PAPER NO. 209

SOME EXPERIMENTS ON SEEPAGE LOSSES IN IRRIGATION CHANNELS.

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The construction of canals in different Doabs of the Punjab has invariably resulted in a rapid rise of spring levels. This incessant rise has in some cases waterlogged the lands and thrown them out of cultivation and in others, conditions of waterlogging are approaching with a very rapid speed. The seepage losses from the canals and the irrigation therefrom have contributed to the sub-soil reservoir to a very large extent with the consequent rise of the spring levels. It is not the object of this paper to give in detail all the factors which contribute to waterlogging nor to find out remedies to remove or counteract the causes. It is intended to describe here briefly the laws of variation of the seepage losses from the canals into the sub-soil water table and to suggest necessary conditions in the design of irrigation channels, so that these losses are reduced. The investigation of the laws of seepage losses from the canals and the acquisition of correct knowledge of these additions to the subsoil reservoir are of first rate importance to this province of the Punjab because it has been abundantly proved by experience that the soil of the plains is such that it requires an enormous and prohibitive amount of money to construct and to maintain seepage drains, to drain off a very infinitesimal part of the seepage losses from the canals and the irrigated fields. It would, therefore, be an unusual achievement and an engineering foresight to know the correct laws of these losses from the canals, and to locate and design them, so that the addition to the subsoil was a minimum.

Percolation and Absorption.

Seepage losses from the canals into the subsoil reservoir used commonly to be called absorption losses. The original experimenters, such as Colonel Dyas (1863) and Mr. Higham (1874), were content to know that the absorption losses in the Main Line of the Upper Bari Doab Canal were 20% and 12½% respectively of the Main Line discharges. Kennedy (1883—Bib. 3) worked out absorption losses as different rates of sinkage per hour for Main Line, Branch Canal, Distributaries and water courses. His results, when reduced to cusecs per million square feet, were 9·75, 2·2, 3·3 and 9·4, respectively.

Woods tried to be more scientific and produced the formula $q = C\,a\,d$ (Bib. 2), where q is absorption in cusecs per million square feet, c is a constant varying from 1·2 to 1·33, a is the reduced wetted perimeter of the channel section and d is its depth. The absorption in this case varied with wetted perimeter and depth. The work done up to that time did not make any reference to how water passed through the soil forming the boundary of the channel and how the position of the spring level below bed affected the results. Bresford (1875) threw the first hint (page 4, Bib. I) indicating that there were two distinct methods in which water was lost from the canals to the subsoil reservoir. It is in fact due to Wilsdon that we get a real start in the scientific investigation of this subject. His Lyallpur experiments were published in the Punjab Engineering Congress Proceedings, 1923 (Bib 4.) He has given a clear picture of what actually happens in the soil when water is lost from a canal by absorption through unsaturated soil (which has a moisture content of less than 23%) and by percolation through saturated soil (which has a moisture content of more than 23%). The term seepage losses stood both for absorption and percolation.

Wilsdon's Experiments.

Wilsdon's experiments as described in the Punjab Engineering Congress Proceedings of 1923 consisted of the determination of the moisture concentration in the soil below a small irrigation channel. From these observations he determined the contours of equal moisture content as sketched below.

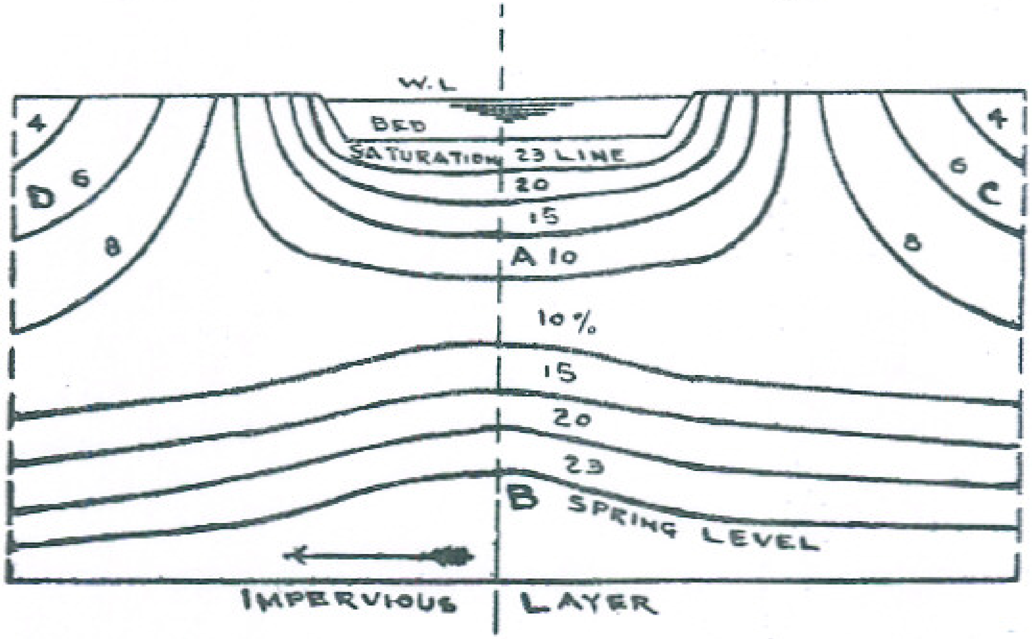


FIG. 1

The contours of moisture concentration are semi-ellipses below an irrigation channel. The moisture content of the soil decreases as one goes down. It is minimum at a a certain point between the groups of curves *A* and *B*. Again the moisture content rises in group *B* down to the spring level. The groups of curves *C* and *D* are due to the evaporation from the adjoining land. These are also semi-ellipses. They have been drawn here assuming that there is no irrigation in close proximity to the channel. These ellipses are practically parallel to the slope of the sub-soil water table at the point of their exit at *C* and *D*. The hump in group *B* is less pronounced if there is a steep slope in the subsoil water. It is a maximum if the impervious boundary is quite near to the spring level or the slope of the sub-soil flow is very flat.

This is a diagrammatic representation of the losses from canals by absorption. Mr. Wilsdon explains that absorption depended on three factors, viz., gravity, capillarity and chemical attraction. He took chemical attraction as being proportional to capillarity and his test showed that gravity played little or no part in the case of absorption. He concluded that the absorption did not vary directly with depth under any conditions, as in Wood's formula.

The case of percolation is very simple. The soil is saturated from the bed of the canal to the sub-soil water table. At every place the moisture content is more than 23%. All of the pore spaces of the soil are already filled in with water. There is no capillarity or chemical attraction. Water simply percolates in the stream tubes around the soil particles under the head available between the free surface of the canal and the subsoil spring level, as influenced by the transmission constant of the soil. The moisture contours are as sketched below :—

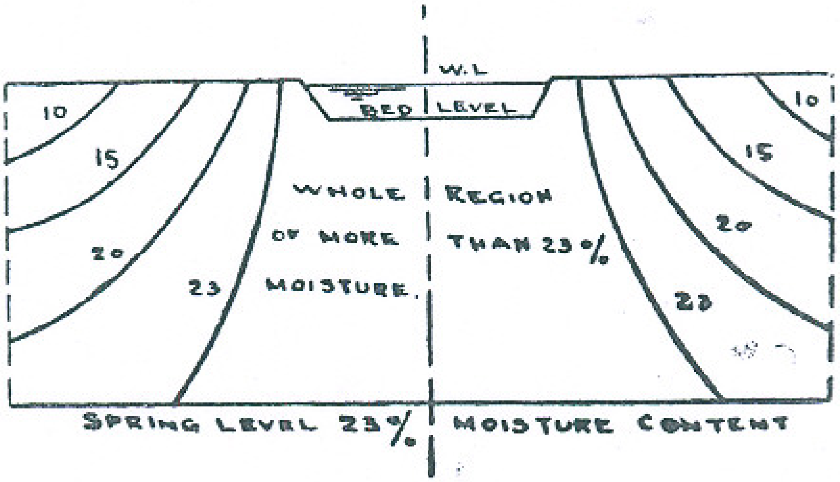


FIG. 2

Scope and object of the Experiments on 14 R. Distributary.

Wilsdon's work, describing and investigating the conditions of percolation and absorption losses, was simply qualitative: but he did work out certain deductions from his experiments from a purely theoretical point of view. These theoretical conclusions, arrived at by him with certain assumptions, were not generally appreciated by practical engineers. Wilsdon himself advocated in his paper published in the Proceedings of the Punjab Engineering Congress of 1923 the necessity and value of quantitative experiments of the actual losses of the canals under both conditions.

These experiments are the first systematic and scientific attempt to evaluate losses from a canal both in the saturated and unsaturated conditions. These experiments were originated and visualized by the Mr. E. S. Crump, C.I.E. and were carried out and completed by the Authors of this Paper.

The previous experimenters did not take into account the position of the spring level below the bed of a channel. In no case was the temperature of the water at bed level of the canal or tank observed, where water seeped through the soil of the bed. The present experiments have shown that the effect of temperature is so very pronounced that this factor alone could cause a variation in results by 66 % in actual canal practice.

In the tank experiments of Kennedy, Woods and Dr. Vaidianathan the end effect of the tanks was not allowed for. The irrigation channels are very long tanks of water. The losses from the bed for a unit length of the channel are either vertically downwards or splayed on both sides. The problem is essentially two dimensional. There is no splay of the percolation cone or the absorption contour along the length of the channel. It is no wonder that the result of tank observations of those experimenters without an allowance of the end effect may be 50 % higher than the results of these experiments under similar conditions otherwise, but end effect being eliminated.

Description of the Experimental Station.

The site for these experiments was selected at R. D. 4000 of 14 R Distributary, taking off at R. D. 4,15,000 of the Upper Jhelum Canal. This site was selected after digging a considerable number of trial pits all over Gujrat Sub Division to locate the desired spring level conditions. It was considered suitable as there was a natural swing in the spring level from about 5½ feet below natural surface to about 10 feet below natural surface. It was also expected to increase the swing by heading up in the Main Line and the 14 R Distributary or by flooding the rea.

The layout of the experimental tank is shown in plate No. 1. The tank is situated parallel to the distributary at a distance of 300 feet on the left side. It is 205 feet long. It has a bed-width of 20 feet and side slopes 1 to 1. The depth in tank has been kept 4 feet. The bed is level and is $2\frac{1}{2}$ feet below natural surface. The water level in the tank has been kept $1\frac{1}{2}$ feet higher than the natural surface against the bank made up of the soil excavated from the bed. In the centre of this long tank, the observation tank is only 5 feet wide, which represents a 5-feet length of a long reach of an irrigation channel, cut off for observations. Watertight cement concrete walls 6″ thick are built as partitions. The foundations of the walls have been taken 1 foot below the bed and the slopes of the tank. The inside soil of the observation was not disturbed while constructing foundations of the partition walls, and the digging outside the walls was well puddled up to bed level. The observation tank was tested out for a head of about a foot, so as to see that there was no creep or blow out, before the experiments started on 1-4-36. The partition walls have got a number of pipes of 2″ diameter connecting 100 feet long tanks on either side of the 5 feet observation tank. The idea was that the water level in the outside tanks should be exactly the same on both sides of the observation tank. The gauge in the outside tank was kept steady during the course of observations. Any slight departure of the water level was shown visually by the points of accurate hook gauges installed at *G* 2 and *G* 3, vide plate No. 1. They were fed directly from 14 R Distributary; the supply being first regulated at *A*, again precisely controlled at *B* and then put into the tanks *C* and *D*.

The observation tank of 5 feet width was fed day and night by means of a tap from an iron tank 4′×4′×4′ installed at *E*, as shown in plate No. 1. The feeding tank *E* was also fitted with a hook gauge which was read before and after each observation. A 2″ diameter pipe was put in at *F* in the centre of the observation tank to read spring levels. The strainer of this pipe was taken down about 16 feet below the normal spring levels recorded at this site so that it recorded the true subsoil water table.

There are six pressure pipes of $1\frac{1}{2}''$ diameter put in the observation tank at points *P* 1 and *P* 2, etc., as shown in plate No. 1, to read the hydrostatic pressures at 0·5 feet, 1 foot, 2 feet, 3 feet, 4 feet and 5 feet below bed level. An accurate hook gauge is fixed at *G* 1 in the observation tank to read its water surface.

The nature of the strata of the subsoil was not given any consideration when selecting the site. Samples were however taken and the result of mechanical analysis is given in Appendix IV.

Automatic Chicken Feed Arrangement.

As the surface area of the observation tank of 5 feet width is very large, viz., 140 square feet, and the surface area of the feeding tank only 16 square feet, it was very important to read the gauge *G* 1 of the observation tank very accurately. An error of 0·01 ft. in this gauge would

be equivalent to 0·1 ft. in the feeding tank which might mean an er
in the results from 2 to 5 %. In order to ensure that the wa
level in the observation tank remained dead level during the course
the observation, an automatic chicken feed arrangement was install
before the observations were started this summer, in June, 1937. T
detail of this arrangement is shown in plate No. 2.

It consists of a round iron tank of inside diameter 3 ft. 9 inch
and height 3·0 ft. This tank is liable to be subjected to a negative
pressure equivalent to about 5 feet head of water and therefore it w
essential to make it airtight. It is made of iron plate of 1/8″ thicknes
stiffened by 3 hoops around it of an angle iron 1½″×1½″ as shown
the drawing. Circular sheet iron is closely rivetted to these three hoo
All rivetting was done very carefully as it was to be air tight. The nece
sity of rivetting was reduced to a minimum by making the cover a
the bottom of the tank of 4 feet diameter; sheet iron of 1/8″ thickne
clamped tight to the circular drum against ¼″ thick rubber washers
means of ¼″ iron bolts and nuts, spaced 1½″ apart. The roof plate r
quired stiffening by two angle irons 1½″×1½″ so that it would not buck
in against negative pressure. A conical top would have been an ide
one to drive out air but it could only be made in a very efficient wor
shop. However a one-foot high and 1½″ diameter pipe was fixed in t
top to drive out air and to fill water in the tank, when required. Th
pipe was fitted with rubber washers above and below and made tight
means of brass nuts. The top of the pipe was provided with a c
which could be screwed airtight by means of a wrench. This ta
was tested to be watertight against a head of 10 feet above the feedi
pipe, before it was declared to be fit for use for the work required.

The circular tank is fitted with a glass tube gauge of ½″ diamet
shown at *B*, plate No. 2. All connections of this gauge have been d
signed and ensured to be airtight. *D* is a hook gauge. The hook
this gauge is a horizontal edge which slides behind the glass tube gau
and is made to coincide with the meniscus of water in the tube and th
the reading of the vernier of the hook gauge is taken. In this way, t
gauge of the chicken feed tank is taken very accurately before and aft
each observation.

F is a 1″ diameter brass cock which is secured to the tank, airtig
against rubber washers. *G* is a flexible tube of 1″ diameter armour
inside to stand negative pressure. *H* is ½″ diameter G. I. pipe conne
ted at its upper end to the armoured pipe *G* by means of a reduci
socket and the lower end cut accurately to a pen-shaped nozzle. T
accurate working of the chicken feed depends to a large extent up
its position and its workmanship. It is fixed in the tank by means
wooden planks secured as shown at *J* in plate No. 2. The corre
position was found by trial and error so that it gave exactly 4 feet dep
in the observation tank, as checked by means of the gauge *G*, in Pla

No. 1. This arrangement ensured an automatic feed to the observation tank during the course of the observation keeping a constant level. It also served as an automatic feed during the night time.

Procedure in the observation.

