GENERAL

The slide-rule described here is designed to simplify and speed up computations that need usually be made by the water engineer, ranging from that of frictional losses in a single pipe, to computing a circuit made up of numerous pipes with different flows.

In working out head losses in a single pipe, the slide-rule does away with the need of finding first the loss per unit length and ther multiplying it by the pipe's total length: both these steps are merged into one.

However, the special use of the slide-rule is in solving problems involving a large number of pipes, e.g. in establishing the resistance curve of a line which both delivers and receives various flows along its route.

According to the usual methods, any section of pipe lying between two successive points of inflow or outflow must be viewed as a separate pipe and computed by itself. The slide-rule, however, abolished this necessity and enables the whole series to be viewed as one unit, when head losses in each section can be read off directly, without separate calculations. Moreover, when the computation has to be repeated for different flows--a typical operation in computing the resistance curve of a water main--all that has to be done is to move the slide to a corresponding new position and to read off a fresh set of results, without recourse to any computations.

In certain cases one is faced with two or more series of pipes without knowing how the flow entering the system would be distributed. A problem of this kind is that of a closed loop, which has always entailed tedious repetitive work of trial and error. In problems of this description, the efficacy of the slide-rule is particularly manifest.

1.   THE INSTRUMENT AND ITS CONSTRUCTION

The instrument is based on the Hazen-Williams formula for the loss of head in a pipe conduit, which reads:

$$H = 1.131 \times 10^{15} \times \frac{(Q)^{1.852}}{(C)} \times D^{-4.87} \times L \quad . \quad . \quad . \quad (1)$$

where   H is the loss of head in metres;

Q -- the flow in cu.m/h;

D -- the pipe's diameter in mm;

L -- the length of the pipeline in metres;

C -- a coefficient representing characteristics of the pipe.

The instrument is in the shape of a slide-rule composed of a frame or guide, in which a tongue or medial slide can be moved lengthways, and of a number of runners which are endless bands or hoops of flexible material encircling the slide-rule and capable of both being turned

around the slide-rule and being slid along it. Every runner bears two scales: a scale of head losses in metres (or feet)[*] (along the left-hand edge of the runner) and a scale of diameters (along the right-hand edge of the runner). Steel pipe diameters are marked in red, while asbestos-cement or concrete pipe diameters are marked in blue. All the runners are identical.

The medial slide bears a grid, with logarithmic divisions across its width corresponding to a range of pipe lengths in metres (or feet)[*], while the divisions along its length being those of flows in cu.m/h and gpm. Over this grid a curve is drawn. The grid and the curve are symmetrical about a vertical axis drawn down the middle of the slide's length. This axis stands for a zero discharge, while to both its sides the scale is marked for discharges up to 500 cu.m/h[**]. In addition, the slide carries on its left-hand side a small scale across its width marked C H.W., giving the values of C.

The instrument enables flows to be determined in asbestos-cement pipes, for which the value of the coefficient C is 135 or for steel pipes with the value of C equal to 90, (higher values are given in other models), corresponding to steel pipes carrying water of a corrosive nature.

(Results can also be obtained for any other value of C, as explained further.)

In the slide-rule described in the attached drawings—maximum discharge is 400 cu.m/h.

Diameters of pipes in all models follow those of standard commercial sizes: In concrete pipes of 18" and over, the nominal size is the real size. In steel pipes of 14" and over, the real size is 1/2" smaller than the nominal size. All other diameters (steel and asbestos-cement) are given in millimetres in the following table:

Nominal Size	2"	3"	4"	6"	8"	10"	12"	14"	16"
Diameters of As.Cem. Pipes (mm)	50	75	99	152	201	252	301	353	404
Diameters of Steel Pipes (mm)		81	106	158	209	263	313		

2. COMPUTATION OF A RESISTANCE CURVE[***]

Let us consider the line diagrammatically shown in Figure 1. This pipeline is fed by a pump A and a reservoir is located at its end. The line is made up of 4 elements: 1000 m 12", 500 m 8", 100 m 6" and 100 m 4"; all pipes are assumed to be made of asbestos-cement (C = 135).

