On improving the aerodynamic stability of H and channel sections

On Improving the Aerodynamic Stability of H and Channel Sections

De l'augmentation de la stabilité aérodynamique de sections en double Té et en U

Über die Verbesserung der aerodynamischen Stabilität von H-förmigen und Kanalquerschnitten

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Introduction

After the dramatic failure of Old Tacoma Narrows suspension bridge on November 7, 1940 major steps have been taken by engineers towards the construction of aerodynamically stable (within the expected range of velocities at the site) suspension bridges of various lengths and forms. All the countermeasures taken so far against the aerodynamic instability in wind fall in the following categories:

1. The modern suspension bridge structures are designed for higher torsional stiffness when compared to that of earlier designs such as the Old Tacoma Narrows bridge. In the case of truss-stiffened bridge decks the increase in the torsional rigidity is achieved by means of stiffening and lateral trusses. In such structures the ratio of the principal natural torsional frequency to that of vertical bending is generally more than 2 compared to only 1.3–1.5 for the Old Tacoma Narrows [1].
2. The geometrical form of the bridge decks has been greatly improved and made more favourable as far as fluid flow over the deck and the consequent aerodynamic stability are concerned. Thus the simple plate-girder designs have almost become outdated and the more elaborate truss-girder and recently box-girder versions appear to be the most common forms of today's suspension bridge decks.

Notable in these advancements are the early work of FARQUHARSON [2], VINCENT [3] and BLEICH [4] in U.S.A., SCRUTON [5] in U.K., SELBERG [6] in

Norway, HIRAI [7] in Japan, KLÖPPEL [8] in Germany and STÜSSI [9] in Switzerland. Scores of later contributions can be found in Refs. [10], [11] and [12].

Of course the improvements achieved in the aerodynamic stability of suspension bridges by means of increasing the stiffness of structure, especially those of torsional modes of oscillations and designing the deck form to be less susceptible to aerolastic vibrations have led to much heavier and more elaborate structures than what is necessary to withstand static loadings including static wind load. Consequently the increase in steel mass and elaborations in the deck configuration have increased the cost of structures drastically. Furthermore, the modern constructional techniques and fabrications have resulted in rather low structural damping values compared to that in earlier constructions, see SELBERG's damping measurements on some Norwegian suspension bridges [13].

Although the departure from the simple plate-girder design has been necessary in the case of long span bridges, the economical attractions of such a simple design, at least for small span suspension bridges, are inevitable.

It is therefore the aim of the present work to revisit the aerodynamic stability of simple *H* and channel sections and examine the possibility of improving the aeroelastic stability by means of attaching simple suitable fairings to both the front and back faces of deck. Such a procedure may prove to provide a sufficient degree of stability to some decks so that any drastic increase in cost may be avoided. Such fairings of course are not meant to carry any significant load and can be fabricated from any conveniently available material as "dummy" structural elements. Furthermore the effect of bottom plates and horizontal flow-splitters in addition to fairings are to be examined in the wind tunnel.

It has to be mentioned that artificial dynamic stabilizers or vibration detuners of either passive or active type may also prove to be effective means of detuning some of the aeroelastic oscillations encountered in suspension bridges. This possibility is presently under investigations.

In general, two distinct types of aeroelastic oscillatory motions are expected in the wind tunnel:

1. Low amplitude uncoupled vertical and or rotational vibrations occuring at usually narrow ranges of low wind speed beyond which stability is restored.
2. Flutter *) oscillations either in single degree or in the bending-torsion coupled form.

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*) The word flutter used in this work means the diverging oscillations of any non-rigid object exposed to a fluid stream and extracting its oscillatory energy from that stream. The stability is not restorable after the flutter on-set by increasing the fluid speed and the non-rigid body referred to in this paper is a deck model section.

In this report we are concentrating on the feasibility of improving the catastrophic oscillatory motion of the latter type. Nevertheless it must be mentioned that in any study concerning an actual bridge deck the former type of oscillation must also be seriously considered. It is interesting to note that fairings have in fact been used on the Long's Creek bridge in Canada for reducing oscillatory motions of former type [14].

Section Models and Test Arrangements

The two types of basic cross-sections considered in this work are shown as section Nos. 10 and 20 in Fig. 1. The channel section model is a simplified form of the first draft for Lokkaren suspension bridge to be constructed in Norway. A linear scale factor of 36 was chosen. The mass of the model was 5.9 kg/m corresponding to nearly 8000 kg/m on the prototype.

The second model, which is basically an H-section, represents a simplified version of the Old Tacoma Narrows. The linear scale factor being 37.5 in this case resulting in a model mass of 5.9 kg/m as in the previous case. This mass was infact maintained throughout the test programme including the section models with fairings.

The variety of configurations tested is shown in Fig. 1. Fairings were attached either in continuous or alternating fashion as suggested in Fig. 2. The channel section was also tested with some propellers attached to the side faces as illustrated in Fig. 3.

