Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 3 (1948)

Artikel: Developments in long-span steel bridges

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DOI: https://doi.org/10.5169/seals-4028

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Ponts métalliques à grande portée

Weitgespannte Stahlbrücken

Developments in long-span steel bridges

Rapport général – Generalreferat – General Report

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Long span bridges may be distinguished technically from the more common ones of lesser span because they call for considerations in their design not covered by conventional specifications. Broadly speaking they belong to the category of unusual structures or structures which in certain respects surpass precedence and involve new or rare proportions. Span length alone in that respect, although a major factor, is not the only criterion. Unusual traffic capacity, great height, extraordinary foundation or erection problems may be important factors which justify the classification of a bridge as unusual and call for original thought and the solution of new problems.

Moreover, span length is a relative term, both chronologically and geographically. What is considered a long span today may become common in a lifetime hence. What may be regarded as an unusually large structure in one country, may have passed into the ordinary class in another. These circumstances therefore must be kept in mind in classifying a bridge as unusual in proportions or character.

The most outstanding motive in the conception of a bridge of unusual proportions is and must be economy in design, construction and operating performance, because at the time of its promotion a structure surpassing precedents has yet to prove the justification of the large expenditures involved. Such economy cannot be assured by merely applying forms of design and specifications which have been found satisfactory and are accepted for ordinary structures. The conception of design for an unusual bridge must be free from the fetters of conventional practice.

The selection of the type of structure, the materials to be used, the evaluation of the forces and their combinations, the adoption of permissible stresses, the stress calculations, the design of structural details and the methods of construction require original study and research which may lead to material, possibly radical, departure from design standards accepted for ordinary structures. The designer may even have to venture the solution of certain problems not yet fully explored by either research or practical experience. In thus exercising greater liberty in the use of his judgement the designer must, however, be aware that this places upon his shoulders heavier responsibilities than when he can be guided by conventional rules of design.

The selection of the proper type presents one of the most important problems to the designer of a long span bridge. In that respect the underlying conditions and conceptions have undergone a material change in the past fifty years. Structural and functional simplicity and clarity have come to be recognized as an essential principle in long span bridge design, because they are consistent with both greatest economy and sound aesthetic conception. They are unquestionably responsible for recent developments which have clearly led to the domination of the field of long spans by the arch and the suspension bridge, the latter almost exclusively for spans in excess of 1 500 or 2 000 feet. The more bulky and complex types, such as the cantilever truss and various hybrid forms, such as combinations of cantilever or arch with the suspension system, as variously proposed in the past, have not been successful of application for long spans.

Opinions have in the past prevailed that because of their large horizontal reactions the arch and the suspension bridge are not well suited except at location where rock or other firm foundations are available. In the present advanced state of soil mechanics and more reliable methods and theories for the determination of permissible soil pressures to assure the necessary stability foundations for arches and suspension bridges may be designed with the same degree of safety as for types producing predominently vertical reactions.

The tendency toward utmost simplicity of structural form and arrangement is also indicated by the increased use of the solid-web rib or the shallow parallel chord truss without spandrel bracing in the case of arch bridges and by the now prevailing suspension system consisting of the plain cables or chains which pass over slender flexible towers and are stiffened by a parallel chord girder along the floor. Systems such as braced cables or suspended trusses which have found wide application for short spans have not proven meritorious for long spans.

The development of high strength materials is of prime importance in the economical design of long span bridges. In fact it is due largely to the great improvements in the quality of steels that it has been possible to extend economically the range of long spans. That advance is most vividly exemplified by the fact that the strength of cable wire has been more than trebled in the past 100 years. A century ago spans of the magnitude of 3 000 or 4 000 feet would have been impossible, not only economically, but physically. Whether the near future will bring further improvements in the strength of steels commercially applicable to bridges is yet uncertain, but it may be expected that the present limits will eventually be raised further.

