SUSPENSION BRIDGES AND CANTILEVERS, THEIR ECONOMIC PROPORTIONS AND LIMITING SPANS

Published @ 2017 Trieste Publishing Pty Ltd

ISBN 9780649716685

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Edited by Trieste Publishing Pty Ltd.
Cover @ 2017

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Trieste

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Submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy, in the Faculty of Pure Science, Columbia University.

BY

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NEW YORK
D. VAN NOSTRAND COMPANY,
23 MURRAY AND 27 WARREN STREETS,
1911.

SUSPENSION BRIDGES AND CANTILEVERS

CHAPTER I

INTRODUCTION

Art. 1

Statement of Problem and Proposed Method of Investigation

Each type of bridge construction has some limiting span-length which it cannot, physically, exceed. This *maximum span* may be defined as the length at which the ratio of the intrinsic weight to the applied weight becomes infinite. In other words, it is the length at which the structure cannot carry any load in excess of its own weight; any attempt to increase the load resulting in members of infinite cross-section. Under the stress of necessity, the span of any type of bridge may be pushed as close as may be desired to the maximum span-length; but this can be done only at a very great sacrifice of economy, as the cost of the structure increases very rapidly when the span approaches the limiting value. The length of the maximum span for any form of bridge may be determined with sufficient definiteness from theoretical considerations applied to the data of actual designs; but it must be borne in mind that the results of such determination are subject to expansive revision when the methods of design or the materials of construction undergo improvement.

In addition to a maximum span-length, each bridge type has an *economic range of spans*, within which it will be less costly than any other form of construction. If, for any two comparable types of structure, a *span of* *equal cost* be determined, that span will be the inferior economic limit for one of the bridge-types and the superior economic limit for the other.

The term *economic span* will be used to designate the span at which the cost of a bridge would exceed the capitalized value of its usefulness to the builders. Although this is a problem of great practical significance, it does not lend itself to accurate treatment in any general manner owing to the large possible variations in local conditions, such as the magnitude and financial importance of the traffic expected, the cost of real estate for land spans and approaches, and the difficulty encountered in locating suitable foundations. The results of a general determination of the economic span, as here defined, will therefore be of doubtful practical value except for purposes of illustration or comparison.

The maximum and economic span-lengths for bridges of ordinary span have been fixed pretty definitely by the results of numerous designs and comparative estimates. We may take our values of these limiting lengths from the consensus of opinion among engineers as evidenced by their uniformity of practice. Thus the ordinary truss bridge finds its range of usefulness between the limiting spans of about 120 and 550 ft., there being but three truss spans exceeding the latter value. Below this range, the steel girder or concrete arch is more economical; above these limits the steel arch enters into competition. The latter construction, in turn, ceases to be economical at about 800 ft., although the proposed Hell Gate Arch is to have a span of 978 ft.

For longer spans, the selection of a bridge structure narrows down to a choice between the *suspension bridge* and the *cantilever*. The relative economy of these two forms of construction has long been a mooted question. It is true that the longest span in existence, viz., the Forth Bridge, is of the cantilever type, but it is a question whether the selection of this type was not a mistake. "It is not a design which would ever be imitated. Its proportions are very injudiciously taken, and there is a failure to reach the degree of economy which ought to exist even in the cantilever."[1]

In the preliminary investigations for the Quebec Bridge, the Phoenix Bridge Company made comparative estimates of a cantilever and a suspension bridge for the 1800-ft. span. "Although the cantilever type exhibited the more economic results of the two as the members were then computed, at the present time the economy of the adopted type is not so clear as it was originally thought to be."[2] The collapse of that ill-fated structure, and the investigations following the completion of the Queensboro Bridge have shaken

[1] W. H. Burr, Proceedings of the Engineers' Club of Philadelphia, December, 1899.

[2] Editorial in *Engineering Record*, Sept. 5, 1908.

the general confidence in the cantilever type of construction and have directed the attention of engineers to the more adequate design of compression members in such structures. When these members are designed in accordance with the recent disclosures, it is a question whether the previously accepted economic limit for cantilevers, viz., about 2000 ft., will not have to be considerably reduced.

The limiting *economic span* for cantilevers is placed by Prof. Burr [1] at 2000 ft. for railway bridges and at 1400–1600 ft. for highway bridges; by Prof. Merriman [2] at 1500 ft.; and by Prof. Melan [3] at 500 meters. Gustav Lindenthal [4] (M. Am. Soc. C.E.) would

[1] Proceedings of Engineers' Club of Philadelphia, December, 1899. *Ancient and Modern Engineering* (New York, 1903), p. 177.

[2] *Roofs and Bridges* (New York, 1905), Part IV, pp. 110, 155.

[3] *Handbuch der Ingenieur-Wissenschaften* (Leipzig, 1906). II. Band, V. Abteilung, s. 206.

[4] *Engineering* (London), December 19, 1890 also Proceedings Am. Soc. C. E., Sept. 21, 1904.