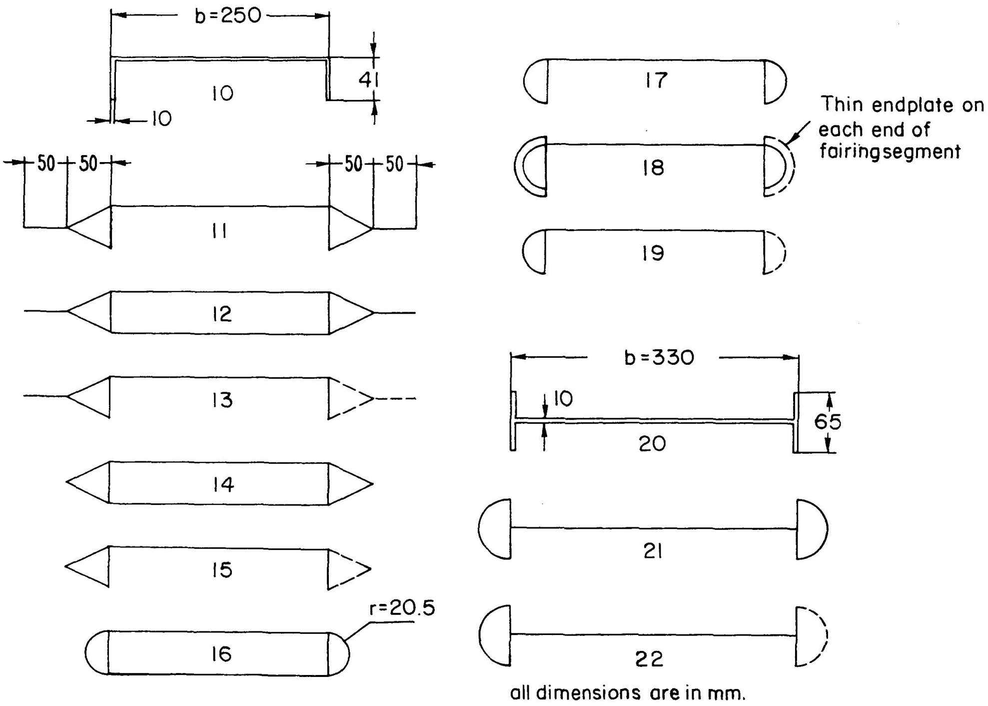

Fig. 1. Section models. When both fairings are drawn in full line then the continuous arrangement of Fig. 2a is employed, otherwise the alternating type of fairings, Fig. 2b is used.

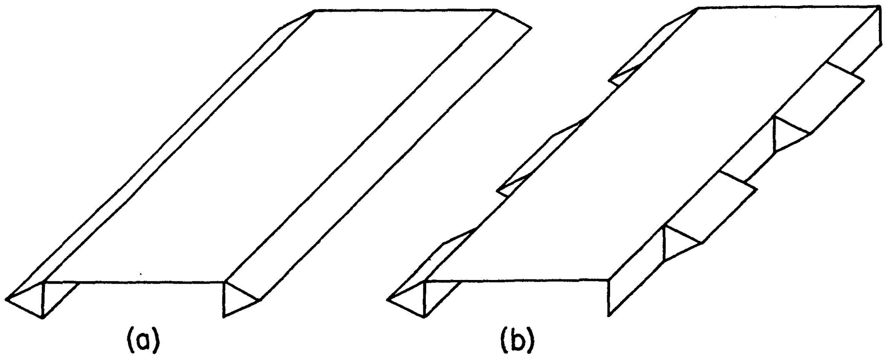

Fig. 2. Continuous and alternating forms of fairing attachment.

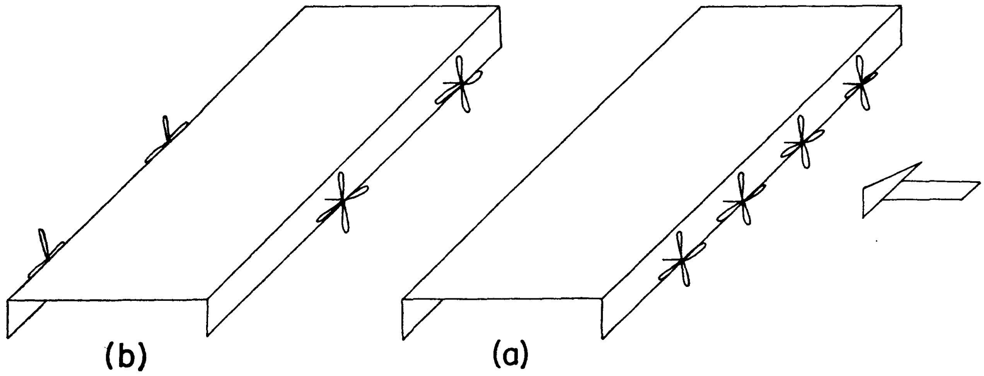

Fig. 3. Models with propellers.

Section models of length 1.06 m were tested in the low-speed wind-tunnel of NTH, Trondheim, with a working section of 1.1 m wide and 1.2 m long. The capacity of the tunnel being approximately 20 m/s.

Each section model was supplied with end-plates to assure the two-dimensional character of air flow. These end-plates were 250×530 mm^2 on channel sections and 250×500 mm^2 on H sections with rounded corners.

Models were stayed with guy wires at an elevation corresponding to the assumed shear-centre location of the prototype. This was taken to be the point of symmetry on H-sections and midchord point on the upper surface of channel-sections.

The rigid section models were suspended by the conventional coil spring rig systems with half the number of springs being located at each end and equidistant from the chord centre line. The supporting system was placed completely outside the airstream.

The distance between the coil springs at each end was adjusted for the correct frequency ratio (N_T/N_V), where N_T and N_V designate the principal torsional (rotational) and bending (vertical) natural frequencies respectively. Frequency ratios of 1.3 and later 1.7 (in a few cases 1.8) were selected. The selection of these specific values is for the following reasons:

The ratio 1.3 corresponds to the extremely torsionally weak (and dangerous) girder-stiffened designs in which there is only one lateral stiffening system. In such a design the deck contributes very little to torsional stiffness. The frequency ratio 1.7 (or 1.8) was chosen to represent a lower estimate of the frequency ratio obtained when two lateral systems are used. That is, addition of horizontal trusses along the bottom part for the channel section say. Such a truss system would probably have small effect on the deck aerodynamics and hence it is not produced on the model.

The entire experimental programme for the comparative study was executed with models suspended by the so-called "flexible rig" which permitted large amplitudes of the order of 0.2 radian to develop for the rotational oscilla-

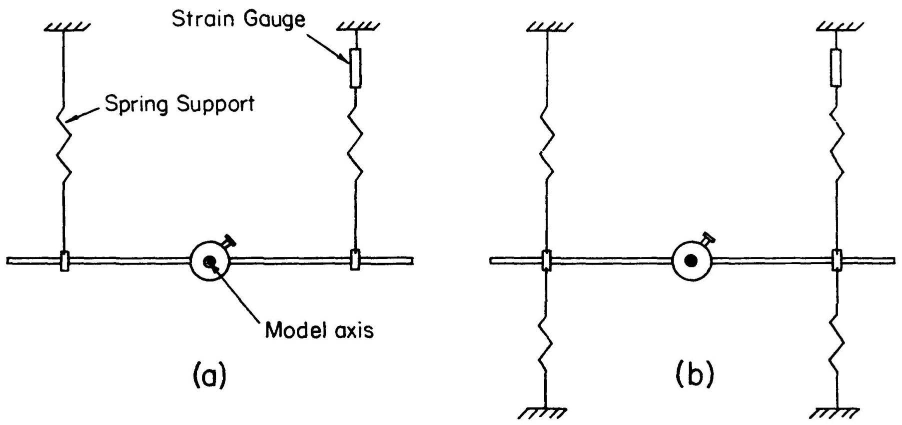

Fig. 4. Supporting systems, (a) flexible rig, (b) stiff rig.