The spring levels were taken before and after observation in the pipe *F* by means of Khosla's sounder, which was suspended from a tape and was gradually lowered in the pipe. When the lower edge of the sounder touches the water level in the pipe it gives a familiar sound. The tape was read at this sound from the top of the pipe. Tape reading plus the length of the sounder gave the position of the spring level below the top. This method of observation of water level in a pipe was found to be pretty accurate and the error in the observation could not be more than 0·01 feet. The average of the two readings before and after was taken to be the mean spring level of the observation.

Temperature readings were taken by means of a Centigrade thermometer generally before and after the observation. When the period of observation was small and was entirely in the forenoon or afternoon, the average of the two readings was taken to be the mean temperature. Sometimes the observation was continued the whole day in winter, then hourly temperatures were taken and their mean value was struck. The method of temperature reading was not found to be a simple affair, as the temperature of the surface water was different from that near the bed of the observation tank. The temperature required was of the water as it entered the bed to be lost in absorption or percolation. The reading was generally taken in the pipe P_2, which had its feeding point 1 foot below bed level. The bulb of the thermometer was covered with a thin layer of wax, lowered down in the pipe and kept there for a couple of minutes in water. It was then quickly taken out, read and recorded. The wax was used so as to reduce possibility of a change in the reading in the time the thermometer was taken out and read. When the pipe did not have enough water the reading was taken by lowering the thermometer on to the bed. The temperatures recorded, therefore, give the actual temperature of water at the bed of the observation tank to a fair degree of accuracy. The daily evaporation during the course of the observations was also taken and recorded but the evaporation was found to be so small even in summer that its value never exceeded 2 per cent of the actual losses from the tank and it was, therefore, neglected.

Before each observation, the observation tank and the outside tanks were brought to exactly 4 ft. gauge by adding water as already explained. After the temperature and spring level readings were taken, time was noted when the water level of the observation tank was exactly 4 ft. as read from hook gauge *G*. When there was no automatic feed arrangement, water from the feeding tank *E*, of which the gauge was recorded before the start of the observation, was let into the observation tank by opening the stop cock *E*. The water level in the observation tank of 5 ft. width was kept within 0·01 foot of the gauge recorded by the hook of Gauge *G* 1. At the close of the observation the feed of the water was regulated at such a rate that the Gauge *G* 1 exactly recorded 4 ft. gauge. Time was again noted and the stop cock of the feeding tank closed, simultaneously the final reading of the gauge in the feeding tank being also recorded. The difference of the two gauge readings multiplied by 16 gave the volume (in cubic feet) of water lost in the interval. Calculations for absorption in cusecs per million square feet then easily followed from the known value of the wetted perimeter of the observation rank, which was 156·8 square feet in this case.

The errors of observation were greatly eliminated by the installation of the automatic chicken feed arrangement (plate 2) and the observation work was very much simplified. It was not necessary for the observer to sit there the whole time. The man on duty filled the tank E, about an hour before the observation was started to a level a couple of inches higher than the top cover plate, so that all air was driven out. The cover of the feeding pipe *E* was tightly secured. The man on duty opened the cock *F* of the chicken feed arrangement, plate 2. In about an hour the water level in the tank dropped so that it could be read in the glass tube gauge *B*. The observer had simply to read this water level by means of the Hook Gauge *D* and note time from his watch. He was required again to take the reading of the water level at the close of the observation generally after six hours. The level in the observation tank was kept dead level, during this period of the observation, by the automatic feed exactly at 4 ft. gauge as recorded by the Gauge *G* 1 in Plate 1. The nozzle *H* of the chicken feed arrangement was set in such a way that the constancy of the required level was ensured. Similarly at night time the man on watch had not to keep awake the whole night to read the observation tank to keep it at four feet gauge. He would put the chicken feed on in the evening and would only get up in the morning to fill it up again for the morning observation. A watch was however kept during day and night, so that under no conditions the difference between the outside and inside tanks was allowed to be more than 2 to 3 inches even when the observation was not on, so that there was no blow out.

The principle of the working of the chicken feed arrangement is very simple. When the cock *F* has been opened after filling the tank and securing cap of the feed pipe *E*, the little air left in the tank expands as water flows out and its pressure is reduced. The pressure of the air inside the tank becomes negative, equal to the head of the water as measured from the water level in the chicken feed tank to the water level in the observation tank. When the top of the nozzle H is covered, there is no flow. If the water level in the observation tank drops below the top of the nozzle *H* then air gets in up the pipe *G* into the tank *A* and an equal amount of water flows out. The process of the air going up and water coming out becomes continous and steady. The air while getting up into the tank against the depth of the water produces a bubbling melodious continuous sound which is a sure signal that the chicken feed arrangement is satisfactorily working.

Effect of Temperature on Seepage Losses.

It has been seen from the temperature observations that there had been a variation of temperature from 10°C to 37°C. The variation of temperature causes a variation in the viscosity of water. It is natural to expect that water of low viscosity will pass quicker through the stream tubes of the soil under the same prevailing conditions of head and pore space than water of high viscosity. Absorption is directly proportional to the velocity of the water, as it enters the boundary of the bed of the experimental tank. It is, therefore, clear that the absorption is inversely proportional to viscosity.

Referring to page 11 of "Hydraulics" by A. H. Gibson (Bib. 6) the variation of the viscosity with temperature is expressed as below :—

$$v = \frac{\cdot 00003716}{1+\cdot 03368T+\cdot 000221T^2}$$

where v is viscosity and T is temperature centigrade.

But velocity V varies inversely as viscosity

$$\therefore\ V \propto (1+ .03368T+.000221T^2)$$

But Absorption A is directly proportional to velocity.

$$\therefore\ A \propto (1+ \cdot 03368T+\cdot 000221\,T^2)$$

A diagram is given in plate No. 3 giving the percentage correction, considering the standard temperature of water to be 25°C. For temperatures above 25°C, the correction factor is negative and for temperature below 25°C the correction factor is positive.

It is clear from this diagram that the temperature effect is so very pronounced that on account of the temperature alone the absorption will drop in winter for a change from 37°C to 10°C by about 66%.

Piping from the canal to the sub-soil reservoir.

The phenomenon of piping is analogous to a breach in a canal. It comes into being as a breach develops in a canal.

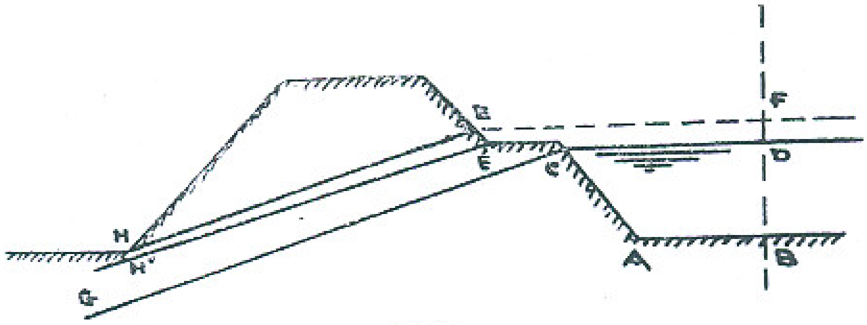


FIG. 3

Let *C D* be the surface of canal water, where it normally runs full supply. *C G* represents the saturation line in the bank. The bank as sketched above, is extra safe. Let there be an excess in the canal, so that water level rises to *E F*. What actually happens is that the line of saturation is changed to *E H*. A breach should not occur, even if the point *H* be higher than the toe of the bank. At the most, water should seep out from the canal. The velocity of the seepage cannot be high enough to dislocate the soil particles of the bank. A failure never occurs by percolation through the banks.

In the normal condition the soil of the bank above *C G*, is dry and has never probably been wetted. The rise of the saturation line from *C G* to *E H* wets for the first time the soil of the trapezium *CGHE* of the bank section. Dry soil on first wetting contracts and the bank stands at places by arching action. Thus an open pipe is formed between *EH* and *E'H'* as shown in the sketch above. Water flows out of it as a leakage as if an open connection exists from water in the canal to that outside. Water coming out starts washing out the soil and eventually develops into a breach. If in the beginning, mouth *E* of the pipe *E H* could be located and closed, the breach would never occur.

These very conditions of a breach were brought into existence in the case of these experiments, when first started on 1. 4. 36. The spring level was about 4·5 ft. below the bed of the observation tank. The absorption was between 4.5 and 5 cusecs per million square feet for the first 20 observations. Then it shot up in a couple of days to 32·7. There was practically no change in the position of the spring level below bed, temperature and other conditions of the experiments. The results of these observations are given in Appendix I of this paper.

Soil below the experimental tank was saturated for the first time. It contracted, forming open pipes from the tank to the subsoil reservoir. Water simply flowed through these holes into the water table below. The observations were stopped and the bed of the observation tank was dried out. Two such holes were visible. A measured quantity of water was put into them, keeping the hole full up to the bed level. It was calculated that the discharge of these two holes, even with a reduced head of 4 feet was sufficient to account for an increase in the results of 12 cusecs per million square feet. These two holes, although their diameters were not appreciable were closed by means of cement slurry. There may be such other holes which were not visible. The disparity of the results in this set of observations was due to nothing else but piping which continued up till 12-7-36 when the observations were stopped again for a re-examination of the bed of the observation tank. The bed was lightly scraped and dressed to the designed levels. It appears that all the invisible holes were closed by the silt slurry depositing on the bed. Piping stopped after 12-7-36.

It is concluded from this, that when a new canal is constructed at a place where spring level is within the zone of saturation below its bed or when the bed level of a canal is lowered in such a way that the water table is brought within such range, the piping is bound to set in when the soil above the water table will be saturated for the first time and contract. The piping in such a case can probably never be efficiently sealed, because the soluble silt will be carried away and only the coarse sand could deposit in such holes. The lowering of the canal under these conditions would result in permanent increase of the seepage losses.

This set of observations (Appendix I) is only considered a breach and has no bearing on the subject of the seepage losses from the canals by way of percolation or absorption.

Results of the experiments.

There are three sets of observations and their results are given in Appendix II of this Paper. All the three sets are plotted in plate No. 4 after being reduced to a mean temperature of 25°C by applying correction factors from plate No. 3.

First set consists of 26 observations from 21-7-36 to 25-8-36. The spring level was rising. It rose from 7·5 feet to 4·8 feet below the free water surface in the observation tank. The depth of water was 4 feet. The observations are shown in circles. The seepage losses decreased from 8·8 cusecs per million square feet to 5 cusecs per million square feet. There is, no doubt, some disparity in these observations but the general trend shows that the seepage losses decreased very nearly directly as the water table rose. The rains failed and the spring level did not go up beyond 0·8 feet below bed.

The second set of observations was taken when the spring level dropped from 4·8 feet to 9·7 feet below the free water surface in the observation tank. These observations were taken from 25-8-36 to 28-2-37. They are plotted as "crosses" in plate No. 4. The first 24 observations showed a steady increase in absorption and practically the conditions of the first set were repeated. The increase in the seepage losses was nearly proportional to the increase in the head from the free water surface in the tank to the water table below bed.

The observations of this set from No. 25 to No. 44 show a decrease in the seepage losses when the spring level dropped from 7½ feet to 9 feet below free water surface in the tank, that is, from 3·5 to 5 feet below bed. The decrease is not uniform and the graph is a well defined curve. The observations from No. 45 to 63 show that the seepage losses were practically constant when the spring level variation was not much, *i. e.*, from 9 feet to 9·7 feet below free water surface of the tank. The seepage losses were constant, of the order of about 3 cusecs per million square feet. The spring level did not vary and the observations were stopped. A firm line is drawn through 63 observations of this set and 26 observations of the first set in plate No. 4.

Third set of observations was started on 11-6-37 after the long closure and after installing the automatic chicken feed arrangement. Observations are given in Appendix II and the results are plotted in plate No. 4 as "dots." The experimental station had remained closed for a long time and the bed of the observation tank remained dried up. It was scraped to the design level and the slurry deposited during the last six months was removed. The observations started with spring level 10.65 feet below the free water surface in the tank. The results for a few days were high on account of dry bed but later became practically steady near about 5 cusecs per million square feet.

This third set has also three distinct phases as were observed in the second set. The seepage losses were very nearly constant from 10·6 feet to 9 feet variation of spring level below the free surface in the observation tank. The seepage loss increased as spring level rose from 9 feet to 6·5 feet. The results in this case increased from 5 cusecs per million square feet to about 8·5 cusecs per million square feet. For the change in spring level from 6·5 feet to 3·75 feet below the free water surface, the seepage losses decreased very nearly uniformly in a straight line. The average line through the results of this set has been drawn as dotted in plate No. 4.

Pressure observations.

The observations of six pressure pipes are given in Appendix III and the results plotted in plates Nos. 5 and 6. There were only two pipes last year with points at 1 foot and 2 feet below the bed and the remaining were put in this year in May, 1937.

The pressures clearly show that the saturated conditions obtain up to 5 feet below bed. The pipes Nos. 5 and 6 did not record any pressure when the spring level was below 5½ feet from the bed. In this condition it was a pure case of absorption. However, it showed that the saturation contour was not so near to the perimeter of the channel as given out by Mr. Wilsdon in his P. E. C. Paper of 1923. It is concluded from these observations that the flow is in partially saturated condition when the spring level is from 3 to 5 feet below the bed. The flow is in saturated condition when the spring level is 3 feet below bed. It is evident from Plate No. 5 that in all cases there is a rapid increase in the pressures in the partially saturated conditions which connotes the increase in seepage losses when conditions change from the unsaturated to the saturated flow.

Discussion of results.

The results of these experiments are clearly shown in plate No.4. The firm line shows the seepage losses both in the saturated and unsaturated conditions when the spring level was dropping. The dotted line shows the seepage losses both in the unsaturated and saturated conditions, when the spring level was rising. There is considerable variation between the two lines. The variation can be put in three groups as explained below :—

1. Spring level from 7 feet to 5 feet below bed.

The absorption loss is very nearly constant in both cases. In one case the average value is about 3 cusecs per million square feet and in the second case the average value is nearly 5 cusecs per million square feet. In the former it was the end of observations which were started about ten months before and it was quite likely that the bed of the observation tank got gradually staunched by the alluvial deposits from the stationary water in the tank : in the latter it was the beginning of a fresh set of observations when the tank bed had remained dry for a couple of months and was scraped to the designed conditions. The difference between the two sets of observations represents the maximum effect of staunching in the tank bed. For application of the results of these experiments to the actual canal practice, it is necessary to accept the higher value.

2. Spring level from 5 feet to 3 feet below bed.

In this region which represent the conditions of partial saturation, the shape of the curve is the same in both cases. The maximum value is also the same very nearly, in both cases. In the case when spring level is dropping, the maximum occurs when the spring level is about 3·5 feet below the bed. When the spring level is rising the maximum value of the seepage losses occurs when the spring level is about 2·5 feet below the bed. The difference between the position of the maximum value is due to Hysterises which one would naturally expect in such cases. Three feet below bed may be taken as the critical position of the spring level, where the maximum absorption would occur. The saturated conditions of the sacs of the soil particles would hold on when the spring level is dropping and therefore the region of the saturated condition would extend to about 3½ feet below bed. When the spring level is rising the complete saturation of the sacs in the soil particles will be retarded from the unsaturated to the saturated conditions, and complete saturation, will therefore, be brought about with spring level about 2·5 feet below due to this phenomenon.

3. Spring level from 3 feet below bed to bed level.

The soil is completely saturated in both cases and the change of the seepage losses by way of percolation is linear. The values of the losses in the case of rising spring levels are lower than those of the dropping levels. This is due to nothing else but the effect of staunching in the period of three months since the time when the observations were restarted. The effect of the staunching will be allowed for, if we accept the maximum value of the seepage losses recorded.

