Aerodynamic Characteristics of Truss-stiffened Suspension Bridges by the Arrangement of Structural Members

(Received May 24, 1979)

by Yoshinobu KUBO,[1] Kusuo KATO,[2] Masaharu SHIGEHIRO,[3]
Toshio MIYATA[4] and Manabu ITO[5]

SYNOPSIS

The aerodynamic instability of complexed structures as the truss-stiffened suspension bridges should be investigated by the only arrangement of structural members at the first step of their aerodynamical design. At the second step of the design, it should be considered to improve the aerodynamic instability by attaching the proper shape plates (fin, flap, etc.) to the structurally designed sections, which have the effect to offer more stable sections of suspension bridges as a result of changing the pattern of separation flow around deck plate. However, the investigation at the first step has not been carried out systematically on the point of view of the arrangement of structural members in conventional researches about the aerodynamic characteristics of suspension bridges. It is discussed in this paper that the aerodynamic stability of truss-stiffened suspension bridges remarkably depends on the arrangement of structural members of main truss.

1. INTRODUCTION

Recent years a lot of researches about the improvement of aerodynamic instability of truss-stiffened suspension bridges have been done. When the flutter oscillation of suspension bridges is investigated, it must be considered which member mainly influences the flutter phenomena. As the flutter of suspension bridges is assumed to be the stall flutter which is caused by the separation flow from the upstream members, the conventional works have been taking the standpoint that the dominant members to the flutter are the handrails and the curbs which are placed at the ends of bridge deck. However, the upper chords of structural frames are located outer than the handrails and their sizes of long-span bridges are similar to the height of handrails, therefore the location of the chords may have similar effects to the flutter oscillation as those of the height of handrails. But recent researches about the improvement of aerodynamic instability have been focussed on changing the structurally designed section to the aerodynamically stable one without considering the arrangement of structural members. They may be roughly divided into two researches. These have been examined by putting proper shape plates (fin, flap, etc.) on the ends of bridge deck,[1)2)] and the vertical plate on the central reserve of that.[3)] The former tries to improve the aerodynamic instability by changing the pattern of separation flow from the upstream members, the latter by changing the reattachment of separation flow. In any case, they alter the structurally designed original shape to an aerodynamically stable one by attaching some plates to the original shape. This means that the design of long-span bridges has been accomplished by means of separating the structural and

---

1) Dr. Eng., Lecturer, Dept. of Civil Engineering, Kyushu Institute of Technology.

2) Research Assistant, ditto.

3) M. Eng., Kitakyushu-city Office.

4) Dr. Eng., Associate Professor, Dept. of Civil Engineering, University of Tokyo.

5) Dr. Eng., Professor, ditto.

the aerodynamical designs without considering the arrangement of structural members.

The work of this paper is to investigate how the aerodynamic responses are influenced by changing the arrangement of structural members and which member of the main truss is dominant to the flutter of suspension bridges. The experiments are carried out by focussing on the relations among the aerodynamic responses and the settlement of deck plate and structural members of main truss.

2. MODELS IN EXPERIMENTS

The following experimental cases are adopted to investigate the aerodynamic stability of suspension bridges by the arrangement of structural members. Fig. 1 shows the cross-section of original model which has the dimensions in experiment, the length of 1.060 m, the weight of 5330 g/m, the moment of inertia of 15.60 g.m.s^2/m, the frequency of torsional oscillation of 3.47 hz, the frequency of bending oscillation of 1.73 hz, and the logarithmic decrement of structural damping in torsional oscillation of 0.0026 to 0.0036 (which depends a little on the torsional double amplitudes 2ϕ). Fig. 1 is used for the explanation of the following experimental cases.

