Application of Electrical Analogy to Draw Flow Nets for Sudden Drawdown Conditions in Earth Dams

by

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Introduction

TO make an accurate stability analysis of the water retaining face of an embankment or an earth dam against sudden drawdown condition one has to draw the flow net for the condition. The method suggested by Terzaghi and Peck (1948) in their book, which is widely followed, is an approximate method though the factor of safety so obtained remains always on the safe side. It is rather difficult to draw the flow net for sudden drawdown condition even in the case of a homogeneous earth dam. This is so because the flow of water in the body of the dam under sudden drawdown condition is in transient state and in this case all the boundaries are not well defined. The free saturation line during sudden drawdown is neither a flow line nor an equipotential line. But the nature of this line is such that its intersections with the equipotential lines are all vertically equispaced and also it meets the upstream slope tangentially.

Shannon (1948) has studied the nature and the movement of this saturarion line with elapsed time using a viscous fluid model. Cedergreen (1948) has used a different form of viscous fluid model to study the same phenomena. Newlin and Rossier (1967) have studied the nature of the free saturation line in the case of right angled triangular flow fields. For their study they made a model of the flow field using subrounded polythelene beads of 3 mm. in diameter kept in position touching each other by a screen having openings slightly smaller than the bead diameter. Coloured Glycerin was allowed to percolate through the pore spaces of the beads to simulate the actual flow conditions in a porous media. They found that the free saturation line at any instant is a flat hyperbola. Poorooshasb and Forati (1969) have studied Newlin's problem analytically using the concept of a permeable membrane (They have defined a permeable membrane). They have shown that their findings agreed with the findings of Newlin and Rossier.

In the present work, with the help of Electrical Analogy Apparatus, a method has been suggested to draw flow net for instantaneous drawdown

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condition in the case of a homogeneous earth dam having impervious horizontal base and downstream filter blanket or rock toe.

The Flow Field

In the case of homogeneous earth dams with horizontal impervious foundations the boundaries of the flow field during sudden drawdown are :

(*i*) The upstream face upto reservoir level (flow line).

(*ii*) The phreatic line of the steady state seepage case together with its upstream modified part close to upstream slope which occurs almost simultaneously with the start of drawdown (flow line).

(*iii*) The base *line upto the upstream end of the foundation* filter blanket (two flow lines).

(*iv*) That portion of the filter blanket which remains under the (steady state) phreatic line (equipotential line). [where there is a provision of rock toe, the upstream face of the rock toe upto the point where the phreatic line meets].

Referring to Figure 1 (*a*), just after sudden drawdown has occured, the potential at *A* which is considered theoretically at 100 percent has been taken to be at 95 percent in this study ; because it is just impossible to imagine a situation where no water will seep out from the body of the dam during the time the water level takes to reach the ground level from the full reservoir level (it is likely to be even less than 95 percent). The potentials at *B* and *C* are zero. The potentinl at '*P*', the point from where the two basal flow lines emanate is at a value which is somewhat less than its steady state seepage value.

The Model of the Flow Field

A shallow tray has been made using thin glass strips of 2.5 cm. width fixed to the bottom glass plate by araldite in the shape of the flow field. In the model the boundary which represents the phrcatic line of the steady stage seepage case has been prepared by dividing it into five numbers of small straight parts (in its modified form), vide Figure 2. This modification in the shape of the phreatic line is believed not to introduce appreciable error in the upstream half of the flow net and whatever error that may creep in will remain within a thin strip of zone running parallel to the phreatic line.

Electrodes placed at *B* and *C*, are connected to zero potential. The upper modified part of the phreatic line has been taken to be horizontal upto the upstream slope, though it is actually a flat curve drooping towards the upsteam slope. The straight part has been taken at a point on the upstream slope where the potential is equal to 95 percent of the total head before drawdown (point *A*). The electrode placed at *A* is strip of copper of length equal to the straight part of the modified phreatic line and it is connected to the full potential of the apparatus. The electrode placed at '*P*' is connected to full potential nob through a variable resistor. Varying the resistance in this circuit the potential at '*P*' is brought to the desired value. The tests were conducted varying the position of '*P*' along the base line.