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[*] Any unit of length may be used, provided it is applied both to the pipe length (referred to later) and the head loss.

[**] In the other two models, maximum discharge is 5000 cu.m/h and 70,000 cu.m/h respectively.

[***] The illustrative problems are for the "500" model and the answers are rounded off to the nearest 0.1 m and 5 cu.m/h.

As one runner is required for each element in the line--select the four runners on the right of the frame and move all the superfluous runners well over to the left of the frame. Set runner 1, representing element 1 (100 metres of 4" pipe) at an arbitrarily selected point on the right-hand side of the frame but manipulated around the frame to such a degree that the 4" (the blue figure) marking on the pipe diameters scale coincides with 100 metres of pipe length on the grid (Figure 3). Runner 2, representing element 2 (100 metres of 6" pipe) is similarly set but at a distance from runner 1, in accordance with the outgoing flow between the elements 1 and 2 in relation to the flow scale, as read off at top or bottom of the grid. In this manner all four runners are set. The runners are moved to the left in the case of a discharge--but to the right in the case of intake.

Now the medial slide is moved to a position in which the left-hand edge of runner 4 cuts the Q scale--any discharge of the pump (280 cu.m/h – in Fig. 4). The curve now crosses the scale on the left edge of every runner and so indicates the head losses in every element in the line. In element 4 the head loss is 3.6 m, in element 3:5.3 m, etc. The left edge of every runner crosses the flow scale (at the top or foot of the medial slide) and gives the flow in its element, (280 cu.m/h in element 4, 180 cu.m/h in element 3). Runner 1 is crossed by the ~~left~~ right-hand curve (and not by the ~~right~~ left-hand one--as for the other runners). This means that the water in element 1 flows in the opposite direction, i.e. from the reservoir, (Fig. 2) and not from the pump.

If we now move the slide to another position, we get another set of results corresponding to another discharge of the pump; for example the slide is moved to a position corresponding to a discharge of 230 cu.m/h (Fig. 5) the head losses in element 4 is 2.5 m, in element 3: 2.9 m, etc. The flow in the elements 4 and 3 is directed from the pump towards the reservoir, and from the reservoir towards the pump in the others.

Every position of the slide gives a set of results corresponding to a given discharge of the pump and we thus obtain a new point of the resistance curve.

3. METHOD OF SOLVING A SIMPLE LOOP

Let us take the case of a simple loop composed of a number of elements where at each junction between two adjoining elements a flow either enters or leaves the loop. Referring to Fig. 6 a loop of this kind is shown, consisting of 4 elements, assumed for the sake of the present example to be asbestos-cement pipes. A flow of 300 cu.m/h enters the loop at a point where the head is +100 m. At three other points, flows leave the loop in the amounts of 50, 100 and 150 cu.m/h respectively. The required data to be supplied by the solution of the loop are, what is the flow in every element (pipe) and what is the head at every junction.

To arrive at the solution, we shall first number the various elements in a chosen direction (in the present example - anticlockwise) and shall bring into use a number of runners equal to the number of elements (Fig. 3).

The remaining runners that are not needed can be slid to the left-hand end of the slide-rule (not shown on the drawing). Of the 4 runners needed for the solution, every one will represent an element of the loop, taken in its numerical order, from right to left. The band of every runner will now be turned around the slide-rule in such a manner as to make the relevant pipe's diameter on the band coincide with its length on the chart's divisions. Thus, the mark of 4" on runner 1 will fall on the 100 m line on the medial slide and the runner will therefore represent element 1 on the loop, which is 4" in diameter and 100 m long. Runner 2 will be slid into such a position as to make the distance between it and runner 1 equal, on the Q (flow) scale, to the flow discharged at the junction between elements 1 and 2. (Should this be an incoming and not an outgoing flow, then runner 2 would have had to go to the right and not to the left of runner 1.)

In this manner, all runners are placed in their proper positions. Runner 1 is then found to lie to the right of runner 4 at a distance corresponding to 300 cu.m/h , since at the junction between the two a flow of 300 cu.m/h enters the loop.