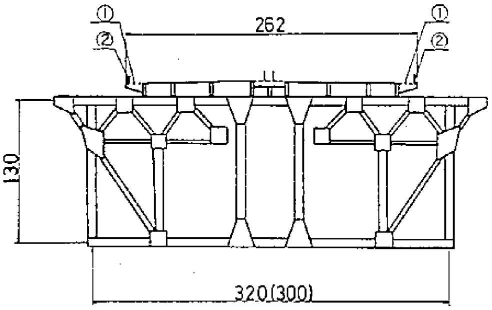


Fig. 1 Cross-Section of Original Model (mm)

Case 1: T-30-O, T-32-O; the original sections with the width of main truss of 30 cm and 32 cm, respectively.

Case 2: T-30-C, T-32-C; the modified sections by covering the gratings ① at the both ends of original models with thin plates.

Case 3: T-30-H_i, T-32-H_i; the modified sections by covering the gratings ① and the handrails ② of the original models, in both cases H_5 and H_{10} mean half and full covered handrails, respectively.

If there is the difference of aerodynamic responses between T-30 and T-32, it is probably based on the difference of width of main truss because the difference of width will make change the pattern of separation flow from the upstream upper chords of main truss. Case 3 is adopted to observe the region of path of separation flow from the upstream upper chords. If there is no difference of the responses, the separation flow from handrails is probably dominant to the flutter oscillation in this case and the layer of separation flow from the upper chords is assumed to be very thick.

Case 4: T-32-D_h; the 32 cm width original sections with the deck plate of the height of h mm from the main truss.

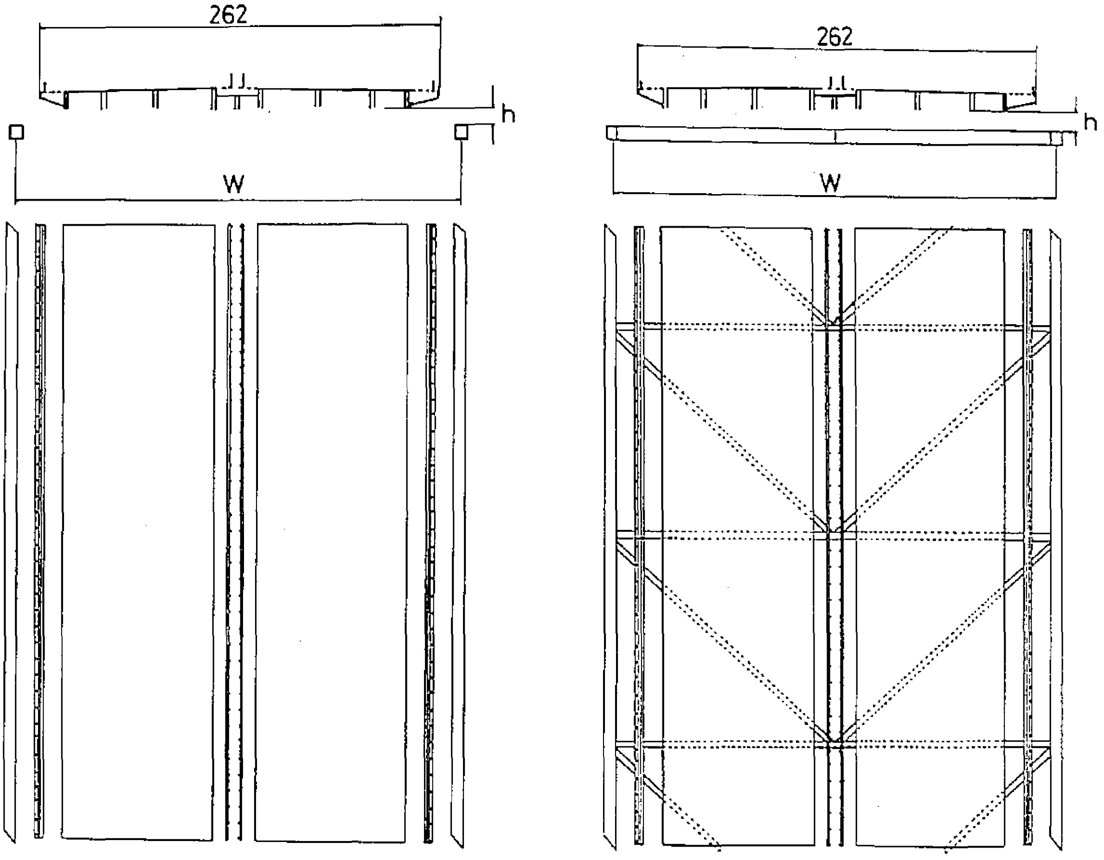
This case is chosen to investigate how the aerodynamic responses are influenced by alteration of the height of deck plate from main truss. As it is difficult to make the model with continuous alteration of width of main truss, the alteration of width is replaced with that of height of deck plate from main truss, for it is assumed that the pattern of separation flow is similar in both alterations.

