable to start the strainer below this level of depression inside the well but in any case the strainer should always start,a few feet below the level to be dewatered. In case the strainer starts above this level of dewatering, pumping shall have to be done by using hoze pipe with a foot valve to avoid suction of air.

8. If centrifugal pumps are used, their pumping level has to be lowered as the pumping proceeds. Usually pumping with a maximum depression of the order of 15ft. or more, pumps can be lowered five feet at a time, the top blind pipe, if made in pieces of five feet each, it is easier to lower the pumps by unscrewing a piece at a time.

9. For dewatering, over pumping with a maximum depression and use of a bigger capacity pump, is very necessary. The lift of these pumps may be avoided as not to impair their pumping capacity.

Interference is helpful in this problem but consideration has to be given while fixing the order of pumps as fall in discharge upto 25% has been found due to this cause with wells at 100 ft. apart.

10. Seven cases of dewatering based upon the laboratory suggestions are discussed in this note. These include the Chichoki Hydel, the Ravi Syphon, the Panjnad weir, the Shadiwal Hydel, the Gujranwala Hydel, the out fall at R.D. 225 Chichoki Hydel, and the Guddu Barrage. The field data in some cases is compared with the laboratory suggestions. In practically all cases the laboratory results have been found to hold in the field.

11. Comparison of dewatering by tube-well and that by well point has been carried out and the working of the two systems, their cost of installation and operation etc., for Chichoki and Shadiwal have been compared. It is concluded that a tube well system of dewatering is cheaper, care free, and does not require any foreign exchange. The well point system is equally efficient but at the present stage of development in this country, this equipment has to be imported and its pumping system working on oil which is also an imported item. In some cases tube well system is superior to well point system.

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Table No. 1.

Analysis of sand collected from Formation around Sheikhupura Drain.

Representative grading of coarse, medium and fine sand according to this country classification.

T. W. No.	Depth. ft.	Sand Classification.	Percentage of sand retained on meshes and opening (mm) as below.						
			0·89 No. 20	0·59 30	0·297 50	0·211 72	0·149 100	0·074 200	Below 0·074 200
1	2	3	4	5	6	7	8	9	10
(a) L_1	160-180	Coarse	5·25	21·0	61·75	9·0	2·5	0·25	0 25
L_2	180-205	,,	2·5	10.00	67·5	14·75	4·25	0·75	0·25
L_3	130-170	,,	2·0	10·75	60·25	15·75	8·25	2·0	1·0
L_3	180-260	,,	0·75	6·25	63·0	18·0	9·25	2·2	0.75
L_5	240-290	,,	2·5	9·25	61·5	15·75	8·5	1·5	1·0
L_7	140-190	,,	4·0	19·35	59·8	10·25	5·35	1·0	9 75
L_9	160-190	,,	5·25	15·0	62·75	10·5	4·75	1·0	0·25
	Mean.		3·09	12·73	63·73	12·9	5·73	1·0	0·5
(b) L_{11}	60-200	Medium	0·75	4·0	49·5	26·75	13·5	4·75	0·75
L_{11}	180-200	,,	1·5	7·0	60·75	20·51	8·25	1·5	0·5
L_{13}	70-90	,,	1·5	3·5	61·75	21·25	9·0	2·25	0·75
L_{13}	90-110	,,	1·0	7·0	69·25	15·75	5·5	1·0	0·5
L_{15}	60-70	,,	0·25	4·25	71·9	12·5	2·0	1·0	1·0
L_{17}	70-80	,,	1·5	4·5	50·5	21·5	18·5	3·5	0·5
L_{19}	60-70	,,	4·0	4·75	50·0	18·75	3·0	0·5	1·0
L_{19}	110-130	,,	0·25	4·0	69·5	19·0	6·25	0·75	0·25
	Mean,		1·34	4·0	61·28	20·21	9·40	2·21	0·65
(c) L_{23}	10-30	Fine	0·25	0·25	19·75	28·25	31·0	17·5	3·0
L_{23}	80-90	,,	0·25	0·75	22·75	29·5	36·5	9·25	1·0
L_{17}	30-70	,,	0·26	0·75	32·98	35·0	25·25	6·25	0·5
L_{15}	20-30	,,	0·25	1·75	44·0	30·5	20·0	2·5	1·0
L_{13}	30-40	,,	1·25	2·75	41·0	25·25	23·0	6·0	9·75
L_{11}	10-30	,,	0·25	0·5	22·5	35·0	28·5	3·75	9·5
L_9	50-60	,,	0·75	1·5	34·5	24 0	20 25	17·5	1·5
L_7	60-80	,,	0·1	0·15	8·5	18·5	46·0	25·0	1·75
L_5	290-300	,,	0·75	3·0	48·5	35·0	11·5	1·0	0·25
L_3	10-20	,,	0·0	0·0	0·75	1·5	28·5	62·0	7·75
	Mean.		0·5	1·17	27·42	27·2	27·0	15·27	2·0