Conclusions.

Of all the problems in Hydraulics that have faced engineers from the earliest times, the one relating to seepage losses in irrigation channels is one of the most complicated and that, perhaps, explains why so little advance has been made therein up to the present day. Laboratory tests, while lending themselves to other cases, seem to fail when applied to seepage losses, because the most important factor—nature of subsoil strata—cannot be reproduced in the laboratory. A notable instance is furnished by an experiment, attempted by Dr. Vaidianathan of the Irrigation Research Institute on clay of which he carried a slice intact from the field, duly waxed which showed no absorption loss for a long time (at least a month), it was kept under observation. This paper deals with an attempt to get some results in the field, under natural conditions of subsoil. Now this varies so enormously from one place to another that the results obtained have a very limited application to the particular strata found at the selected site. Again, variation in head, under which seepage takes place, has been fixed at one figure. Briefly the following conclusions for these limited conditions have been reached :—

(*a*) Variation in distance of spring level below bed of a channel definitely affects the amount of seepage losses, as such distance reduces to an extent that partially saturated or fully saturated condition of subsoil occurs.

(*b*) Maximum losses in seepage take place at a certain distance of spring level from bed in the saturated zone, and with further rise, such losses diminish again.

It is admitted that these conclusions do not carry the problem very far. All that is claimed is that a new and more scientific way has been shown to be practicable in work of this kind, allowing for the following factors :—

(i) Variation in spring levels.

(ii) End effect, which was never allowed for in any previous work.

(iii) Steady head of water by an automatic feed arrangement without expensive apparatus.

A great deal of more work is required to allow for following further factors, known or suspected to effect results which unfortunately could not be arranged to be done in the time and means available for these experiments :—

(iv) Variation in Subsoil Strata.
(v) Different depths.
(vi) Variation in gradient of subsoil flow at the site.
(vii) Staunching effect of bed during observations.

Further investigation of the subject is already being attempted by the Authors of this paper on Main Line, Upper Jhelum Canal, about R. D. 2,60,000 (situated nearly 5 miles south-east of Rasul Headworks) with a view to taking into account the new factors, mentioned above. The method has again been suggested by that well known veteran Irrigation Engineer, Mr. E. S. Crump, who unfortunately for us, has recently retired from service but whose help has however been made possible for some time more. The method is as simple and accurate as it is new. It consists of a watertight masonry or concrete barrel, cutting off a portion of actual bed with an open mouth at one end on one slope of the canal. The loss of water is shown in a magnified form at the entrance where it can be observed and measured accurately, at the same time, making it possible to work under field conditions. The question of staunching effect due to feeding silt laden water is the only factor, which it has not been possible yet to allow for. This work is still in a preliminary stage and may form the subject of another paper in future. All engineers interested in this problem are invited to come and see it in progress, if they can find time or happen to pass that way in the course of performance of other duties. It is hoped that some of those who study this Paper will start experiments on these or improved lines and help in the solution of this most complex problem.

Bibliography of books referred to.

1. Remodelling of distributaries on old canals. Punjab Irrigation Branch Paper No. 10.... 1905.

2. Absorption losses of canals. By Woods : Punjab Engineering Congress........................1917.

3. Lining water courses. Punjab Irrigation Branch Paper No. 19.

4. Percolation and absorption in soils, by Wilsdon : Punjab Engineering Congress.....1923.

5. Memoir of the Punjab Irrigation Research Institute, Vol. V, 1936, by Dr. Vaidianathan.

6. "Hydraulics," by A. H. Gibson.

APPENDIX I.

Observation from 1-4-36 *to* 12-7-36 *showing piping to Sub Soil Water Table.*

Serial No.	Date.	Average Spring level below bed.	Average temperature.	Cu. ft. of water absorbed.	Duration of observation.	Absorption in cusecs per million sq. ft.	Corrected absorption to 25°C. (Average temperature.)
1	1-4-36	4.88	25.175	28.40	10 hrs.	5.03	5.01
2	2-4-36	4.78	24.50	28.12	10 ,,	5.00	5.07
3	3-4-36	4.78	25.00	25.44	10 ,,	5.50	4.50
4	4-4-36	4.745	23.62	24.56	10 ,,	4.35	4.49
5	5-4-36	4.695	23.25	23.04	10 ,,	4.078	4.26
6	6-4-36	4.68	22.87	24.80	10 ,,	4.389	4.60
7	7-4-36	4.67	23.12	24.584	10 ,,	4.362	4.56
8	8-4-36	4.755	22.42	26.648	10 ,,	4.716	5.11
9	9-4-36	4.772	22.25	26.96	10 ,,	4.772	5.20
10	10-4-36	4.78	21.87	25.44	10 ,,	4.502	4.857
11	11-4-36	4.775	22.37	26.752	10 ,,	4.735	5.00
12	12-4-36	4.82	22.50	27.36	10 ,,	4.842	5.13
13	13-4-36	4.79	23.25	28.80	10 ,,	5.097	5.31
14	14-4-36	4.74	24.42	29.84	10 ,,	5.281	5.36
15	19-4-36	4.77	25.50	29.20	8 ,,	6.453	6.38
16	20-4-36	4.69	24.58	26.96	8 ,,	5.958	6.018
17	21-4-36	4.71	24.58	24.16	8 ,,	5.339	5.392
18	22-4-36	4.67	24.16	44.88	6 ,,	13.239	13.503
19	23-4-36	4.635	25.93	95.152	8 ,,	21.028	19.608
20	24-4-36	4.582	23.19	106.496	8 ,,	23.535	24.595
21	25-4-36	4.62	23.50	106.816	8 ,,	23.606	24.426
22	27-4-36	4.555	25.46	118.096	8 ,,	26.099	25.839
23	28-4-36	4.54	25.46	122.064	8 ,,	26.976	26.706
24	29-4-36	4.505	26.29	125.920	8 ,,	27.828	27.108
25	30-4-36	4.75	27.37	126.00	8 ,,	27.846	26.526
26	1-5-36	4.42	27.54	131.472	8 ,,	29.055	27.545
27	4-5-36	4.43	28.78	157.632	8 ,,	34.836	32.836
28	5-5-36	4.41	26.61	129.312	8 ,,	28.578	27.658
29	6-5-36	4.41	25.91	103.968	6 ,,	30.670	30.07
30	7-5-36	4.46	23.67	78.048	6 ,,	23.024	23.774
31	8-5-36	4.525	24.32	73.680	6 ,,	121.735	22.06
32	9-5-36	4.51	24.69	67.088	6 ,,	19.791	19.941
33	29-5-36	5.99	31.37	48.672	6 ,,	14.358	12.57
34	30-5-36	5.88	29.41	44.20	6 ,,	13.039	11.87
35	31-5-36	5.81	28.21	41.160	6 ,,	12.142	11.32
36	1-6-36	5.66	29.14	38.768	6 ,,	1.336	10.40
37	2-6-36	5.64	27.54	38.80	6 ,,	11.346	10.40
38	3-6-36	5.60	26.06	34.72	6 ,,	10.242	10.02
39	4-6-36	5.54	27.66	34.40	6 ,,	10.148	9.58
40	7-6-36	5.48	28.42	33.072	6 ,,	9.756	9.06
41	8-6-36	5.43	28.97	31.96	6 ,,	9.430	8.66
42	9-6-36	5.37	29.62	34.048	6 ,,	10.044	9.16
43	10-6-36	5.35	29.55	37.968	6 ,,	11.180	10.13
44	11-6-36	5.41	27.62	37.248	6 ,,	10.988	10.36
45	12-6-36	5.37	28.16	38.448	6 ,,	11.342	10.60

Serial No.	Date.	Average Spring level below bed.	Average tempera-ture.	Cu. ft. of water absorbed.	Duration of obser-vation.	Absorption in cusecs per milllon sq. ft.	Correct-ed ab-sorption to 25°C. (Average tempera-ture.)
46	15-6-36	5.43	28.14	53.928	6 hrs.	15.908	14.88
47	16-6-36	5.46	27.56	54.240	6 ,,	16.00	15.19
48	17-6-36	5.51	28.16	58.320	6 ,,	17.204	16.10
49	18-6-36	5.55	29.71	58.064	6 ,,	17.128	15.65
50	20-6-36	5.39	30.52	51.520	6 ,,	15.198	13.50
51	28-6-36	5.73	27.75	53.68	6 ,,	15.835	14.90
52	29-6-36	5.62	27.04	27.248	6 ,,	13.938	13.35
53	30-6-36	5.54	27.77	47.328	6 ,,	13.961	13.11
54	1-7-36	5.45	32.54	49.120	6 ,,	14.490	12.32
55	2-7-36	5.47	30.26	46.000	6 ,,	13.570	12.13
56	3-7-36	5.46	34.04	46.000	6 ,,	13.570	10.18
57	6-7-36	5.09	30.54	37.952	6 ,,	11.195	9.94
58	7-7-36	4.86	31.00	30.240	6 ,,	13.381	11.78
59	8-7-36	4.80	32.52	45.280	6 ,,	13.357	11.38
60	9-7-36	4.76	33.04	32.560	6 ,,	9.605	8.13
61	10-7-36	4.65	32.06	41.440	6 ,,	12.224	10.52
62	11-7-36	4.465	32.10	39.04	6 ,,	11.5168	9.90
63	12-7-36	3.635	31.88	38.96	6 ,,	11.493	10.30

APPENDIX II.

1st Set of observations rising Spring from 3.6′ below bed to 0.82′ below bed.

Serial No.	Date.	Average Spring level below bed.	Average temperature.	Cu.ft. of water absorbed.	Duration of observation.	Absorption in cusecs per million sq. ft.	Corrected absorption to 25°C. (Average temperature.)
1	21-7-36	3.52	33.5	35.68	6 hrs.	10.525	8.825
2	22-7-36	3.41	33.25	34.888	6 ,,	10.29	8.62
3	23-7-36	3.28	32.125	31.20	6 ,,	9.166	7.886
4	24-7-36	3.215	31.25	30.40	6 ,,	8.968	7.868
5	26-7-36	3.04	31.875	28.80	6 ,,	8.50	7.35
6	27-7-36	3.16	29.25	28.76	7 ,,	7.27	6.65
7	27-7-36	2.515	30.25	26.04	6 ,,	7.68	6.81
8	30-7-36	2.42	32.75	24.72	6 ,,	7.29	6.29
9	31-7-36	2.47	31.875	25.96	6 ,,	7.66	6.62
10	1-8-36	2.48	31.75	20.36	5 ,,	7.207	6.347
11	2-8-36	2.46	32.875	24.080	6 ,,	7.103	6.00
12	3-8-36	2.50	32.625	24.20	6 ,,	7.139	6.069
13	6-8-36	2.29	33.25	21.92	6 ,,	6.47	5.45
14	7-8-36	2.22	31.50	21.60	6 ,,	6.37	5.59
15	8-8-36	1.91	33.25	20.96	6 ,,	6.18	5.18
16	9-8-36	1.84	32.75	20.32	6 ,,	5.99	5.18
17	10-8-36	1.78	30.125	24.96	6 ,,	7.36	6.60
18	11-8-36	1.67	29.0	24.80	6 ,,	7.32	6.70
19	12-8-36	1.60	30.25	25.16	6 ,,	7.42	6.65
20	13-8-36	1.5175	31.75	25.52	6 ,,	7.53	6.50
21	14-8-36	1.43	30.50	16.52	4 ,,	7.31	6.50
22	15-8-36	1.36	31.875	22.112	6 ,,	6.52	5.65
23	17-8-36	1.31	32.52	23.52	6 ,,	6.94	5.91
24	21-8-36	0.95	32.00	20.20	6 ,,	5.96	5.15
25	23-8-36	0.90	30.25	19.00	6 ,,	5.605	5.040
26	25-8-36	0.87	32.375	19.84	6 ,,	5.85	5.00

APPENDIX II.

2nd Set of observations Spring Level Dropping from 0.82′ below bed to 5.7′ below bed.

Serial No.	Date.	Average Spring level below bed.	Average temperature.	Cu. ft. of water absorbed.	Duration of observation.	Absorption in cusecs per million sq. ft.	Corrected absorption to 25°C. (Average temperature.)
1	25-8-36	0.87	32.375	19.84	6 hrs.	5.85	5.00
2	27-8-36	1.09	32.75	23.64	6 ,,	6.97	5.90
3	4-9-36	1.46	31.875	15.24	4 ,,	6.75	5.64
4	5-9-36	1.35	32.25	24.44	6 ,,	7.21	6.18
5	7-9-36	1.43	32.5	24.384	6 ,,	7.19	6.13
6	10-9-36	1.46	32.0	21.16	6 ,,	6.24	5.38
7	12-9-36	1.48	32.0	21.00	6 ,,	6.195	5.345
8	15-9-36	1.77	29.0	28.68	6 ,,	8.46	7.69
9	17-9-36	1.88	29.0	25.32	6 ,,	7.47	6.70
10	19-9-36	1.94	30.125	28.16	6 ,,	8.30	7.55
11	10-10-36	2.10	25. 5	26.44	6 ,,	7.80	7.72
12	12-10-36	2.176	25.25	24.32	6 ,,	7.17	7.13
13	13-10-36	2.21	25.375	24.40	6 ,,	7.20	7.15
14	14-10-36	2.15	25.50	24.64	6 ,,	7.27	7.20
15	19-10-36	2.605	25.25	20.80	6 ,,	6.14	6.11
16	20-10-36	2.66	25.00	22.00	6 ,,	7.79	7.79
17	21-10-36	2.79	25.00	27.52	6 ,,	8.12	8.12
18	22-10-36	2.915	24.75	26.00	6 ,,	7.68	7.73
19	23-10-36	2.945	25.00	26.48	6 ,,	7.81	7.81
20	29-10-36	3.205	23.75	28.16	6 ,,	8.31	8.56
21	30-10-36	3.190	23.75	25.84	6 ,,	7.62	7.85
22	31-10-36	3.215	23.875	25.88	6 ,,	7.64	7.83
23	2-11-36	3.37	21.50	25.92	6 ,,	7.65	8.30
24	3-11-36	3.395	21.50	25.76	6 ,,	7.60	8.35
25	4-11-36	3.455	21.00	20.04	6 ,,	6.75	7.50
26	5-11-36	3.52	20.25	13.96	6 ,,	6.18	6.90
27	6-11-36	3.58	20.25	21.44	6 ,,	6.33	7.07
28	7-11-36	3.62	20.375	19.44	6 ,,	5.74	6.40
29	10-11-36	3.67	19.375	17.20	6 ,,	5.07	5.81
30	16-11-36	3.765	18.75	14.08	6 ,,	4.15	4.81
31	17-11-36	3.795	18.50	12.80	6 ,,	3.78	4.42
32	18-11-36	3.87	18.00	12.64	6 ,,	3.78	4.42
33	22-11-36	4.07	17.125	9.96	5 ,,	3.53	4.27
34	24-11-36	4.16	15.75	10.08	6 ,,	2.97	3.72
35	27-11-36	4.305	15.50	10.04	6 ,,	2.96	3.72
36	29-11-36	4.35	16.50	10.44	6 ,,	3.08	3.78
37	2-12-36	4.515	18.25	11.16	6 ,,	3.29	3.86
38	5-12-36	4.49	16.75	7.92	6 ,,	2.34	2.86
39	8-12-36	4.505	15.25	9.008	6 ,,	2.66	3.40
40	11-12-36	4.545	16.00	9.008	6 ,,	2.66	3.38
41	15-12-36	4.51	16.25	8.64	6 ,,	2.55	3.15
42	19-12-36	4.635	13.375	7.68	6 ,,	2.27	3.00
43	25-12-36	5.13	11.00	7.04	6 ,,	2.08	2.98
44	26-12-36	5.13	10.875	7.04	6 ,,	2.08	2.995

Serial No.	Date.	Average Spring level below bed.	Average temperature.	Cu. ft. of water absorbed.	Duration observation.	Absorption in cusecs per million sq ft.	Corrected absorption to 25°C. (Average temperature.)
45	27-12-36	5.195	11.625	7.20	6 hrs.	2.12	2.98
46	1-1-37	5.48	12.625	8.00	6 ,,	2.36	3.20
47	2-1-37	5.485	13.875	7.84	6 ,,	2.31	3.11
48	3-1-37	5.49	13.75	7.04	6 ,,	2.07	2.72
49	4-1-37	5.55	13.375	7.69	6 ,,	2.27	3.00
50	5-1-37	5.59	12.75	7.84	6 ,,	2.31	3.11
51	6-1-37	5.70	12.00	7.44	6 ,,	2.20	3.06
52	9-1-37	5.535	12.50	6.272	6 ,,	1.99	2.71
53	13-1-37	5.37	10.60	6.808	6 ,,	2.01	2.84
54	15-1-37	5.37	10.50	6.576	6 ,,	1.94	2.79
55	17-1-37	5.35	10.50	6.528	6 ,,	1.93	2.78
56	19-1-37	5.355	11.00	6.40	6 ,,	1.89	2.68
57	21-1-37	5.395	10.75	6.36	6 ,,	1.86	2.71
58	22-2-37	5.145	15.875	8.96	6 ,,	2.64	3.30
59	23-2-37	5.025	17.25	9.12	6 ,,	2.69	3.24
60	24-2-37	4.985	17.25	9.04	6 ,,	2.67	3.22
61	27-2-37	4.915	15.625	8.16	6 ,,	2.41	3.02
62	28-2-37	4.91	17.8754	7.72	6 ,,	2.28	2.70

APPENDIX II.