Case 5: TM-W-D_h; the modified models which have the only upper chords of main truss and the deck plate of original section with the height of h mm from the upper chords. The width W is changed in 5 steps of 26, 28, 30, 32 and 34 cm.

Fig. 2 (a) gives the reference to the explanation of Case 5. This case will supply the informations about the effect of upper chords to the flutter oscillation of suspension bridges.

Case 6: TK-W-D_h; the modified sections with the upper side K-truss of main truss of the width W the same as Case 5 and with the deck plate whose height is h mm from the upper side K-truss.

Fig. 2 (b) is K-truss for Case 6. The last case will teach us the influence of K-truss which has



(a) Model for Case 5

(b) Model for Case 6

Fig. 2 Cross-Section of Modified Models (mm)

diagonal and lateral members between both upper chords. The pattern of separation flow may be changed by the diagonal members after the upstream upper chords in the direction of main flow.

It will be made clear from the results of the above mentioned cases that the arrangement of structural members is important in the investigation of the aerodynamic responses of truss-stiffened suspension bridges.

3. RESULTS OF WIND TUNNEL TESTS

The experiments are carried out in focussing on obtaining the aerodynamic responses by using the two-dimensional models with angles of attack (α) of 0°, ±2°, ±4°, ±6°. The results are shown in Figs. 3 to 7 whose abscissas and ordinates have the dimensions of wind velocity (V) and double amplitudes of torsional oscillation (2ϕ), respectively.

(a) Test of Case 1 (Fig. 3)

Both sections have no responses of steady state oscillation at the angle of attack smaller than those of 0° over the wind velocity in experiments. Concerning the critical wind velocity (V_{cr}) which causes abruptly the torsional flutter of suspension bridges, V_{cr} of the model with narrow width of main truss is higher than that of wide one at all angles of attack. The model with narrow width is more favourable in aerodynamical design than the wide one in this case.

(b) Tests of Case 2 and 3 (Fig. 4)

The model with narrow width is more stable than the wide one as similar to Case 1 according to the results of Case 2. On the other hand, both