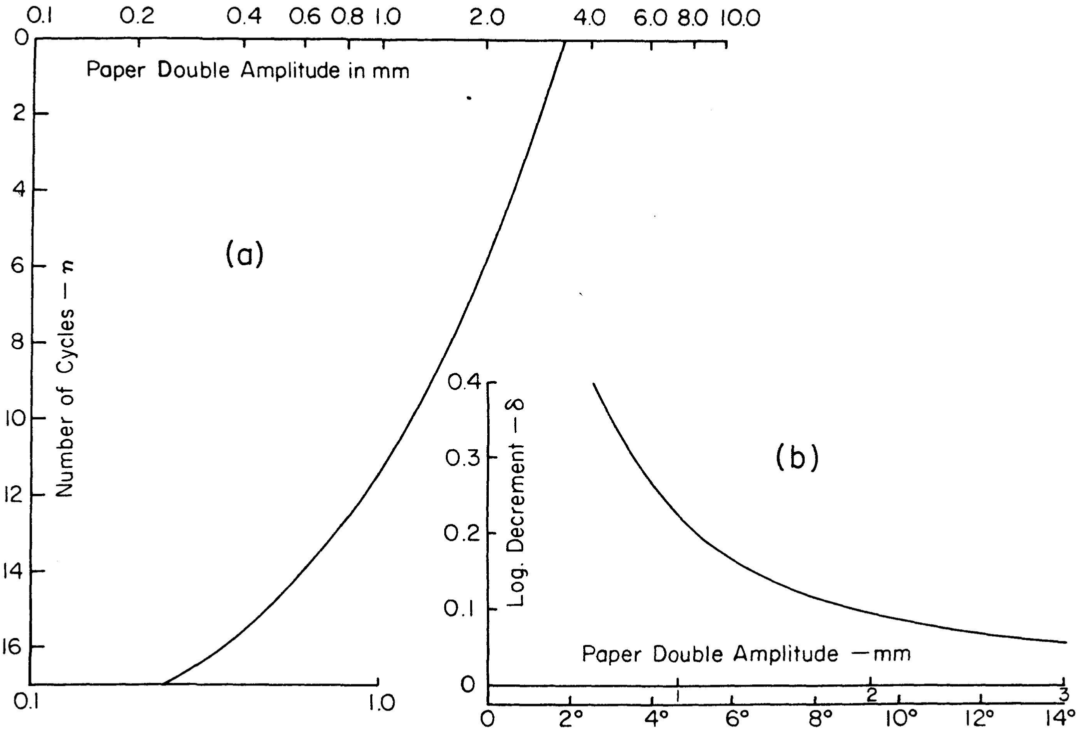

Fig. 5. Mechanical damping of the flexible rig.
(a) n vs. $\ln \alpha_0$, (b) δ vs. $2\alpha_0$.

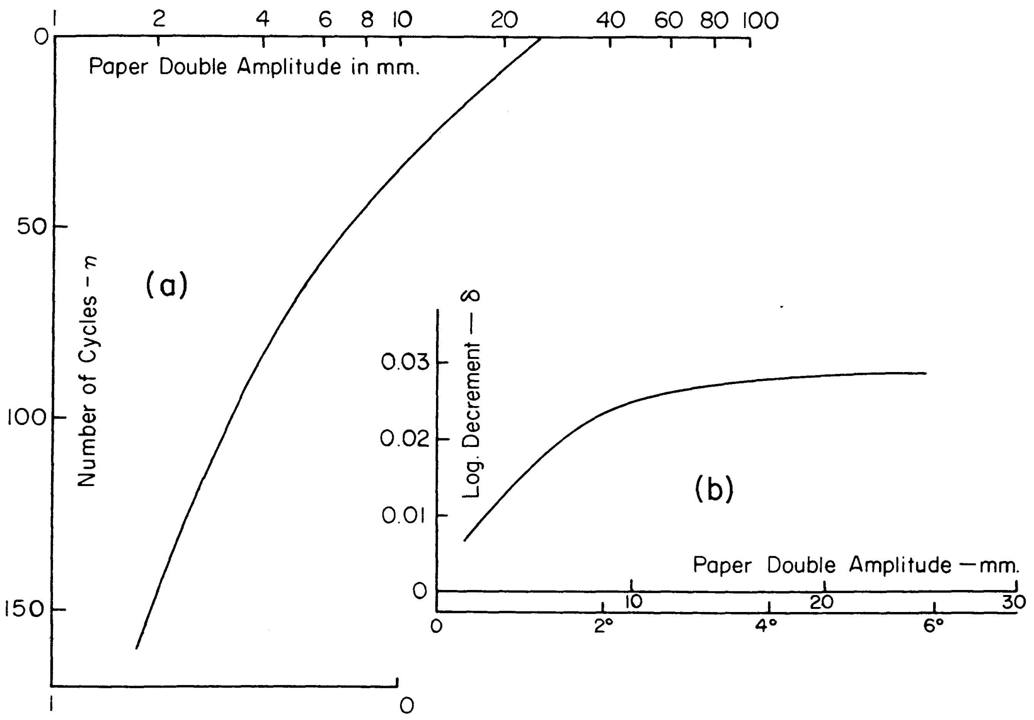

Fig. 6. Mechanical damping of the stiff rig.
(a) plot of n vs. $\ln \alpha_0$, (b) plot of δ vs. $2\,\alpha_0$.

tions. Parts of the model tests were repeated with the so-called "stiff rig". These two rigs are schematically shown in Fig. 4.

The major difference between the two supporting systems (rigs) is not only the different stiffnesses but also the great difference between the values of the torsional damping (measured in still air). There is greater damping capacity in the flexible rig than stiff rig as revealed by damping curves in Figs. 5 and 6. The difference in vertical damping was less pronounced. The typical logarithmic decrement of vertical oscillation was 0.01 for flexible and 0.006 for stiff rig respectively.

Attention is drawn to Fig. 5 and to the fact that the flexible rig exhibits a logarithmic decrement curve resembling dry friction at low amplitudes. This was some kind of unwanted surprise during the data reduction period.

