AERODYNAMIC CHARACTERISTICS OF H-SHAPED SECTION CYLINDER IN LAMINAR AND TURBULENT FLOWS

by

Yoshinobu KUBO*, Katsuyoshi SAKURAI** and Suikai AZUMA***

SYNOPSIS

The aerodynamic instability of H-shaped section cylinder is investigated in both laminar and turbulent flows by varying structural damping decrement. This cylinder has two types of oscillations under wind action in the same way as the rectangular cylinder. The one is vortex excited oscillation at lower wind velocity, the another is galloping (namely self-excited one) at higher wind velocity.

The experimental results show that these phenomena occur in the remarkably different way between in laminar and turbulent flows. In the laminar flow the vortex excited oscillation occurs clearly at the wind velocity corresponding to the frequency of wake vortex equal to the characteristic frequency of the cylinder, but in the turbulent flow this phenomenon scarcely does and the oscillation becomes mainly galloping one. This oscillation is influenced by the intensity and the scale of turbulent flow adding to the structural damping decrement.

1. INTRODUCTION

Recently it is frequently reported that the hanger of Langer girder bridge, which is usually constructed by H-shaped steel, collapsed at the connection between hanger and girder on account of fatigue of the connection by the wind induced oscillation.

The aerodynamic characteristics of H-shaped section cylinder have not been studied so much in comparison with many studies of those of another bluff bodies, for example circular and rectangular cylinders. It is very important to study the aerodynamic characteristics of H-shaped section cylinder from the view point of the aerodynamical design of hanger of these kinds of bridges in order to prevent above mentioned accidents.

The key of the study is to make clear the mechanism of vortex excited oscillation at lower wind velocity, of galloping one at higher wind velocity and of the transient process from the former to the latter, adding to this to know the characteristics of these phenomena in turbulent flow because the real structures are always in the natural wind with every moment fluctuating velocity. In this paper the structural damping decrement of the system is considered to be one of the parameters influencing the aerodynamic responses in both laminar and turbulent flows, and in turbulent flow two factors are considered, which are the intensity and the scale describing the propers of turbulent flow.

2. EXPERIMENTS

The tests are carried out by the spring balance method in wind tunnel with the test section of 40 × 40 cm and with the wind velocity (V) 0 m/s to 7 m/s. Fig.1 (a) shows the system changing the structural damping decrement continuously by changing the voltage and current to the electro magnet. Fig. 1 (b) shows the system for shaking the active model by making the arm vibrate in constant frequency by exciting the electro magnet in constant time interval from the signal of oscillator. The amplitude in exciting becomes maximum one at the frequency of agreement

---

* Dr. Eng., Lecturer, Dept. of Civil Engineering, Kyushu Institute of Technology.
** Graduate Student, ditto.
*** Okinawa Prefecture Office.

between the characteristic one of main spring and that of sub-spring. This method comes to be able to shake the active model without creating the beat in the responses of active model. Fig.2 shows the active model with the dimension of web width (*B*) of 4 cm and the flange depth (*D*) of 4 cm, the length (*L*) of 38 cm and the thickness (t) of 0.3 cm.