3rd Set of Observations Spring Level rising from 6.6' below bed to 0.21ft. below bed.

Serial No.	Date.	Average Spring level below bed.	Average temperature.	Cu. ft. of water absorbed.	Duration of observation.	Absorption in cusecs per million sq. ft.	Corrected absorption to 25°C. (Average temperature.)
1	11-6-37	6.55	27.25	17.24	5 hrs.	6.00	5.73
2	12-6-37	6.35	27.0	16.58	5 ,,	5.86	5.63
3	13-6-37	6.125	27.5	15.80	5 ,,	5.59	5.31
4	14-6-37	6.02	26.5	16.35	5 ,,	5.78	5.61
5	15-6-37	5.91	28.0	15.91	5 ,,	5.63	5.26
6	16-6-37	5.825	31.75	15.44	5 ,,	5.46	4.73
7	17-6-37	5.81	30.00	15.03	5 ,,	5.32	4.79
8	18-6-37	5.775	30.25	14.81	5 ,,	5.16	4.46
9	19-6-37	5.745	30.00	14.59	5 ,,	5.16	4.64
10	21-6-37	5.695	30.00	15.53	5 ,,	5.49	4.94
11	22-6-37	5.64	30.25	16.13	5 ,,	5.71	5.11
12	23-6-37	5.635	30.25	16.24	5 ,,	5.47	5.14
13	24-6-37	5.63	30.25	16.35	5 ,,	5.87	5.17
14	25-6-37	5.675	30.50	16.58	5 ,,	5.86	5.22
15	27-6-37	5.755	30.625	16.69	5 ,,	5.90	5.20
16	28-6-37	5.79	30.00	16.91	5 ,,	5.98	5.38
17	30-6-37	5.63	31.00	17.13	5 ,,	6.06	5.33
18	1-7-37	5.51	30.25	15.47	5 ,,	5.47	4.90
19	8-7-37	5.73	30.75	17.13	5 ,,	6.06	5.04
20	9-7-37	5.655	28.25	16.13	5 ,,	5.71	5.04
21	10-7-37	5.46	28.25	15.91	5 ,,	5.63	5.10
22	11-7-37	5.37	31.25	16.02	5 ,,	5.67	4.97
23	12-7-37	5.33	28.5	15.58	5 ,,	5.51	5.01
24	13-7-37	5.30	28.125	15.03	5 ,,	5.32	4.83
25	17-7-37	4.875	34.35	14.59	5 ,,	5.16	4.19
26	18-7-37	4.785	33.25	16.13	5 ,,	5.71	4.79
27	19-7-37	4.71	33.25	19.09	6 ,,	5.63	4.72
28	20-7-37	4.695	32.00	16.88	6 ,,	4.97	4.29
29	22-7-37	4.44	29.50	15.91	5 ,,	5.63	5.12
30	23-7-37	4.26	32.00	15.44	5 ,,	5.46	4.71
31	24-7-37	4.13	33.75	14.97	6 ,,	4.41	3.66
32	25-7-37	3.875	33.75	21.00	6 ,,	6.19	5.14
33	26-7-37	3.735	29.75	19.12	5 ,,	6.76	6.10
34	27-7-37	3.20	32.0	23.21	6 ,,	6.84	5.91
35	28-7-37	3.13	32.875	24.31	6 ,,	7.17	6.04
36	29-7-37	2.875	32.75	22.43	5 ,,	7.94	6.73
37	30-7-37	2.63	30.30	24.31	5 ,,	8.60	7.69
38	31-7-37	2.69	30.25	26.52	5 ,,	9.38	8.40
39	1-8-37	2.55	30.00	23.65	4 ,,	9.38	8.44
40	2-8-37	2.43	32.00	23.76	4 ,,	9.77	8.43
41	3-8-37	2.59	31.75	22.76	5 ,,	8.05	7.01
42	4-8-37	2.47	31.00	23.65	4 ,,	9.38	8.25
43	5-8-37	2.33	30.00	23.59	4 ,,	9.28	8.35
44	6-8-37	1.9125	31.00	24.31	5 ,,	8.60	7.57

Serial No.	Date.	Average Spring level below bed.	Average temperature.	Cu. ft. of water absorbed.	Duration of observation.	Absorption in cuses per million sq. ft.	Corrected absorption to 25°C. (Average temperature).
45	7-8-37	1.54	32.00	22.76	5 hours	8.05	6.94
46	8-8-37	1.365	31.50	20.44	5 ,,	7.23	6.26
47	9-8-37	1.205	31.50	17.90	5 ,,	6.33	5.51
48	10-8-37	1.035	32.00	15.80	5 ,,	5.59	4.84
49	11-8-37	0.94	32.50	14.84	5 ,,	5.12	4.36
50	12-8-37	0.815	32.00	13.26	5 ,,	4.69	4.05
51	13-8-37	0.81	32.00	13.26	5 ,,	4.69	4.05
52	14-8-37	0.795	31.625	13.15	5 ,,	4.65	4.05
53	15-8-37	0.705	31.00	12.49	5 ,,	4.42	3.89
54	16-8-37	0.575	32.125	11.16	5 ,,	3.95	3.40
55	17-8-37	0.535	30.00	11.27	5 ,,	4.23	3.77
56	18-8-37	0.505	31.25	10.94	5 ,,	3.87	3.39
57	19-8-37	0.495	31.00	10.83	5 ,,	3.83	3.37
58	20-8-37	0.61	32.00	10.83	5 ,,	3.83	3.30
59	21-8-37	0.50	32.00	12.49	5 ,,	3.42	2.97
60	22-8-37	0.275	30.50	11.60	5 ,,	4.10	3.65
61	23-8-37	0.19	30.25	11.05	5 ,,	3.91	3.50
62	24-8-37	0.135	31.00	11.60	5 ,,	4.10	3.61
63	25-8-37	0.10	31.50	9.17	5 ,,	3.24	2.38
64	26-8-37	0.17	32.50	10.28	5 ,,	3.64	3.10
65	27-8-37	0.195	32.00	10.17	6 ,,	3.00	2.59
66	28-8-37	0.13	33.00	10.17	6 ,,	3.00	2.52
67	29-8-37	0.16	31.875	8.84	5 ,,	3.12	2.70
68	30-8-37	0.15	31.00	10.17	6 ,,	3.00	2.70
69	31-8-37	0.11	31.25	10.05	6 ,,	2.96	2.59
70	1-9-37	0.145	30.00	11.16	6 ,,	3.29	2.96
71	2-9-37	0.145	29.00	10.39	6 ,,	3.06	2.80
72	3-9-37	0.135	29.25	10.83	6 ,,	3.19	2.87
73	4-9-37	0.140	30.375	10.17	6 ,,	3.00	2.69
74	5-9-37	0.10	32.00	11.38	6 ,,	3.36	2.90
75	6-9-37	0.08	32.50	11.49	6 ,,	3.39	2.89
76	7-9-37	0.03	32.00	9.94	6 ,,	2.93	2.53
77	8-9-37	0.135	31.50	9.83	6 ,,	2.90	2.53
78	9-9-37	0.24	32.00	10.71	6 ,,	3.16	2.73
79	10-9-37	0.275	31.00	9.28	6 ,,	2.73	2.40
80	11-9-37	0.20	31.00	9.39	6 ,,	2.77	2.44
81	12-9-37	0.21	31.00	9.72	6 ,,	2.72	2.44

APPENDIX III

Pressure at Different Points Rising Spring Levels.

Serial No.	Date.	Pressure above pressure point 0.5 below bed.	Pressure above pressure point 1.0 below bed.	Pressure above pressure point 2.0 below bed.	Pressure above pressure point 3.0 below bed.	Pressure above pressure point 4.0 below bed.	Pressure above pressure point 5.0 below bed.
1	11-6-37	1.65	1.30	1.90	0.15		
2	12-6-37	2.03	2.03	1.02	0.56		
3	13-6-37	1.69	1.65	1.635	0.42		
4	14-6-37	1.58	1.59	1.50	0.55		
5	15-6-37	1.52	1.55	1.43	0.62		
6	16-6-37	1.40	11.40	1.355	1.70		
7	17-6-37	1.29	11.26	1.26	0.79		
8	18-6-37	1.27	1.20	1.225	0.83		
9	19-6-37	1.27	1.17	1.19	0.86		
10	21-6-37	1.07	0.84	1.13	0.92		
11	22-6-37	1.01	0.87	1.10	0.95	0.05	
12	23-6-37	0.96	0.77	1.08	0.99	0.15	
13	24-6-37	0.86	0.67	1.02	1.03	0.25	
14	25-6-37	0.79	0.59	1.02	1.03	0.30	0.05
15	27-6-37	0.74	0.50	0.92	1.01	0.27	0.15
16	28-6-37	0.68	0.50	0.91	0.99	0.28	0.20
17	30-6-37	0.64	0.47	0.87	0.99	0.32	0.25
18	1-7-37	0.62	0.48	0.87	0.98	0.32	0.27
19	8-7-37	0.35		0.62	0.76	0.29	0.25
20	9-7-37	0.32		0.60	0.72	0.29	0.26
21	10-7-37	0.33		0.58	0.73	0.30	0.27
22	11-7-37	0.34		0.58	0.72	0.32	0.27
23	12-7-37			0.57	0.72	0.32	0.27
24	13-7-37			0.55	0.71	0.32	0.27
25	17-7-37			0.48	0.70	0.32	0.28
26	18-7-37			0.47	0.70	0.33	0.29
27	19-7-37			0.47	0.70	0.33	0.29
28	20-7-37			0.45	0.68	0.33	0.29
29	22-7-37			0.45	0.68	0.32	0.29
30	23-7-37			0.41	0.68	0.32	0.29
31	24-7-37			0.41	0.70	0.34	0.29
32	25-7-37			0.40	0.71	0.35	0.29
33	26-7-37			0.42	0.75	0.36	0.31
34	27-7-37			0.46	0.84	0.35	0.32
35	28-7-37	0.39	0.42	0.51	0.92	0.37	0.32
36	29-7-37	0.46	0.44	0.55	1.00	0.38	0.34
37	30-7-37	0.53	0.50	0.62	0.13	0.40	0.34
38	31-7-37	0.49	0.50	0.69	1.20	0.41	0.33
39	1-8-37	0.53	0.55	0.74	1.27	0.42	0.34
40	2-8-37	0.57	0.59	0.87	1.32	0.43	0.35
41	3-8-37	0.46	0.60	0.82	1.42	0.44	0.37
42	4-8-37	0.46	0.58	0.85	1.40	0.44	0.36
43	5-8-37	0.49	0.60	0.88	1.48	0.46	0.38
44	6-8-37	0.62	0.65	0.93	1.53	0.48	0.36
45	7-8-37	0.85	0.77	1.02	1.64	0.49	0.38

Serial No.	Pressure above pressure point 0.5 below bed.	Pressure above pressure point 0.5 below bed.	Pressure above pressure point 1.0 below bed.	Pressure above pressure point 2.0 below bed.	Pressure above pressure point 3.0 below bed.	Pressure above pressure point 4.0 below bed.	Pressure above pressure point 5.0 below bed.
46	8-8-37	0.95	0.92	1.11	1.76	0.49	0.36
47	9-8-37	0.99	1.03	1.20	1.88	1.52	0.38
48	10-8-37	1.09	1.13	1.29	2.48	0.53	0.38
49	11-8-37	1.13	1.22	1.40	2.09	0.54	0.38
50	12-8-37	1.21	1.29	1.50	2.20	0.57	9.39
51	13-8-37	1.27	1.38	1.60	2.30	0.60	0.40
52	14-8-37	1.33	1.42	1.73	2.41	0.65	0 42
53	15-8-37	1.26	1.44	1.75	2.47	0.65	0.41
54	16-8-37	1.29	1.49	1.84	2.55	0.66	0.42
55	17-8-37	1.32	1.52	1.91	2.62	0.69	0.43
56	18-8-37	1.33	1.56	1.98	2.70	0.72	0.43
57	19-8-37	1.33	1.58	2.02	2.75	0.73	0.44
58	20-8-37	1.33	1.57	2.03	2.80	0.75	0.46
59	21-8-37	1.32	1.59	2.08	2.83	0.76	0.45
60	22-8-37	1.54	1.59	2.19	2.92	0.79	0.47
61	23-8-37	1.59	1.75	2.24	2.97	0.81	0.47
62	24-8-37	1.60	1.82	2.30	3.03	0.82	0.48
63	25-8-37	1.65	1.87	2.38	3.08	0.85	0.48
64	26-8-37	1.64	1.90	2.41	3.13	0.86	0.48
65	27-8-37	1.55	1.88	2.45	3.16	0.87	0.48
66	28-8-37	1.57	1.90	2.48	3.21	0.92	0.49
67	29-8-37	1.56	1.90	2.51	3.25	0.92	0.50
68	30-8-37	1.50	1.88	2.51	3.25	0.95	0.51
69	31-8-37	1.54	1.89	2.53	3.29	0.97	0.52
70	1-9-37	1.61	1.92	2.56	3.29	1.03	0.60
71	2-9-37	1.58	1.91	2.56	3.31	1.11	0.70
72	3-9-37	1.55	1.92	2.59	3.33	1.15	0.73
73	4-9-37	1.55	1.91	2.60	3.36	1.19	0.75
74	5-9-37	1.49	1.89	2.60	3.36	1.20	0.76
75	6-9-37	1.50	1.88	2.58	3.35	1.21	0.76
76	7-9-37	1.65	1.94	2.61	3.38	1.24	0.77
77	8-9-37	1.69	1.98	2.65	3.41	1.25	0.79
78	9-9-37	1.79	2.04	2.69	3.45	1.29	0.80
79	10-9-37	1.82	2.09	2.73	3.49	1.28	0.81
80	11-9-37	1.76	2.08	2.74	3.50	1.29	0.79
81	12-9-37	1.77	2.11	2.77	3.52	1.31	0.82

APPENDIX III

Pressure at different points dropping spring level.