Discussions of Test Results

Channel Sections

The torsional response curves for all the channel sections are presented in Fig. 7 about which the authors are quite enthusiastic. There are a number of interesting points to be observed:

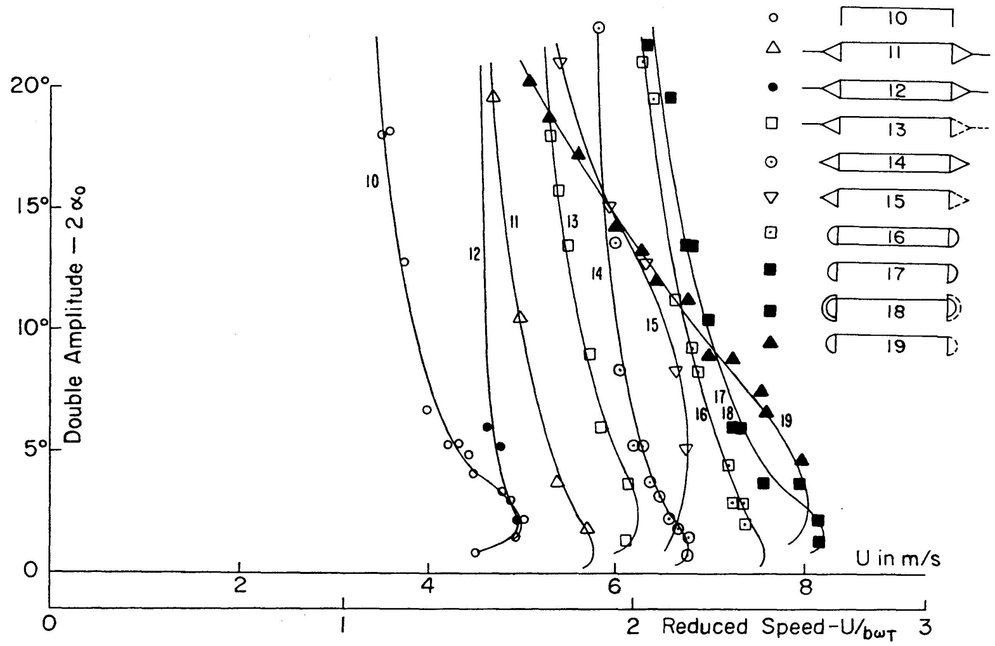

Fig. 7. The flutter torsional response. Models tested with the flexible-rig, $N_T/N_V = 1.7$.

1. A number of sections with fairings and without bottom plate yielded better results than the two box configurations (section Nos. 12 and 14) which are the only two models (in this work) for which airfoil classical theory may nearly hold.
2. All amplitude response curves are of the lean-back type. This is mainly attributed to the amplitude dependency of the system's damping as demonstrated in Fig. 5.
3. The alternating form of fairings attachment proved to provide as good, if not better, response results compared to those of the continuously attached fairings case.
4. Perhaps the most unexpected fact is that the basic channel section (No. 10) behaved as good as it did. According to Selberg's systematic tests (reference [6]) on similar sections one should expect a monotonically increasing response curve (not lean-back) and further the starting velocity would be only about half of the value obtained in the present tests. In all the tests the velocity of no return (when unlimited amplitudes are developed) was surprisingly high compared to section No. 14 which is commonly accepted as having excellent form quality.

All tests were carried out at three angles of attack. While the results for the case of zero angle are presented in Fig. 7 those of +5 and −5 degrees are tabulated in Table 1.

Sections 11 and 12 exhibited considerable static tilt (resembling divergence phenomenon) at relatively low wind velocities. The static tilting under the

Table 1. Catastrophic Flutter Speeds, Models Tested with Flexible-Rig, High Damping

Section Model		Flutter velocity m/s Angle of attack $+5°$	Angle of attack $-5°$	Angle of attack $0°$	% of improvement for 0° angle of attack
Section Model	No. 10*)	3,9		5,1	—
,,	No. 11*)	4,5	4	5,85	14
,,	No. 12	4,4	4	5,1	0
,,	No. 13	4,8	7,2	6,5	27
,,	No. 14	6,15	5,4	6,95	36
,,	No. 15	4,65	8,4	6,85	34
,,	No. 16	4,8	4,85	7,65	50
,,	No. 17	4,8	6,25	8,25	61
,,	No. 18	4,9	6,20	8,30	62
,,	No. 19	5,20	8,2	8,05	58

*) All section models are numbered in Fig. 1.

wind load basically increased the effective angle of attack which caused the onset of flutter at an unusually low wind velocity for such sections. This is mainly due to the extra large value of the section width as it has been pointed out early by FRANDSEN [15].

As the primary object of the tests was to find simple means of improving stability, only the two best sections, Nos. 17 and 19, with the basic section No. 10 were tested also in the stiff rig, the results of which are presented in Fig. 8. The response curves in Fig. 8 are rather disappointing in the respect that the reduced damping has caused the models to oscillate at lower reduced velocities compared to the corresponding values obtained from the flexible

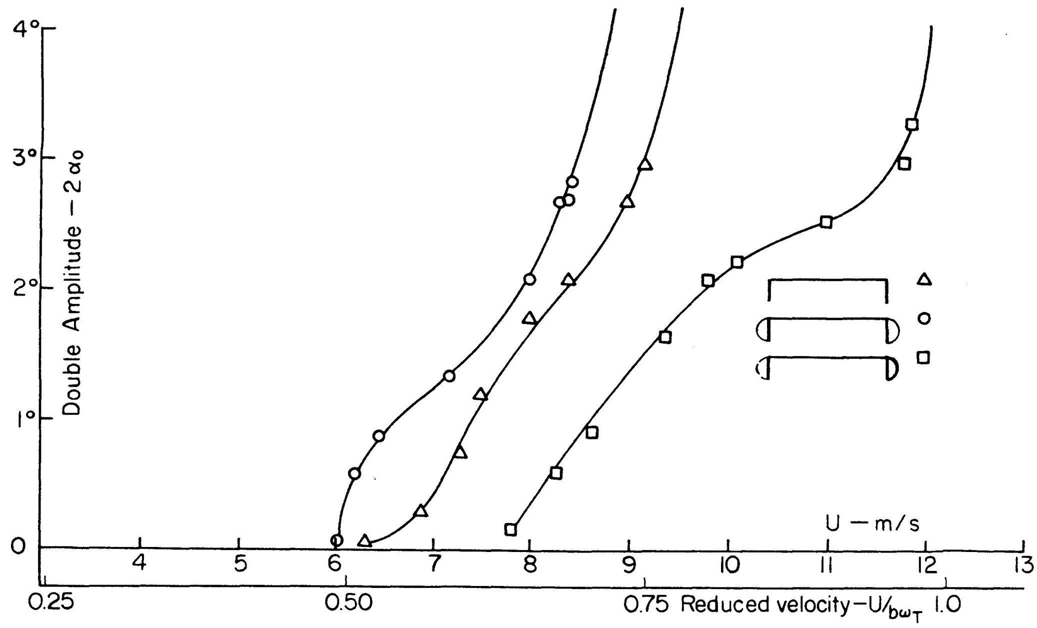

Fig. 8. The flutter torsional response. Model tested with stiff rig, $N_T/N_V = 1.7$.

rig. Furthermore the response curves of Fig. 8 are all of monotonicly increasing type. For the basic section, this is in agreement with Selberg's results, see reference [6].