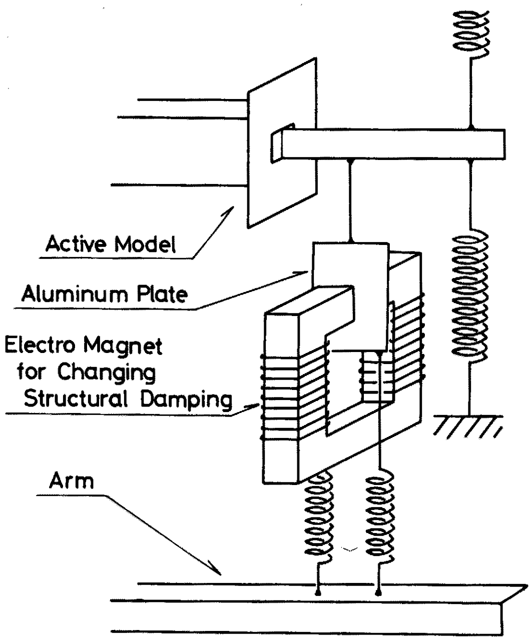

Fig. 1 (a) Equipment for Changing Structural Damping

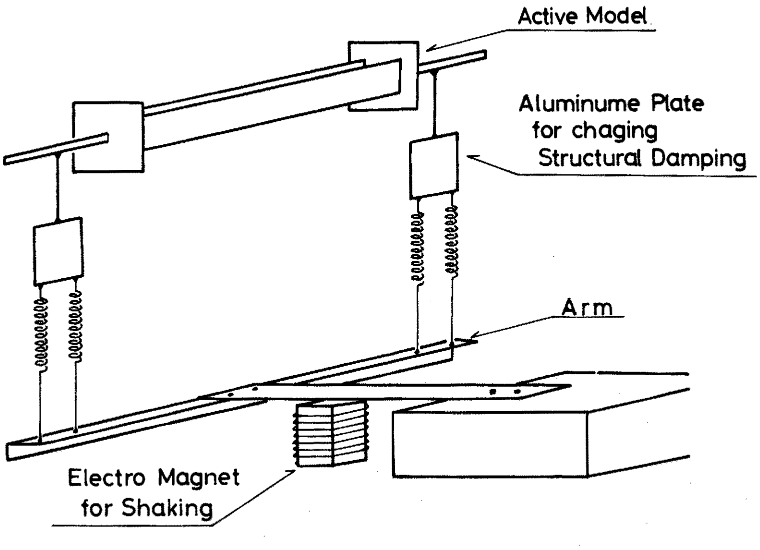

Fig. 1 (b) Equipment for shaking

The test in the turbulent flow is carried out by using the five grids for generating the turbulent flow as shown in Fig. 3 and Table 1 and Fig.4 shows the position of the active model and the grids in the wind tunnel. The fluctuating wind velocity of wake is measured by the hot wire anemometer at the down stream of 15 cm from the active model, the frequency of wake vortex is discussed in comparison with the aerodynamic responses.

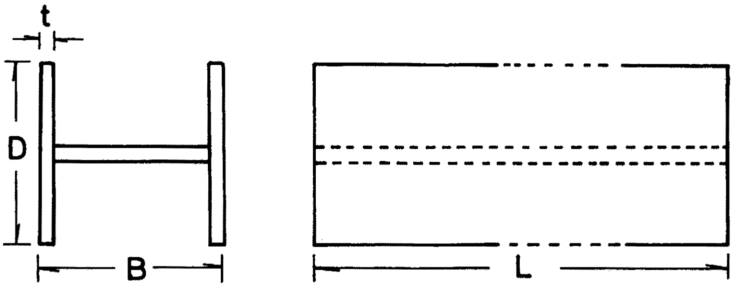

Fig. 2 Active Model

Table 1 Grids for Generating Turbulent Flows

Grid No.	L (cm)	B (cm)	L/B	$\overline{U}$ (m/s)	In (%)	Lx (cm)
I	12.0	2.0	6	4.56	4.40	4.88
II	12.0	3.0	4	4.88	6.26	6.40
III	12.0	4.0	3	5.40	9.90	12.77
IV	8.0	2.0	4	4.60	6.42	7.41
V	16.0	4.0	4	4.08	9.76	6.46

