Optimization of the prestressing in the cables of a cable-stayed bridge

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Optimization of the Prestressing in the Cables of a Cable-Stayed Bridge

Optimisation de la précontrainte dans les câbles d'un pont à haubans

Optimierung der Vorspannung in den Kabeln einer Schrägseilbrücke

DIETHELM FEDER
Dr.-Ing.
M.A.N.
Gustavsburg, GFR

1. Reasons for prestressing

It is well known that the cables of a cable-stayed bridge have to be prestressed in order to utilize the high strength of the cables and to reduce the bending moments in the main girder.

The degree of prestressing required depends on the structural system of the bridge, the relative stiffness of the cables and the girder, and the ratio of live load to dead load. Finding the most economic relation between the longitudinal stiffness of the cables and the bending stiffness of the main girder is a complicated optimization problem in itself.

Here, only a short description is given of how prestress in the cables was optimized for a given structural system. The aim was to get a uniform distribution of moments in the main girder without overloading the cables.

2. The Deggenau cable-stayed bridge

The bridge in question carries a motorway across the Danube in Eastern Bavaria and has two spans of unequal length, i.e. 290 m and 145 m (Fig. 1). It has one central tower and the large opening is back-stayed by three cables to the small opening and mainly to the eastern abutment. The main girder has a two cell box-section of 14 x 4.5 m with cantilevering deck supported by struts.

The cables are composed of spiral strands arranged in three layers in a rectangular pattern (Fig. 2), for more details about this bridge see [1].

3. Optimality conditions

In static analysis the bridge was treated as a space frame in linear elastic theory with the aid of a standard computer program.

The loading case "end displacement" of a certain cable then delivers a complete set of influence coefficients reflecting the effect of prestressing. Thus, from the loading cases "end displacement" of all the cables one can easily obtain the coefficients for the value of any internal force or moment due to prestressing:

$$S_i = \sum_k a_{ik} X_k$$

with S_i = internal force or moment
a_{ik} = influence coefficient
X_k = prestressing (end displacement of cable k)

The optimality criteria to be considered were the following (see also Fig. 3):

a) The tensions in the cables were not to exceed the maximum allowable values and should not become negative.

b) The moments in the main girder were not to exceed the strength of the girder required for cantilever erection.

c) The moments at the tower base were to be kept to a minimum.

With 6 different cables, 6 positive and 5 negative limit moments for the main girder, and two limit moments for the tower base this gives a set of 25 inequality conditions for the 6 unknown cable end displacements.

4. Practical solution

Assuming that the system would behave inherently reasonable, the number of inequalities was reduced to 19 by dropping the condition that cable tensions should not become negative.

A further reduction was possible due to the fact that positive bending moments in the girder between cable points were not critical.

It was then tried to solve the remaining set of 13 inequalities by means of a standard computer program for linear programming. As it turned out this program failed to give a reasonable solution because, being geared to economic problems only, it could not handle negative values on the right hand side. Merely changing signs all through the equations concerned did not help.

Since there was neither time nor a specialist available to overcome these difficulties, the number of variables and restrictions was further reduced by engineering judgement. The remaining set of 10 inequalities with 5 unknowns was handled as overdetermined system of linear equations by a computer program producing a least squares solution. This approach gave surprisingly satisfactory results for all the values that were to be optimized.