Serial No.	Date.	Pressure above pressure point 1.0 below bed.	Pressure above pressure point 2.0 below bed.	Remarks.
1	25- 8-36	0.92	1.49	
2	27- 8-36	o.92	1.55	
3	4- 9-36	0.93	1.61	
4	5- 9-36	0.96	1.64	
5	7- 9-36	0.94	1.63	
6	10- 9-36	1.07	1.855	
7	12- 9-36	1.045	1.815	
8	15- 9-36	1.05	1.83	
9	17- 9-36	1.03	1.82	
10	19- 9-36	1.035	1.82	
11	10-10-36	1.01	1.90	
12	12-10-36	1.01	1.93	
13	13-10-36	1.025	1.915	
14	14-10-36	0.975	1.87	
15	19-10-36	0.97	1.85	
16	20-10-36	0.96	1.83	
17	21-10-36	0.94	1.815	
18	22-10-36	0.94	1.82	
19	23-10-36	0.93	1.82	
20	29-10-36	0.91	1.82	
21	30-10-36	0.91	1.815	
22	31-10-36	0.915	1.815	
23	2-11-36	0.915	1.81	
24	3-11-36	0.90	1.80	
25	4-11-36	0.90	1.80	
26	5-11-36	0.90	1.80	
27	6-11-36	0.885	1.785	
28	7-11-36	0.885	1.785	
29	10-11-36	0.87	1.83	
30	16-11-36	0.83	1.79	
31	17-11-36	0.825	1.785	
32	18-11-36	0.815	1.77	
33	22-11-36	0.80	1.735	
34	24-11-36	0.78	1.735	
35	27-11-36	0.775	1.71	
36	29-11-36	0.75	1.70	
37	2-12-36	0.745	1.675	
38	5-12-36	0.72	1.665	
39	8-12-36	0.70	1.64	
40	11-12-36	0.69	1.61	
41	15-12-36	0.66	1.59	
42	19-12-36	0.66	1.575	
43	25-12-36	0.615	1.525	
44	26-12-36	0.625	1.52	
45	27-12-36	0.615	1.56	

Serial No.	Date.	Pressure above pressure point 1.0 below bed.	Pressure above pressure point 2.0 below bed.	Remarks.
46	1-1-37	0.605	1.53	
47	2-1-37	0.60	1.525	
48	3-1-37	0.595	1.52	
49	4-1-37	0.59	1.52	
50	5-1-37	0.58	1.51	
51	6-1-37	0.58	1.50	
52	9-1-37	0.57	1.50	
53	13-1-37	0.58	1.52	
54	15-1-37	0.54	1.56	
55	17-1-37	0.535	1.455	
56	19-1-37	0.515	1.43	
57	21-1-37	0.52	1.425	
58	22-2-37	0.27	1.21	
59	23-2-37	0.295	1.23	
60	24-2-37	0.305	1.235	
61	27-2-37	0.29	1.225	
62	28-2-37	0.295	1.23	

APPENDIX IV

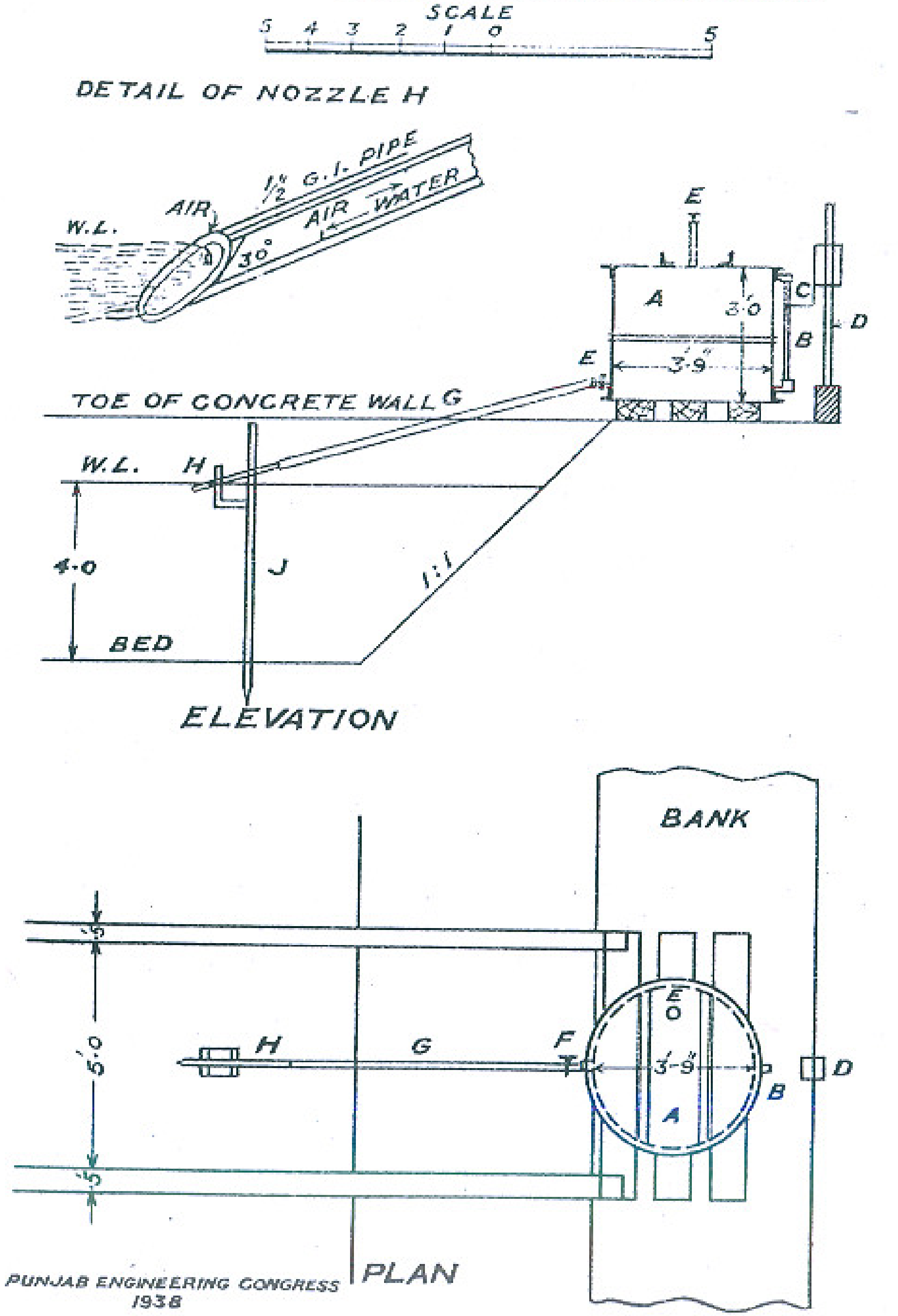
Mechanical Analysis of Soil Samples.

(Results represented in percentage on air dry basis)

Serial No.	Description.	% Coarse sand (particles above 0·2 mm).	% Fine sand (particles from 0·2 to 0·02 mm).	% Silt (particles from 0·02 to 0·01 mm.)	% Fine Silt (particles 0·01 to 0·002 mm).	% Clay (less than 0.002 mm).
1	0.5 ft. below bed	25.93	61.92	1.80	1.70	2.25
2	1.0 ft. ,,	38.27	49.78	1.00	1.50	2.75
3	1.5 ft. ,,	34.33	36.27	6.88	7.38	7.25
4	2.0 ft. ,,	1.49	27.44	24.25	22.63	15.88
5	2.5 ft. ,,	4.26	36.50	20.13	17.75	12.88
6	3.0 ft. ,,	6.04	32.01	22.5	17.63	13.50
7	3.5 ft. ,,	5.20	25.18	21.13	22.30	17.83
8	4.0 ft. ,,	2.66	20.98	19.00	26.13	23.00
9	4.5 ft. ,,	2.32	21.54	15.13	27.00	26.25
10	5.0 ft. ,,	2.82	20.85	13.95	25.23	28.45
11	5.5 ft. ,,	1.04	20.38	15.00	25.50	29.38
12	6.0 ft. ,,	1.45	27.27	15.13	23.13	24.38
13	6.5 ft. ,,	2.18	32.79	15.08	21.93	20.00
14	7.0 ft. ,,	0.67	45.26	13.68	17.95	13.13
15	7.5 ft. ,,	0.40	30.12	13.98	23.65	21.88
16	8.0 ft. ,,	0.32	17.65	13.63	29.75	28.38

PLATE 2
PAPER NO. 209

AUTOMATIC CHICKEN FEED ARRANGEMENT



DETAIL OF NOZZLE H

ELEVATION

PLAN

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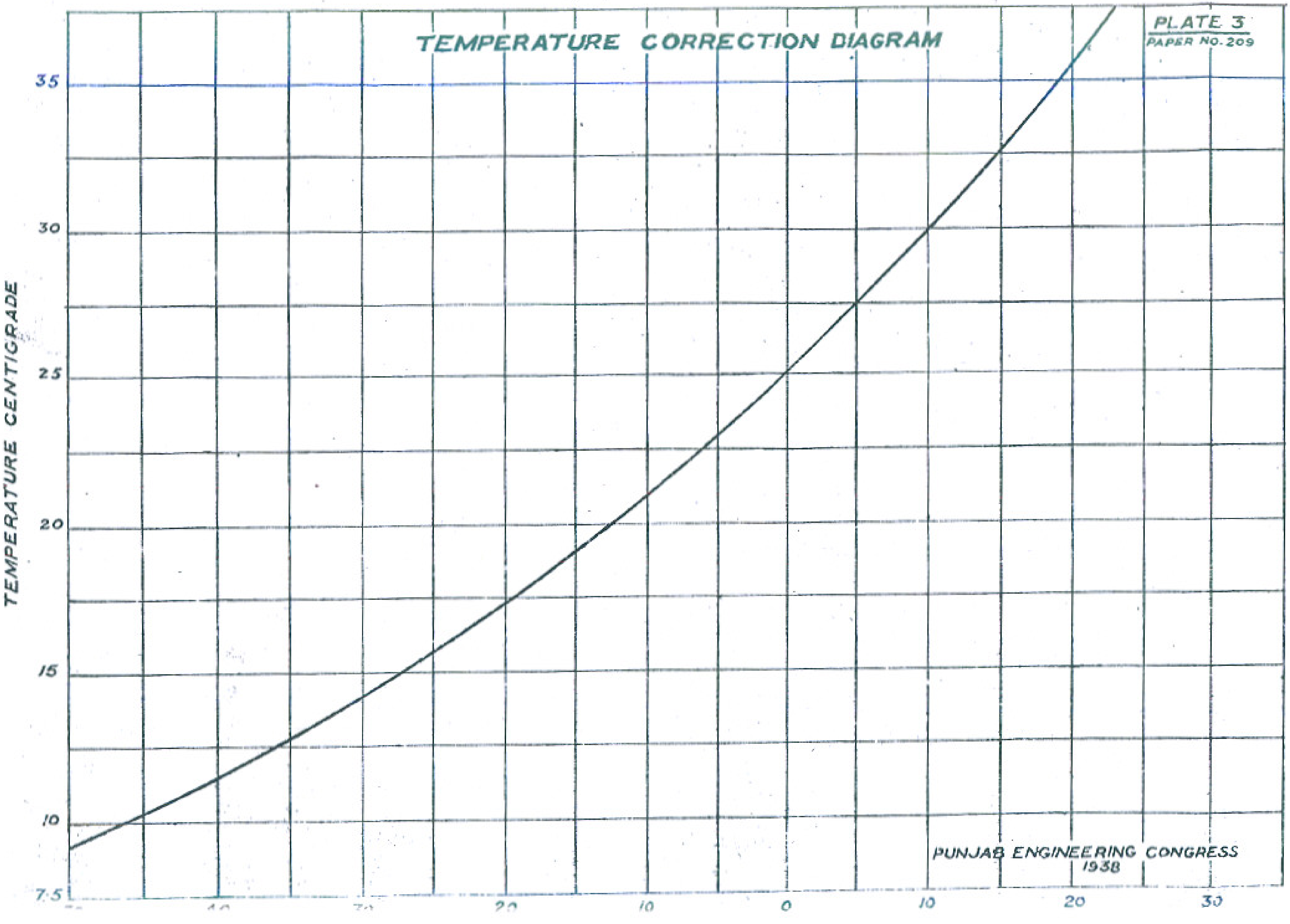

PLATE 3
PAPER No. 209

TEMPERATURE CORRECTION DIAGRAM

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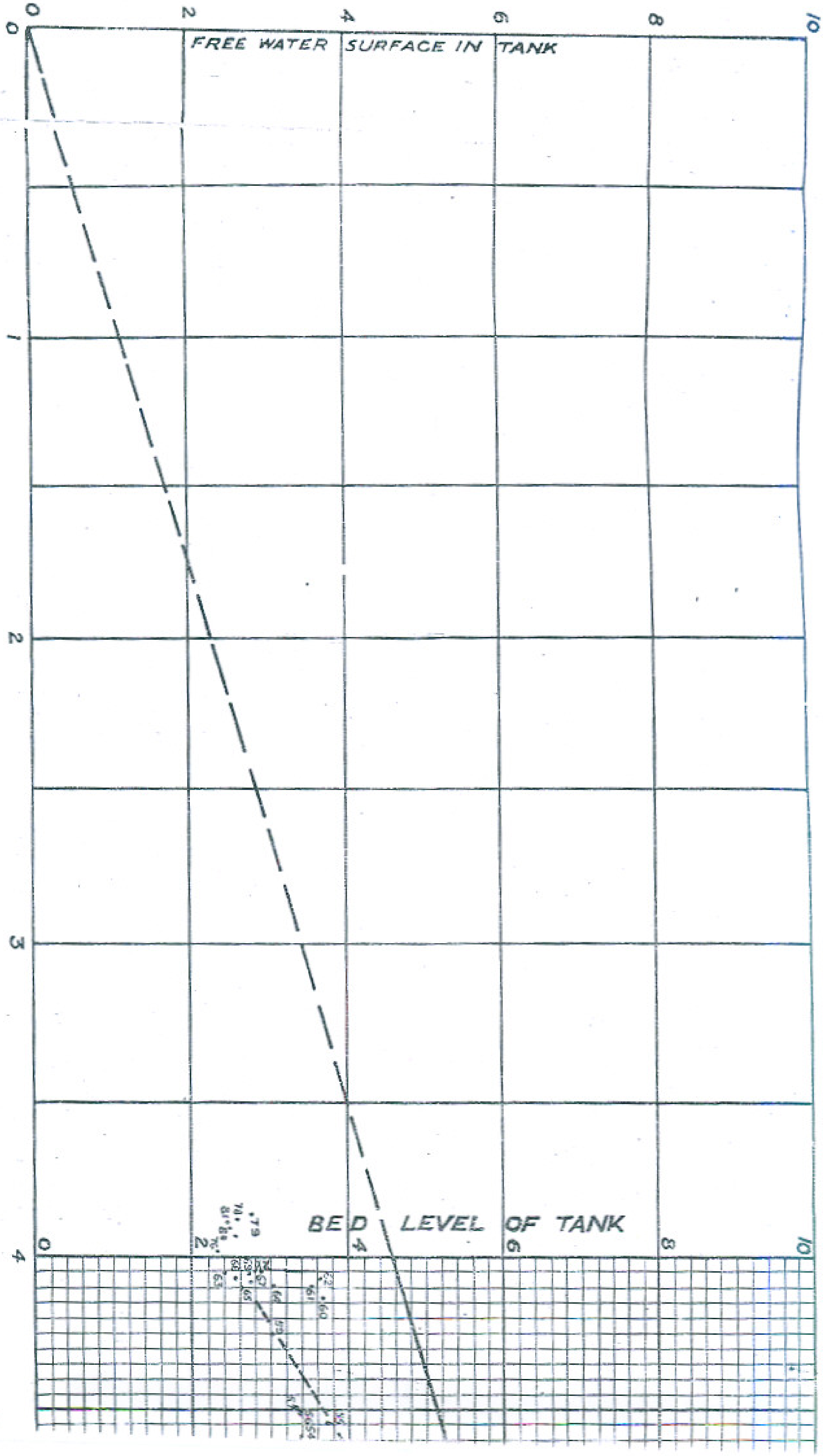


