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Radical Deck Designs for Ultra-Long Span Suspension Bridges

Nouvelle forme de tabliers pour les ponts suspendus à grandes portée

Brückenträger für Hängebrücken ausserordentlicher Spannweite

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SUMMARY

A review of the aerodynamic problems encountered in the design of bridge decks is given, together with solutions adopted in the past and proposed for the future. When the separate problems of aerodynamic stability of the deck and protection of the traffic from high winds are considered together, a new form of deck emerges. The traffic would be completely enclosed in two pear-shaped tubes and the deck would be aerodynamically stable up to the highest wind speeds.

RÉSUMÉ

Un résumé est donné des problèmes aérodynamiques rencontrés dans la forme des tabliers, avec les solutions adoptées autrefois et proposées pour le futur. Lorsque les problèmes de la stabilité du tablier et la protection du trafic vis-à-vis de forts vents sont considérés ensemble, une forme nouvelle des tabliers se présente. Le trafic serait complètement enfermé en deux tuyaux en forme de poire et le tablier serait stable aérodynamiquement lors des vents les plus violents.

ZUSAMMENFASSUNG

Dieser Beitrag gibt eine Uebersicht der aerodynamischen Probleme beim Entwurf von Brückenträgern, mit ausgeführten Lösungen und Vorschlägen für die Zukunft. Aus der Kombination der Windstabilität und des Schutzes des Verkehrs vor starken Winden ergibt sich eine neue Trägerform. Der Verkehr wird in zwei birnenförmige Rohre gelegt und der resultierente Brückenträger bleibt auch bei höchsten Windgeschwindigkeiten stabil.

1. INTRODUCTION

The history of long span bridge design has been a series of quantum leaps, when spans have roughly doubled, followed by long periods of evolution. The last such leap occurred in the early 1930s with the George Washington and Golden Gate bridges. Since then, the longest single span has increased by only 10%

There are natural limits to the unsupported spans of different types of bridge. These limits have been increased in recent years, by the development of stronger and lighter structural materials to support the weight of the traffic. On very long spans however, the static weight-carrying capacity is not the only problem. Wind effects become a crucial feature to be considered in the structural design and the aerodynamic shape of the deck

2. AERODYNAMIC STABILITY AND RESPONSE

There are various types of aerodynamic instability of the deck which must be avoided up to the highest wind speeds. Coupled bending-torsion flutter occurs when the two frequencies coincide. Static divergence is a non-oscillatory instability which occurs when the aerodynamic forces have reduced the torsional frequency to zero. Galloping and stall-flutter are instabilities in pure bending and pure torsion respectively.

Unlike the true instabilities, resonant responses of the deck are rarely destructive, although they can cause discomfort and reduce the fatigue life of the bridge. Such responses occur when the frequency of the vortices shed in the wake of the deck coincides with that of one of the structural modes at low or moderate wind speeds.

Whilst undesirable resonant responses can be suppressed by minor aerodynamic modification or tuned dampers, the avoidance of aerodynamic instability dominates the design of ultra-long spans. Various structural and aerodynamic solution to the stability problem have been either proposed or adopted in the past [1].

2.1 Torsional stiffness

Raising the torsional frequency of the deck, by using either a truss or a fully enclosed torsion box, has been standard practice on long spans for many years. Its purpose is to separate the bending and torsion frequencies sufficiently to ensure that coupled flutter cannot occur up to the highest wind speeds. On potentially unstable deck sections, it also raises the critical stall-flutter speed.

Nevertheless, the additional structural weight of the deck increases the deadload on the cables, so that purely structural solutions become uneconomic on ultra-long spans.

2.2. Perforated decks

Small slots between the carriageways of conventional truss decks have been used to increase the aerodynamic stability for many years. The reason for this phenomenon was not understood until research was undertaken for the first truly perforated deck (with multiple slots) proposed for the crossing of the Messina Straits.

The slots have two effects. They reduce the destablising aerodynamic pitching moment in inclined winds and increase the aerodynamic damping in the torsion mode. The first of these effects ensures that the torsional frequency remains reasonably constant up to much higher wind speeds so that it does not coincide with that of bending. The damping effect delays the onset of coupled flutter and eliminates the possibility of stall-flutter.

2.3 Twin decks

The author's twin-deck proposal (Fig.1) used both aerodynamic and structural inertial forces to ensure aerodynamic stability. A large open gap between two rigidly connected carriageways provides the aerodynamic advantages of a deck with multiple perforations to an even greater degree. In addition, the moment of inertia of the combined decks reduces the torsional frequency (but not the torsional stiffness) to a value below that of bending. Thus coupled bending-torsion flutter cannot occur and the only aerodynamic instability is static divergence. Since the torsional stiffness is provided by the widely spaced cables, no torsion box is needed, although the stiff transverse beams increase the dead-load to some extent.

3. PROTECTION OF TRAFFIC FROM WINDS

There has been increasing interest shown by bridge owners in the problem of protecting the traffic from adverse weather conditions, so that the bridge can remain open at all times. Unfortunately some of the proposed solutions create aerodynamic problems for the bridge structure itself.