References

[1] Feder, D.: Donaubrücke Deggenau, Strasse Brücke Tunnel 5 (1975), S. 114/17

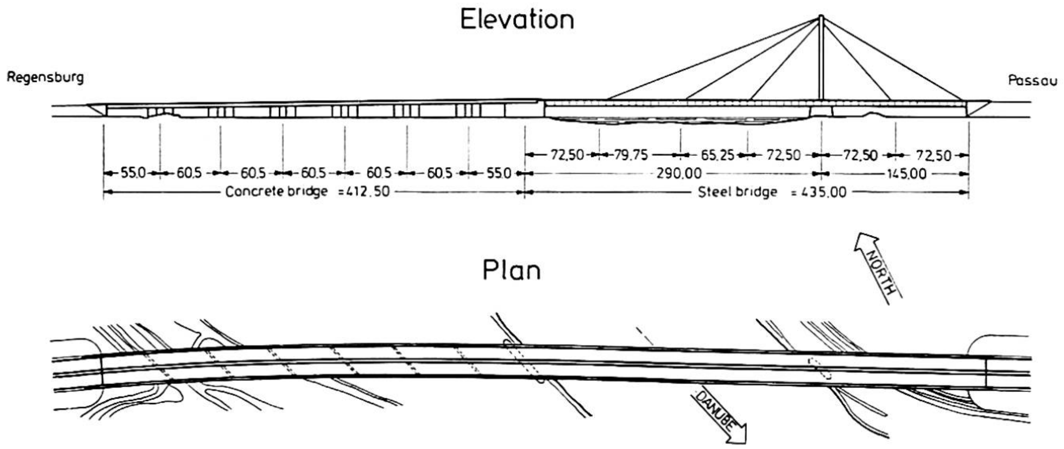

Fig. 1: Deggenau cable-stayed bridge

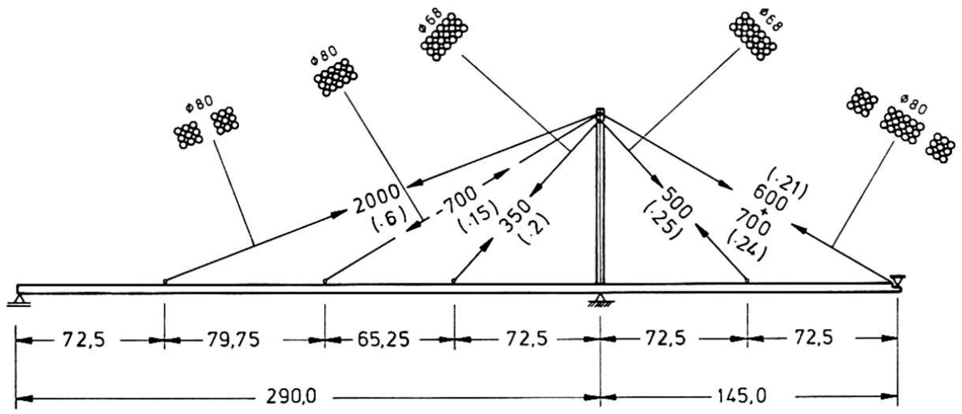

Fig. 2: Cable sections and prestressing:
prestress [kN], (cable end displacements [m])

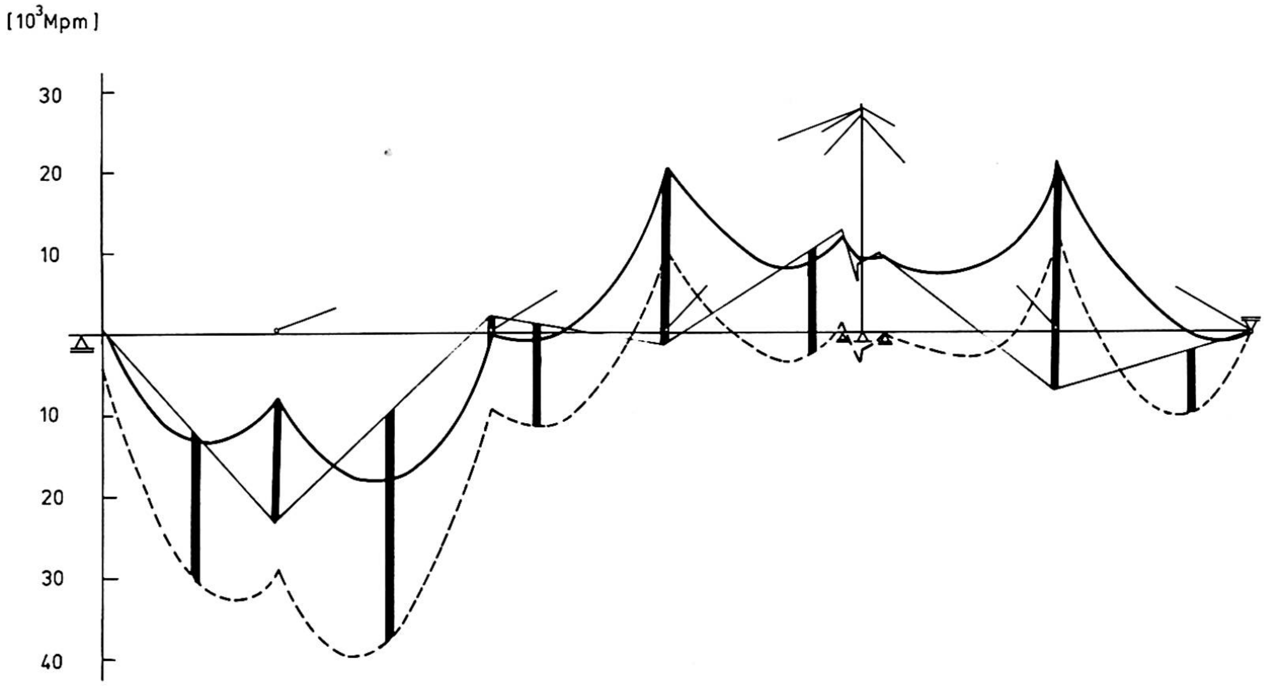

Fig. 3: Optimality criteria and moment distribution
in main girder

SUMMARY

The paper deals with an optimization that has been used in the design of a cable-stayed bridge. The optimality criteria are briefly discussed, difficulties encountered are described, and the engineering approach applied for the solution is outlined.

RESUME

L'article traite de l'optimisation retenue pour le calcul d'un pont à haubans. Les critères d'optimisation sont discutés, les difficultées rencontrées sont décrites, et la méthode d'ingénieur employée est présentée.

ZUSAMMENFASSUNG

Der Beitrag befasst sich mit einer Optimierung, die bei der Berechnung einer Schrägseilbrücke benutzt wurde. Es werden kurz die Optimalitätskriterien diskutiert, aufgetretene Schwierigkeiten werden beschrieben, und das für die Lösung angewendete ingenieurmässige Vorgehen wird umrissen.