VARIATI

VARIATION OF SEEPAGE LOSSES WITH THE POSITION OF SPRING LEVEL

ALL RESULTS CORRECTED TO AN AVERAGE TEMPERATURE OF 25° C

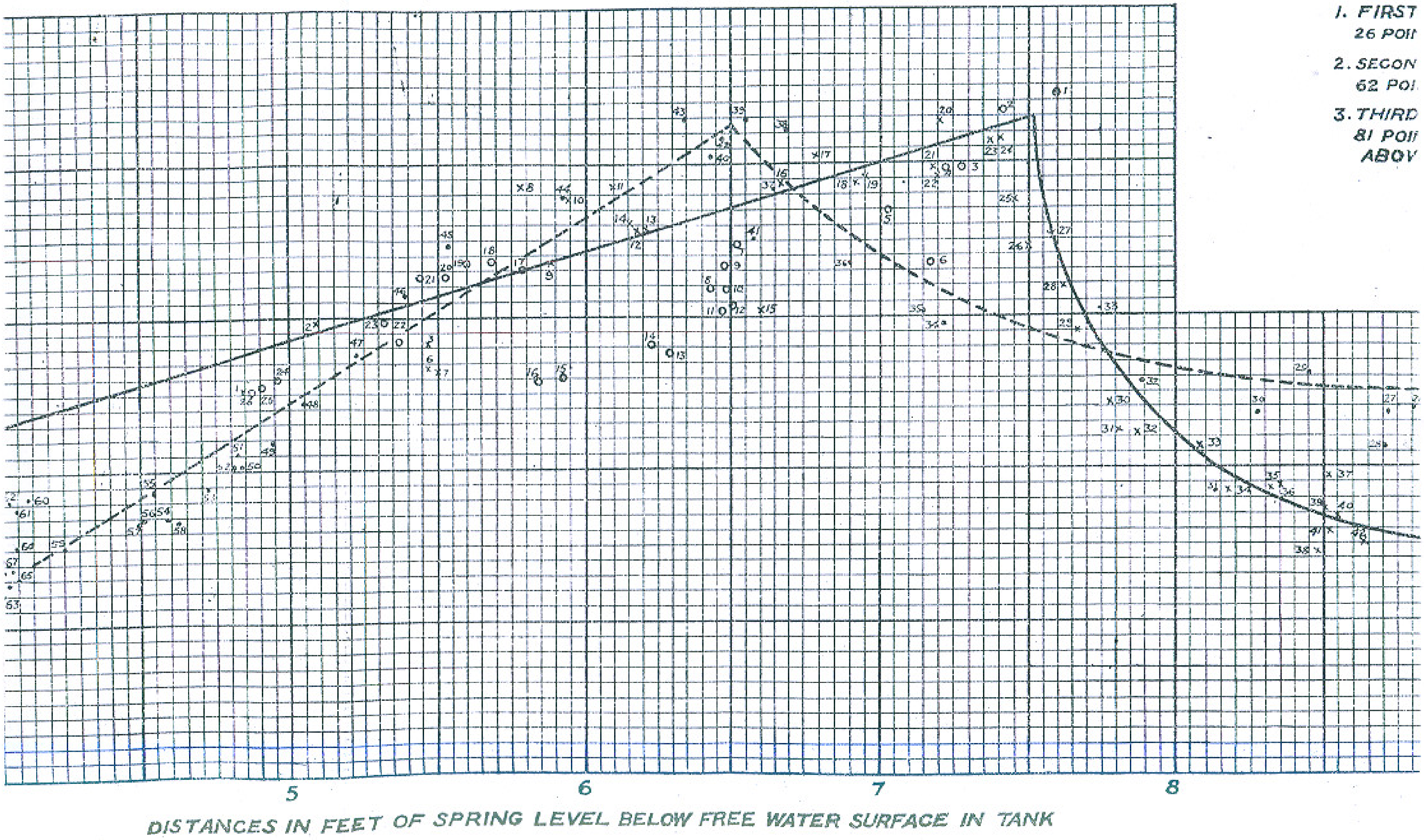
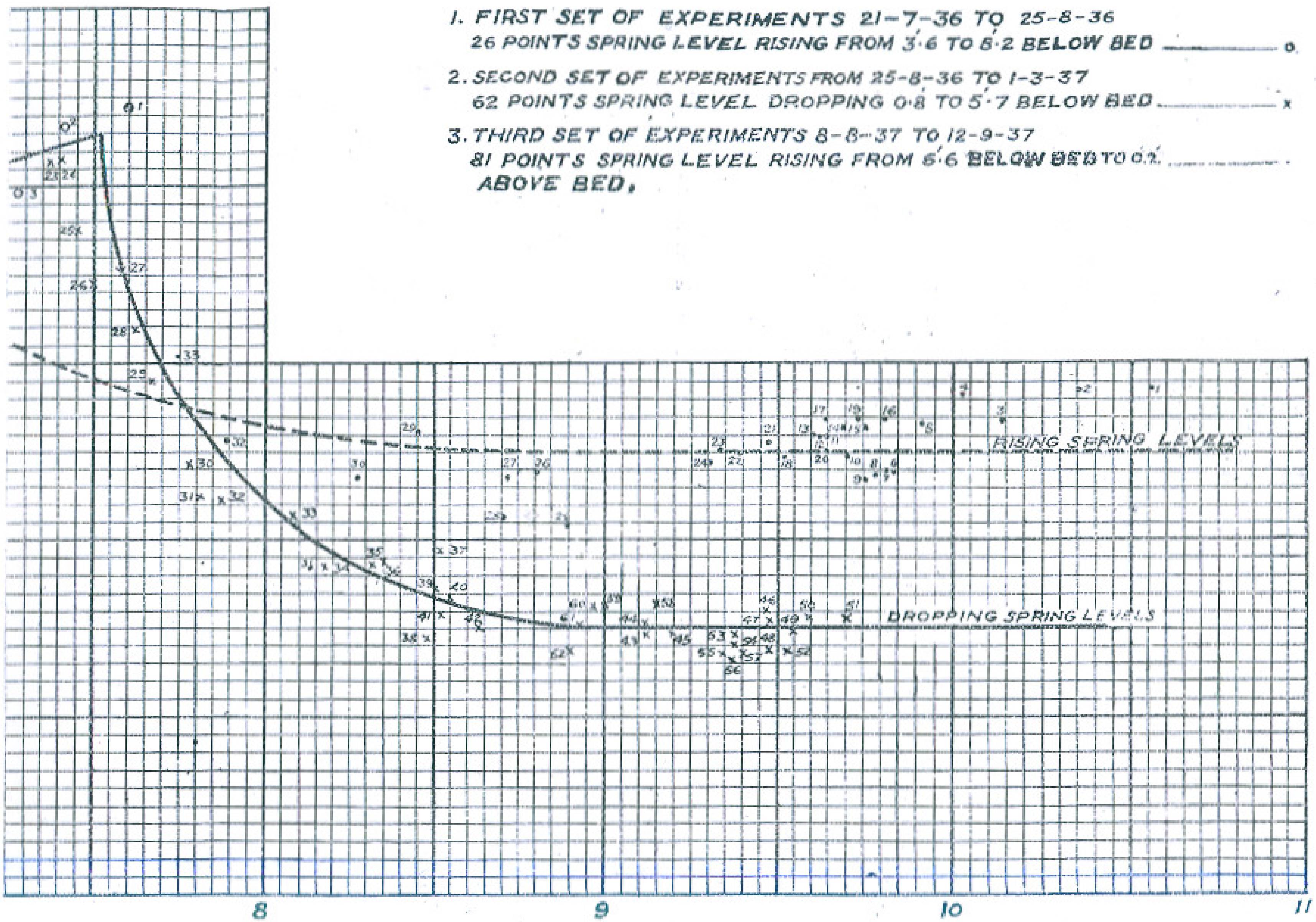


PLATE 4
PAPER NO. 209

RING LEVEL
C



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1938

PLATE 5
PAPER NO. 209

HYDROSTATIC PRESSURE DIAGRAM FOR DIFFERENT POINTS BELOW BED

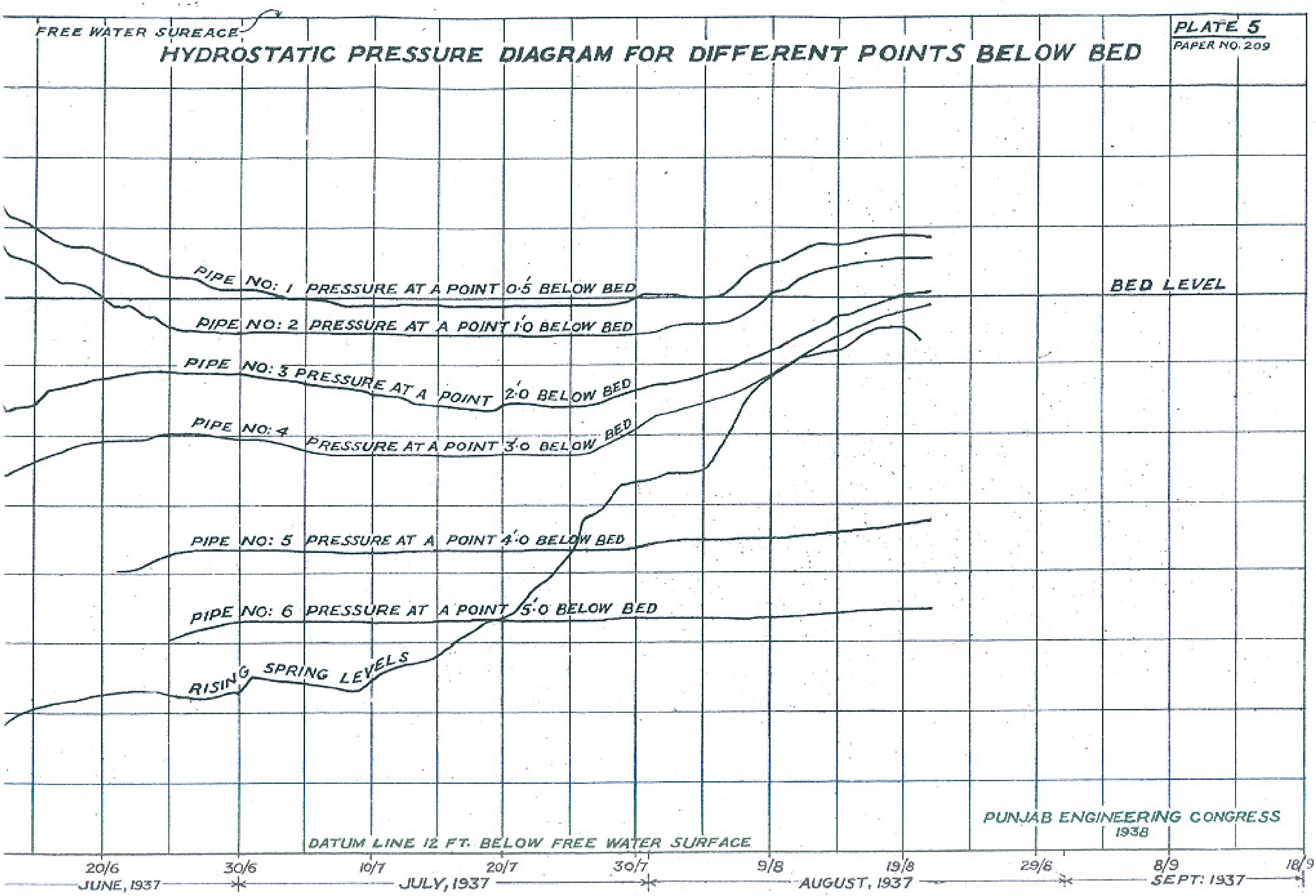

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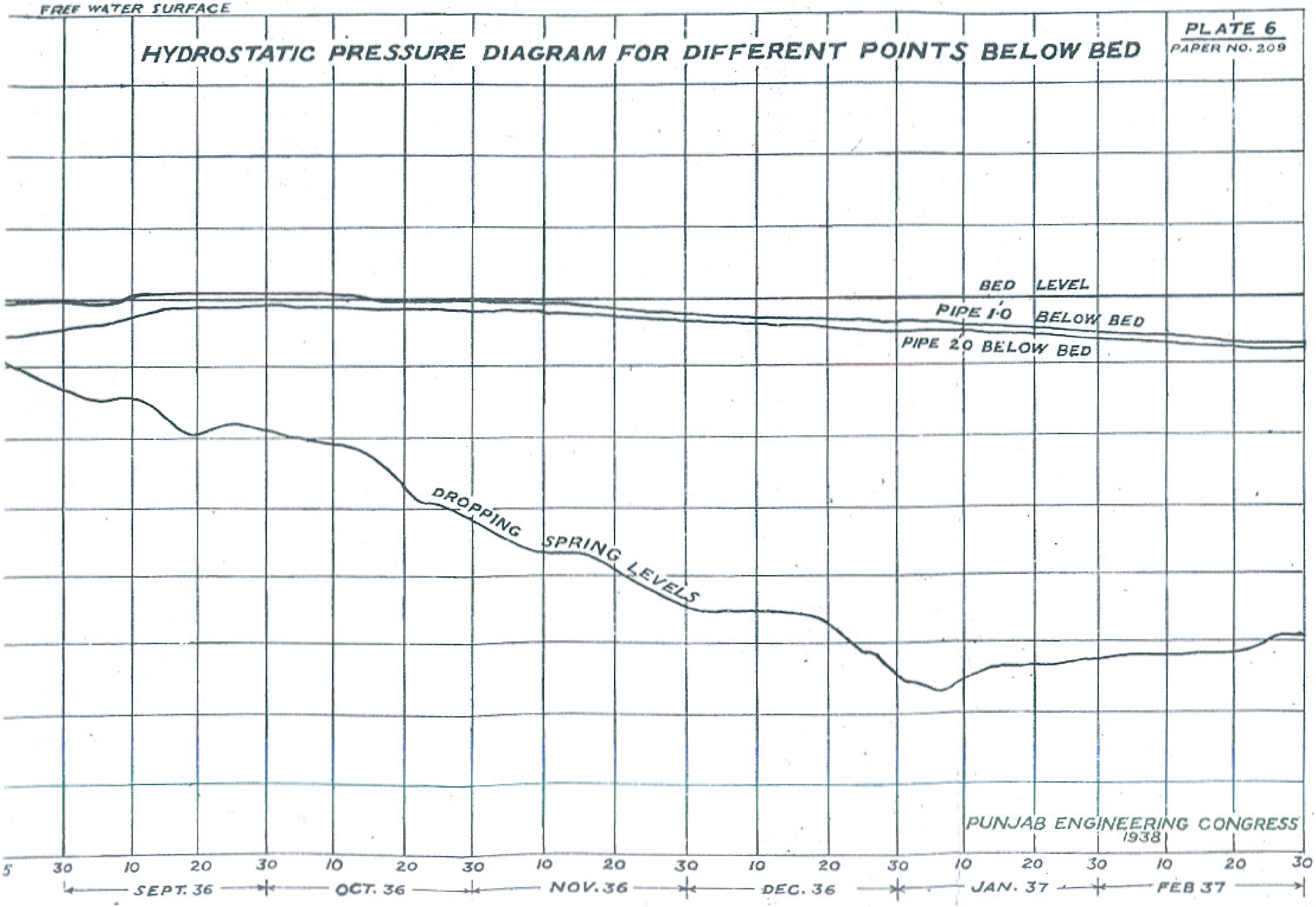
PLATE 6
PAPER NO. 209

HYDROSTATIC PRESSURE DIAGRAM FOR DIFFERENT POINTS BELOW BED



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1938

DISCUSSION.