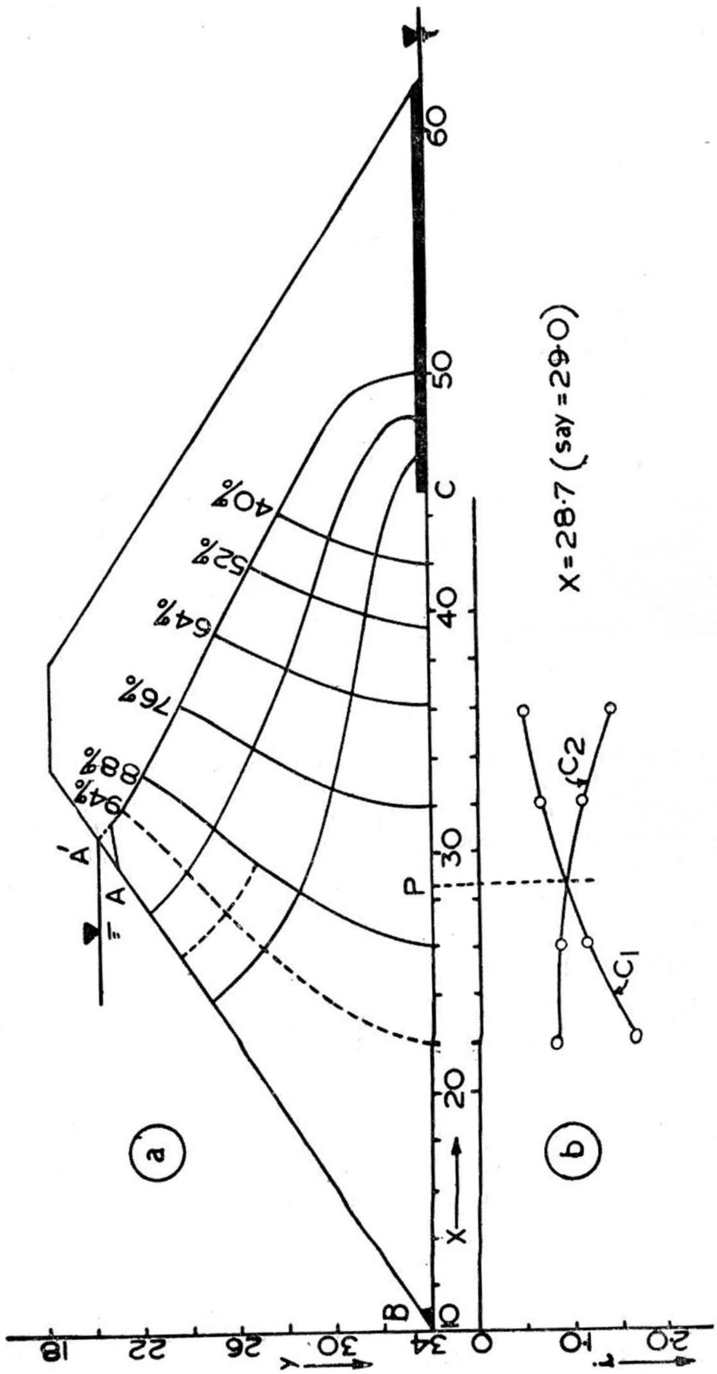


FIGURE 1a and 1b

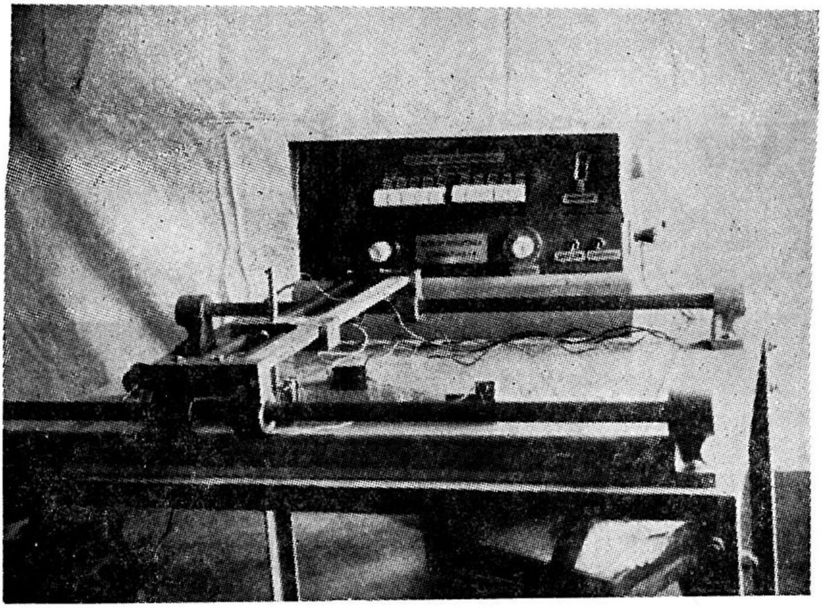


FIGURE 2 : A view of the Electrical Anology tray with detail connections.

Tap water has been used as the conducting media. Having connected the probe and the electrodes as indicated above, the readings of potentials at various points in the flow field which are in the form of a grid, are taken. Knowing the potentiais at the nodal points of the grid, the equipotential lines and then the flow lines have been drawn. The study has been conducted changing thc position of '*P*' along the base and the potential at '*P*' from a value of 55 percent to 85 pereent of the total head.

The Electrical Analogy Apparatus

The apparatus used is a marketed one. The makers description of the apparatus is briefly given below :

> "The electronic components of the electrical analogy tray apparatus consists of three primary circuits, the selecting, the amplifying and the indicating units. These circuits are made of the relevant high accuracy electronic components................ The voltage across the centre of the arm of the bridge circuit is applied to the amplified circuit................ The output of the amplifier is rectified by the rectifier tube before being applied to the null indicator electron ray tube. This is a voltage indicating device which indicates visually by means of a fluorescent target, a change in the controlling voltage. The pattern of the target varies from fully shaded area when the bridge is out of balance to a fully fluorescent area when the bridge is balanced".