There are indications, however, that there will be distinct possibilities for economy in the design of long span bridges through reduction in the weight of the floor structure. Light-weight types of highway decks have already found extensive application, but their possibilities for very long spans have not been exhaustively explored. The use of light-weight metals, especially aluminum alloys, also looms as a possibility with decreasing cost of commercial production of these metals compared to steel and deserves careful investigation. In view of the advanced state of welding in steel structures and the saving in weight which can be effected by its use, that type of connection may also offer advantages, at least in the floor construction of long spans.

The determination of loads and forces acting on the structure in conjunction with the limitations of the working stresses to secure adequate safety without waste of materials deserves special consideration in the design of bridges of unusual size. The loads and unit stresses generally specified for common bridges prove wasteful in long spans. In connection with the latter the designer must be influenced by the probability of occurrence of extreme forces, and combinations of such forces, since in long spans they are more remote than in ordinary bridges. The adoption of relatively lower forces or higher unit stresses, or both, are therefore well justified in the design of long spans.

Distinction in that respect must also be made between members on which the safety of the structure depends and those whose failure would not necessarily endanger the structure. Thus, for instance, the lateral system of a long span suspension bridge may properly be designed with relatively high unit stresses, the more so since experience has amply demonstrated that the sustained static windforce actually acting on such bridges remains well within the usually assumed maximum pressure.

The same applies to the stiffening trusses of long span suspension bridges with respect to the live load. In this respect the idea which prevailed in the early part of this century that suspension bridges must be designed for live loads as « rigid » systems has been found erroneous and wasteful for long and heavy spans. Through the adoption of the flexible system, combined with the application of the « deflection theory » in place of the « elastic theory », very important economies have been effected in the design of long span suspension bridges. Experience has demonstrated that these « flexible » bridges possess ample rigidity under highway traffic and modern electric traction.

The failure of the Tacoma Narrows Bridge in 1940 and oscillations observed under wind action on a number of other modern suspension bridges have, however, drastically forced attention to the necessity of proportioning such bridges adequately against the development of such dynamic movements. For an entirely adequate solution, particularly for very long spans, this problem calls for further extensive research, but it is possible, on the basis of present knowledge and available empirical data to derive design criteria which assure ample resistance against oscillations with reasonable economy.

With the endeavor to utilize the materials in long span bridges to utmost economy by stretching load assumptions and unit stresses there must, however, be coupled maximum efficiency of the structural make-up of members and details. These are often of unusual design and proportions in large bridges and must receive most thorough study with respect to both primary and secondary stresses. That the strength of an otherwise well designed structure may be reduced to a fraction by a weak structural detail was drastically revealed in the failure of the great cantilever bridge across the St. Lawrence River near Quebec in 1908.

The stress analysis in large bridges deserves to be carried to unusual refinement in order to eliminate uncertain stresses to a minimum. It is gratifying that in the past twenty five years great strides have been made in the development and refinement of stress theories. One of the most fertile fields in this respect has been the development of refined methods of calculating the stresses in stiffened suspension bridges. The papers submitted to the Liege Congress by S. O. Asplund and M. Courbon are valuable contributions to these theories.

One of the developments of recent years which has greatly aided the clarification of stress action in large and unusual structures is the growing practice of testing the stress conditions by means of models of parts, or whole, structures. Largely because such tests are expensive and time consuming this practice has not been carried to the desirable extent, but it is to be hoped that the construction of every bridge of unusual proportions will offer opportunity for further research of this kind.

The method of construction is a most important phase which calls for careful study in the design stage of a large bridge since it may affect materially the economy of the design. Certain methods of erection, as for instance the use of elaborate temporary falsework structures may become prohibitively expensive in long spans and must give way to methods which avoid falsework altogether, or reduce its use to a minimum. The paper submitted to the Liege Congress by A. Roggeveen illustrates interesting examples of the careful study given to the erection method for tied arches in order to accomplish proper stress action with the least amount of temporary structures.

The field of long span bridges has yet possibilities of wide extension. Spans of 5 000 ft and more are today not only entirely practicable, but with increasing economy in their design opportunities for their construction are bound to expand. Every such expansion will present to the profession new problems demanding intensified study and research and not in the least application of original thought in the conception and development of the design.