An important conclusion to be drawn from the comparison of the previous two figures is the revealing fact that damping is one of the primary factors in the aerodynamic stability of unstreamlined objects.

Comparison of Figs. 7 and 8 with those presented in reference 6 indicates that the damping level in that reference, which is as a matter of fact not stated by Selberg, has been fairly low. It is therefore not unexpected that a series of old Norwegian girder-stiffened suspension bridges (with apparently high structural damping values) behave much better in reality than predicted by Selberg. It is to be feared that the damping in modern, "clean" and composite structures is fairly low which has a consequent reverse effect in the stabilizing effort.

The damping capacity of a structure is a perfidious quantity. It is hard to predict, and most complicated to improve, at least within the topological frame of the original structure.

It is felt that Selberg's damping results [13] of a series of the Norwegian short span bridges should be regarded with sound scepticism when speaking of modern structures.

The relative merits of the alternating type of fairings are maintained in the results of Figs. 8 and 9. This indicates that fairings might be the life-saver for channel sections provided the improvement asked for is not more than say 30%.

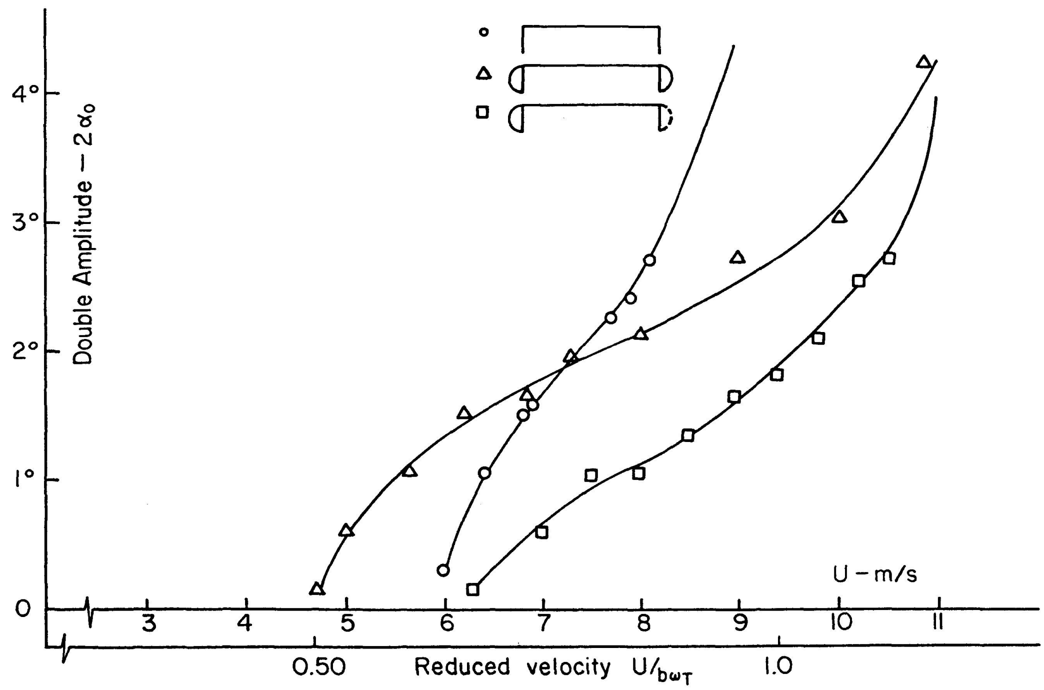

Fig. 9. The flutter torsional response. Models tested with stiff rig, $N_T/N_V = 1.3$.

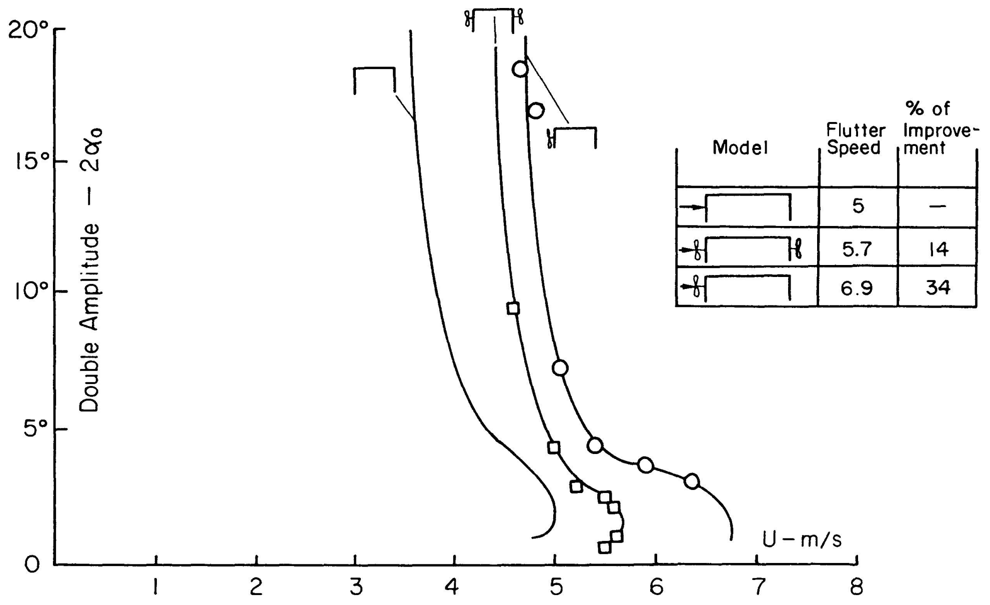

Fig. 10. Effect of propellers on the torsional response.

