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Autor: Dilger, Walter H. / Tadros, Gamil S. / Sherif, Alaa

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Design and Construction of a Multispan Cable-Stayed Bridge

Projet et construction d'un pont haubané à travées multiples

Entwurf und Erstellung einer mehrfeldrigen Schrägseilbrücke

Walter H. DILGER
Professor
Univ. of Calgary
Calgary, AB, Canada

Dipl. Ing 1959, Dr. Ing 1965, both from Technical University Stuttgart. Joined U of C in 1966. Teaches structural design. Special consultant for bridges and other structures. Member SCI consortium.

Gamil S. TADROS
Civil Engineer
Speco Eng. Ltd
Calgary, AB, Canada

Speco Engineering B.Sc. 1963, Cairo University. Ph.D. 1971 U of C. Specialist in structural design. Member SCI consortium.

Alaa SHERIF
Graduate Student
Univ. of Calgary
Calgary, AB, Canada

The University of Calgary. B.Sc. 1987 Cairo University. Structural engineer 1987–89.

SUMMARY
The method of construction proposed for a multiple span cable-stayed bridge with a slender prestressed concrete deck is described. Since the 250 m long deck is poured in one operation on a steel truss the analysis of the construction stages is relatively simple and the deformation of the truss during construction has only a small effect on the final forces.

RESUME
L'article décrit la methode de construction proposée pour un pont haubané à travées multiples avec un tablier mince en béton précontraint. Le tablier de 250 m de longueur est coulé en une opération sur une poutre à treillis en acier; l'analyse des étapes de construction est simple et les déformations du treillis pendant la construction ont un effet négligeable sur les sollicitations résultantes.

ZUSAMMENFASSUNG
Die Baumethode für eine mehrfeldrige Schrägseilbrücke mit schlanker Fahrbahnplatte wird beschrieben. Da die 250 m lange Fahrbahnplatte in einem Guss auf einem Stahlfachwerkträger hergestellt wird, sind die Beanspruchungen die durch die Durchbiegung des Stahlträgers erzeugt werden, relativ gering.

1. INTRODUCTION

A fixed link across Northumberland Strait between New Brunswick and Prince Edward Island has been a dream project for Canadian Engineers for more than a century. In the late sixties this project was in the final planning stages when it was cancelled in favour of a 15 year regional development plan. In the late eighties the project was revived and at present time three consortia are competing for the contract to build the bridge, among them the SCI consortium. The final decision regarding this project is expected in 1991 after a two year period to conduct an environmental assessment review of the project.

This paper describes one of the two options developed by the SCI group for the fixed link with special emphasis on the interaction between method of construction and design.

2. DESCRIPTION OF THE PROJECT

2.1 Location

The total length of the proposed bridge is approximately 13 km and it will cross the Strait at its narrowest point. The bridge will connect Port Borden, the present ferry terminal on Prince Edward Island, with Cape Tormentine on the New Brunswick side. The maximum water depth is only about 30 m and the average depth is 20 m. The soil investigations indicate that sedimentary rock (sandstone, mudstone, siltstone) is overlain by glacial till which is up to 9.5 m thick.

2.2 Environmental Conditions

The environmental conditions are rather harsh and ice normally covers the Strait from mid-December till mid-April. The ice force on a cylindrical pier is about 2.0 MN per metre width. The 10 and 100 year wind speeds at 10m above the water are 126 and 161 km/h, respectively. The corresponding wave heights are 3.7 and 4.7 m and the maximum current velocity is 2.0 m/s.

2.3 Geometry

According to the Proposal Call Information the minimum span length is 150 m with a navigational channel of 200 m near the middle of the Strait. The minimum clearance is 28 m except over the navigation channel where it is 49 m. The structure discussed in this this paper is a multispan cable-stayed bridge with 250 long spans and a deck width between curbs of 11.00 m. Closely spaced cables are arranged in the fan configuration and supported by a pair of diamond-shaped towers with a tie beam at the deck level (Fig. 1). This tower configuration was chosen to provide the stiffness required for unbalanced live loads. The A-type tower configuration above the deck minimizes the size of the tower legs since they are primarily subjected to axial compression. The open diamond configuration rather than wide wall-like tower was selected in order to reduce

