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

Band: 13 (1988)

Artikel: Considerations for wind effects on a 1990m: main span suspension bridge

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DOI: https://doi.org/10.5169/seals-13103

Considerations for Wind Effects on a 1,990 m – main span Suspension Bridge

Effet du vent sur la portée principale (1990 m) d'un pont suspendu

Windeinflüsse bei einer Hängebrücke von 1990 m Spannweite

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SUMMARY
The paper presents some design considerations for wind effects on a very long span suspension bridge, the Akashi Kaikyo (Straits) Bridge, with a total length of 3,910 m. Included here are primarily the studies of comparison of various deck configurations such as truss and box stiffening constructions and their variations to combat the flutter instability in relation to the whole bridge design.

RÉSUMÉ
L'article présente quelques considérations faites au stade du projet sur les effets du vent sur un très long pont suspendu, le pont sur le détroit de Akashi Kaikyo avec une longueur totale de 3910 m. Les études et comparaisons de différents types de tablier de même que les constructions en treillis ou en caissons et leurs réactions aux instabilités dues à l'oscillation du pont sont considérées.

ZUSAMMENFASSUNG
Dieser Beitrag behandelt die Bemessungsüberlegungen betreffend der Windeinflüsse bei einer Hängebrücke grosser Spannweite, der Akashi Kaiko Brücke mit einer Gesamtlänge von 3910 m. Es werden hier vor allem die Studien der verschiedenen Brückenträger und Versteifungskonstruktionen zur Verhinderung von Wind-Instabilität behandelt.

1. INTRODUCTION

Construction of the Akashi Kaikyo Bridge which will cross the Akashi Straits with a shore-to-shore distance of about 4 km, has been a matter of many years' standing within the Honshu-Shikoku Bridge Project in Japan. The official go-ahead came in 1986, but actual construction works commenced in the spring of 1988. Comparisons among various design proposals and construction methods were made, based on such conditions as topography and geology of the sea bottom, tidal current speed, the navigational lanes, etc., as well as the considerations on the difficulty, term and cost of construction. They led to the choice of a three-span, two-hinged suspension bridge with a total length of 3,910 m (a main span of 1,960 m and side spans of 960 m), which would be the longest span length in the world. Its extremely flexible features would require, in particular, careful procedures and considerations for specified limit states, which represent aerodynamically static and dynamic effects and stability of the superstructure as well as satisfactory earthquake resistance of the substructure. From the very beginning of the project, numerous investigations have been carried out on these problems. The paper presents outlines of some considerations for wind effects, in particular, a competition among deck configurations of typical proposals to combat the flutter instability.

2. SUMMARY OF CONSIDERATIONS FOR WIND EFFECTS

In order to determine the bridge scheme and construction method, the Honshu-Shikoku Bridge Authority has been conducting various surveys and studies on structural designs. Initially, the Akashi Kaikyo Bridge was planned in the form of a combined highway-railroad bridge with a double deck trussed construction. Afterwards, however, owing to a change in social circumstances, the policy was altered to the construction of a highway bridge with six lanes. The final plan of the span construction is as shown in Fig.1.

In the meantime, in the early stage of design and investigation, the proposal of (1) trussed deck constructions was emphasized on the basis of former experiences in the Honshu-Shikoku bridges, while (2) shallow closed box decks, aiming at lower wind load and lighter dead load and (3) non-stiffened deck construction with open slots, feasible for higher stability were proposed to make various comparisons. Those cross sections are No. 11-17 in Figs.2 and 3. The aerodynamic stability was generally studied through sectional model wind tunnel tests in a smooth flow. It was found at this stage that few trussed constructions could satisfy the requirements for flutter stability.