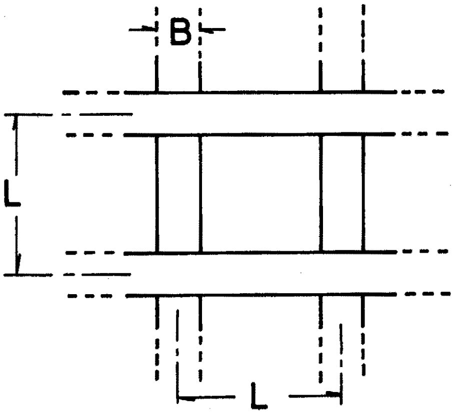

Fig. 3 Grid for generating Turbulent Flow

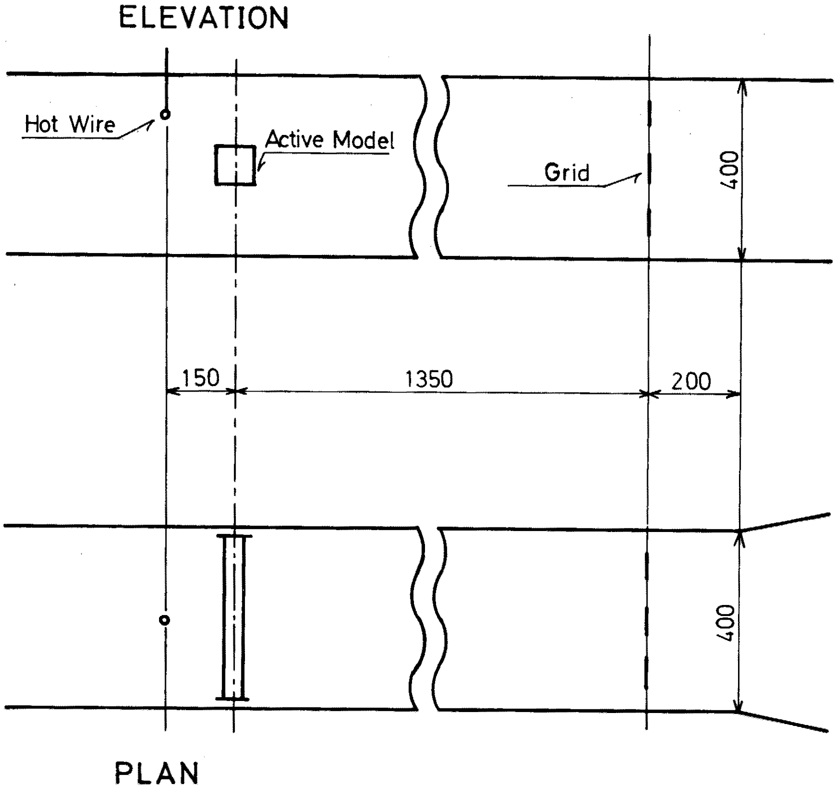

Fig. 4 Position of Grid and Active Model

3. EXPERIMENTAL RESULTS

3.1 Responses at lower wind velocity in laminar flow

Fig.5 shows responses in various structural damping decrements. The typical response curves in larger structural damping decrement are separated into the vortex excited and galloping oscillations. All of the response curves abruptly appears at the wind velocity of 1.38 m/s because the Strouhal number of this cylinder is 0.145 from another test, the characteristic frequency is 4.99 c/s and the representative length is 4 cm. The amplitude of response increases with the increment of wind velocity and has a local maximum value at certain wind velocity (call it the local maximum wind velocity) and abruptly takes small value at the little higher wind velocity than the local maximum wind velocity. These non-linear phenomena at lower wind velocity make difficult the theoretical analysis of aerodynamic responses of bluff bodies. At higher wind velocity the galloping oscillation occurs with stable and unstable limit cycles. This phenomenon is the nonlinear oscillation to be able to analyzed in some extent by the successful method, which is the quasi-steady method using the forces in steady state and the effective angles of attack. But this method is not useful to analyze the vortex excited oscillations at lower wind velocity. It can be seen from the response curve in Fig.6 that the local maximum amplitude occurs at the wind velocity corresponding to the frequency gap of wake vortex from first to second synchronization region. This tendency appears in the response curves which are separated into the vortex excited and the galloping oscillations. In order to find the model to be able to analyze the both non-linear oscillation, it may be useful to find the experimental equations to divide the responses into vortex excited one and galloping one. Fig.7 (a) shows the relation between the structural damping decrements and the local maximum amplitudes, Fig.7 (b) shows the relation between the structural damping decrements and the local maximum wind velocity. These are the results of response curves in large structural damping decrements which are separated into vortex excited oscillations and the galloping one. The purpose is to estimate the amplitudes corresponding to the frequency gap of wake vortex in the responses at lower structural damping decrement which is not separated into two types of oscillations. These plotted curves are assumed to be able to be fitted by the exponential type curves following as

$$V_m = Ae^{-c\delta}+B \quad \text{and} \quad \eta_m/b = A'e^{-c\delta}+B'$$

where V_m is the local maximum wind velocity, δ is the structural damping decrement of the system, η_m is the local maximum amplitude and b is the web width, respectively. The value of the parameters *A, B, C, A', B', C'* are shown in Figs. 7 (a) and (b).

