ON THE THEORY AND CALCULATION OF CONTINUOUS BRIDGES

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PREFACE.

The following pages are divided into three chapters. The first presents by way of introduction some of the elementary principles of continuous girders, and the fundamental ideas relating to the calculation of strains. The second gives the theory of flexure as applied to the continuous truss of constant cross section, and exhibits it in formulæ (I) to (VI), ready for application to any particular case; and the third gives an example of the computation of strains in a continuous truss of five unequal spans, with some useful hints concerning the practical building of such bridges.

The theory of flexure indicates that, by the use of continuous instead of single span bridges, a saving in material of from twenty to forty per cent. may be effected. It is easy indeed to say that this advantage will be entirely swallowed up by the effect of changes of temperature, increased labor of erection, or additional cost of workmanship, but by no amount of reasoning can such disadvantages be estimated. Theory indicates a large saving, whether or not it can be realized. may only be determined by trial. Other nations have built and are building continuous bridges, and their experience has not yet shown that the system is inferior to that of single spans. The interest now prevailing among American engineers in the subject, and the fact that at some recent bridge lettings plans have been offered for a continuous structure, seem to indicate that the system will also be tried here.

This little book may then perhaps be of value to bridge engineers, as well as to students in general.

M. M.

New Haven, Conn., July 19, 1876.

THEORY AND CALCULATION

OF

CONTINUOUS BRIDGES.

When a straight bridge consists of several spans, each entirely independent of the others, it is said to be composed of *simple girders*. If, on the other hand, it consists of a single truss extending from one abutment to the other without any disconnection of parts over the piers it is called a *continuous girder*. A load placed upon any span of a continuous beam influences, to some extent, each of the other spans, and hence its complete theory is much more complex than that of the simple one. This very complexity however has rendered the subject an attractive one to mathematicians, who, pursuing science for science's sake, have investigated the laws of equilibrium which govern it. These laws with the many beautiful consequences attending them form one of the most interesting chapters of mathematical analysis, and as such have interest and value independent of their application in engineering art.

It is the object of the present paper to present in as simple a form as possible some of the main principles and laws most needed by the engineer, and to illustrate their application as fully as space will permit to the practical designing of continuous bridges.

CHAPTER 1.

The first point to be observed in considering either a simple or continuous girder is that all the exterior forces which act upon it are in equilibrium. The exterior forces embrace the weight of the girder and the loads upon it which act downward, and the pressures or reactions of the supports which act upward. In order that these may be in equilibrium, it is necessary that *the sum of the reactions of all the supports must be equal to the total weight of the girder and its load.*

Thus, if a simple girder of uniform section and weight rest at its ends upon two supports, the reaction of each support will be one-half the weight. Exactly in the center between the two supports or abutments, let us suppose a pier to be placed just touching, but not pressing against the beam, which, at that point, has a deflection below a straight line joining the two abutments. Then the condition of things is in no way altered, for the weight being W, each abutment reacts with a force $\frac{1}{2}$ W, while the pier bears no load. Raise now the pier so as to lift the girder above the line of deflection and it receives a part of the weight W, while the reactions of the abutments become less than $\frac{1}{2}$ W. If the pier be raised higher and higher, it will at length lift the girder entirely from the abutments and bear itself the whole load W. In every position, however, the sum of the reactions of the three supports is equal to the total load. For example, when the three are on the same level it may be shown that the reaction of each abutment is $\frac{3}{16}$ W, and that of the pier $\frac{10}{16}$ W.

This illustration shows also that *small differences of level in the supports occurring after the erection of a bridge cause large variations in the reactions of its supports and in the strains in its several parts.* A simple girder having a deflection of one inch, would, if raised one and three-fifth inches at the center, be entirely lifted from the abutments. In the first case the upper fiber would be in compression, the lower in tension; in the second case, the upper would be in tension, the lower in compression. If the center were raised only one inch, the reversal would be only partial, the upper fiber becoming subject to tension for a short distance on each side of the middle. This fact often used as an argument against continuous bridges, is really an objection only when the piers are liable to settle after erection. Differences of level, previously existing, do not act prejudicial when the bridge is built upon the piers, and with a profile corresponding to them.

The mathematical theory of the continuous girder enables its reactions and internal strains to be found for any assumed levels of the supports, provided only that the differences of level are very small compared with the length of the spans. However interesting such investigations may be in themselves, they are of little importance in practice, since it has been shown that when all the points of support are on the same level, the greatest economy of material results.* In all that follows, then, we shall regard the girder as resting on level supports, or, what is the same thing, that it was built with a profile corresponding to that of the piers.

The loads upon a bridge and the reac-

* Weyrauch; *Theorie der continuirlichen Träger*, p. 129. Winkler; *Lehre der Elasticität*, p. 155.