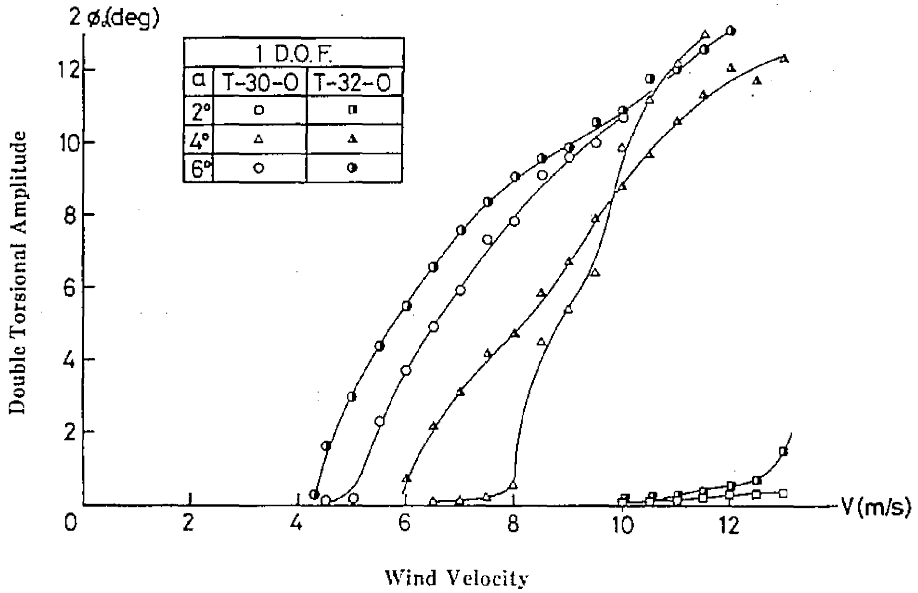


Fig. 3 Responeses of Torsional Oscillation of Case 1

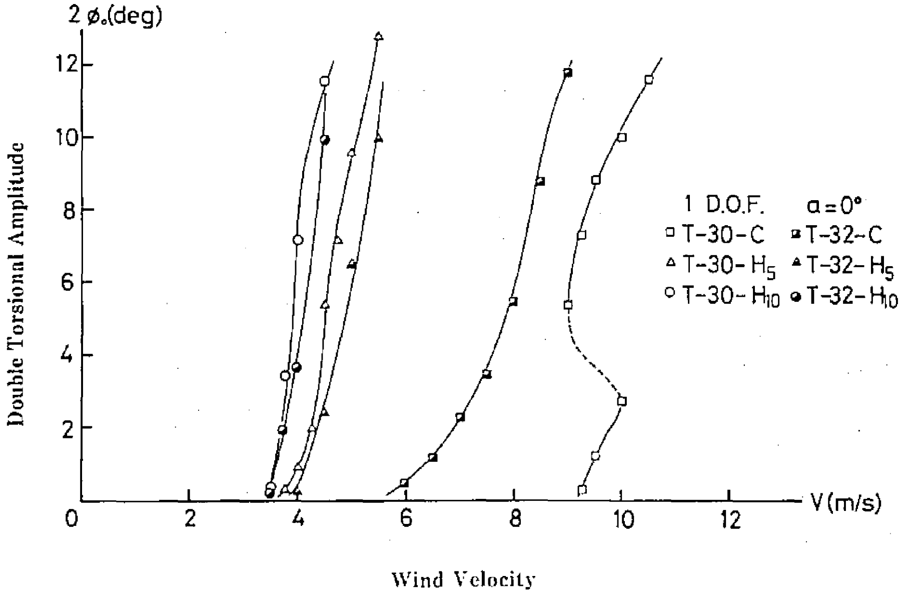


Fig. 4 Responses of Torsional Oscillation of Case 2 and 3

responses of the models with narrow and wide width are nearly equal in Case 3. This means that the plates covering the handrails have the effect to prevent the separation flow from the upper chords from passing over the plates, as a result of that, the flutter oscillation of this case is assumed to be generated by rather the separation flow from the plates than that from the upper chords.

(c) Test of Case 4 (Fig. 5)

According to the results of Case 1 to 3, the aerodynamic responses depend on the width of main truss. Case 4 is used to investigate the influences of the height of deck plate from the main truss to the aerodynamic responses. Fig. 5 is the result of the height of 0 mm to 10 mm of deck plate from main truss with the width of 32 cm at the angle of attack $\alpha = +6^\circ$. This figure shows that the critical wind velocity becomes high with increasing the height of deck plate ·

(d) Test of Case 5 (Figs. 6, 7)

The results of Case 1 to 4 teach us that the aerodynamic responses depend on the width of main truss and the height of deck plate. Case 5 is adopted to investigate the effect of the width of upper chords and the height of deck plate from the upper chords. Figs. 6, 7 show the responses of Case 5 at the angle of attack $\alpha = +4^\circ$, including the case without structural members (i.e. with only deck plate) at the same angle of attack. Fig. 6 is the case of the height of 0 mm and Fig. 7 is that of 4 mm. Concerning the width, the model does not always become more stable with decreasing the width, but there is probably the most suitable width to the aerodynamic responses of suspension bridges. They have the tendency to be unstable with increasing the height except for the case of width 26 cm between both chords.