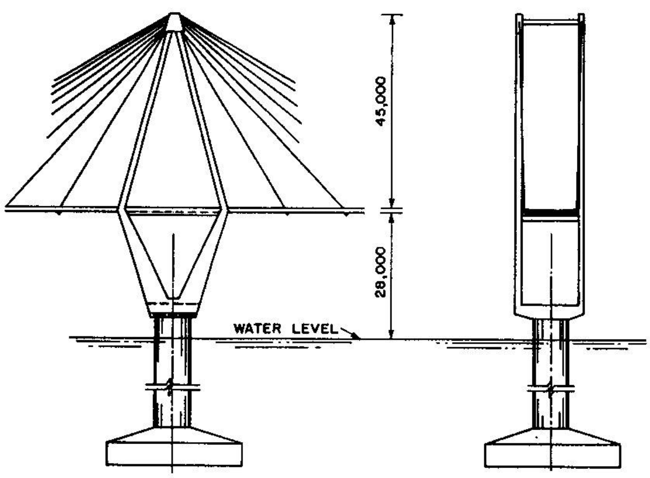

Fig.1 Tower configuration

the hazard to traffic produced by the difference in lateral wind pressure between two wide parallel walls. Also, the diamond shaped configuration is very appealing from an aesthetic point of view. The lower legs are subjected to large moments under unbalanced live loads so that their dimensions have to be increased from 2 m at the deck level to 5 m at the pier table. The pier table is located as low as possible so as to generate a large open space between deck, towers and pier table. This space is used to accommodate the large steel truss for the construction of the concrete deck.

3. CONSTRUCTION

3.1 General

Conventional construction methods such as precast or cast-in-place segmental construction are not suitable for such a project, because they would either take excessively long to construct such a long bridge, or they would require extensive, costly equipment together with many experienced erection crews, both of which are not available. As a result new techniques had to be developed. Among the various options considered was the construction of a full cable-stayed span in a dry dock on shore and towing it to the site. However, the method discussed in this paper is a cast-in-place concrete deck on a steel truss extending over two spans. The truss which has a depth of 20 m, a width of 12 m and a total length of about 520 m weights approximately 3300 t and fits between the space provided below the bridge deck. The truss is launched by means of hydraulic jacks. To support the free ends of the cantilevers during launching, flotation tanks are lowered from the inside of the truss and submerged in the water to produce a constant uplift force of about 3 MN. Because of the more than 40 identical spans this construction method is very economical. Time of construction of one span is 4 to 5 weeks.

3.2 Detailed Description of the Method of Construction

The following steps describe the construction procedure.

(1) Lowering of the truss and submerging of flotation tanks from inside of truss (Fig. 2, Stage 1).

(2) Launching of truss by means of hydraulic jacks (Fig. 2, Stage 2).

(3) Withdrawal of flotation tanks, followed by some additional launching and lifting of truss till deck form is 300 to 500 mm above final position of deck soffit. Note the step in top chord at point (a) to accommodate the already finished span.

(4) In elevated deck position, rebars and prestressing tendons are placed and simultaneously the stay-cables are installed by temporarily anchoring them to the top chord of the truss. The cable drums are lowered into the truss at point (a), Fig. 2. Stage 3 and moved on trolleys to the anchor locations. The cables close to the tower will be slack at this time because of the elevated deck position.

(5) Pouring of the concrete deck (1800 m^3) in one continuous pour.

(6) After the concrete has reached sufficient strength the temporary anchors are released thus transferring the cable forces to the concrete deck. Subsequently, the truss is lowered until the deck is freely suspended from the cables. At this stage all the cables have reached their desired forces. Cable force adjustment can be made if necessary. The truss is lowered sufficiently to leave enough clearance below the deck for launching.

(7) While the deck is being produced the precast segments for the new tower are erected.