Response curves obtained with propellers are given in Fig. 10. The results show the benefit of modifying the flow pattern over the deck. The best of the two propeller arrangements gives approximately the same contribution to stabilization as the alternating type of fairings did.

It is however doubtful that a designer would be convinced, at this stage, about possible advantages of stabilizing propellers. They took funny, not least from the fact that the model versions (4 blades, outside diameter 100 mm i.e. more than twice the depth of the girder itself) resembled closely the propellers made by children playing with paper origami in jolly moments.

The response curves given for the family of sections derived from the channel form are those for the torsional oscillation which in fact was dominating. However it should be mentioned that in many cases some coupling with the vertical mode was observed.

The degree of coupling was indicated by the shift in the apparent axis of rotation. The shift of axis relative to longitudinal axis was quite high for section Nos. 11, 12, 14 and 16 on one extreme and very small for the basic channel section on the other hand.

H-Sections

While addition of suitable fairings to the channel section improved the aerodynamic stability to a marked extend, this beneficial effect is proved to be less pronounced when the basic section is of an H-form as shown in Figs. 11 and 12. Moreover, the reduced wind velocities obtained for the three members of the H-section family are so low compared to the corresponding channel section results that no motivation for further improvement of the H-section is found in this work.

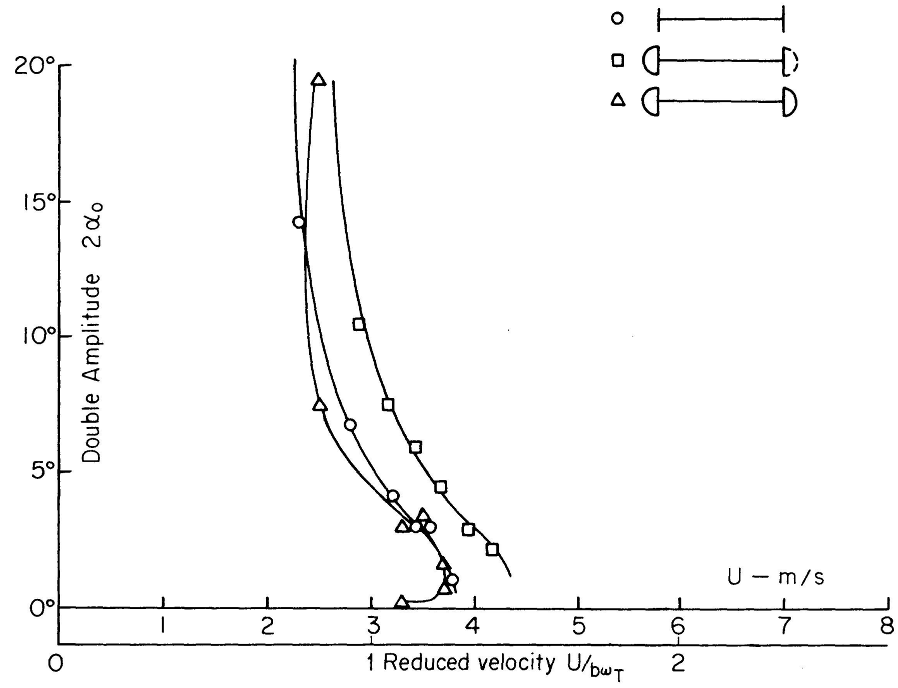

Fig. 11. The flutter torsional response. Models tested with flexible rig, $N_T/N_V = 1.8$.

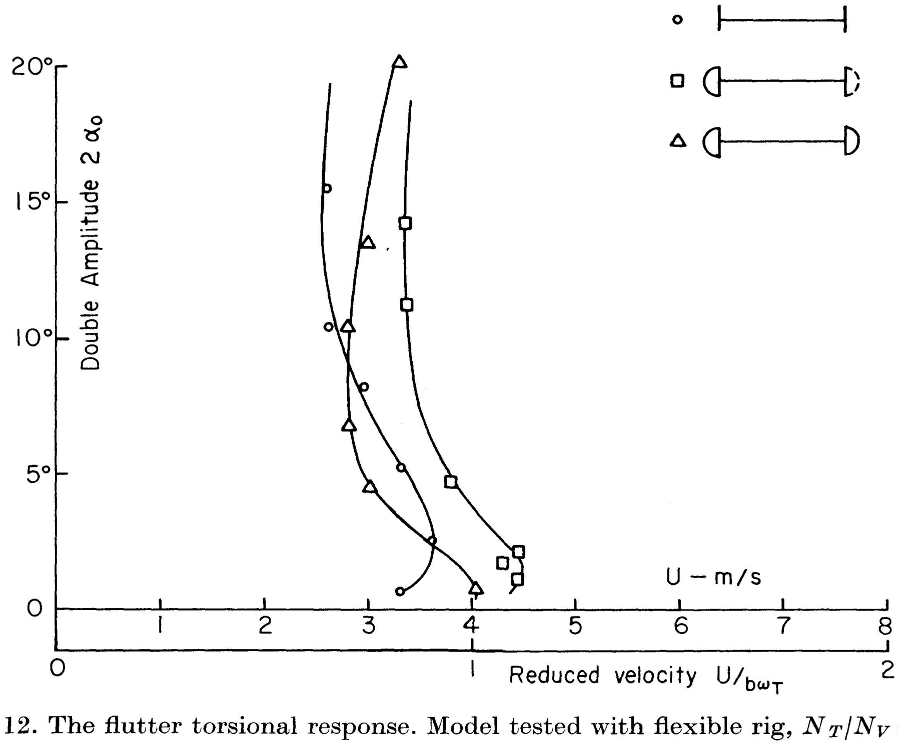

Fig. 12. The flutter torsional response. Model tested with flexible rig, $N_T/N_V = 1.3$.

Comments on Extrapolation of Model Results from one Level of Damping to Another

In two earlier papers [16], [17] SCANLAN and SABZEVARI proposed the following mathematical model for analysing the suspension bridge flutter problem:

$$\ddot{h} + 2\,\zeta_h\,\omega_h\,\dot{h} + \omega_h^2\,h = H_1\,\dot{h} + H_2\,\dot{\alpha} + H_3\,\alpha\,, \tag{1}$$

$$\ddot{\alpha} + 2\,\zeta_\alpha\,\omega_\alpha\,\dot{\alpha} + \omega_\alpha^2\,\alpha = A_1\,\dot{h} + A_2\,\dot{\alpha} + A_3\,\alpha\,, \tag{2}$$

where the vertical and rotational displacements are represented by h and α respectively. ζ_r is mechanical damping ratio with respect to critical (in $r = h$ or α degree of freedom) and ω_r denotes natural undamped frequency ($r = h$ or α).