(e) Test of Case 6 (Figs. 8, 9)

Comparing Case 4 with Case 5, the result of Case 5 has a reverse tendency to that of Case 4 about the influence of the height to the aerodynamic responses. It is assumed that the difference of this tendency is caused by the existence of diagonal members between upper chords. The reponse curves in Figs. 8 and 9 have similar tendency as Case 4. Therefore the aerodynamic responses are delicately influenced by the existence of diagonal members between upper chords.

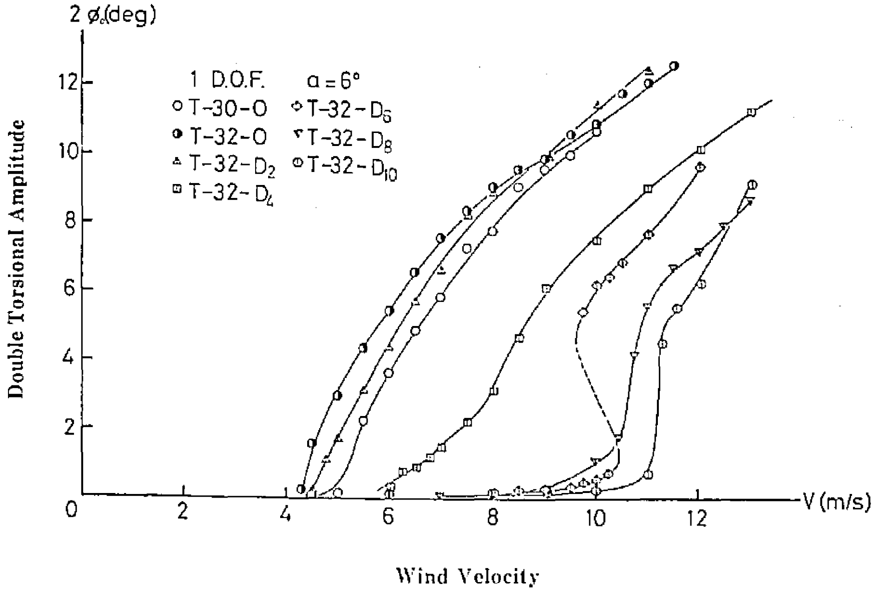


Fig. 5 Responses of Torsional Oscillation according to the Height of Deck Plate from Main Truss (Case 4)

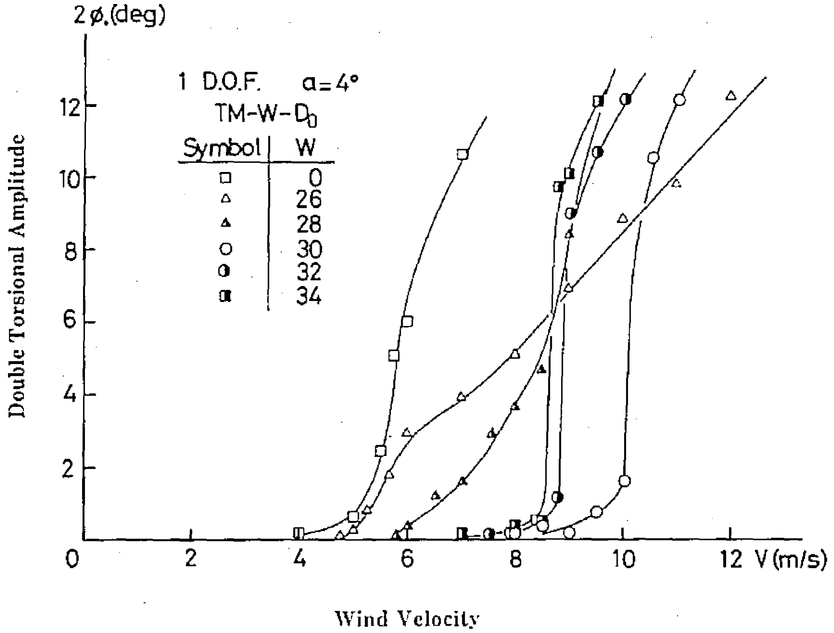


Fig. 6 Responses of Torsional Oscillation of Case 5
(Height of Deck Plate from Upper Chords is 0 mm)