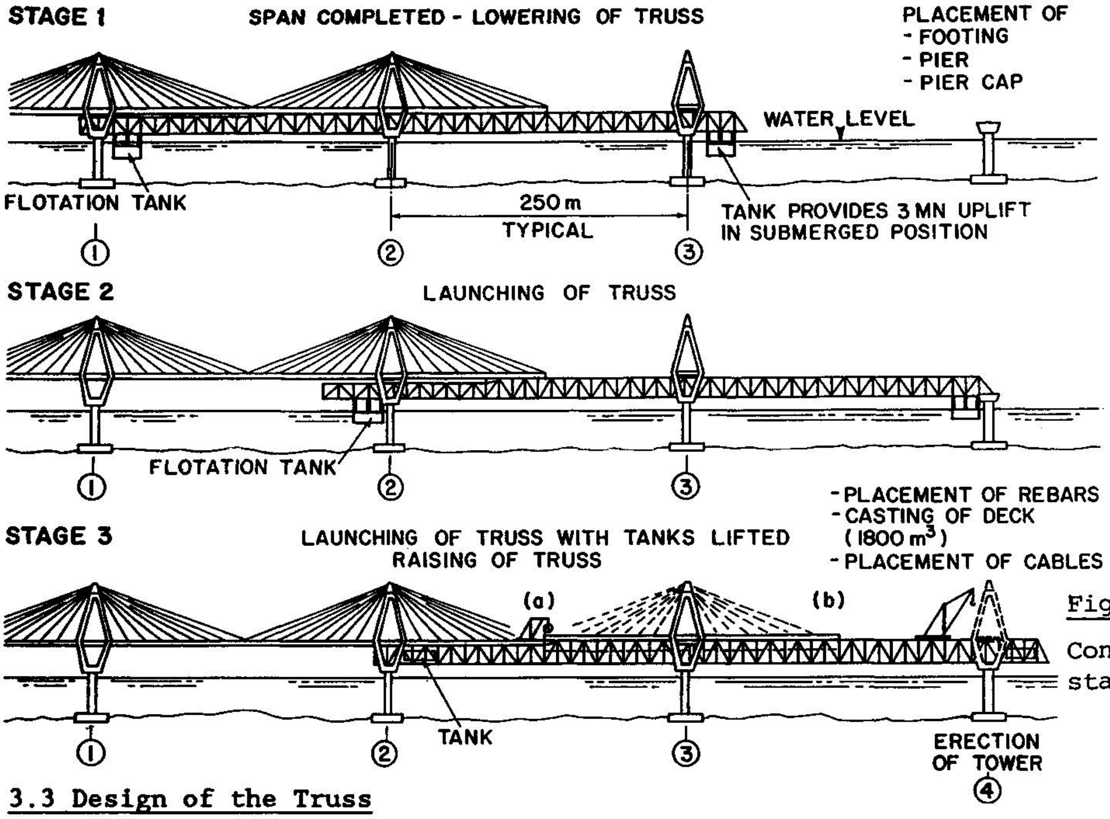

Fig.2 Construction stages

3.3 Design of the Truss

The truss is designed to resist the maximum forces generated during construction, including wind and current forces during launching, assuming the deck to be produced 500 mm above its final level. The maximum forces are due to its own weight plus a portion of the weight of the deck. The temporary anchorage and stressing of the stay-cables to the top chord of the truss greatly assist the truss in carrying the weight of the concrete. The level of the deck forms during construction above the final position of the deck soffit depends on the force that can be anchored economically to the top chord of the truss.

The location of the truss posts and diagonals is governed by the location of the cable anchors as the cables should be anchored at the joints. The joint spacing, in turn, governs the length of the pier table since during launching the bottom chord can only be supported at the joints as shown in Fig. 3.

4. INTERACTION BETWEEN DESIGN AND CONSTRUCTION

4.1 General Comments

In order to achieve a level deck for the completed bridge all the deformations during the various stages of construction, as well as the time-dependent effects have to be considered. In the present paper the following deformations developing during construction are discussed.

