The Canadian Engineer

VOL. IV.—No. 5. TORONTO, SEPTEMBER, 1896. PRICE, 10 CENTS $1.00 PER YEAR.

The Canadian Engineer.

ISSUED MONTHLY IN THE INTERESTS OF THE

CIVIL, MECHANICAL, ELECTRICAL, LOCOMOTIVE, STATIONARY, MARINE AND SANITARY ENGINEER; THE MANUFACTURER, THE CONTRACTOR AND THE MERCHANT IN THE METAL TRADES.

SUBSCRIPTION—Canada and the United States, $1.00 per year; Great Britain, 6s. Advertising rates on application.

OFFICES—62 Church Street, Toronto; and Fraser Building, Montreal.

BIGGAR, SAMUEL & CO., Publishers,

E. B. BIGGAR
R. R. SAMUEL

Address—Fraser Building, MONTREAL, QUE.

Toronto Telephone, 1892. Montreal Telephone, 2589.

All business correspondence should be addressed to our Montreal office. Editorial matter, cuts, electros and drawings should be addressed to the Toronto office.

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STORAGE OF WATER IN EARTHEN RESERVOIRS.*

BY SAMUEL FORTIER, M. CAN. SOC. C.E.

(*Concluded from last issue.*)

In cold climates like those of Canada and the Northern States, it is important that the high water line be kept below the frost line in the upper portion of the dam. Failure might also be caused in weak embankments by the formation of ice at the flow-line.

In both cold and warm climates there is the danger of waves over-topping the embankment. The maximum height of waves which may occur on the surface of any reservoir of known dimensions may be roughly estimated by Stephenson's formula $H = 1.5 \sqrt{F} + (2.5 \sqrt[4]{F})$ in which H is the height of the waves in feet and F the fetch or distance in nautical miles through which the waves act. According to the above formula, the heights of waves on ordinary reservoirs would vary from two to three feet. On the smallest the waves would be more than 2 feet high and seldom more than 3 feet on the largest. It is evident, therefore, that this formula does not apply to small surfaces of water, but as the error is on the side of safety, and since the top of even small reservoirs should be raised at least two feet above high water; the formula can be trusted to give approximate results.

The practice of the writer for years in designing the cross-sections of reservoir embankments has been to determine first the breadth at the flow-line. Then through the extremities of this distance converging lines can be drawn to suit the angle of repose of the material and other necessary conditions. Great differences exist as to this dimension. While writing this article there lie before the author the descriptions of five reservoirs each 30 feet deep, and their respective breadths at the flow-line are 28 feet, 34 feet, 40 feet, 45 feet and 53 feet. After making ample allowance for a difference in the quality of the materials, there should not be a difference of nearly 100 per cent. in the widths of the embankments, providing the work in each case has been carefully done.

With a view to unifying the results and economizing material, the writer obtained by circular letters, private correspondence and otherwise, descriptions of about 100 reservoirs located in nearly every State of the Union. Out of the hundred 75 were chosen as typical of existing conditions, and their depths of water and breadths of embankment at the flow-line were plotted on cross-section paper. The co-ordinates for each of the 75 reservoirs were the abscissa (x) which represented the breadth in feet of the embankment at the flow-line, and the ordinate (y), which represented the depth in feet of the water in the reservoir. The curve formed by joining all the points was so nearly that of a straight line that the following equation of a straight line was adopted.

$$y = x - 5.$$

For outer and inner slopes of two horizontal to one vertical, and with the top of the embankment from two to six feet above the flow-line, the above empirical formula gives top-widths and flow-line widths for depths of water from 10 feet to 45 feet as follows:

TABLE VI.

Depth of water in reservoir. Feet.	Outer slope.	Inner slope.	Top width. Feet.	Distance between top of embkt. and surf. of water. Feet.	Breadth at flow line. Feet.
10	2 to 1	2 to 1	7	2	15
15	"	"	8	3	20
20	"	"	11	3½	25
25	"	"	14	4	30
30	"	"	19	4	35
35	"	"	22	4½	40
40	"	"	25	5	45
45	"	"	31	6	55

In impounding water to a depth greater than 40 or 50 feet, safe construction requires the introduction of berms. Thus, in a reservoir 60 feet deep, there should be near the middle of each slope a berm of 5 or 6 feet in width, and when we deduct the width of these two berms, the top width is limited to about 30 feet, while the formula still holds approximately true.

Regarding the 75 typical reservoirs referred to, it may be here stated that their inner slopes varied from a maximum of 4 to 1 to a minimum of 1 to 1, and averaged 2.61 to 1, while their outer slopes averaged 2.1.

TABLE VII.

Outer Slopes.					Inner Slopes.				
2	reservoirs	1	to	1	2	reservoirs	1	to	1
23	"	1½	"	1	23	"	1½	"	1
2	"	1¾	"	1	2	"	1¾	"	1
41	"	2	"	1	31	"	2	"	1
1	"	2¼	"	1	1	"	2¼	"	1
3	"	2½	"	1	1	"	2¾	"	1
3	"	3	"	1	11	"	3	"	1
					2	"	4	"	1
75 reserv's aver. 2 to 1.					75 reserv's aver. 2.61 to 1				

It is evident from the foregoing that American

*A paper read before the Canadian Society of Civil Engineers.