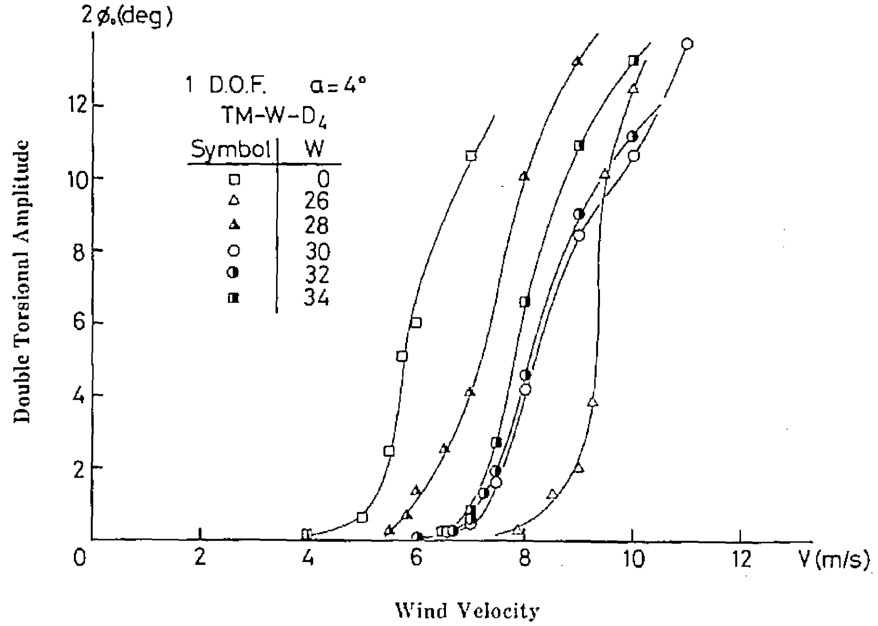


Fig. 7 Responses of Torsional Oscillation of Case 5
(Height of Deck Plate from Upper Chords is 4 mm)

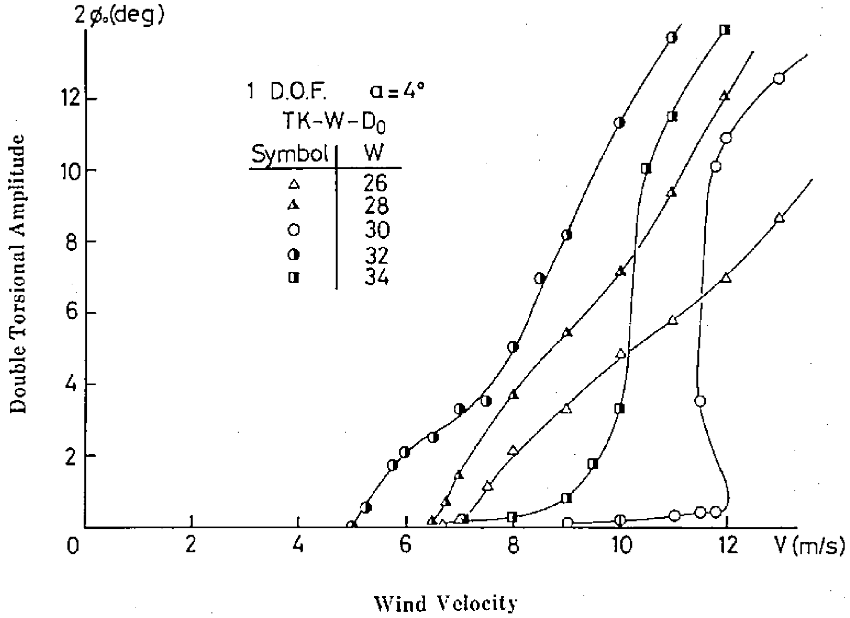


Fig. 8 Responses of Torsional Oscillation of Case 6
(Height of Deck Plate from Upper Chords is 0 mm)

