$$15{,}000 = P_L\left(\frac{8 + h}{2}\right) \text{ or } P_L = \frac{30{,}000}{h + 16}$$

$$P_D = 100h$$

$$P = \frac{30{,}000}{h + 16} + 100h = \text{total superimposed load per}$$

square foot on cover.

The beam culverts similar to those described are often used where the arch culvert might just as well be employed. The argument most often advanced by advocates of the beam culvert, as compared with the arch, is increased waterway. Other possible advantages are a simplicity of arrangement of false work and a greater ease of analysis. Taking up this last argument, while it is admitted that the reinforced beam is a comparatively simple structure and the arch a very complex one, it will be shown, nevertheless, that there is no such advantage, since an arch designed by the very same method is the stronger of the two.

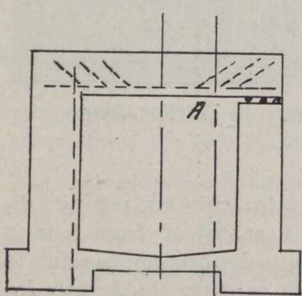

Fig 11.

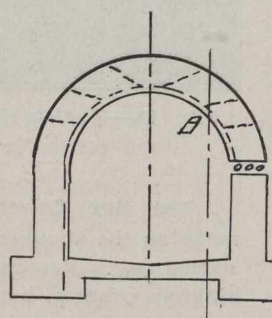

Fig. 12.

Fig. 11 shows a flat top culvert of usual design, consisting of a concrete beam, reinforced with steel tension members embedded near the lower edge, and shearing members arranged diagonally near the ends, supported on reinforced concrete abutments with the bed of the stream paved with concrete.

It is an easy matter to determine the proportions of such a beam required to carry a given load, the beam being a comparatively simple structure from a mathematical standpoint.

Fig. 12 represents an arch having the same span and height of opening and reinforced in a similar manner and with the same thickness of material at any point in the span.

A comparison of the two designs, the properly designed beam culvert of Fig. 11, and the arch culvert derived from it in Fig. 12, shows that the arch culvert is far the stronger and more efficient design, although by no means a properly designed arch.

Assume both beam and arch supported on rollers, so as to be absolutely free from all horizontal forces and unable to offer any resistance to horizontal thrusts. Now, with the same loading on the two structures, the bending moments at any given point of the span are the same for both. Thus the bending moment at A, of the beam is the sum of the moments of all forces to the right of that point. The same is true of the bending moment at the point B, of the arch, since all the forces are vertical and equal in both structures. The bending moment is balanced by the moment of resistance of the section, which is greater in the arch at every point except the crown, where it becomes equal to that at the middle of the beam. At any vertical section other than the crown, the compression is slightly greater in the arch than in the beam, but the tension and shear are less, and at no point of the arch is the compression greater than at its crown, which, like the middle of the beam, is the weakest point in the structure, neglecting shear. In shear the arch has a very decided advantage over the beam, as the section is very much increased at the region of maximum shear. We have, then, the remarkable deduction that a very badly designed arch, not even capable of resisting horizontal thrusts, is as strong as a properly designed beam, having the same section and reinforcement.

If we take both structures under practical conditions, all pressure back of the abutments tends to weaken the beam culvert, by increasing the compressive stresses in the upper fibres of the beam.

No provision can be successfully made in the beam for contraction or expansion.

In the case of the arch, all pressure back of the abutments adds to the strength of the structure, since it sets up moments counter to those produced by the vertical loads, thus tending to reduce the bending moments at the weakest sections. Every inch of upward curvature in a beam culvert increases its strength.

Design of Arch Culverts.—The variations in the design of arch culverts have considerable effect on the cost and efficiency. To combine the least cost with the greatest efficiency, the following conditions should be considered:

(1) The amount of masonry.
(2) Simplicity in the work of construction, forms, etc.
(3) The design of the wing walls.
(4) The design of the junction of the wing walls with the head walls.
(5) The safety and permanency of the structure.

These conditions are more or less antagonistic to each other, but to obtain the best results in design a proper proportion must be reached between the opposing conditions

Arch culverts differ only in size from ordinary arches except that the invert is frequently paved.

A common method of connecting the wings to the abutments is to make an angle of fifteen to thirty degrees away from the axis of the arch and to build them up with the usual batter and thickness. The angle of the wings may be determined by the natural conditions, such as rate of stream, ice conditions and material back of wings.

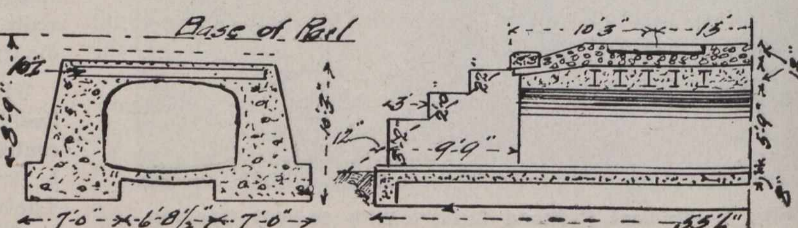

Fig. 13.—Embedded I-Beam Culvert.

To give the best entrance to the culvert for the water and ice, the wings should be carried up to the springing line of the arch flush with the inside face of the abutment and with the same batter. This leaves an entrance to the culvert perfectly smooth, and without corners in which ice or timber might block.

For small concrete arches, plain, from five to fifteen feet in span, they are generally semi-circular arches. For twenty to thirty feet, segmental arches offer some advantages; for the same length of intrados a little wider span is given, the area of the waterway is a little greater, for the same length of span there is a little less masonry. The segmental arch, on the contrary, requires ten to twenty-five per cent. greater thickness of arch ring and abutments.