Mr. **Nand Gopal** in introducting the Paper said that he was in charge of Balloki Division in 1927-28, when the variation in supply reaching the Barrage from the Upper Chenab Canal first attracted attention. Meters at the two ends were ordered by Chief Engineer to be checked but no satisfactory explanation was found. In the years 1930-33, he happened to be in Gujranwala Division (U. C. C.) and noticed the same phenomenon of the supply at the two ends of Main Line in that Division varying from season to season without any apparent rhyme or reason. For the first time it was suspected that such variation could not be merely seasonal but had something to do with variation in spring levels. The idea continued to agitate his mind. In 1935-36 when he joined the Gujrat Division (U. J. C.) he found similar happenings on this canal. It was lucky that Mr. Crump was his Superintending Engineer and he took the first opportunity to discuss this point with him together with his Sub-Divisional Officer Mr. Sharma. The former with his usual generosity and skill suggested ways and means of carrying out experiments on the problems. Details were discussed and a plan of work decided upon. The opportunity was unique. Mr. Crump with his unprecedented knowledge of Hydraulics was there to guide them through all the difficulties and Mr. Sharma, who had done so much already in advancing the science of water distribution in the Irrigation Department, was ready to undertake hardships that all experimental work must always involve. The work was pushed forward with all speed and the results were before the members, Mr. Nand Gopal said, in the form of this Paper.

2. The Authors by no means claimed that they had fully discovered the laws of seepage from canals. The subject was far too complicated to admit of an easy solution at one attempt. It could only be said that a good start had been given. In the olden days it was considered that the losses from canals by seepage were influenced by the kind of soil below bed and by the wetted surface. Later, depth was found to be another factor. It was now known that the position of spring level with reference to the bed was also a factor that could not be ignored.

3. It might have been noticed that on page 20 of the Paper the paragraph headed "Pressure Observations" was rather too brief. The Authors owed an explanation for not throwing more light on this part of the experiments. The fact was that this part was not included in the original scheme of work and was an afterthought. Consequently only two pressure pipes were put in after the first set of observations had been started or rather after the "breach" in the subsoil had occurred. Even then, only casual attention was given to them. Later, however, during *interim* discussions with Mr. Crump, Dr. Bose and Dr. Vaidyanathan, it was suggested that such pipes could yield very useful results and more were therefore put in and observations recorded regularly and carefully. Since the writing of the Paper, these observations (and others)

had been continued and the results along with mechanical analysis, tabled in Appendix IV were plotted graphically in the plate attached. Results plotted in Plate No. 6 of the Paper were preliminary observations and should not form the basis of any conclusions. Even now, the observations were being carried on and these did not appear to have reached a stage when any definite conclusions could be drawn. However, it was hoped that on some later date the Authors would find an opportunity to do so, when possible, and place them before the members.

4. From an extension of these experiments, alluded to in the last paragraph of this Paper, which might form the subject of another Paper in the near future, as work had only recently been started and had not reached a stage when definite conclusions could be drawn, it appeared probable that yet another factor might have to be considered, viz., the gradient of subsoil water table below the bed of a channel. Further, variation in depth relative to spring level, particularly when spring level was above bed, seemed to make for more complications. Under these conditions, it was easy to see how difficult the problem was. If the introduction of this Paper would succeed in inviting other experimenters to take an interest in this problem and help the profession with their knowledge and work, the object of this Paper would have been achieved.

Mr. **C.C. Inglis** congratulated the Authors on their Paper which confirmed Mr. Crump's theory that losses from a canal were approximately proportional to the difference in level between water in the canal and the subsoil water table only, until a limiting value was reached at which continuous saturation ceased. When the subsoil water table fell below this, losses decreased rapidly until the loss became steady.

Experiments in this connection were instituted at Mr. Crump's suggestion by Mr. Thomas, at Khadakvasla, using soil columns of various lengths packed in metal containers varying in length from 1 ft. to 11 ft. with the lower ends submerged in water.

Fig. 1 showed 3 ft. soil column. Water was maintained constant to a depth of 6" over the soil column by an automatic feed. Small pipes were screwed into the sides of cylinders at intervals of 1 ft. for observing temperatures and these prevented air being entrapped. Barometric pressures, temperatures of water and soil, and rate of evaporation were observed. No necessity for a correction for barometric pressures was indicated. The silt used contained a considerable amount of fine material and the staunching effect was very marked; so that losses decreased for periods up to three months. Sometimes slips occurred which caused a temporary increase in percolation.

FIGURE SHOWING
3 FEET SOIL COLUMN

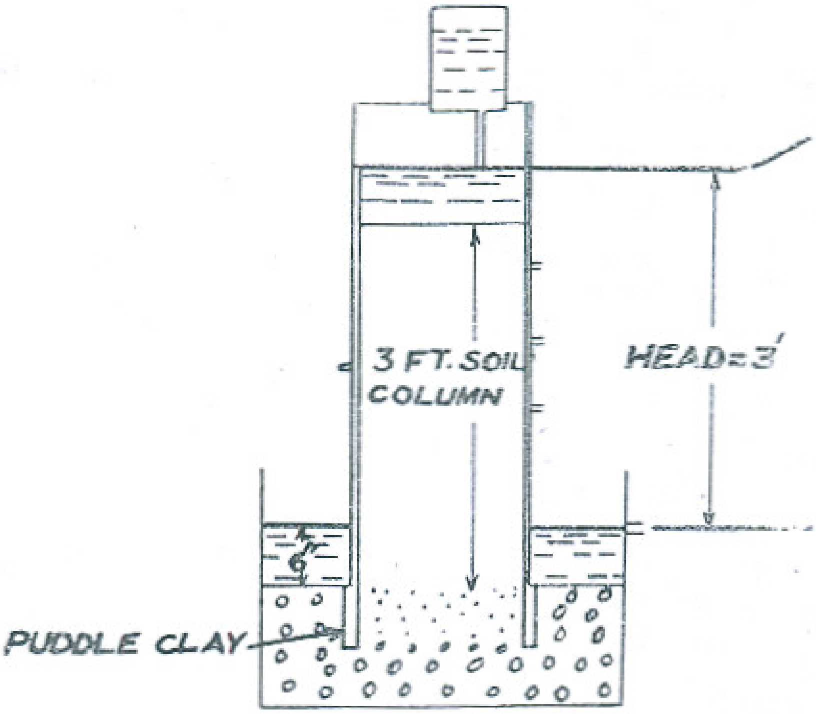


FIG. I

Fig. 2 showed the effect of staunching. Only final steady readings were accepted for comparison. Where the subsoil water table was at more than 3 ft. below the channel bed the final loss was only 1 cusec per million sq. ft. For smaller differences between the bed of the canal and the subsoil water table considerable difficulty had been met with in getting accurate data, because there was a strong tendency for fissures to develop. To show how sensitive the columns were, the entrance of a rat into the water downstream caused a fissure to develop. This part of the experiment, the Speaker said, was still in progress. Four points were shown 1'0", 1'6", 2' and 3' below the bed level of the canal, which indicated that similar results would be obtained in this experiment as in those carried out by the Authors and that the maximum loss occurred where the subsoil water table was about 2'6" below the bed of the canal, as shown in Fig. 3.

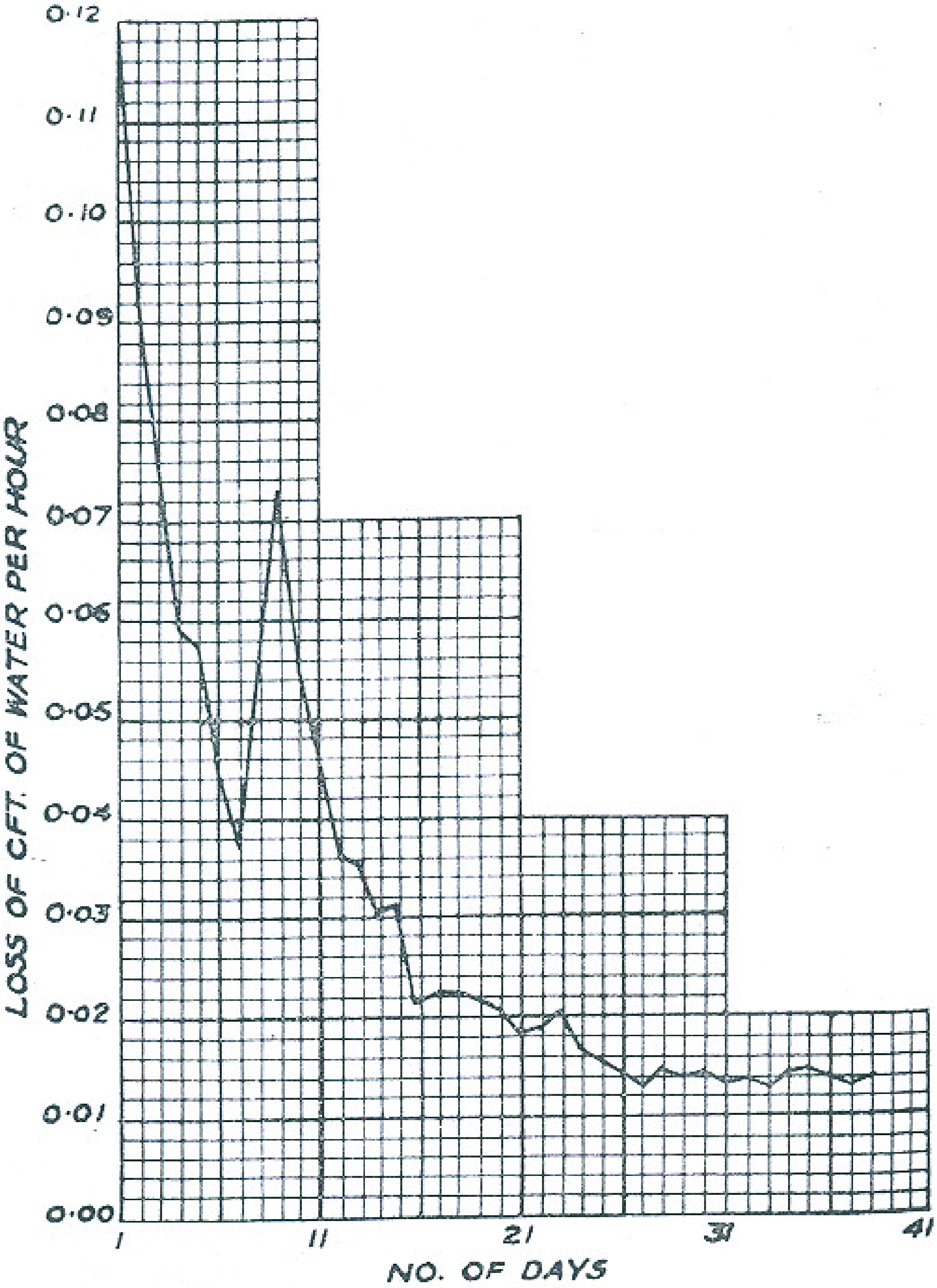

LOSS IN CFT. PER HOUR FROM SOIL COLUMN 3 FT. LONG AND HEAD OF 3 FT. USING KHADAKWASLA RED SILT.

FIG. 2

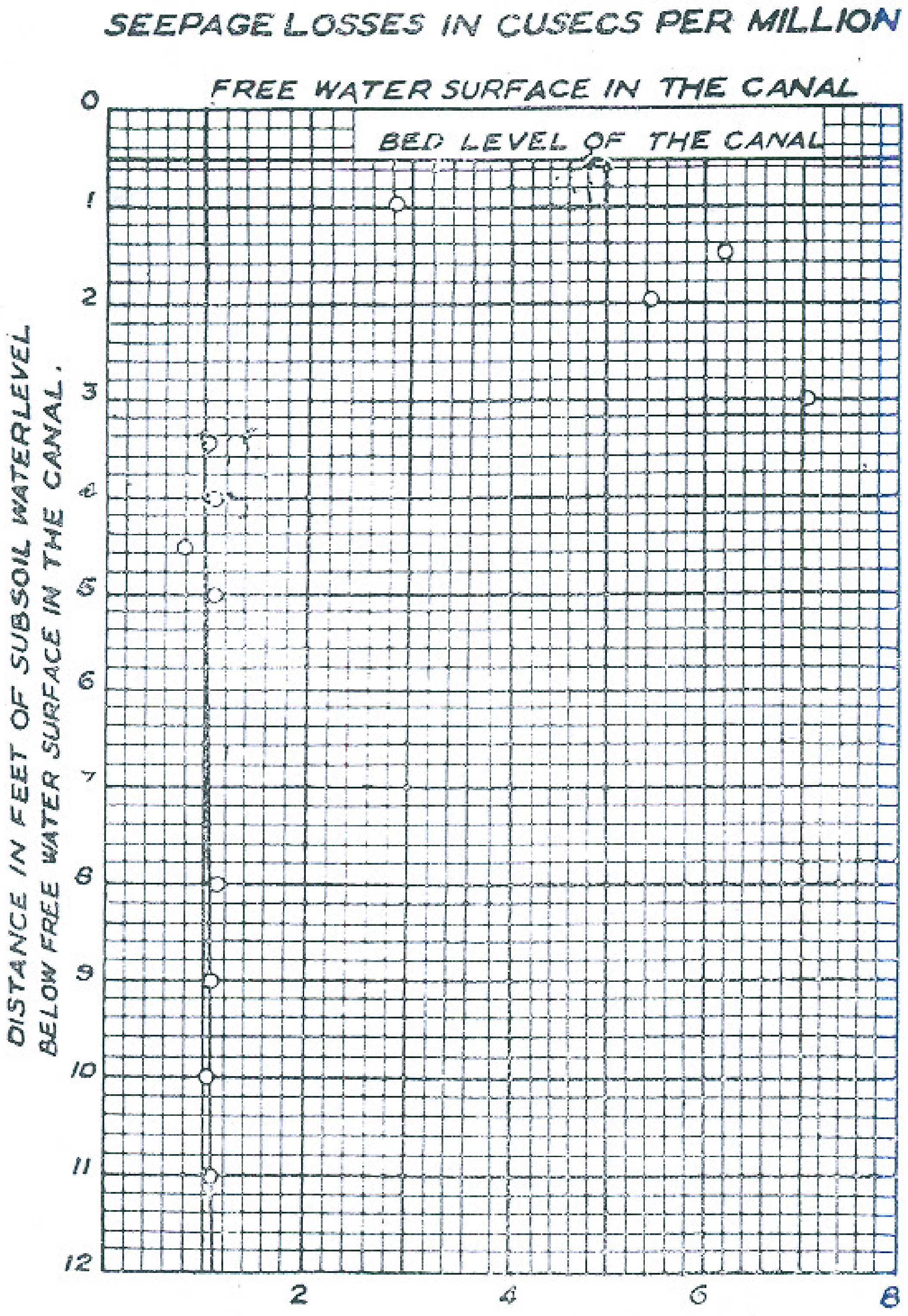

SEEPAGE LOSSES IN CUSECS PER MILLION
FREE WATER SURFACE IN THE CANAL
BED LEVEL OF THE CANAL
DISTANCE IN FEET OF SUBSOIL WATERLEVEL BELOW FREE WATER SURFACE IN THE CANAL.
0
1
2
3
4
5
6
7
8
9
10
11
12
2
4
6
8

FIG. 3

Mr. **N. D. Gulhati** remarked that on page 15, the Authors described the difficulties they met with in the use of a thermometer, and a thin layer of wax on the bulb was definitely not a happy solution. A very easy way lay in the use of an ordinary Maximum and Minimum Thermometer, and he would suggest to the Authors to try that in their future experiments.