3.1 Wind barriers

Slatted fences, erected at the deck extremities, can be designed to give considerable protection to the traffic in high winds. However, such barriers can reduce the aerodynamic damping in the torsion mode and cause stall-flutter.

3.2. Enclosed decks

A partially-enclosed deck was proposed for the Tsing-Ma crossing in Hong Kong to protect emergency vehicles from typhoon winds. Large gaps in its upper and lower surfaces however, ensured that it remained aerodynamically stable.

The deck of the Eurobridge proposal for the Channel Link was totally enclosed in a very deep oval tube, completely protecting the traffic from wind, rain and snow. The high torsional stiffness and the aerodynamic shape of the deck eliminated any likelihood of torsional oscillations. Nevertheless the aerodynamic drag would have been high, and both galloping instability and resonant vortex-shedding responses would have presented potentially serious problems for the bending modes.

In an unpublished proposal, the author suggested that a truly elliptic tubular deck, approximately 30% thick, would fulfil the requirements for an enclosed deck (Fig.2). It would completely protect the traffic and have both low aerodynamic drag and high torsional stiffness. Wind tunnel experiments on a section model of such a deck have largely confirmed the predictions. No reference to the report is given in this paper, since the details of the results are confidential to the companies who sponsored the test program.

4. THE DOUBLE PEAR-SHAPED DECK

When the concepts of the twin bridge and the enclosed elliptic deck are merged a totally new form of bridge deck results (Fig.3). Two separate pear-shaped tubes carry the road traffic internally. They are cantilevered on each side of a large central gap by deep transverse beams at intervals along the span. If required, open railway tracks may be carried within the transverse beams, partially protected from the wind by the road traffic tubes.

4.1 Aerodynamic stability

In winds from either direction, the windward deck has a large radius of curvature at its trailing edge and thus generates little aerodynamic lift. In contrast, the leeward deck behaves like a thick aerofoil section with a moderately sharp trailing edge. These facts can be used to tailor the combined "tandem biplane" section to give little or no midchord pitching moment in inclined winds. The tortional frequency would thus remain sensibly constant up to the highest wind speeds, so that neither coupled flutter nor static divergence could occur.

4.2 Traffic lanes

High-sided commercial vehicles would be carried in the deepest sections of the decks nearest to the centre. Lighter traffic would travel on raised carriageways inside the shallower deck extremities. Further separation of the two types of road traffic would be provided by locating the mergency lanes between them.

4.3 Structure

High torsional stiffness would no longer be needed to prevent wind-induced instabilities. Nevertheless, assymetric traffic patterns on opposie carriageways could produce unacceptable rotations of the deck unless some torsional stiffness is provided. Such rotations would, however, be minimised by the proximity of the heavy road vehicles and the rail traffic to the centre of the deck. A single central tower, between the two carriageways at each pier, would then support the suspension cables. Any additional torsional stiffness needed could then be provided by a box or truss surrounding each of the deep traffic tubes.

5. ACKNOWLEDGEMENT

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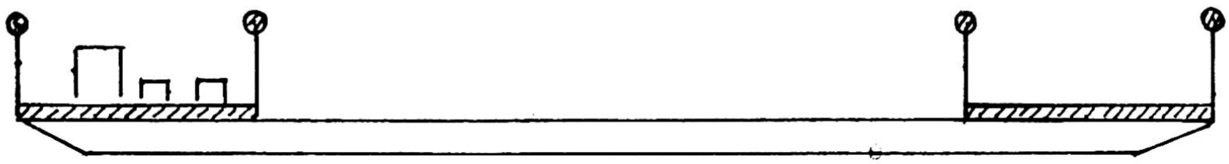

Fig.1 Twin deck

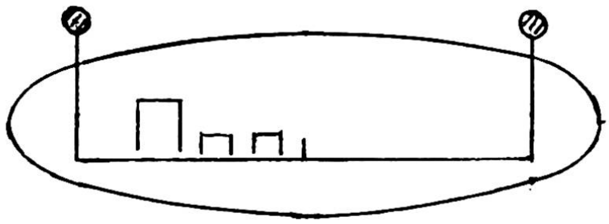

Fig.2 Elliptic deck

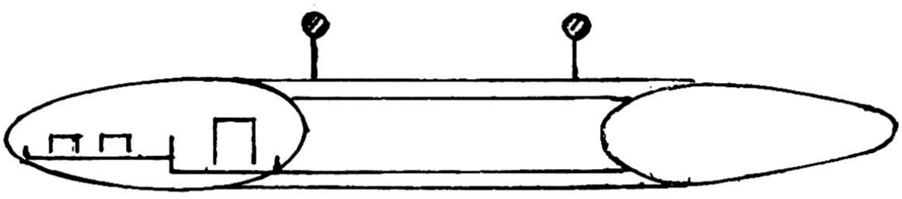

Fig.3 Double pear-shaped deck