Table No. 2. 2 a.

Dewatering of Ravi Syphon.

Discharge and depression head statement of 23 tube wells installed in 1st set up.

Note:—In 1st set up following 23 tube wells were located as in Fig 4.

T.W. No.	Date 1.2.57. Depression Head in ft.	Discharge in cusecs	Date 6.3.57. Depression head in ft.	Discharge in cusecs.
1.	13·8	0·70	9·8	0·67
2.	10·4	0·57	16·0	0·57
3.	9·2	0·40	12·9	0·49
4.	15·3	0·80	13·0	0·52
5.	15·0	0·56	17·0	0·56
6.	15.9	0·45	9·3	0·59
7.	—	—	22·1	0·52
8.	16·7	0·88	21·0	0·47
9.	16·0	0·87	21·9	0·50
10.	13·7	0·50	10·4	0·57
11.	16·1	—	19·7	0·62
12.	13·7	0·58	8.4	0·52
13.	14·2	0.62	10·8	0·60
14.	13·8	0·62	9.3	—
15.	19·7	0·84	16·7	0·69
16.	21·1	0·60	14·3	0·57
17.	12·2	0·58	11·1	0·56
18.	21·1	0·39	14·7	0·49
19.	15·8	0·80	12·4	0·82
20.	19·5	0.89	17·1	—
21.	17·0	0·81	16·5	0.48
22.	23·6	0·72	17·2	0·48
23.	17·2	0·85	11·1	0·68
	Average : 14·8 ft.	Average Total 14·0 cusecs	Average 13·7 ft.	Total : 12·0 cusecs

Table No. 2 b.

Discharge, depression head and lift statement of 26 tube wells in 2nd set up.

Note :—In 2nd set up 26 tube wells were located as in Fig. 4,

Date of observation. 27.4.57

T.W. No.	R.L. of Pumps.	R.L of Delivery	Lift in ft.	Depression Head in ft.	Discharge in cusecs.
1.	678·0	708·0	30·0	—	0·77
2.	678·2	708·1	29·9	11·8	0·40
3.	682·2	708 0	27·8	15·3	0·39
4.	680·3	708.0	28·7	23·4	0·91
5.	686·3	708·0	21·7	12·6	0·41
6.	683·6	708·0	24·4	19·8	0·42
7.	682·25	708·0	25·75	18·5	0·42
9.	688·5	708·0	19·5	15·3	0·42
15.	681·4	710·0	28.6	16.9	0·89
16.	684·25	710·0	25·75	16 9	0·92
17.	67·72	710·0	32 8	17·1	0·62
18.	685.85	710·1	22·25	16 3	0·45
19.	681.05	710·0	28·95	19·0	1·00
21.	687·1	710·0	22·9	15·0	0·67
23.	681·6	708·0	33·0	16·5	0·65
26.	675·0	708 0	33.2	15·3	0·77
27.	674·8	708·0	38·9	16·0	0·62
28,	674·1	708·0	29·9	16·3	0·62
29.	775·1	608·0	32·9	11·7	0·72
30.	674·8	708 0	33·2	16·0	0·6
31.	676·1	708·0	31·9	16·9	0·97
32.	—	708·0	—	15·4	0·68
33.	673.6	708·1	34·5	17·1	0·35
34.	673·0	708·0	35·0	9·0	0·43
35.	672·7	708·2	35·5	11·7	0·66

Average : 13·9 ft. Total : 15·86 cusecs.