For conveniently locating the coordinates of the nodal points, the "probe" is mounted on a guide which moves on a trolly. The trolly moves over a pair of parallel bars fixed to the table over which the flow model is kept. The null point is obtained with an accuracy of 0.5 percent of the applied potential. The apparatus works on an A.C. supply of 250 V, 50 cycles, vide Figure 2.

Test Procedure with Discussion

Immediately after sudden drawdown, with seepage of water from the body of the dam, the base line becomes two flow lines (basal flow lines), one flowing towards the upstream toe and the other towards the downstream filter blanket or the rock toe, as the case may be. It is clear that the two basal flow lines are horizontal. To make an electrical flow-field-model in conformity with the flow field one needs to know the true position of the watershed point '*P*' from where these two basal flow lines emanate, flowing in opposite directions, besides the established potential at the watershed point '*P*' soon after sudden drawdown has taken place. Once these two values of '*P*' are known, then the whole experiment turns to be a routine use of electrical analogy model to draw the flow net. In these tests attempts have been made to find out these values of '*P*' in relation with the base width and the total head so as to draw the flow net by the help of a simple Electrical Analogy apparatus.

For homogeneous earth dams (incompressible fill) with the horizontal impervious foundations, the nature of flow net for sudden drawdown condition has been shown by Terzaghi and Peck (1948)and Singh and Prakash (1964). In these flow nets one finds the position of the watershed point '*P*' (though not shown in their figures) to have remained somewhat directly below the point at which the reservoir level touches the upstream slope before drawdown.

Determination of Position of 'P'

When the gradients at different points along the base line are plotted considering first as if the entire base is draining towards the upstream toe (then again considering it to be draining towards the downstream filter blanket or rock toe), soon after instantaneous drawdown has taken place, the curves C_1 and C_2 have been obtained as shown in Figure 1 (*b*). These curves intersect at a point '*P*' which has been taken as the watershed point to begin with. [To calculate the gradients at different points, it has been assumed that the potentials at upstream toe and that at the filter blanket are zero and the fall of gradient is uniform from any given point taken for consideration to one of the zero potential points, depending on the flow directiton considered. The potentials at various points considerd have-been aken equal to their steady state seepage values]. Tests were then conducted keeping *P* at (28, 34), (29, 34) and (30, 34) [Refer Figures 3(*a*), 3(*b*), and 3(*c*)]. It is obvious that as the position of *P* shifts towards the downstream side of the dam, the equipotential lines, meeting the upstream slope, move gradually away from the upstream toe at their lower ends where they meet the base. This shifting of equipotential lines gives relatively lower value of pore pressure at any point on a given failure surface. Furthermore the position of '*P*' should be such that in the resulting flow net the family of equipotential lines should have almost similar shape and pattern. Any unusual kinks or distortions would result in an unsatisfactory flow net. Taking all these into account it may be said that the actual position of *P* is some where close to the point (29, 34).

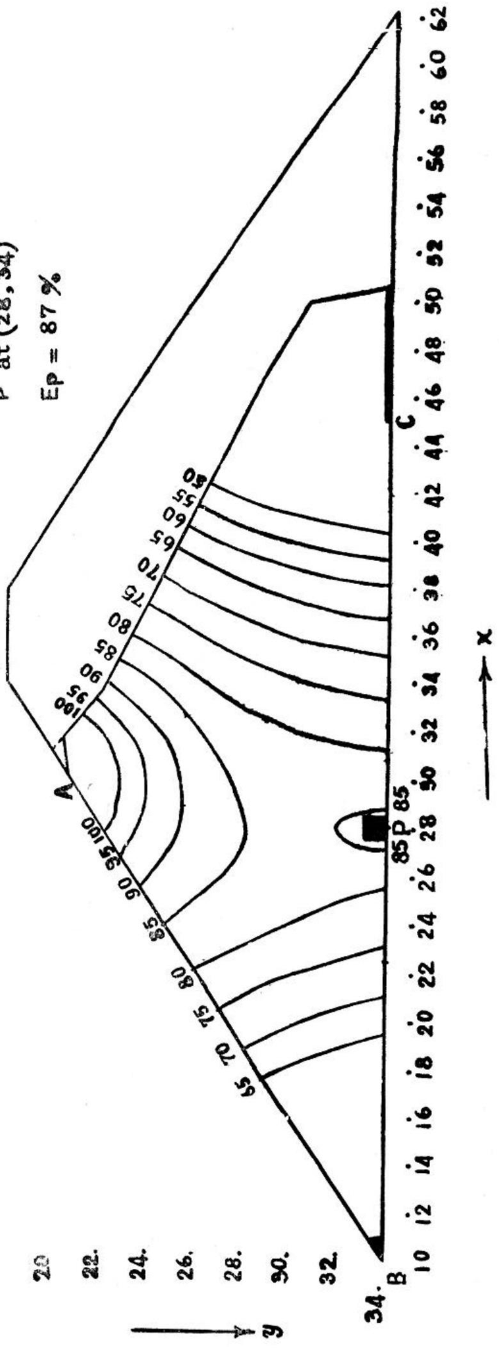


FIGURE 3 (a)