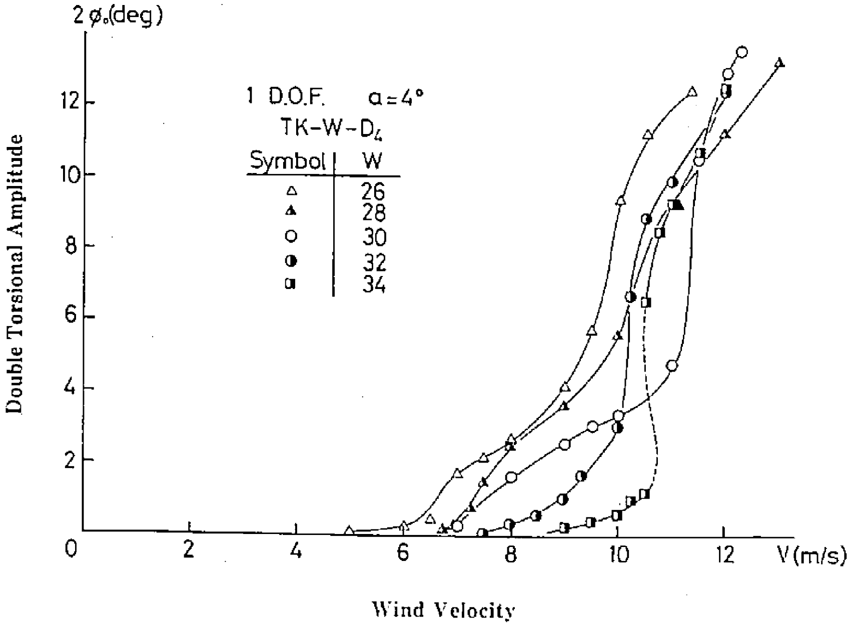


Fig. 9 Responses of Torsional Oscillation of Case 6
(Height of Deck Plate from Upper Chords is 4 mm)

4. CRITICAL WIND VELOCITY ACCORDING TO ARRANGEMENT OF STRUCTURAL MEMBERS

The critical wind velocity is discussed with relation to the height of deck plate from main truss and the width of that. The critical wind velocity in this section means the velocity corresponding to the double amplitudes of $2\phi = 1^{\circ}$ in the response curves.

(1) Critical wind velocity — height of deck plate (the case of constant width of 32 cm of main truss). According to Fig. 10 which shows the relation between the critical wind velocity and the angle of attack, it has the general tendency that the critical wind velocity becomes high at most angles of attack with increasing the height of deck plate from the main truss. In this case, it may be concluded that T-32-D_8 is most favourable section. In order to investigate the effects of K-truss (upper side truss of main truss), Fig. 11 is offered which shows the relation between critical wind velocity and height of deck plate for 3 cases of Case 4, 5 and 6. With respect to the critical wind velocity to the height of deck plate, Case 4 has a reverse tendency to Case 5, but it has the similar one to Case 6. This means that the aerodynamic responses depend on not only the upper chords but also the diagonal members between both chords. It is considered that a little difference between Case 4 and Case 6 is caused by the another members, for example the side trusses and the gasset plates to connect the truss members. It may be concluded that the upper side K-truss mainly influences to aerodynamic responses of truss-stiffened suspension bridges.

