Waterways should be neither needlessly large, nor of too small dimensions, involving on the one hand unnecessary expense for first construction, and on the other hand, injury to the road, washouts, expensive repairs, and delay to traffic.

The materials available for culvert construction in addition to timber, are sewer pipe, concrete pipe, iron pipe, brick, stone, and concrete. Culverts are sometimes made of one of these materials alone, or of two or more in combination. When the dimensions of a bridge are reached, concrete and stone abutments and piers, with iron or steel superstructure; or stone, brick or concrete, alone or in combination, are the materials gaining favor.

For the small culverts, sewer pipe is very economical and durable if well laid. To render them secure against the test of a Canadian climate, they should be laid with a good grade, and the ends protected with concrete, stone or brick headwalls with deep aprons. The joints should be made water tight with cement. These precautions will provide against the action of frost, and will prevent the culvert being undermined by water passing along the outside of the pipe, either from the ends or through the joints. Care should be taken to excavate a concave bed for the pipe to rest in, always laying the spigot ends up grade. The pipe at the outlet should be set flush with the surface of the ground. If set higher than the surface the fall of water will wash out a depression and will in time undermine the end of the culvert. A too rapid grade will cause the same result. It is frequently well to cobble-pave the outlet, where this undermining action is likely to occur.

Excellent culvert pipe of concrete can be manufactured cheaply in any gravel pit under the immediate direction of the municipal engineer. The pipes are three or four inches in thickness according to diameter; which latter may safely and conveniently reach three feet. The implements required are of the simplest kind. The most important are two steel, spring cylinders, one to set inside the other, leaving a space between the two equal to the thickness of the finished concrete pipe. By "spring-cylinder," it may be explained, is meant such a cylinder as would be formed by rolling an iron plate into a tube without sealing the joint. With the smaller of these cylinders the edges overlap or coil slightly; but are so manufactured that the edges may be forced back and set into a perfect cylinder.

These two cylinders with joints flush, are set on end, the one centrally inside the other, and on a firm board bottom. The concrete made of first-class cement and well screened gravel, is then tamped firmly but lightly into the space or mould between the two cylinders. The tamping-iron used to press the concrete into place is so shaped as to fit closely to the cylinders. The concrete is allowed to stand in the mould for a few hours, when the cylinders are removed; the outer and larger cylinder by inserting an iron wedge into the joint, and forcing the edges apart; the inner cylinder, by inserting the wedge into the joint and turning the edges so as to allow them to again overlap, returning to the shape of a coil. The outer cylinder having thus been made larger, and the inner one smaller, they can readily be taken away, and the concrete pipe is then left until thoroughly hardened. Just such a number of pipes as are actually required for the season's work need be manufactured; the implements required are inexpensive, and the pipe may be made by the municipality for actual cost, which, after a little experience, can be reduced to a very small amount. Culverts of concrete pipe are laid in a manner similar to those of sewer pipe.

There is no departure which would more enrich the highways than the general use of stone and concrete for the construction of bridges and culverts. They cost more in the first instance, but the longer life, the fewer repairs needed, the greater convenience, the lesser liability to accident, render them in every way desirable. Concrete and stone are the only materials with which really permanent work of this nature can be constructed. Bridges and culverts of rubble masonry have existed in Scotland and Ireland with scarcely any repairs for more than a century, since before the time of Telford and Macadam. Concrete bridges and roadbeds built by the Romans nearly 2000 years ago are still in use in spite of efforts to destroy them in military operations. The cost of this class of work is constantly decreasing through the cheapening and improving of cement, through the lessened expense of procuring stone and crushing it, and through growing experience in the use of cement. In Scotland it is common for farmers to contract for rubble concrete bridges, provide the stone, and hire masons to do the work. In this way the entire expenditure is kept in the locality, among the people who pay the taxes, and is therefore, in spite of a slightly greater cost, not unpopular. Up to forty foot spans, this construction is not difficult.

In the construction of a stone arch, the first consideration is the foundation. The depth to which the excavation must be made will depend chiefly upon the span of the arch, and the nature of the natural soil on which it will rest. The chief object is that it shall be secure. If bed-rock comes to the surface it may be safe to rest the base of the arch upon it without any further excavation. A firm hardpan may exist a short distance below the surface of the ground. But a quicksand, or other insecure footing, may necessitate the sinking of piles, or the placing of a wide, and perhaps deep, concrete base. But the foundation must be sufficient to provide that the washing of water cannot undermine it, that the lateral thrust of the embankments cannot move it, nor that the weight of loads cannot cause it to sink. No more definite rule can safely be given than to make the most of local circumstances, with always a fair margin for safety. Full-centre arches, that is, entire semi-circles, are easily formed, possess great strength, and have little lateral thrust, but with wide spans, they necessarily rise to a correspondingly great height, and cannot always be employed. A segmental or flat arch will lessen the rise, but has a considerable lateral thrust which necessitates very strong abutments. A compound arch, made up of a number of different circles, when rightly proportioned, combines the advantages of the two, reducing the height, and at the same time having an excellent appearance. The thickness of the arch and abutments depends on a number of details, the chief of which are: The form and size of the arch, the quality of the material composing it, and the character of the workmanship. The haunches or shoulders should be built from the spring of the arch half way to the top.

With regard to the masonry, first-class hydraulic cement should be used. The arch stones should be full-bedded in cement, and each course afterwards thoroughly grouted. Each stone should be cleaned and dampened before being placed in the arch. Improperly dressed stones should be re-cut, as no hammering should be allowed after the stones are set. The ring-stones should be dressed into a wedge shape, so that they will radiate truly from the centre of the circle, and should be so dressed that the joints need not exceed three-eighths of an inch in width. The ring-stone should be of such thickness as to expose ten inches on the inside or face of the arch. The exterior of the arch should be flushed with a one inch coat of cement and surface then smoothed off.

Arch-culverts and bridges of cement-concrete can be more cheaply constructed than can masonry arches, and, if careful workmanship is employed, are quite as serviceable. They are formed by constructing a curbing and thoroughly ramming the concrete into it in successive layers. The manner of mixing the concrete depends on the character of the cement used, some cements being slow setting, others quick setting; some will set well in water, while others will not; some will allow a considerable proportion of water to be used in forming the mortar, while other cements should be but slightly moistened. One feature in connection with concrete culvert work is that, with the curbing and centres in place, any intelligent workman can, by following the instructions of the engineer, lay the concrete. Manufacturers complain that masons, in the great majority of cases, entirely disregard the instructions given them with respect to the mixing of cement, and follow their own methods of mixing common mortar; while a man totally unaccustomed to work of this description will obey instructions carefully and minutely. Concrete cannot be mixed and put in place like common mortar, and by overlooking this fact, much concrete work has failed, and has brought the material into disrepute in some localities.

The most substantial substructures of bridges are of either stone or concrete. In their construction sufficient excavation must at first be made to properly contain the abutment, and this earth may be refilled again so as to form approaches to the bridge. The excavation completed, when concrete is used in whole or in part, the portion thus constructed must be boxed and curbed in a substantial manner the exact size and shape