It is considered that these experimental equations correctly estimate the amplitudes corresponding to the local maximum one which appears in the response curves of larger damping decrement, for the local maximum wind velocity appears in the region of frequency gap and the estimated amplitude is on the response curve as shown in Fig.8.

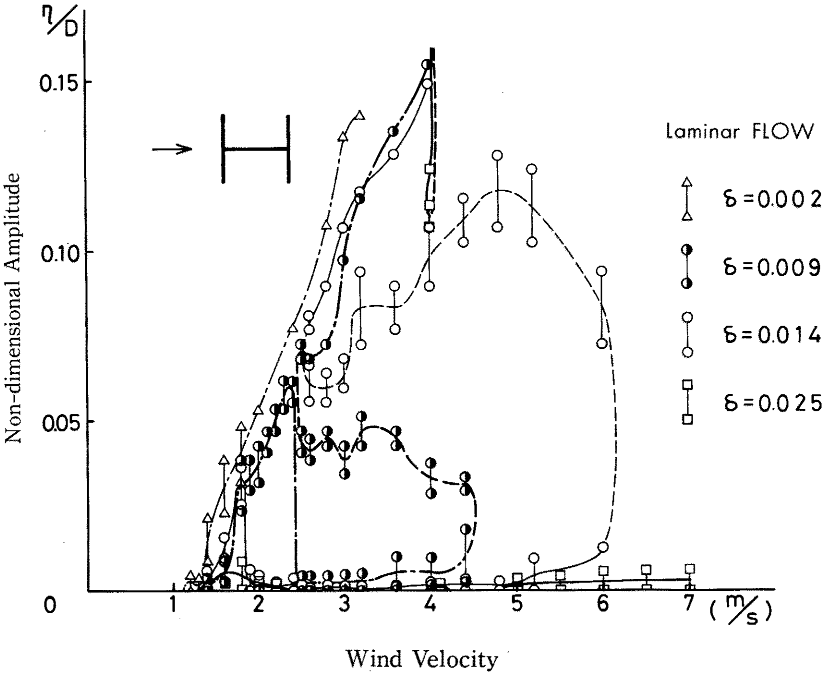

Fig. 5 Responses of H-shaped Section Cylinder in Laminar Flow

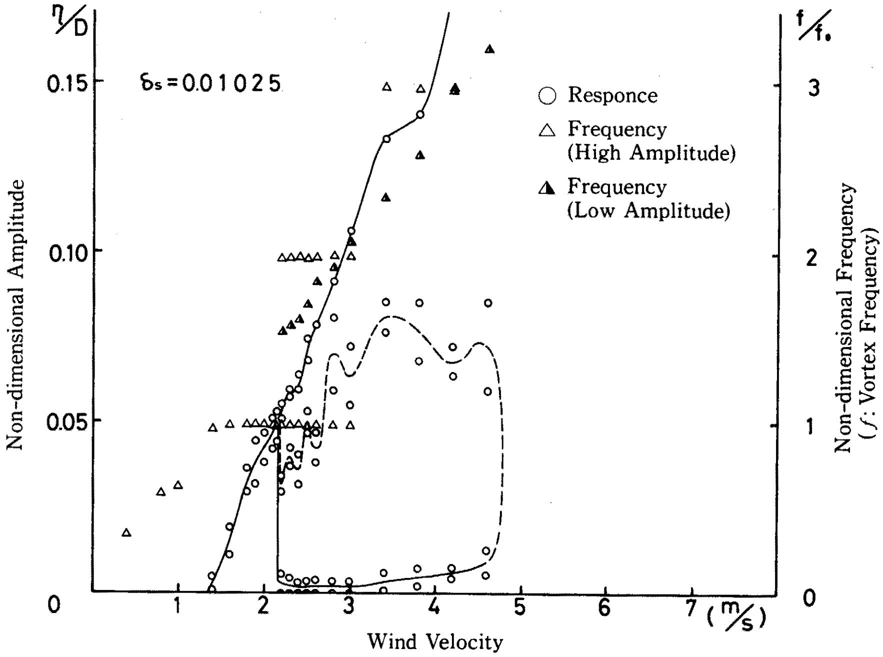

Fig. 6 Responses and Vortex Frequencies in Laminar Flow

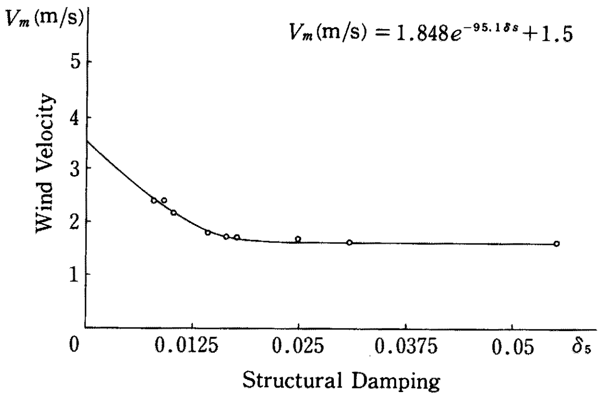

Fig. 7 (a) Wind Velocity of Maximum Amplitude of Vortex-induced Oscilation—St. Damping