H_i and A_i ($i = 1, 2, 3$) are aerodynamic coefficients to be evaluated experimentally for each bridge deck model as a function of reduced velocity. Due to inherent nonlinearities in the aerodynamics involved these coefficients are also amplitude dependent, but for the present time those values appropriate for the on-set of flutter instability are considered. A catalogue of such coefficients is given by SCANLAN and TOMKO [18].

The attention is now drawn to the problem of predicting the changes in flutter velocity due to any change in the mechanical damping value. This discussion is limited to cases where damping plays an important role such as the case of the basic H- or channel sections dealt with experimentally in this work. From the experiences with these two sections it is correct enough to put $\dot{h} = 0$, $A_1 = 0$ (case of no bending flutter) and $A_3 = 0$ (because of no significant deviation in torsional frequency from that of no wind conditions). Hence Eqs. (1) and (2) are reduced to:

$$\ddot{\alpha} + 2\left(\zeta_\alpha - \frac{A_2}{2\,\omega_\alpha}\right)\omega_\alpha\,\dot{\alpha} + \omega_\alpha^2\,\alpha = 0\,. \tag{3}$$

Hence the effective damping of the model motion with wind blowing and that of the prototype are respectively:

$$\gamma_{model} = \left(\zeta_\alpha - \frac{A_2}{2\,\omega_\alpha}\right)_{model} \tag{4}$$

and

$$\gamma_{prototype} = \left(\zeta_\alpha - \frac{A_2}{2\,\omega_\alpha}\right)_{prototype}. \tag{5}$$

Combining Eqs. (4) and (5) as to eliminate the aerodynamic term, thus resulting in:

$$\gamma_{prototype} = \gamma_{model} + [(\zeta_\alpha)_{prototype} - (\zeta_\alpha)_{model}] \tag{6}$$

or in terms of the corresponding logarithmic increment (or decrement) we will have:

$$\delta_{prototype} = \delta_{model} + [(\delta_\alpha)_{prototype} - (\delta_\alpha)_{model}]\,. \tag{7}$$

Expression (7) indicates that the logarithmic decrement (or increment) of the prototype is that experienced in the tunnel with model mechanical damping being subtracted and the prototype damping substituted. Of course the same argument is also valid for uncoupled bending flutter provided the corresponding values of vertical damping are substituted in Eq. (7).

So by such a procedure it is possible to predict the horizontal shift of points of the response curve on $2\,\alpha_0 - \frac{U}{b\,\omega}$ plots caused by not fulfilling of the similarity requirement of having identical damping values between model and prototype, see SCRUTON [5] and SELBERG [13].

The prediction of the behaviour of the basic channel section at $+5$ degrees angle of attack and for higher level of damping is made from the measurement of logarithmic increment on the same configuration but at a much lower damping value. The plot of logarithmic increment for section No. 10 tested at $+5°$ angle of wind incident is presented in Fig. 13. The amplitude level for which the plot of Fig. 13 is valid is about 2 degrees double amplitude.

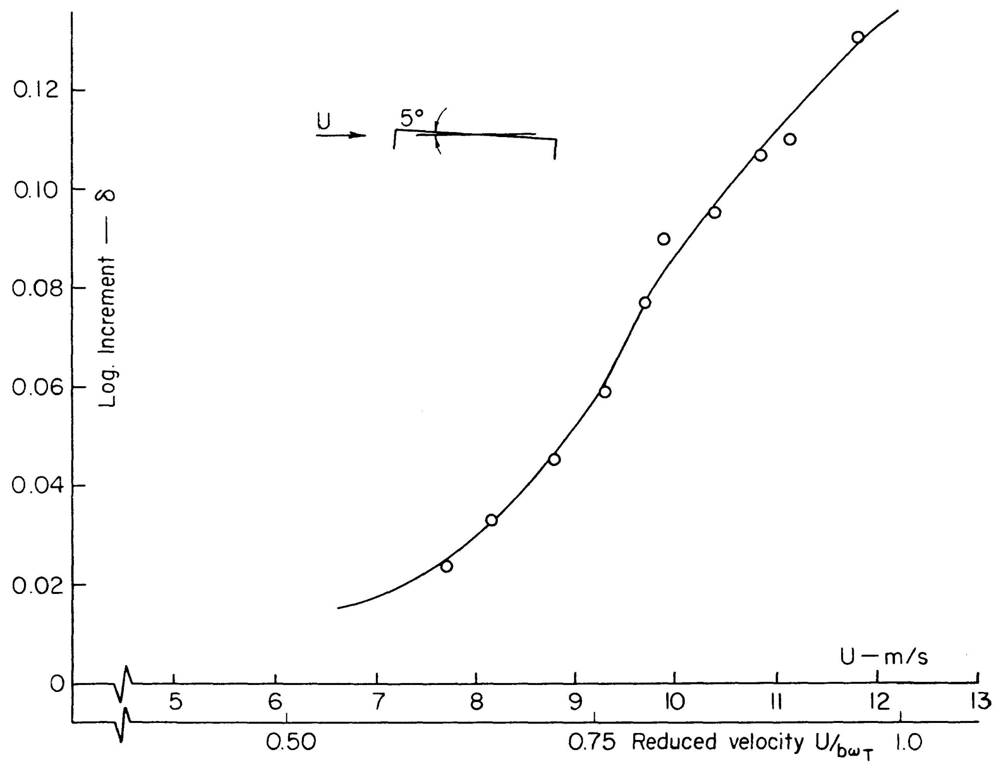

Fig. 13. Plot of logarithmic increment vs. velocity for the channel section at 5° angle of attack.

Conclusions

The following conclusions are drawn from the investigations carried out in this work.

1. The aerodynamic stability of simple channel sections can significantly be improved by attachment of suitable fairings to its side faces. While fairings, within the range of frequency ratios considered in this work, proved to render stabilizing effects to channel section, round- or sharp-edge fairings did not have marked effect on that of the H-section.