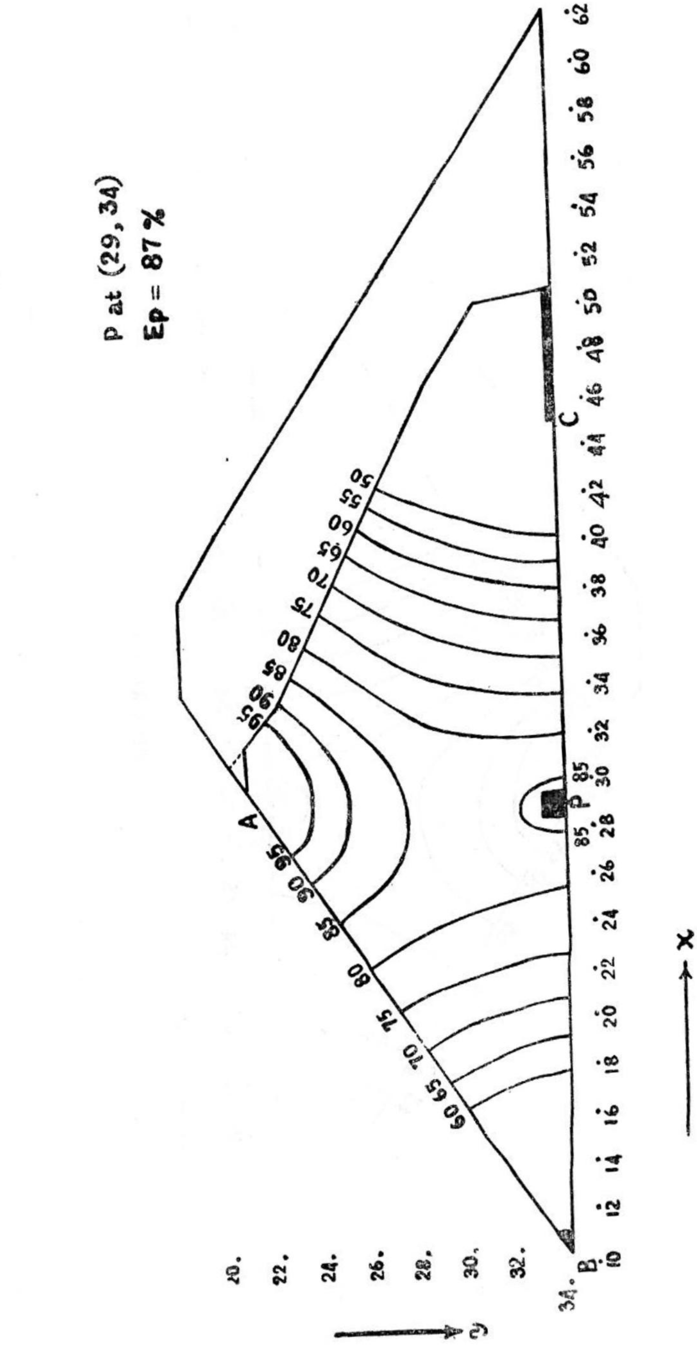


FIGURE 3 (b)

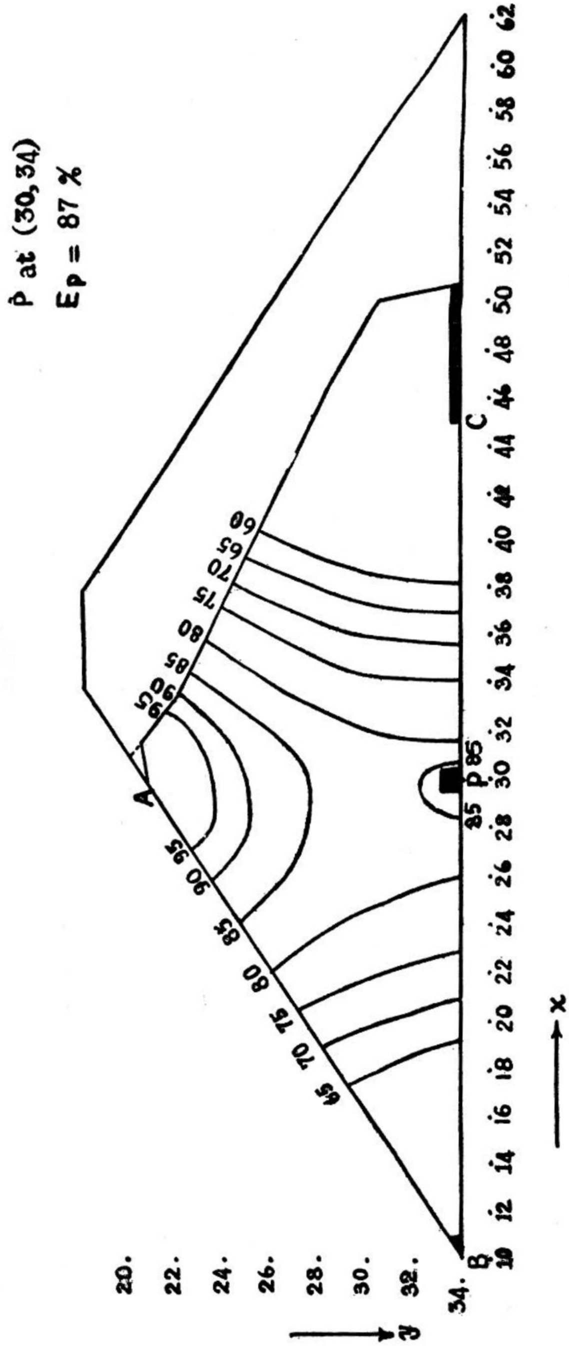

P at (30, 34)
Ep = 87 %
A
B
C
P
x
y
60 65 70 75 80 85 90 95
95 90 85 80 75 70 65
85 85
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62
20. 22. 24. 26. 28. 30. 32. 34.