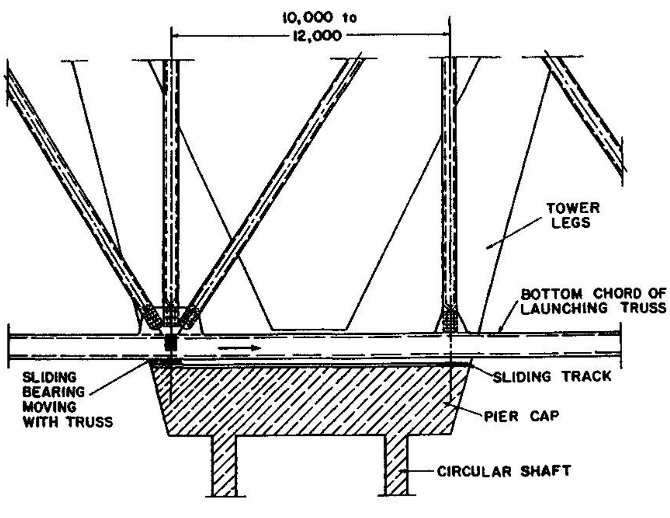

Fig.3 Truss moving on pier table

Time-dependent effects and the effect of the heat of hydration are not considered here.

- Deflection of truss due to self weight
- Deflection of truss due to temporary cable forces
- Deflection of truss due to weight of concrete
- Deflection of deck after lowering it into its final position.

Two different elevated positions for the production of the deck are investigated:

(1) 500 mm above the final level
(2) 300 mm above the final level.

4.2 Deflection of the Truss

The truss axis was assumed to be initially level. Under its own weight (including the weight of the steel forms) the truss deflects a maximum of 230 mm ($\approx \ell/1100$) as shown in Fig. 4, curve (1). After the application of the temporary cable forces to the top chord of the truss, the truss is almost level again, see Fig. 4, curve (2).

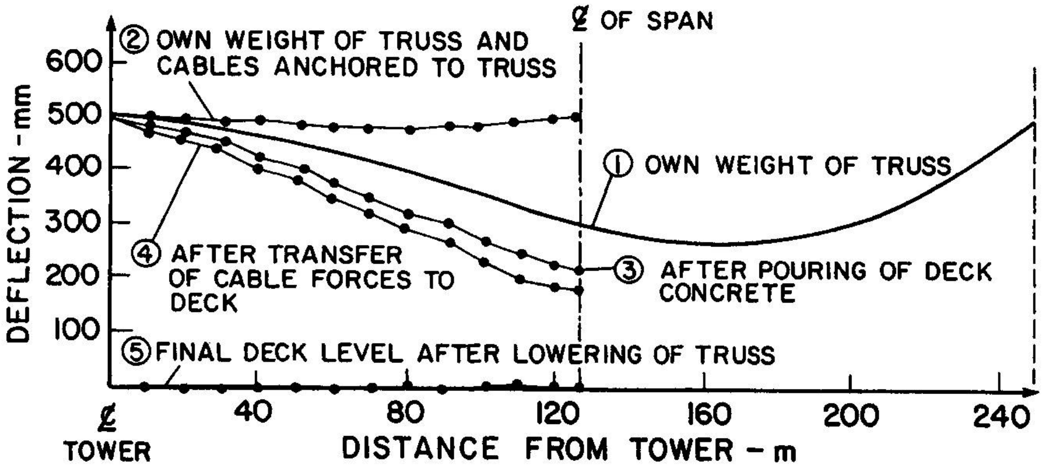

Fig.4 Deflections of truss and deck during construction for temporary deck elevation + 500 mm

The temporary cable forces in the elevated position of the truss are based on the cable lengths which were established in a separate geometrically nonlinear analysis for the completed structure under dead load. The cable stresses under this loading condition were assumed to be 0.375 f_{pu} where f_{pu} is the tensile strength of the cables.

The forces in the cables anchored at 120 m and 60 m from the centre line of the tower are listed in Table 1 for the different construction stages. Also listed are the forces in selected truss members.

The weight of the deck concrete produces a deflection of almost 300 mm at the centerline of the span (Fig. 4, curve 3). The transfer of the cable forces from the truss to the deck adds 50 mm to the deflection of the truss. Upon lowering of the truss the deck moves into an almost perfectly level position and the forces reached in the cables are within 1 percent of those established in the preliminary analysis for the dead load.