Résumé

La considération principale dans la conception, la construction et la mise en œuvre des ponts de grande portée ou présentant d'autres caractéristiques spéciales, doit être celle de l'économie. Ceci exige de la part du constructeur des considérations, des recherches et des essais souvent inusités et même nouveaux.

La question du choix d'un type est aujourd'hui résolue du fait que seules des constructions simples et claires, telles que les ponts arqués et les ponts suspendus, sont à même de s'imposer dans la construction actuelle. Si la qualité améliorée de l'acier a rendu possible la construction d'œuvres puissantes, ce développement résulte d'une réduction dans

le poids par l'emploi d'alliages légers ou de la soudure. Les efforts énormes qui apparaissent exigent des conceptions particulières concernant les tensions admissibles et la sécurité des divers éléments de construction. La conséquence en est l'introduction de la théorie des « changements de forme » en remplacement de la théorie « de l'élasticité ». Le problème de l'oscillation sous l'influence du vent exige de nouvelles recherches, pour lesquelles nous possédons aujourd'hui des données utiles. L'économie doit également être obtenue par le procédé de montage.

En projetant des ponts à grande portée, il est essentiel de prévoir la répartition des efforts d'une manière plus détaillée. Des améliorations constantes dans les méthodes de calcul, ainsi que des essais sur modèles, nous aideront à atteindre le but recherché.

Zusammenfassung

Der Leitgedanke beim Entwurf, Bau und Betrieb einer hinsichtlich ihrer Spannweite oder anderer Merkmale aussergewöhnlichen Brücke muss die Forderung der Wirtschaftlichkeit sein. Diese verlangt vom Erbauer ungewohnte und oft neuartige Ueberlegungen, Forschungen und Versuche.

Die Frage der Systemswahl ist heute soweit entschieden als sich nur einfache und klare Bauformen wie Bogen- und Hängebrücken durchsetzen können. Hat die Verbesserung der Stahlqualität die neuesten grossen Bauten erst ermöglicht, so deutet die Entwicklung auf Gewichtseinsparungen durch Leichtmetall- oder geschweisste Konstruktionen hin. Die auftretenden ungewöhnlichen Kräfte rufen besonderen Bestimmungen über die zulässigen Beanspruchungen und Sicherheiten der verschiedenen Bauteile und haben bei Hängebrücken die Einführung der « Formänderungstheorie » an Stelle der « Elastizitätstheorie » zur Folge gehabt. Weiteres Studium verlangt das Problem der Schwingungen unter Windeinfluss, über das heute schon brauchbare Entwurfsunterlagen vorliegen. Auch durch Verbesserung der Montageverfahren kann die Wirtschaftlichkeit gehoben werden.

Beim Entwurf weitgespannter Brücken muss das Kräftespiel möglichst lückenlos und verfeinert erfasst werden. Ständige Verbesserungen der Berechnungsverfahren und neuestens auch Modellversuche helfen uns, dieses Ziel zu erreichen.

Summary

The chief consideration in the designing, construction and use of bridges that are unusual owing to their span or other characteristics must be that of economy. This requires of the builder unusual and often new deliberation, research and tests.

The question of selecting a system is solved for the present, inasfar as only simple and clear styles of construction are involved, such as arches and suspension bridges. If improved quality of steel has made modern large structures possible, the development points to saving of weight by using light alloys or welded structures. The unusual forces that are becoming apparent call for special definitions as regards admissible claims and safety of the various components. The consequence of this has been, in the design of suspension bridges, the introduction of the « deflection theory »,

in place of the « elastic theory ». Further study is also required for the problem of oscillation caused by wind, for which we have today serviceable data for designing. Economy can also be improved by better erection methods.

When designing large span bridges the play of forces must be improved and no omissions allowed. Constant improvement in the methods of calculating, and more recently tests on models, will help us to achieve this aim.