FIGURE 3 (c)

Determination of Potential 'P'

Without placing the electrode in the flow model at '*P*' but connecting the electrodes at *B* and *C* to zero potential and the metal strip at A to full potential, when the test was conducted it was seen that the potential potential around '*P*' ($x=29, y=24$) was 55 percent [The calibration of the indicating system was such that it read between 10 percent and 110 percent that is, the absolute zero potential was equivalent to 10 percent reading and full potential value was equivalent to 110 percent reading of the indicating system. Metal strip placed at '*A*' having been connected to full potential nob, thus for the test, 95 percent of the actual head has become equivalent to 110 percent reading in the indicating system and 1 percent increase in the true head was equal to 100/95 percent increase in the indicating value for the given set up. Hereafter, whenever any percentage of potential will be mentioned, it will always mean the indicating value unless otherwise explicitly said].

When it has been taken that the potential at *A* has fallen through only by 5 percent, it is not possible for the potential at '*P*' to fall by an amount of 28 percent within the same elapsed time (steady state value was 83 percent). The actual value of potential at '*P*', therefore, must be higher than 55 percent but should be less than its steady state seepage value which is 83 percent of the total head vide Figure 1(*a*). [83 percent true value is equal to 97.3 or 97 percent indicating value]. Thus it can be said that the potential one can apply to electrode at '*P*' for the test must remain between 68 percent (indicating value) and 97 percent (indicating value).

Keeping the electrode in position at '*P*' (29, 34) and supplying a potential of 68 percent to it when the potential at the nodal points were measured, it gave a flow net as shown in Figure 4, Figure 5(*a*) and Figure 5(*b*) are flow nets drawn from tests conducted having applied potential at *P* (29, 34) 89 percent and 94 percent respectively. It may be seen in these Figures that the flow lines close to the base have upward gradients which thereby suggests the development of some sort of an artesian pressure zone around *P*. The area under the loop formed around '*P*' by the equipotential line having minimum potential value, limits the zone of artesian pressure. The minimum value of the equipotential line that forms a loop around '*P*' is 84 percent. To have a minimum area of artesian zone around *P* the true value of potential at *P* should, therfore, be such that the loop formed by 84 percent equipotential line around *P* would enclose the minimum area. It may be seen in Figure 5(*a*) that when the applied potential at *P* was 89 percent the equipotential line of 84 percent was forming a loop around *P* enclosing an appreciable area. Thus, the upper limit of potential to be applied at *P* is limited to 89 percent. Having determined the upper limit the next step taken was to determine the possible value of potential that should be applied at '*P*' to have a loop of minimum area. For this purpose, tests were conducted applying potentials of 87, 86 and 85 percent at *P* and then the equipotential lines those form loop around *P* have been drawn in all these cases. These are shown in Figure 6(*a*), 6(*b*) and 6(*c*) respectively. It may be seen that an applied potential of 87 percent at *P* (actual value is 73 percent) satisfies the requirement whereas in Figure 6(*b*) and Figure 6(*c*) the loop area around '*P*' is larger than that in Figure 5(*a*) suggesting thereby that the required value of potential at '*P*' is remaining at a value higher than 86 percent.

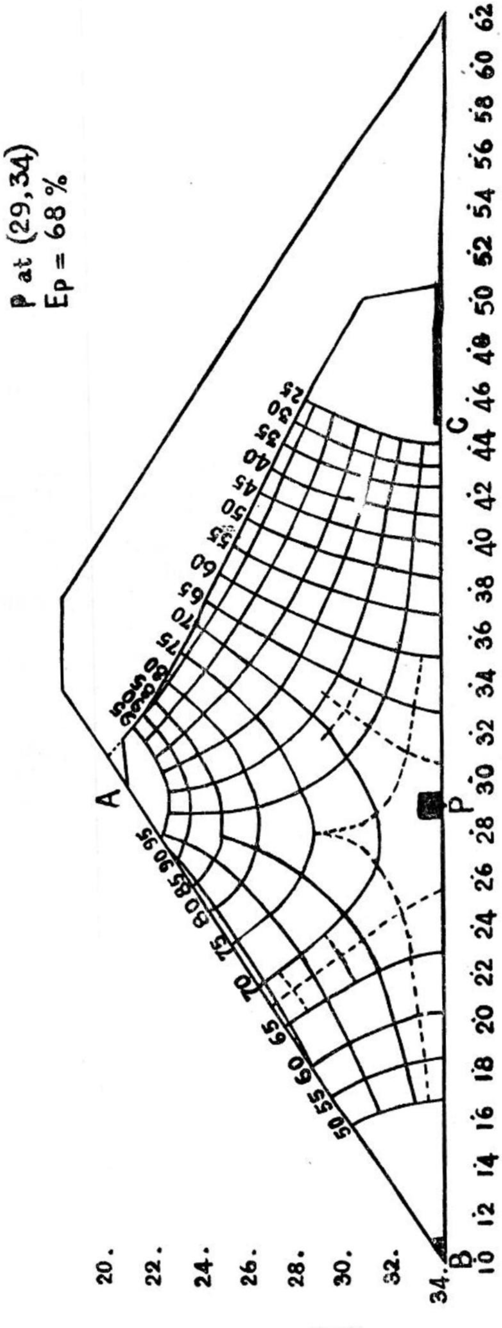

P at (29,34)
Ep = 68 %
A
B
C
P
x
y
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62
20. 22. 24. 26. 28. 30. 32. 34.