When all the runners are placed in position, the medial slide is moved (Fig. 5) to a position in which the right-hand flank of the curve cuts off the same total losses of head (on the head loss scales) as the left-hand flank. Each flank accounts for 5.5 m. This position supplies the solution for the loop: the curve cuts off on every scale the loss of head in the corresponding elements; the left-hand edge of every runner cuts on the Q-scale the flow passing through the respective element and the direction of flow is indicated by the fact that all the runners inter-sected by one flank of the curve show one direction, and by the other flank-the opposite direction.

Runner 1 shows 70 cu.m/h, runner 2---20 cu.m/h, runner 3---130 cu.m/h and runner 4---230 cu.m/h. In elements 1 and 2 the flow is in one direction while in elements 3 and 4 it is in the reversed direction. The full solution of the loop is shown in Fig. 7.

In any case where the coefficient C--of steel pipes--is greater or less than 90 (or 100--in the "5000" model) it will be necessary to effect a shift on the diameter-scale to a position above or below the point where the pipe's diameter is marked. The correct position will be found with the aid of the C-scale: (not shown on the drawing). The correct distance above or below the nominal diameter mark will be equal to the distance between the given value of C and the value of C - 90 on the C-scale.

In the case of a number of pipes of different diameters, where there is no outflow at the points of junction, an equivalent length should first be determined. If, for example, a 100 m length of 4" dia. is given and it is necessary to convert it into an equivalent length of another diameter--one moves a runner to a position where the 4" mark coincides with the ·100 m line (as in the example at para. 3) when it will be found that the marks for all other diameters on that runner fall on divisions of length which are in fact the equivalent lengths sought.

When dealing with a loop with flows outside the limits of a medial slide's divisions, all the flows can be divided by 2 and, after solution of the loop, the values for loss of head can be multiplied by 3.6.

4. ADDITIONAL EXAMPLE (A net fed by two reservoirs)

Where a given pipe network is fed by two reservoirs (see Fig. 8), such a case can be solved in a similar manner to a loop but, while in a loop the solution is based on one and the same head where its branches join, here it is based on a difference of heads (in the present example, a difference of 8.5 m).

For this case the runners are set as shown in Fig. 3 and the medial slide is then moved so as to make one flank of the curve (the left-hand one) cut off a loss of head which is 8.5 m greater than that cut off by the other flank (Fig. 4).

Fig. 9 shows the resultant flows: the lower reservoir supplies 20 cu.m/h; the upper reservoir--280 cu.m/h.

5. SOLUTION OF COMPOUND LOOPS

The solution of networks composed of more than one closed loop involved a somewhat longer procedure. Below are two examples for solving a network composed of two loops.

(a) Solution of network containing 3 trunk lines (Fig. 10)

The runners for each trunk are first set up in separate groups. Then one assumes a certain flow entering trunk 1 and determines (with the aid of one flank of the curve) the loss of head in that trunk. Following this, the curve is moved to the group of runners for trunk 2 and the flow is found which would produce in this trunk the same loss of head.

The flow in trunk 3 is found in two ways: (a) in the same way as in trunk 2; (b) as the difference between the total flow entering the net-work and the flows entering trunks 2 and 3. If the flows found by both methods for trunk 3 are identical, then the assumption for the flow entering trunk 1 is correct; if the figures do not coincide, their mean should be taken and the process repeated, this time starting with trunk 3. The trials are continued until a sufficiently accurate result is obtained.

