possible chance of a water-fall being formed, any soil except rock will be subject to erosion, with the attendant danger of undermining.

The steeper the fall, the greater is the efficiency of the culvert. The velocity of the water varies as the square root of the change in slope, so that in changing the grade from a two-tenths to an eight-tenths per cent., the capacity of the opening is theoretically doubled, provided, of course, that the water can get away when it reaches the end.

If the outlet ditch is straight, it need not be either as wide as the culvert or on as steep a grade, the water will enlarge the channel; but if the outlet must be crooked or curved, then eddies must be looked for, and, if necessary, the banks rip-rapped.

The nature of the bed of the stream will, in general, determine the fall, the theoretical maximum being 1½:1, but in any case it is not good practice to put either masonry or concrete footings on a slope. Although this is sometimes done, they should always be stepped down, the excess cost being negligible.

Construction.—After the centre line and the grade are established, the notes are best entered in a field book kept for the purpose, a cross-section of the road-bed and a cross-section and plan of the culvert being drawn therein, showing the various elevations, and a key to the excavation of the footings (Figs. 9 and 10). On a stormy day in winter a field book is much easier handled than a few yards of blue-print paper, besides which, the chances of errors in the staking-out, and erection are greatly minimized.

Usually all that the contractor requires in the way of stakes is the centre line of the culvert, and the faces of the end-walls. If the culvert is skew with the centre line of the dump, then the end-walls must be staked out parallel to this centre line. The elevation of the top of the footings and the invert is all the levels that are generally necessary.

When the excavation is out, the bottom should be tested with a sounding rod to determine its density, and also to make sure whether the material in sight is not merely a mattress covering some softer material underneath. A knowledge of the local geography is of the greatest use. It the strata lie fairly horizontal, river gullies in the vicinity give a fair idea of the underlying soil, although these must not be absolutely relied upon. If the strata happen to dip, there is a chance that one portion of the footings will rest on a softer soil than the other. If the dip is not very great, a uniform footing can be got by stepping down, but if this will not remedy matters, then the footing on the softer soil must be enlarged so that the resistance to settlement will be the same on both soils.

The best foundation soils are ledge rock, shale, indurated clay, and gravel, in the order named. The stability of sand and clay depend a great deal upon the amount of moisture present, their composition, and the possibility of the latter flowing under pressure. Of course, the same precautions are not necessary as with bridge piers and buildings, as a slight settlement will do no harm, provided that it is fairly even. The weight of a culvert is very small compared with that of the embankment on top, and if the subsoil will not hold up the embankment, then any culvert may be expected to fail also. The final test as to whether piling is necessary is in the pile-driving itself, for if they drive easily, then of course they are needed. A sounding rod in experienced hands will give a good idea of the strength of the sub-soil, but if the culvert is larger than 12 feet it is better to drive a test-pile. In any case, if there appears to be a chance of settling, it is best to build the culvert in sections of ten feet or so, the sections being separated with one or two thicknesses of tar paper, and then, if uneven settlement does occur, each section will settle vertically without impairing the strength of the culvert as a whole.

In Canada, the least depth to be safe from frost is four feet, and if quicksand is encountered, the excavation must be protected with sheet-piling. If, however, the quicksand is not found until the last foot or so, the sheet-piling may be omitted by widening the excavation a foot all round, and then digging out a small portion of the quicksand at a time and replacing it with coarse gravel or broken stone until the whole of the bottom is protected with a mattress.

When the invert is paved, and the soil is good, then all the depth of the foundations under the walls needed is 18 inches, provided that the aprons and wings are sunk to the full depth of 4 feet. (Fig. 10). On a long culvert this will effect a considerable saving.

Backfilling.—In backfilling any masonry culvert, only one method of procedure should be allowed, and that is to fill and tamp both sides before any material is dumped on the top, and especially so when a dump is being made by the "en-fill" method, for such a fill acts as a semi-fluid, and exerts a most powerful pressure on anything in its path.

REPORT OF BOARD OF ENGINEERS ON THE SHOAL LAKE AQUEDUCT.

DEFECTS in the portion of the aqueduct constructed during the summer of 1915 having been reported to the Administration Board of the Greater Winnipeg Water District, and doubts having thereby arisen as to the cause of these defects, the possibility of repair and the means of avoidance of similar or other defects in the work yet to be constructed, a list of twelve questions were, by resolution of the board, submitted to the consulting engineer, Mr. James H. Fuertes, and to the chief engineer, Mr. W. G. Chace, with instructions to report to the board specifically thereon. Following the receipt of this report and after consideration the Administration Board passed a resolution under which it was decided to secure an independent report on the subject from a board of engineers, consisting of Col. H. N. Ruttan, of Winnipeg; Mr. J. G. Sullivan, chief engineer of the Canadian Pacific Railway; and Mr. R. S. Lea, of Montreal. These gentlemen having agreed to act, they were instructed as follows:—

"That the question submitted, the replies thereto, and the report of the consulting engineer, James H. Fuertes, and the chief engineer, W. G. Chace, thereon, be considered, and any other information procured by the special board of consulting engineers to enable them to report specifically, agreeing or disagreeing with the conclusions or opinions of Messrs. Fuertes and Chace, more especially on all points dealing with (1) the efficiency of design and detail plans for the various portions of the work; (2) the cause of the defects now developed in the work done last year; (3) the practicability of repair, and the probable cost of such repair; (4) the stability and quality of the work done last year; and (5) as to the consulting engineer and chief engineer's proposed method of avoiding a recurrence of any of the