FIGURE 4

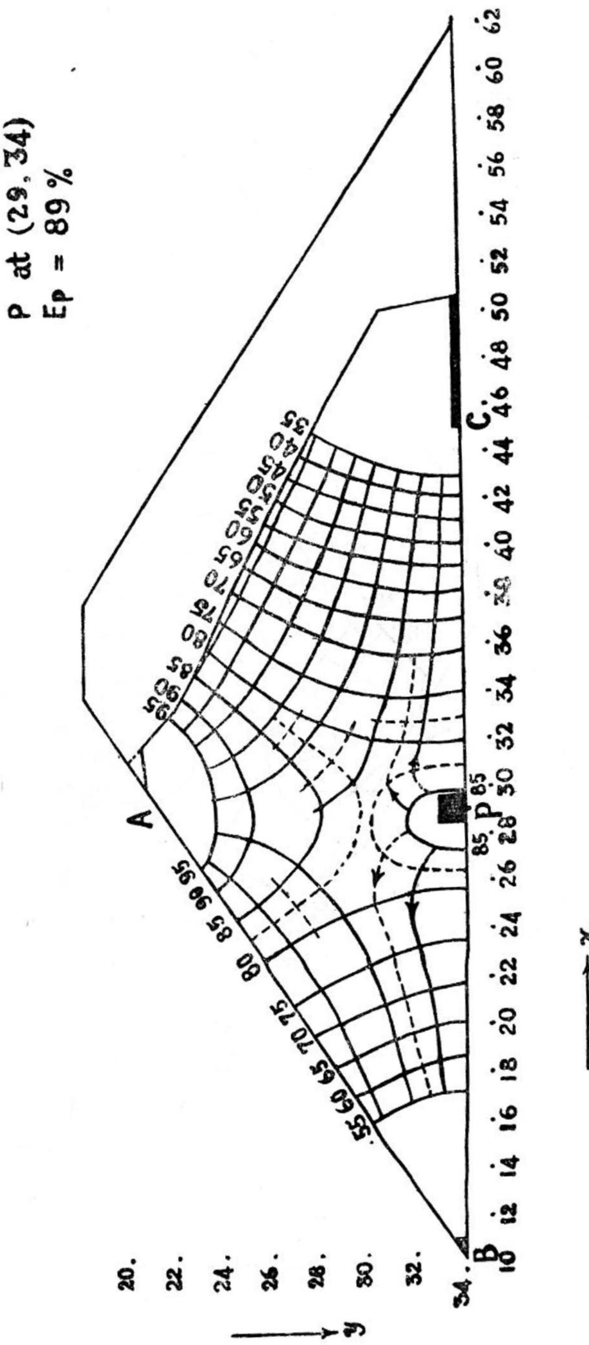


FIGURE 5 (a)

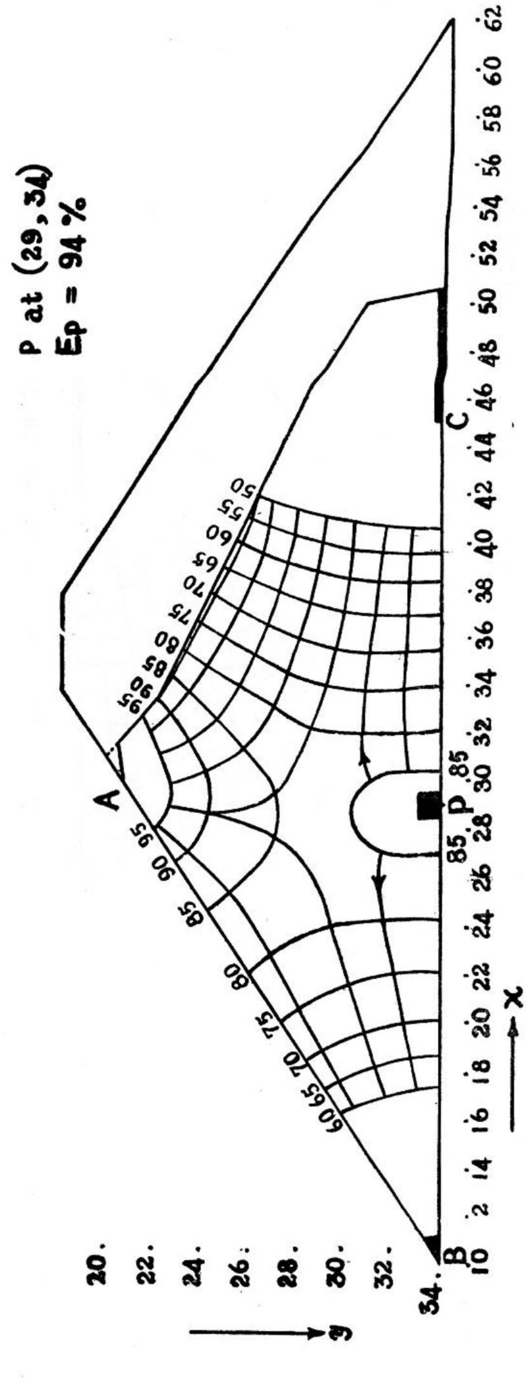


FIGURE 5 (b)