Referring to such results at early stage, the design considerations for wind effects began in earnest in 1982, as the time was getting ripe for the execution of the bridge construction. At this stage of the investigation, all the problems due to a very long span ever experienced were reconsidered, particularly the effects of turbulent wind and the wind environment of the Akashi Straits, while the study on suppression of flutter and vortex excitation were also continued. These works have been conducted through field data analyses, wind tunnel tests and numerical analyses. As far as the proposals were concerned, several box decks and variations were compared to search for better deck constructions with respect to flutter stability than trussed decks, which were also studied to get more rational design proposals under the wind load. The examples are the cases of No. 21, 22 and 71, and from No. 23 through No. 62 in Figs.2 and 3. It was concluded up to the present that two cases could fulfil the prescribed flutter stability requirements and were to be investigated in more detail. Those were a conventional truss deck and a closed box deck combination of two different heights.

As for the preliminary design procedures for wind effects on the Akashi Kaikyo Bridge, the design code established in 1976 was to be temporarily applied, while some alteration would be expected in a short time. According to the present code, primary provisions are as follows; (1) reference wind speed of 43 m/sec (wind speed of 150 year return period, 10 min. average and at 10 m height above sea level) is provided for the site of the Akashi Straits. (2) Design wind loads are calculated by equivalent wind speed of about 74 m/sec after a correction of peak gust response effect. (3) Critical wind speed of flutter must be higher than 78 m/sec in wind incidence between 3 and -3 degrees.

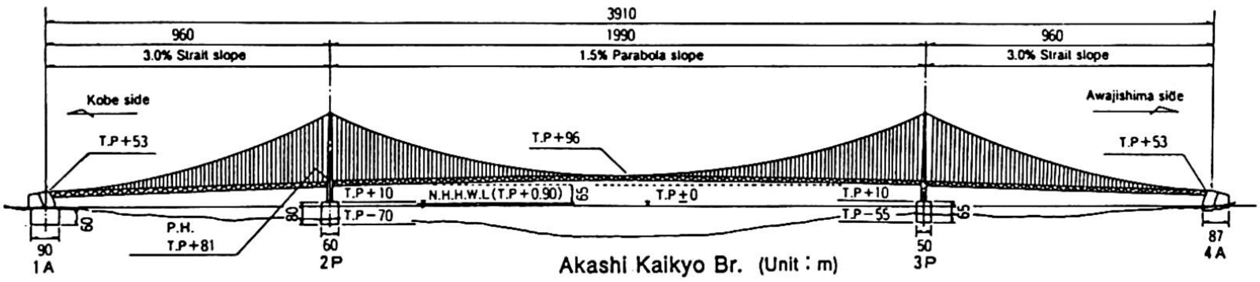
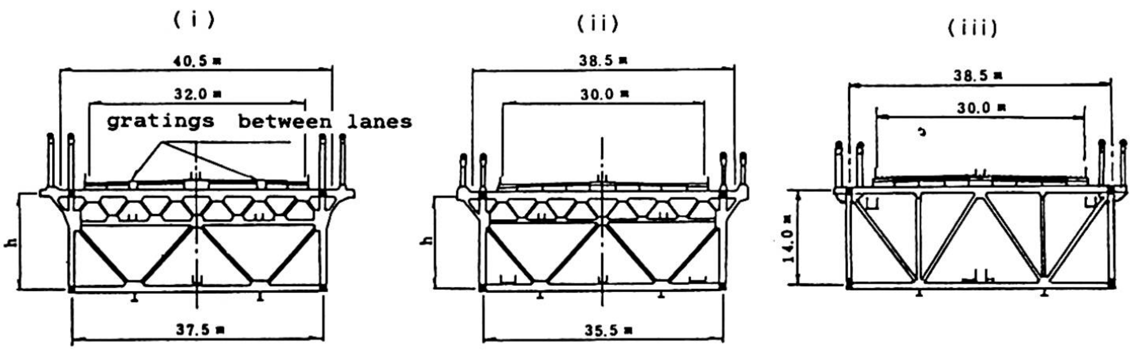