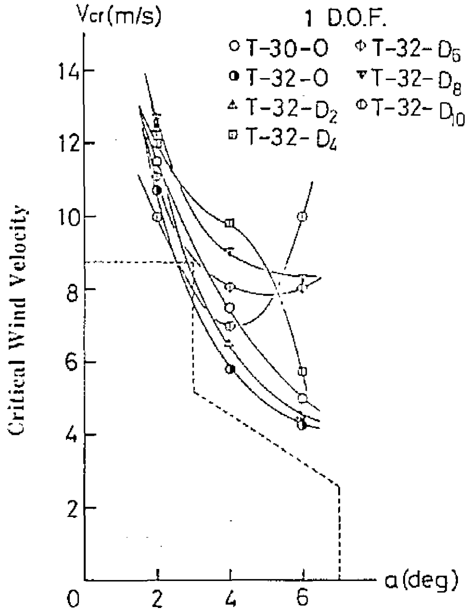


Fig. 10 Critical Wind Velocity to the Alteration of Angles of Attack

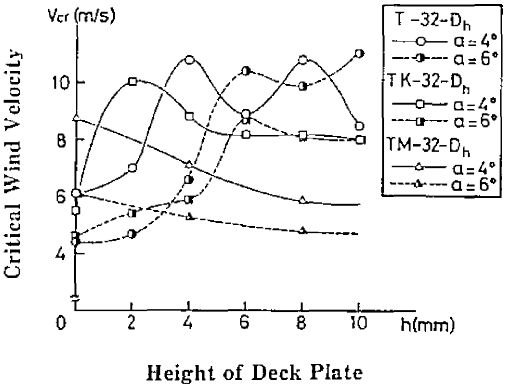


Fig. 11 Critical Wind Velocity to the Alteration of Deck Plate from Upper Height of Chords with Constant Width of 32 cm

(2) Critical wind velocity — width of upper chords (Cases 5 and 6)

Fig. 12 shows the relation between the critical wind velocity and the width of upper chords in the case without the height of deck plate from that. Both cases have similar tendency that the critical wind velocity becomes high with increment of the width of upper chords and takes a maximum value at the width of 30 cm but becomes low with increment of that over 30 cm. The maximum value is about two times as large as the minimum one. This means that the choice of proper width of main truss is very important to improve the aerodynamic instability of long-span suspension bridges.

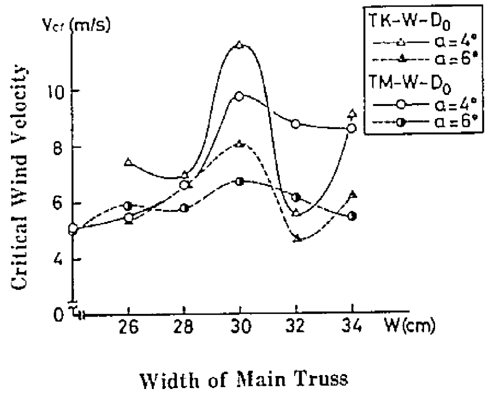


Fig. 12 Critical Wind Velocity to the Alteration of Width of Upper Chords with and without Diagonal Members

5. CONCLUDING REMARKS

The conclusions from the present investigations are followings.

(1) The aerodynamic stability of long-span suspension bridges remarkably depends on the arrangement of structural members.

(2) The flutter oscillations of suspension bridges depend on not only the separation flow upper chords but also the change of flow pattern by the existence of diagonal members between upper chords. The effects of diagonal members appear remarkably in the case of alteration of height of deck plate from main truss.

(3) It is possible to connect the structural and the aerodynamical designs by the consideration of arrangement of structural members in the design of truss-stiffened suspension bridges.

6. ACKNOWLEDGEMENT

This research carried out by the financial support of the bounty for scientific study of Educational Ministry of Japan.

7. REFERENCES

1) Wardlaw, R.L., "Some Approaches for Improving the Aerodynamic Stability of Bridge Road Decks," Proceedings of 3rd International Conference on Wind Effects on Buildings and Structures, 1971, pp. 931-940.

2) Okubo, T., Narita, N., and Yokoyama, K., "Some Approaches for Improving Wind Stability of Cable-Stayed Girder Bridges," Proceedings of 4th International Conference on Wind Effffects on Buildings and Structures, 1975, pp. 241-249.

3) Shiraishi, N., Matsumoto, M., Kojima, H., and Kobayashi, S., "Experimental Investigation on Flutter Characteristics of H-shaped Sections, "Proceedings of 4th Symposium on Wind Effects on Structures in Japan, 1976, pp. 183-190.