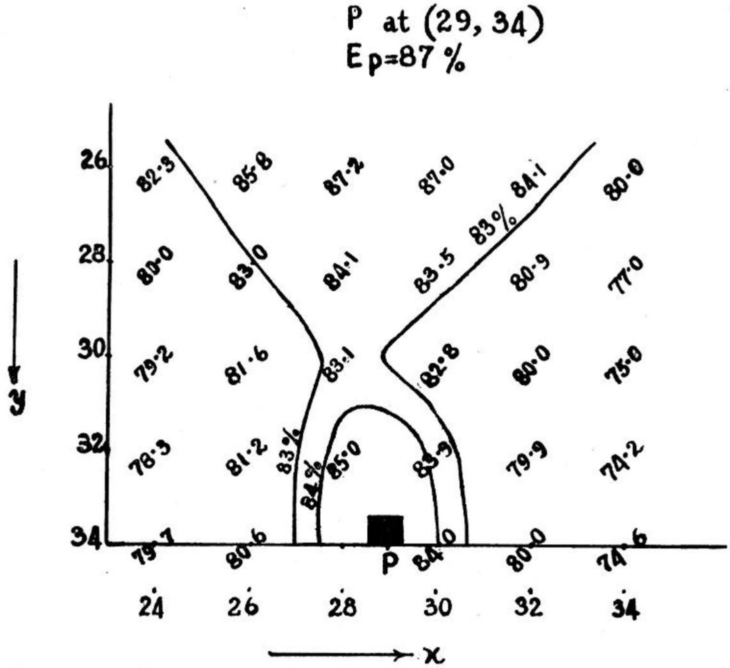


FIGURE 6 (a)

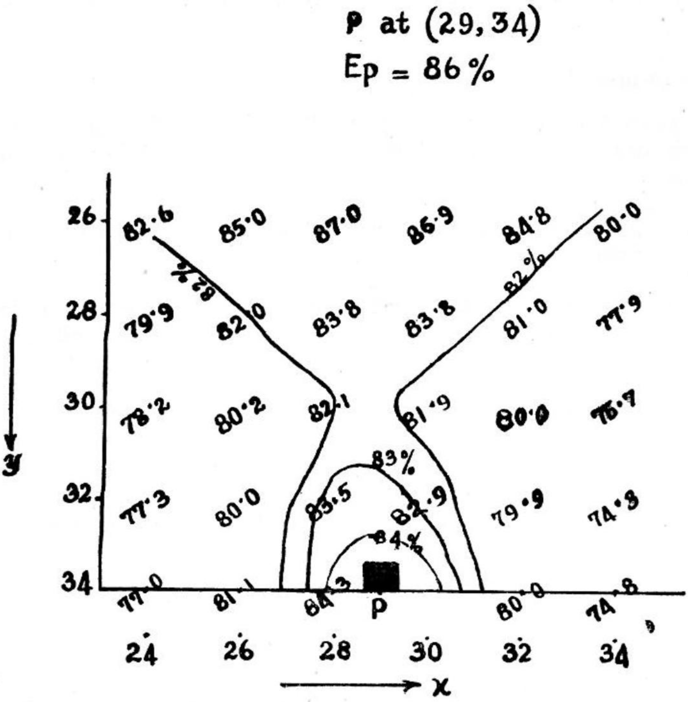


FIGURE 6 (b)

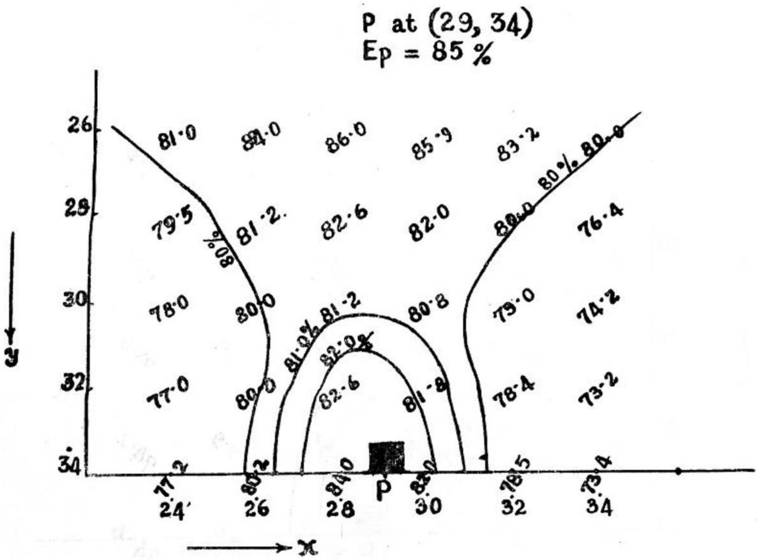


FIGURE 6 (c)

Once the position of '*P*' and potential at '*P*' are known it becomes easy to draw the flow net by the help of Electrical Analogy tray in the usual way. The flow net so drawn with these values of '*P*' has been shown in Figure 7.