(b) Solution of network containing two loops (Fig. 11)

A solution is first found for a simple loop, as though element 2 does not exist. (This will supply result No. 1). Then one determines the difference of head between junction 1-2-3 and junction 2-4-5. Assume this difference to be $2 h_1$. Take one half of the difference, namely h_1, and determine the flow in element 2 corresponding to a loss of head equal to h_1. Denote the flow by Q_1. The direction of this flow is towards the junction with the lower head, say, junction 2-4-5. The loop is then solved again in such a way that the outgoing flow at junction 1-2-3 is greater by the amount of Q_1 than in solution No. 1 and the outgoing flow at junction 2-4-5 is less by the same amount. The difference of head between the two junctions is determined again as being equal to h_2. The mean value of the two is then taken: $1/2 (h_1 + h_2) = h_3$ and the process is repeated until it is found that $h_n = h_{(n + 1)}$ to the required degree of accuracy.
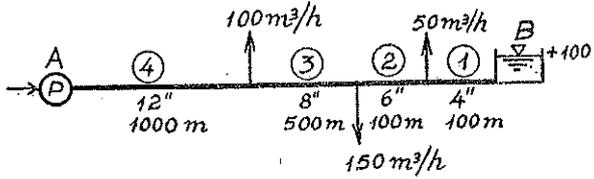
Fig. 1
A pump and a pipeline
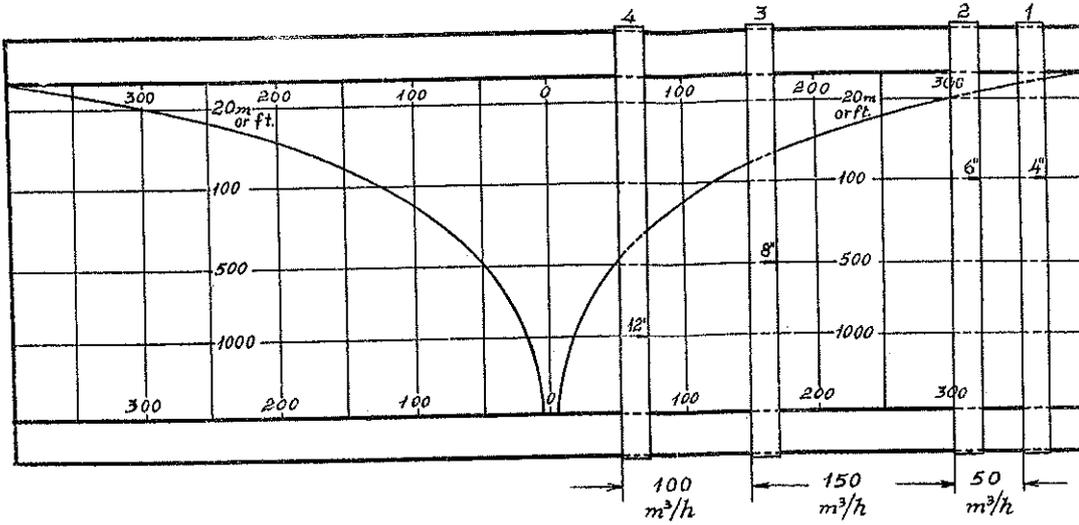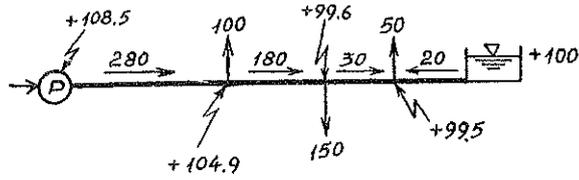

