DESIGN AND SPECIFICATION OF A CONCRETE BRIDGE ABUTMENT.*

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The past few years have seen a tremendous growth in the use of concrete, plain and reinforced. One has only to look at the remarkable growth of the Portland cement industry, both in the United States and Canada, to realize this fact. Cements have, of course, been known for a very long time, but within the past twenty-five years the cost of the manufacture of Portland cement has, through a great deal of scientific study, been very much reduced, and the same time the quality and uniformity of the cement have been greatly improved. These facts in a large degree account for the great increase in its consumption.

With the increase in the use of Portland cement concrete, the study of its qualities has gone hand in hand. The use of steel to overcome the inability of concrete to resist tensile stresses was a remarkable discovery. This combination of concrete and steel is made possible by the fortunate coincidence of their coefficients of expansion and contraction. It virtually gave the world a new material, steel concrete, the possibilities of which, with further study and knowledge, will certainly be very great.

In the use of every new material mistakes are bound to occur, sometimes through lack of knowledge, sometimes through carelessness or through attempts at the impossible. These failures should not discourage the use of reinforced concrete when carefully and conservatively applied by one who has sufficient knowledge of its possibilities.

One of the greatest fields for the use of reinforced concrete has, so far, been its application to railway structures, such as retaining walls, culverts, abutments, bridges, buildings, etc. It is peculiarly adapted to these purposes for the following reasons:—

1st. It is more economical than solid masonry or concrete.

2nd. It is more durable; for concrete, properly reinforced, can stand all stresses, including temperature and shrinkage stresses, without cracking; and steel, protected by concrete, is rustproof.

3rd. It is fireproof.

4th. There is practically no maintenance cost, since the concrete improves rather than deteriorates with age.

5th. It is a material in which the stresses can be accurately determined, and is in consequence of greater reliability than masonry.

6th. Its erection requires very little, if any, skilled labor, and any form of construction can be employed without shopwork, the only materials necessary being timber for forms, materials for concrete, and steel bars.

The introduction of any new material, of course, depends upon its initial cost; the more economical it is, the more general its use will become. For this reason reinforced concrete has already been used extensively by railroads in the United States, principally in the West. A knowledge of its properties is, of course, necessary, the lack of which, and a natural conservatism, makes some engineers reluctant to give it their unqualified recommendation. With the great increase in its use and the greater knowledge thus being gathered every day, it will not take very long before reinforced concrete will be everywhere recognized as a standard form of construction.

The abutment herein described was designed by the writer in order to compare it with a standard abutment of plain concrete made by the National Transcontinental Commission. The end in view was to show the greater economy of material effected by the use of concrete reinforced.

Before proceeding with the design, it will be necessary to devote a few words to the formulae employed and the assumptions made. The whole design really resolves itself into the solution of beams and cantilevers, thus making necessary the use of some theory of flexure for reinforced concrete beams. There are a great many of these theories differing from one another in several respects. The majority of these theories are what may be termed straight line formulae; for they assume a constant modulus of elasticity for concrete in compression, whereas this modulus is a variable decreasing with increasing stress. In the formulae employed in this discussion a parabola is assumed as the compression curve of concrete. There are two main groups of formulae: those attempting to represent the condition of the beam under working conditions and working stresses, and from these assumptions arriving at the safe load that any beam can carry; and those representing the beam at its ultimate carrying capacity and hence at ultimate stresses, and from these assumptions arriving at the load which will cause any beam to fail, and then by the application of a safety factor to this load, determining the safe load to which the beam may be subjected. When straight line formulae are used, that is, when it is assumed that the ratio of strain or deformation of any fibre is directly proportional to its distance from the neutral axis, and that concrete in compression has therefore a constant modulus of elasticity, the area of compression may be represented as a triangle.

Providing the assumptions were correct, it would follow then that the condition of a beam under working conditions would be represented by substituting in a formula working stresses based on the ultimate stresses allowable in the material used. In other words, the compression area at any working stress would be in the same proportion to the compression area at ultimate stress as the assumed working stress to the ultimate stress.

It has, however, been now established without doubt that the assumption of a uniform modulus of elasticity for concrete in compression is incorrect. The stress-strain curve cannot correctly be represented by a straight line. Some other curve must be assumed, and a parabola has been generally chosen as the closest approximation. It cannot be denied that with the use of straight line or empirical formulae, safe designs may be made, but it must appeal to every engineer that a formula representing conditions as clearly as possible is much more desirable. When such a formula is derived, based on the assumption of a variable modulus of elasticity, the use of working stresses in connection with it must be condemned, principally, because at present there are in existence very few data on the condition of beams under ordinary working conditions. Nearly all the stresses up to date have been to destruction, and from these the ultimate strength of beams is fairly well-known. Secondly, assuming a parabola or any other curve excepting a straight line as the cross-strain curve of concrete, the ratio of the area of the ultimate compression curve to the area of the compression curve for any working fibre stress cannot be the same as the ratio of ultimate stress. These ratios must vary as some function of the second or third power according to the equation of the curve assumed. The assumption of working stresses in a case like this will therefore naturally not give the required factor of safety, and in some cases not even be a possible condition; that is, the assumed stresses in the steel and concrete may never occur together. From the above it would seem to be far more consistent and conservative, until further knowledge on the subject has been gained, to base formulae on the ultimate strength of the concrete and the elastic limit of the steel, applying the factor of safety to the loads.

Formulae can further be divided into two groups, those basing the ultimate strength of a beam on the ultimate strength of the steel, and those basing the ultimate strength on the elastic limit of the steel. When calculations for the strength of beams were first made, it was naturally assumed that the working stress allowable in the steel was some factor of its ultimate strength. Closer inspection and study of tests made this very doubtful. It is readily seen that, when steel is strained beyond the elastic limit, the bond between concrete and steel is destroyed, due to the reduction of the cross-section of the steel. If the bond is one of adhesion

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