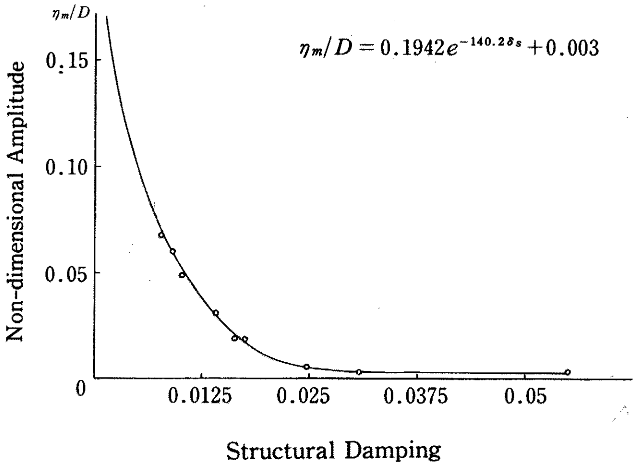

Fig. 7 (b) Maximum Amplitude of Vortex-induced Oscilation— St. Damping

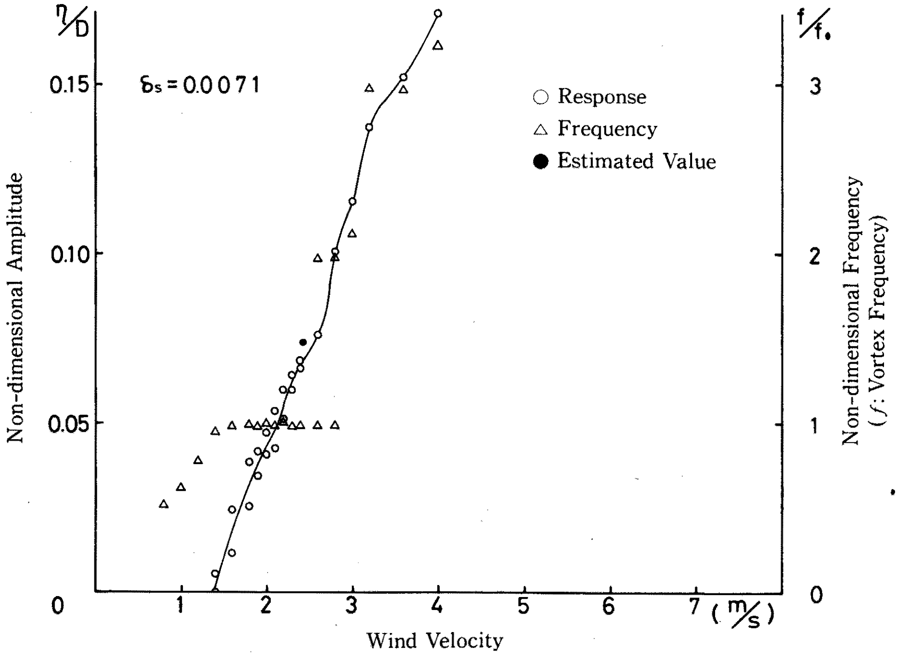

Fig. 8 Responses and Vortex Frequencies in Laminar Flow

3.2 Responses at higher wind velocity in laminar flow

The unstable limit cycle, which is shown by the chain lines in Fig. 5, has the tendency that it extends the region to the higher wind velocity with increment of the structural damping decrements, but the stable limit cycle of high amplitude appears on the similar response curves independently of the structural damping. Adding to this, this stable limit cycles appears in the regions of second and third synchronizations of wake vortex as shown in Figs. 6, 8 and 9. On the other hand, the stable limit cycle of lower amplitude has the frequency of wake vortex of Strouhal component without synchronization. This means that all of the responses with higher amplitude than the certain one have the synchronized wake vortex frequency with harmonics. Consequently, it must be considered that the analysis of the response in the region of galloping should be done by considering the non-linear equation with the effect of harmonics of external forces. From the view point of this, the quasi-steady theory may not correctly describe the phenomenon of galloping, for this theory does not considered the effect of the harmonics of the external forces. The difficulty of higher order synchronization is to have to introduce the model which causes wake vortex frequency gap in continuous response curves.