Fig.2
Flow scheme when discharge is 280 m³/h

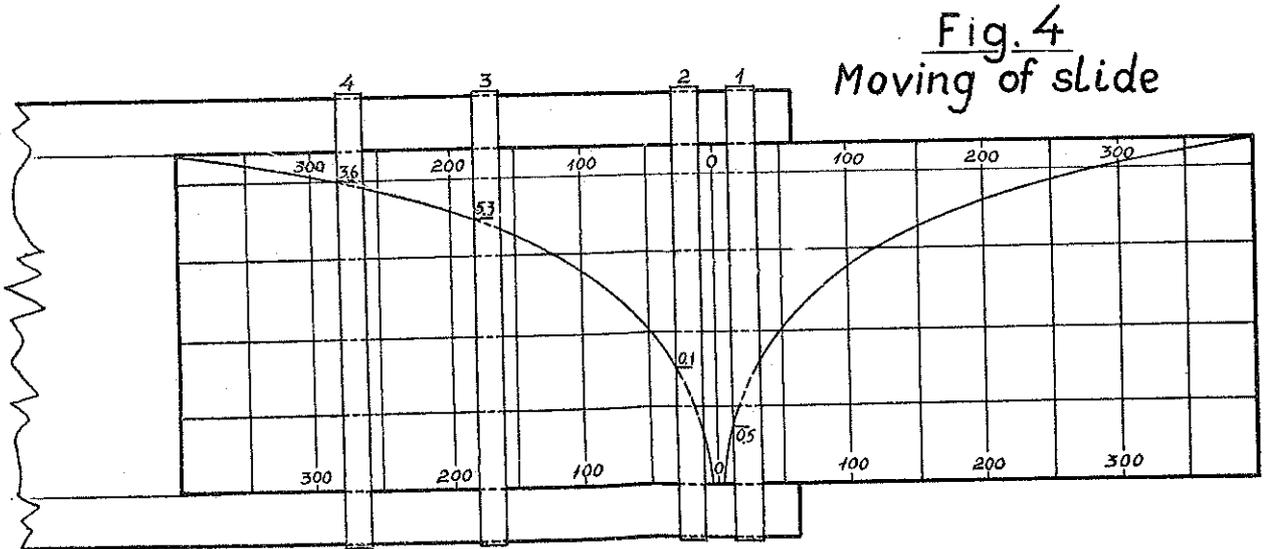

Fig.3
Runners are set in position

Fig.4
Moving of slide
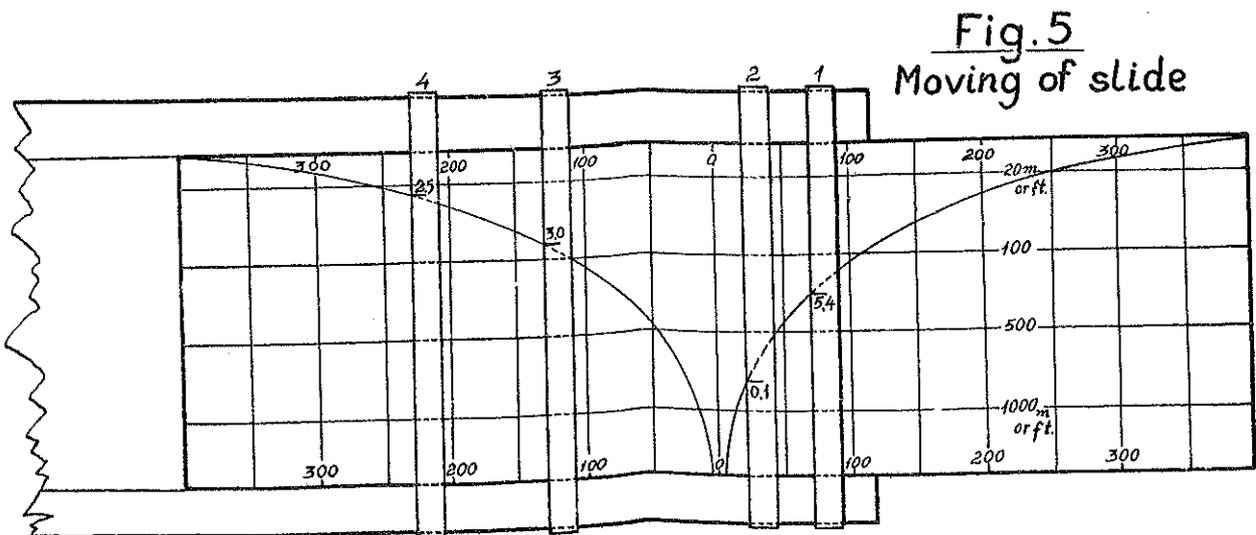
Fig.5
Moving of slide

Fig. 6
A Loop

100 m³/h

③

500 m   8"

④

1000 m   12"

④

150 m³/h

②

50 m³/h

100 m 6"

100 m 4"