2. For even the fairings to be effective, the bridge deck must be torsionally sound, that is, bridges with very small torsional stiffness ($N_T/N_V = 1.3$) have little chance of withstanding to even moderate wind velocities. Thus for any type of girder-stiffened design where the lateral stiffening structure lies essentially in one plane, addition of a second set of lateral stiffeners for increasing the torsional resistance is unavoidable. This conclusion is in conformity with the well documented records of aeroelastic oscillations of Old Tacoma Narrows and the Golden Gate suspension bridges.
3. It is interesting to observe that the addition of fairings in small lengths in an on-and-off pattern has yielded equally good, if not better, results as compared to those with continuous fairings.
4. A simple technique is described for estimating the on-set of flutter (single degree) for a prototype from the model tests with damping values not necessarily equal to that of the prototype.

Notation

A_i Aerodynamic coefficient.
b Deck cord of basic sections No. 10 or 20.
H_i Aerodynamic coefficient.
h Vertical displacement.
n Number of cycles.
N_i Frequency ($i = T, V$).
U Wind velocity.
α Rotational (torsional) displacement.
δ Logarithmic decrement or increment.
ζ_r Mechanical damping ratio with respect to critical ($r = h$ or α).
γ_r Recorded damping ratio (r = model, prototype).

Acknowledgements

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References

1. SMITH, F. C., and VINCENT, G. S.: Aerodynamic Stability of Suspension Bridges, Part II, Mathematical Analysis, Bulletin No. 116, Part 2, p. 14–20, University of Washington Engineering Experiment Station, Oct. 1950.
2. FARQUHARSON, F. B., VINCENT, G. S. and SMITH, F. C.: Aerodynamic Stability of Suspension Bridges, Bulletin No. 116, Parts 1–5, University of Washington Engineering Experiment Station, 1949–1954.
3. VINCENT, G. S.: Summary of Laboratory and Field Studies in U.S. on Wind Effects on Suspension Bridges, Symp. Wind Effects on Buildings and Structures, N.P.L., England, paper 20, 1965.
4. BLEICH, F. et al: The Mathematical Theory of Vibration in Suspension Bridges, Bureau of Public Roads, 1950.
5. SCRUTON, C.: Experimental Investigation of Aerodynamic Stability of Suspension Bridges with Special Reference to Proposed Severn Bridge, Proc. Institution of Civil Engineers, London, Vol. 1, Part 1, No. 2, March 1952.
6. SELBERG, A.: Oscillation and the Aerodynamic Stability of Suspension Bridges, Acta Polytechnica Scandinavia, Ci 13, 1961.
7. HIRAI, A.: Aerodynamic Stability of Suspension Bridges Under the Influence of Wind Load, Bauingenieur, Berlin, Vol. 31, No. 11, Nov. 1956.
8. KLÖPPEL, K. und WEBER, G.: Teilmodelversuche zur Beurteilung des aerodynamischen Verhaltens von Brücken, Der Stahlbau, Berlin, Heft 3 und 4, 1963.
9. STÜSSI, F. und ACKERET, J.: Zum Einsturz der Tacoma-Hängebrücke. Schweiz. Bau, No. 117, 1941.
10. Proceedings of International Symposium on Wind Effects on Buildings and Structures, N.P.L. 26–28 June 1963, Teddington, England.
11. Prooceedings of International Symposium on Suspension Bridges, Laboratório Nacional de Engenharia Civil, 7–10 November 1966, Lisbon, Portugal.
12. Proceedings of Third International Conference on Wind Effects on Building and Structures, Tokyo University, 6–11 September 1971, Tokyo, Japan.
13. SELBERG, A.: Damping Effect in Suspension Bridges, IABSE Publication, Vol. 10, 1950.
14. WARDLAW, R. L.: Some Approaches for Improving the Aerodynamic Stability of Bridge Road Decks, Proc. 3. International Conference on Wind Effects on Buildings and Structures, Tokyo, Paper IV-28, September 1971.
15. FRANDSEN, A. G.: Wind Stability of Suspension Bridges, Application of the Theory of thin Airfoils, International Symposium on Suspension Bridges, paper No. 43, Lisbon 1966.
16. SABZEVARI, A. and SCANLAN, R. H.: Aerodynamic Instability of Suspension Bridges, Proc. ASCE Journal of Engineering Mechanics Division, Vol. 94, No. EM 2, April 1968.
17. SCANLAN, R. H. and SABZEVARI, A.: Experimental Aerodynamic Coefficients in the Analytical Study of Suspension Bridge Flutter, Journal of Mechanical Engineering Science, Vol. 11, No. 3, June 1969.
18. SCANLAN, R. H. and TOMKO, J. J.: Airfoil and Bridge Deck Flutter Derivatives, Proc. ASCE Journal of Engineering Mechanics Division, December 1971.

Summary

The aeroelastic behaviour of simple girder-stiffened suspension bridges is revisited. It is shown that while attachment of round- or sharp-edge fairings to wind and leeward sides could improve the aerodynamic stability of channel sections, fairings would not affect that of H-sections, at least within the frequency ratio range of $N_T/N_V = 1.3 - 1.8$.

Extrapolation of a bridge deck behaviour from that of the corresponding model tested at a different level of damping in the wind tunnel is discussed.

Résumé

On revoit dans ce travail le comportement aérodynamique des ponts suspendus à poutre raidissante simple. On montre que l'emploi de carénages arrondis ou aigus pour le côté exposé au vent et pour le côté abrité du vent peut augmenter la stabilité aérodynamique des sections en U, alors que pour les sections en double Té, elle n'est pas influencée par les carénages, du moins pour le domaine des rapports de fréquence $N_T/N_V = 1{,}3 - 1{,}8$.

On discute ensuite l'extrapolation pour le comportement d'un tablier de pont à partir d'essais sur modèles testés en soufflerie à différents niveaux d'amortissement.

Zusammenfassung

Das aeroelastische Verhalten einfacher trägersteifer Hängebrücken wird neuerlich untersucht. Es wird gezeigt, dass die Anbringung runder oder scharfkantiger Enden an den Wind- und Leeseiten die aerodynamische Stabilität von Kanalquerschnitten verbessern konnte, während sie für H-förmige Querschnitte nicht beeinflusst wird, zumindest nicht innerhalb des Frequenzverhältnisses von $N_T/N_V = 1{,}3 - 1{,}8$.

Es wird dann die Extrapolation des Verhaltens einer Brückenfahrbahn gegenüber jenem eines entsprechenden Modells bei Versuchen von verschiedenen Dämpfungsniveaus im Windkanal diskutiert.