Fig.1 General View

Fig.2 Dimensions and Cross Sections of Typical Proposal of Truss Deck

series number		11	12	13	21	22	71
cross section		(i)			(ii)		(iii)
span length l (m)		1,000+2,000+1,000			950+2,000+950		960+1,960+960
sag ratio f／l		1/9.5			1/8.5		1/9.5
deck height h (m)		14	12	8	14	12	14
dead load (t/m/Br)	deck w_s	26.7	26.2	25.3	27.5	26.8	28.0
	cables w_c	18.7	18.7	17.8	16.0	15.8	16.0
	total	45.4	44.9	43.1	43.5	42.6	44.0
torsional frequency f_T (Hz)		0.148	0.136	0.113	0.152	0.136	0.137
tor. rigidity of deck $GJ \times 10^{-8}$ (tm^2)		1.98	1.53	0.73	1.51	0.83	1.00
flutter stability by wind tunnel test		OK	OK	NO	OK	NO	under test



3. CONSIDERATIONS ON TRUSS DECKS

Geometry of primary members of the truss deck bridge are to be determined by wind loads. The trussed construction is generally quite rational in structural mechanics, which leads to frequent adoption as a traditional stiffening deck of a suspension bridge. Among the Honshu-Shikoku bridges, trussed decks produced good results for the Innoshima, Ohnaruto, Shimotsui and South- and North-Bisanseto bridges. As for the Akashi Kaikyo Bridge, truss decks were proposed from the beginning of design competitions (Fig.2). Wind tunnel tests led to some stable cross section designs against flutter instability. These cases provided few problems in vortex excitation, gust responses, statical instability, etc. as well.