Summary of procedure

To summarize the complete procedure to draw flow nets for sudden drawdown case in homogeneous earth dams, the following steps are mentioned :

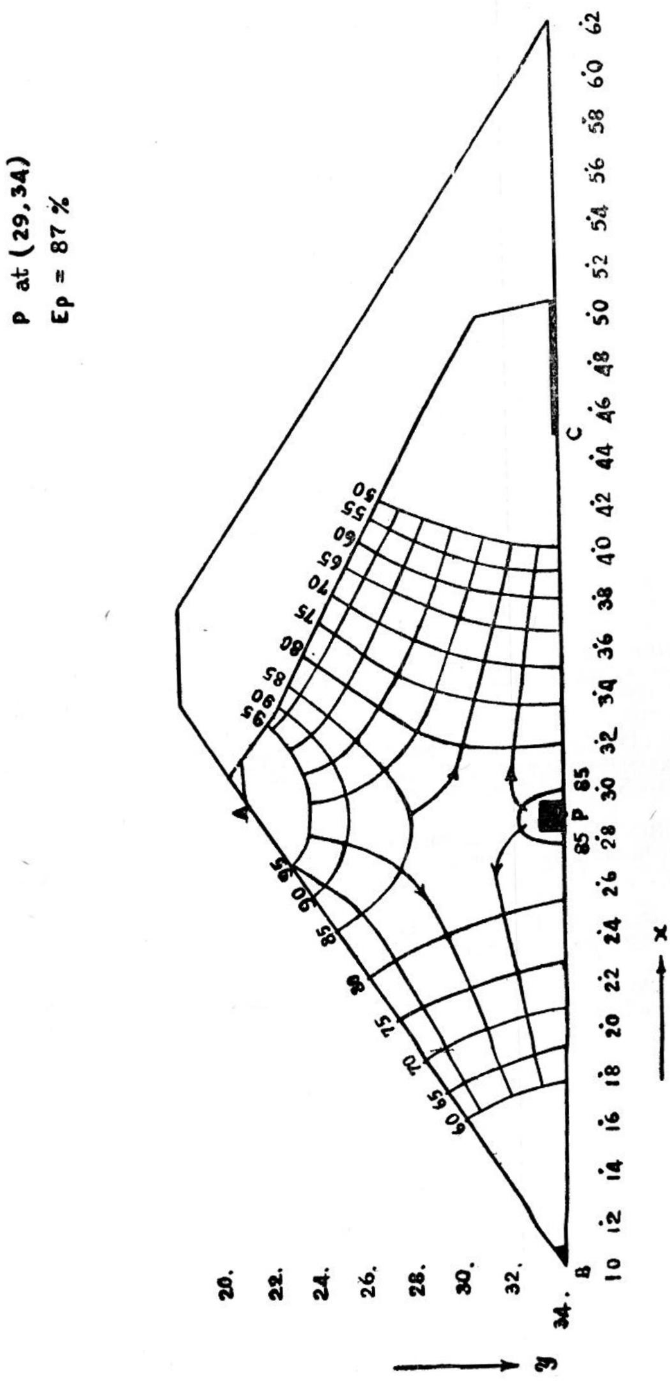
(*a*) The transformed section of the dam is to be drawn to a suitable scale.

(*b*) The steady state phreatic line is to be determined following either *A*. Cassagrande's or *L*. Cassagrande's method depending on the applicability for the given case.

(*c*) A model flow field is to be prepared using sheet of either glass or plastic and suitable electrodes preferably of copper are to be made.

(*d*) The position of watershed point *P* is to be determined as has been shown in Figure 1(*b*).

(*e*) The electrode at *P* is to be given a potential equal to a value 5 percent less than the potential value during steady state seepage. Connecting other electrodes in the usual way, the potentials at the model points in the flow field are to be measured. From these values, the equipotential lines may be drawn.


P at (29, 34)
Ep = 87 %
A
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P
85
85
x
y
10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62
20. 22. 24. 26. 28. 30. 32. 34.
60 65 70 75 80 85 90 95
95 90 85 80 75 70 65 60 55 50

FIGURE 7

(*f*) Then the equipotential line having a minimum potential value and forming a loop around *P* is to be located.

(*g*) Subsequent tests are to be conducted reducing the potential at '*P*' until the area of the loop under the equipotential line determined in step (*f*) becomes the minimum.

(*h*) The maximum potential at '*P*' which gives the minimum loop area is the required value of potential at '*P*' that is likely to develop during sudden drawdown. Now, having known the values of potential at all the electrodes (*A*,*B*,*C* and *P*) the Electrical Analogy test is to be performed from which the required flow net may be drawn for the sudden drawdown condition of the given problem.

Acknowledgement

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