If the truss axis is straight for the no load condition, then the concrete hardens in the deflected configuration represented by curve (3) in Fig. 4, i.e. there is some initial curvature built into the deck which is a maximum in the vicinity of the tower. Upon lowering the deck into its final position a positive moment will be introduced. The resulting bending stresses (±0.4 MPa) are beneficial in the region of the supports at the tower and for this reason there is no need to introduce some initial camber into the steel truss. These stresses will, of course be reduced by creep.

The truss forces of Table 1 indicate that the maximum compression force (28.45 MN) occurs after pouring the deck while the maximum tension (33.20 MN) develops after the cable forces are transferred to the deck. The maximum cable force to be anchored to the truss is 2.45 MN.

The deflection to be expected if the deck is at +300 mm during construction are shown in Fig. 5. The maximum cable force to be anchored is 2.67 MN which corresponds to an increase of 9 percent relative to the +500 mm case. The maximum compression force in the truss is 24.39 MN (17% reduction) and the highest tension decreases by 23 percent to 26.95 MN. The final cable forces are the same in both cases. (see Table 1).

5. CONCLUSION

The proposed method of construction is an efficient and expedient way to construct multiple span cable-stayed bridges. Because of the flexibility of the solid deck slab, the deformations of the truss supporting the cast-in-place concrete deck do not have a significant effect on the stresses in the deck.

Deck elev.	Construction Stage	Force in stay cables(1) - MN		Forces in truss Members(2) - MN		
		1	2	1	2	3
	(1) Truss weight	-	-	16.45	-12.94	2.38
500 mm	(2) Temporary cables +(1)	1.82	-	-3.23	-6.94	-1.38
	(3) Concrete weight +(2)	2.45	0.41	26.56	-28.45	2.03
	(4) After transfer of cable forces to deck	2.62	0.38	33.2	-25.76	3.31
	(5) Deck in final position	2.95	1.63	16.45	-12.94	2.38
300 mm	(6) Temporary cables +(1)	2.05	0.46	-6.90	-3.69	-2.18
	(7) Concrete weight +(6)	2.67	0.97	19.0	-24.39	-1.49
	(8) After transfer of cable forced to deck	2.91	0.98	26.95	-20.51	2.73
	(9) Deck in final position	2.95	1.63	16.45	-12.94	2.38

(1) Cables 1 and 2 are anchored at 120 m and 60 m, respectively from centreline of tower
(2) Members 1 and 2 are top and bottom chords at pier,
Truss member 3 is bottom chord at the centre of the span.

Table 1 Forces in selected stay cables and truss members

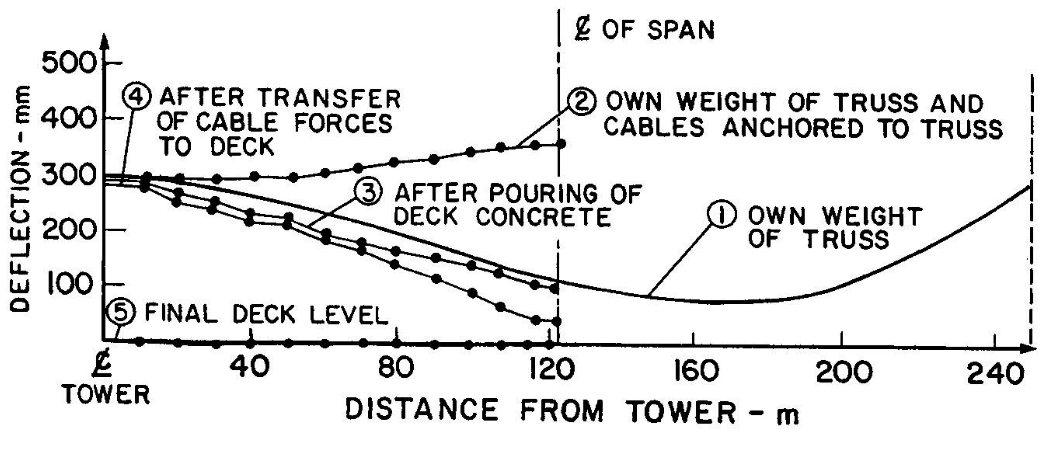

Fig.5 Deflection of truss and deck during construction for temporary deck elevation + 300 mm