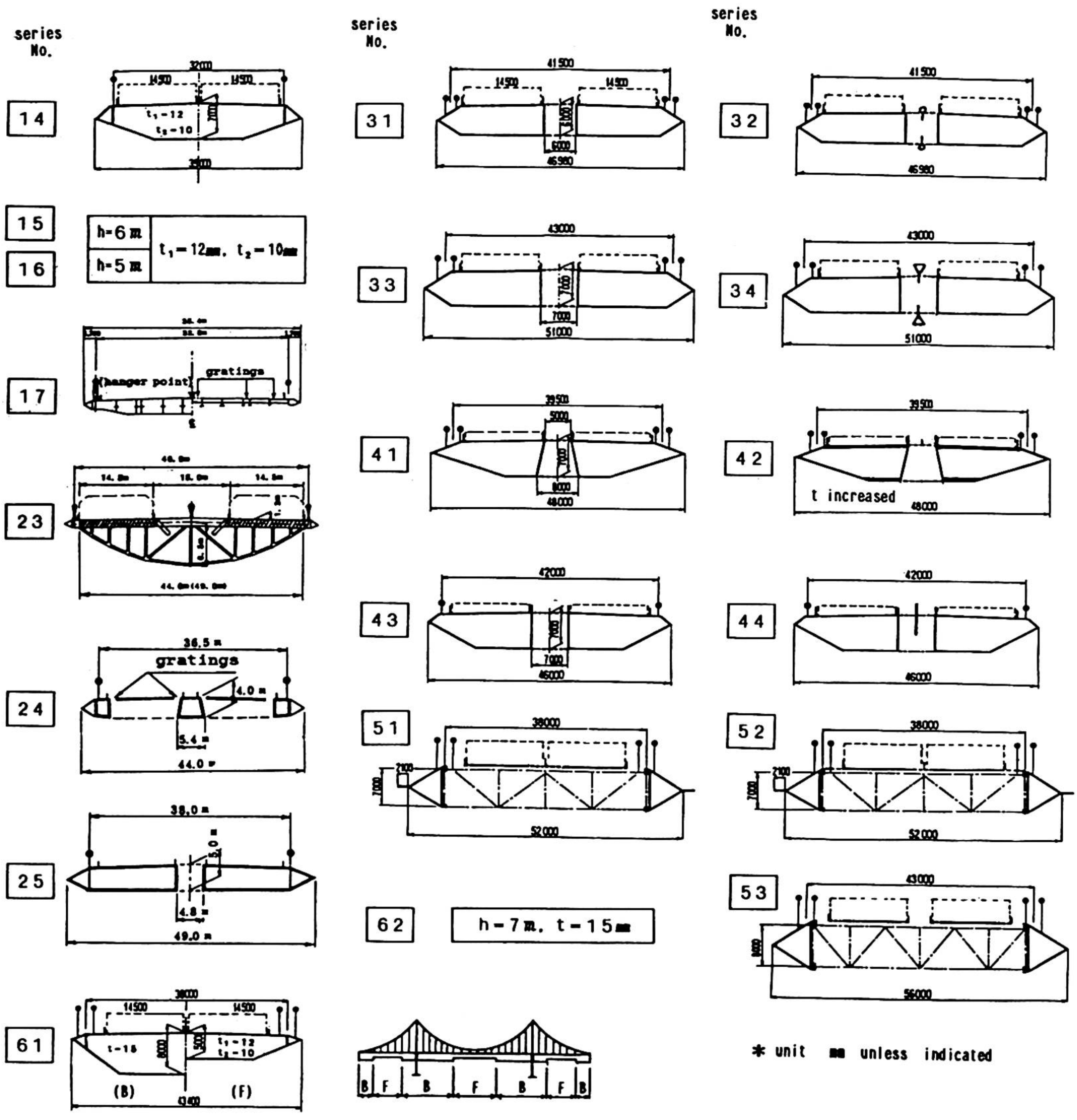


Fig.3 Cross Sections of Typical Proposals of Box Deck and Variation

It has been recognized that the truss construction was generally unfavourable in a higher drag wind load as well as a heavier dead load. In case of the Akashi Kaikyo Bridge, the greater lateral deflection of the deck reached more than 30 m at span center under the design wind load. However, this effect on the substructure design could not be a major design factor, because another severe seismic loads predominated over in the determination of the pier dimensions. Therefore, present attention for the truss decks is to seek after the more practical, economical and stable improvement of structural designs implementing less drag wind loads.