Looking through the observed temperatures on page 29, the maximum was 34—35° Centigrade, which corresponded to 94°F. This was rather a high temperature for canal water. The small supply from the steel tank could not possibly have much effect 5′ below the surface, as water was a bad conductor of heat. The maximum temperature of river water at Khanki, observed during the summer of 1937, was 76°F. Day to day variations in the temperature, as found by the Authors, were also unusual. Evidently the temperature and consequently the shape of the curve on Plate IV was considerably influenced by the weather.

The Authors did not give any detail of how they determined the daily evaporation. From page 28, it was seen that the total absorption in 6 hours was as low as 6·3 c.ft., which spread over a surface area of 140 sq. ft. represented a depth of about half an inch. The evaporation on a hot day during the same period of six hours had been known to be as much as $\frac{1}{10}$th of an inch, which equaled 20% of the total loss against 2% found by the Authors.

No detail was given as to how the six pressure pipes were installed. It was very necessary to know what precautions were taken to see that the pressures indicated in the pipes were correct for the depth at which they were supposed to read.

He would also like to enquire from the Authors whether or not, waves on the surface of the water effected their chicken feed arrangement.

On page 12 the Authors stated: "The present experiments have shown that the effect of temperature is so very pronounced that this factor alone could cause a variation in results by 66%..". There was, however, no mention in the Paper of any experiments conducted to prove the statement. Did the authors make any observation for this temperature effect, or did they only rely on Gibson's "Hydraulics"? If on the latter, he suggested that experiments might be conducted to verify the correction made for temperture.

S. **Ajit Singh Kalha** observed that the Authors had made a pointed reference to the factors which seemed to effect the seepage losses from our canals. They had tried to account for the change of viscosity due to change of temperature but they did not seem to have observed whether the presence of fine silt which was practically in solution altered the viscosity or not. If it did, it would also affect the seepage losses. The second point to determine would be as to what would be the effect of the presence of fine silt when the loss was by way of percolation and when it was by way of absorption. It had been shown by Mr. Khosla in his pressure observations on Panjnad weir (Paper No. 162, Punjab Engineering Congress, Session 1933) and by Mr. Uppal on its model (Paper No. 18, Punjab Engineering Congress, Session 1935) that the presence of the silt blanket affected the pressure observation or in other words the percolation that takes place. It was to be enquired if the Authors took this point into consideration in their experiments. The silt content of water being fed did not seem to be recorded. If it could be done for any future experiments they might add to our knowledge of this complicated problem.

Dr. **N.K. Bose** said that the outlines of this Paper were given by Mr. Crump last year before the Congress. Since then he (Dr. Bose) had had an opportunity of visiting the site of these experiments. He had been impressed by the thoroughness with which the experiments were being carried out, except for two suggestions that he made to the Authors of these experiments. One was about getting an idea of the character of the subsoil to the watertable below the bottom of the experimental tank and another about putting the pressure points at definite intervals down to the watertable. This information had now been supplied by the Authors and they had put these experiments on a new footing. The Authors said, and Mr. Crump had said the same thing last year, that these experiments dealt with losses from a canal both in the saturated and unsaturated condition. Dr. Bose disagreed with this view and then gave his reasons for doing so. He said that the table given in Appendix IV showed clearly that between 3·5 ft. and 4·0 ft. below the bed of the tank, there was a sharp change in the nature of the soil, a similar change was also indicated at 2·0 ft. below bed. It appeared that up to 1·5 ft. or 2·0 ft. the soil was very sandy and porous, at about 2·0 ft. below bed it became more clayey and less porous and between 3·5 ft. and 4·0 ft. it became very much more clayey and almost impervious. So that when the watertable dropped from 0·82 ft. below bed to 3·5 ft. below bed (see Apendix II, 2nd set) the seepage from the bed increased from 5 cusecs to 8·56 cusecs. At this point the watertable went into the impervious clay layer and the saturated connection between the bed of the tank and the watertable was cut off and the seepage dropped almost instantaneously to a very small but steady value. The same change occurred in the third set (Appendix II), the watertable rising from 6·6 ft. to 0·21 ft. below bed. So long as the watertable was below 4·0 ft, *i.e.*, in the impervious clay layer, the seepage loss was small and fluctuated about a steady value. As the watertable came nearer to the border line between 3·5 ft. and 4·0 ft., a saturated connection between the bed of the canal and the watertable was established and the loss due to seepage increased suddenly. As the watertable further approached the bed of the canal the working head diminished and the seepage loss fell off.

So that what the Authors called unsaturated flow was really not the normal type of unsaturated flow but a severance of the saturated connection between the bed of the canal and the watertable as the latter receded into a very impervious layer where the flow of water was infinitesimal. This statement was supported by the pressure observations given in Plate V. Here pipes Nos. 5 and 6 were 4·0 feet and 5·0 ft. below bed and as such were in this impervious layer. How impervious this layer was would be at once apparent if we followed the rising spring level curve. As this curve crossed the 4·0 ft. and 5·0 ft. horizons the pressures recorded by these pipes did not shew any change, pipe No. 6 not showing the least rise even though the watertable was about 4·5 ft. higher; the pressures recorded by pipe No. 5 also showed very little rise; whereas the pipes 3 and 4 rose almost immediately as the watertable reached them. This showed conclusively that the clay layer that started between 3·5 feet and 4·0 feet below bed was almost impervious and as the water-table receded into it the saturated flow from the bed of the canal could not reach it so that its drainage capacity was reduced and the seepage loss fell off.

Dr. Bose hoped the Authors would carry out these experiments at a site more favourably situated so that the normal unsaturated conditions might be attained. Knowledge so obtained would then be of great value.

The **Authors**, in reply to the remarks of Mr. C. C. Inglis, explained that the quantitative results of the seepage losses in a laboratory on artificially packed columns were not likely to be reliable for any practical use because the pore space in an artificially packed column of soil could not be arranged similar to that in a natural stratum outside in the field. The Authors were glad to note that the laboratory experiments of Mr. Thomas, under Mr. Inglis, also showed that the loss by percolation was the maximum when the spring level was about 2·5 ft. below the bed of the experimental channel which corroborated the findings of the Authors in the field tests on a full size scale.

In reply to the remarks of Mr. N. D. Gulhati the Authors said that the maximum and minimum thermometer was later actually used in these and other experiments in preference to an ordinary centigrade thermometer. The temperature of the water in the experiments was bound to be higher than what Mr. Gulhati found in the Chenab River at Khanki because water in the tank was still and heated by the sun practically uniformly by means of convection currents.

Mr. Gulhati took the lowest value of the absorption losses, *viz.*, 6·3 c.ft., which was in winter when the temperature was the lowest and the evaporation would be the least and almost insignificant. His estimate of evaporation, viz., $^1/_{10}$th of an inch on a hot day, was also very high.

The pressure pipes put in had no strainers but had open ends which were driven to the place where the pressures were to be recorded.

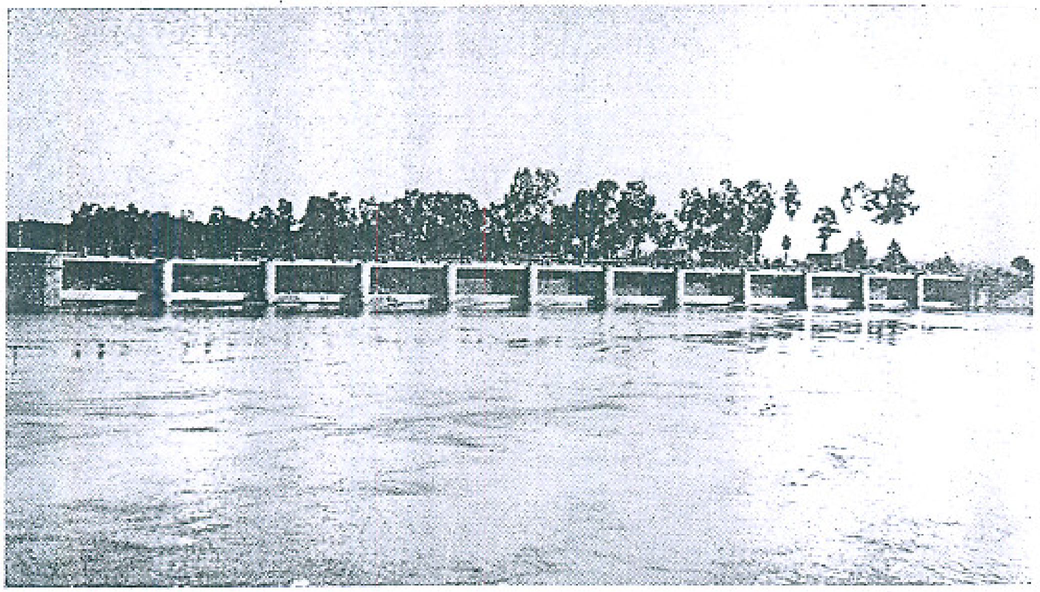
Physicists had already done detailed experiments on the variation of viscosity of water with temperature which could only be done in very elaborate and up-to-date laboratories. It was, therefore, expedient to accept those results for temperature correction of seepage losses. Engineers should hardly waste time on problems which had been thoroughly thrashed out by the scientists already.

In reply to the remarks by S. Ajit Singh Kalha the Authors said that the fine silt in a canal could not form a blanket over the bed as it would be carried away by flowing water and therefore the pressure of fine silt charge in the water could not affect the losses in the canals. The Authors had already taken this into account in the tank experiments.

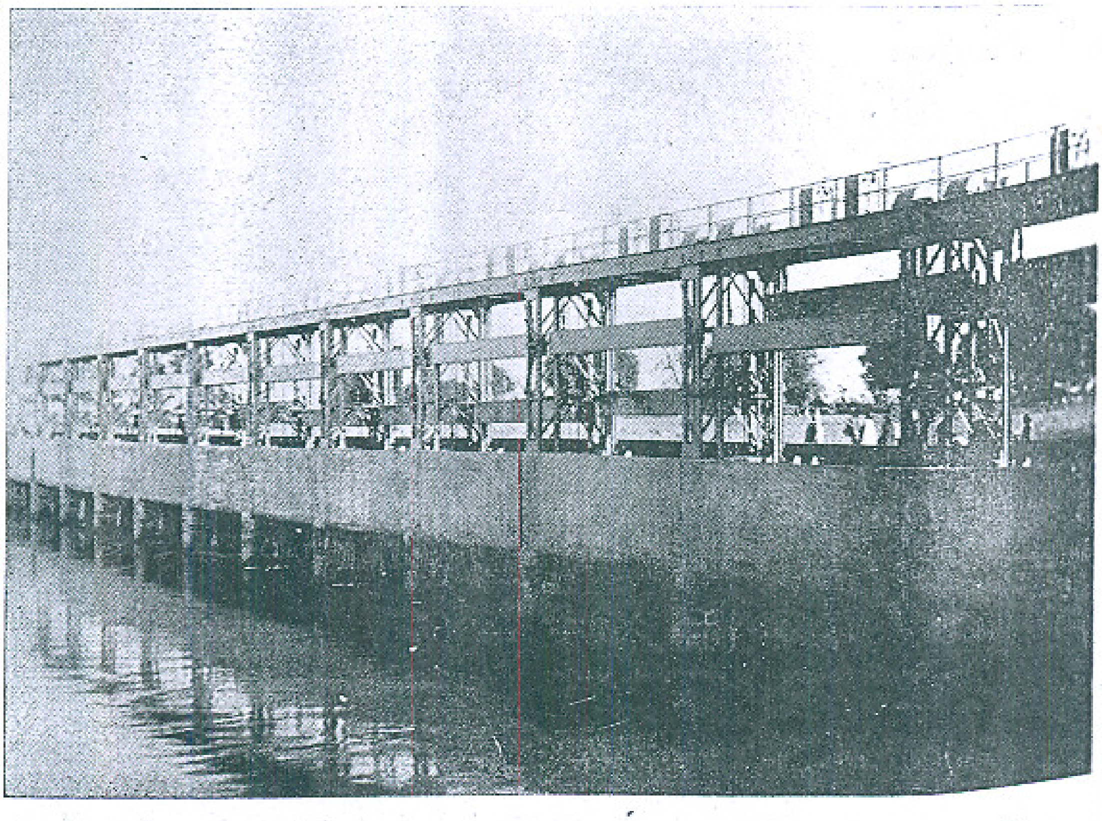
In reply to the remarks of Dr. N. K. Bose the Authors wrote that the experiments carried out and described in this Paper truly represented the seepage losses both in the saturated and unsaturated condition. It was true that the soil conditions changed between 3·5 ft. and 4 ft. below bed. The percentage of clay in soil changed from about 15% to about 25%. The soil 4 ft. below the bed was not all clay but approximately it contained 25% clay and 25% sand and about 50% fine sand. A soil having about 75% of coarse stuff could hardly be called impervious. It was just a coincidence that the maximum value of losses was at 3·4 ft. below the bed in the 2nd set of observations (dropping spring levels) but in the 3rd set of observations the maximum value of the losses occurred at about 2·5 ft. below bed (rising spring levels). Had the contention of Dr. Bose been correct, the seepage loss under saturated condition should have been a maximum between 3·5 ft. and 4 ft. below bed in all sets of observations, which was not the case. Dr. Bose was perhaps making a drastic guess that the pore space in a soil containing about 25% of clay would be very little. The Authors were of opinion that a soil containing even about 60% of clay could have a pore space of about 20% which was enough to admit through it the losses of the order observed in these experiments.

Pressure observations subsequent to those published in the Paper showed that the completely unsaturated conditions were established when spring levels dropped 5 ft. below the bed. All pipes were recording no pressures when the spring level remained between 5 ft. and 7·5 ft. below bed.

The subsequent investigations after submission of this Paper showed that pressure pipes 4 ft. and 5 ft. below bed did not represent true pressures. The pipes had open ends and the unequal pressure in saturated conditions thrust into them about 4 inches of very fine stuff which consolidated those, choking them partially. The pipes were kept clean and they had perfectly responded to the dropping spring levels. The observations were now in hand for the rising spring levels. This side of the experiments was not yet mature for discussion and therefore had to be left to a later occasion.



Upper Chenab Canal Head Regulator, Marala (1927).



Upper Chanab Canal Head Regulator as remodelled in 1937.