①

+100

300 m³/h

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100 m³/h   +97.5

130

230

150 m³/h   +94.6

20

50 m³/h

+94.6

70

+100

300 m³/h
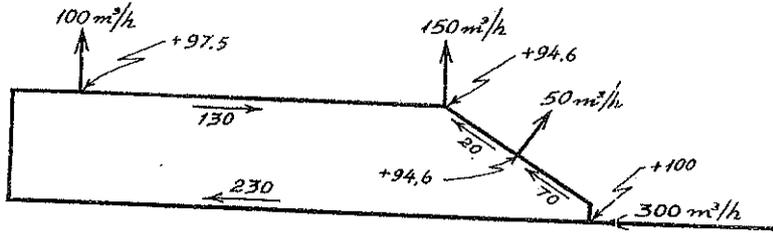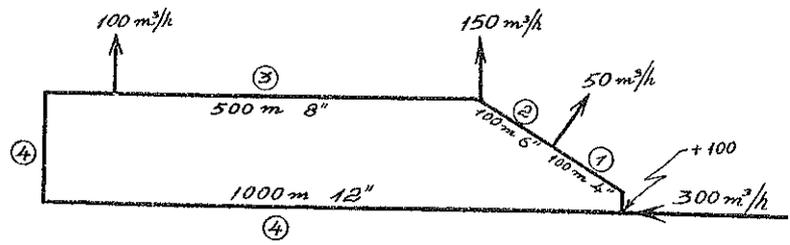
Fig. 7
Schematic representation
of solution

Fig. 8
A network fed by two
reservoirs

+108.5

12"   1000 m

④

100 m³/h

8"   500 m

③

① +100

4"
100 m

50 m³/h

② 6"
100 m

150 m³/h

+108.5

280 m³/h

+104.9

100 m³/h

50 m³/h

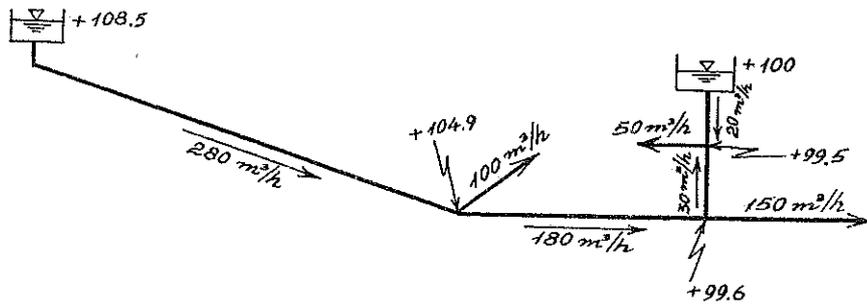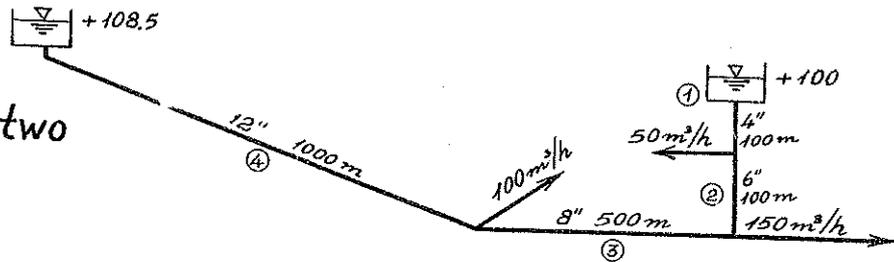20 m³/h

+100

+99.5

50 m³/h

180 m³/h

150 m³/h

+99.6

Fig. 9
Schematic representation
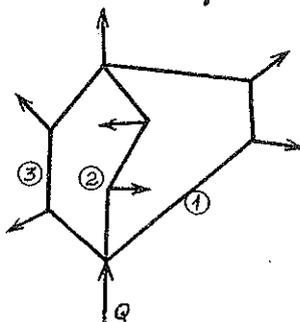of solution

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Fig. 10
A pipe system of three parallel branches

③   ②   ①

Q

Fig. 11
A two loops system

Qc   QB

④

⑤   ②   ③

QA

QD   ①

⑥

Q