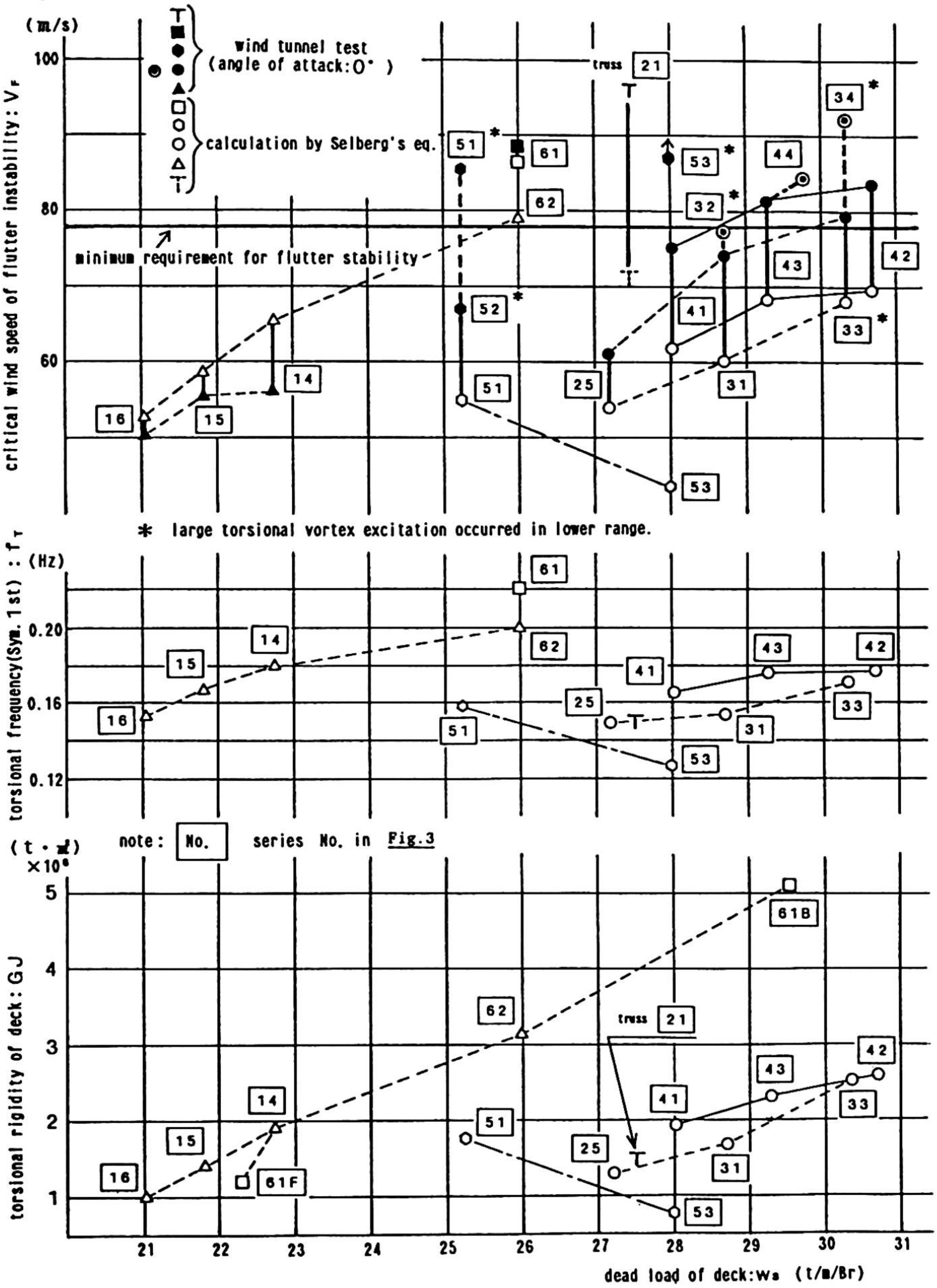


Fig.4 Flutter Stability Competition of Typical Deck Proposal

4. CONSIDERATIONS ON BOX DECKS AND VARIATIONS

It was appreciated that the closed shallow box deck would have the advantage of a relatively favourable stability, a lower drag wind load, a lighter dead load, etc. According to the conventional design of the box deck, geometry of primary members can be usually determined by only minimum thickness of metal requirement for maintaining rigidity and corrosion preservation, because the wind and live loads leave a considerable stress margin. When a closed shallow box deck for the case of 2,000 m main span is designed, owing to the minimum thickness requirement, the onset wind speed of flutter is considerably lower than the required level because of fairly low torsional natural frequency. A calculation shows that range of the mainspan length for the required level of flutter stability to be satisfied is less than only 1,700 m according to the Japanese code.

In order to overcome this weak point for box decks, two alternative means to raise critical flutter speed were considered; (1) a structural approach to provide greater torsional stiffness by increasing metal use or by optimizing deck allocation, or (2) an aerodynamic approach to improve flutter properties by providing a couple of open slots between deck surfaces or by combining a sort of stabilizer. Typical proposals of box decks and variations are as shown in Fig.3. Referring to the results of wind tunnel tests vs. dead load of deck construction, which are indicated in Fig.4, it was concluded at present that the most economic and stable deck configuration might be a combination of two closed box decks of different heights. Further investigations are still in progress.

5. CONCLUDING REMARKS

An outline of the considerations and investigations for wind effects on the Akashi Kaikyo Bridge made so far are described in this paper. The present conclusions are as follows; (1) the design for wind effects on a very long-span suspension bridge with 2,000 m main span could be carried out by an extension of the conventional design method. (2) Some deck configurations of truss satisfied the required level of flutter stability. In conjunction with the substructure design, the dead and wind loads were not necessarily definite design factors since the seismic loads might predominate. (3) As for the box decks, some means had to be found whereby the critical flutter speed could be raised to the required level without onsets of vortex excitation. The structural approach to provide greater torsional stiffness by arranging an appropriate steel increase in the bridge axis was quite effective, compared with aerodynamic alteration of the deck configurations to improve flutter properties, for instance, by providing a couple of open slots between deck surfaces. (4) Other aerodynamic effects such as vortex excitation, gust response and statical instability are also important factors, among which the effects of gust response have an appropriate contribution in the wind loads, fatigue design, etc.

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