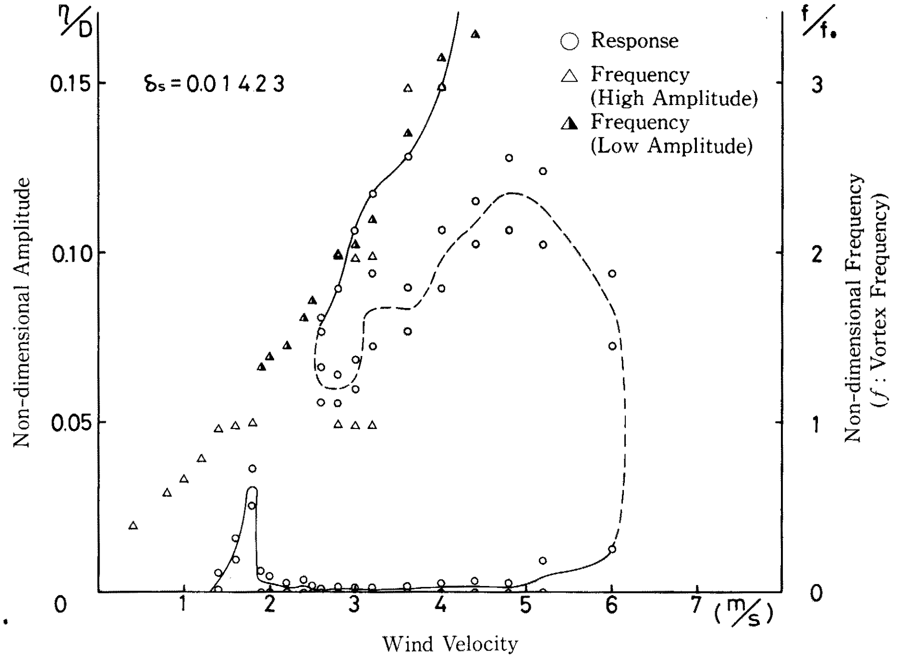

Fig. 9 Responses and Vortex Frequencies in Laminar Flow

3.3 Responses in turbulent flows

The synchronization in laminar flow appears as the weak synchronization in turbulent flow as shown in Figs. 10, 11 and most of the frequency of wake vortex becomes the one according to Strouhal component. The response curves are similar to the stable limit cycle with high amplitude in laminar flow as shown in Fig.12. The remarkable difference in both flows is occurence of strong synchronization or not. The mechanism of oscillation has no essential differences. But the amplitudes of oscillation have the same order in both flows. Consequently, it can be guessed that the real structure has the possibility that the oscillation is easily induced by the turbulent flow, in spite of this, most of the reports, which reports the accidents according to this kind of oscillation, have the stand point that these kinds of oscillations are induced by only laminar flow with lower wind velocity (namely vortex excited oscillation). Fig.13 shows the effect of structural damping decrement to the response in turbulent flow. Increment of damping decrement makes the response curve extend to higher wind velocity similar to that in laminar flow. Figs. 14 and 15 show the effect of scale and intensity of turbulent flow, respectively. The turbulence characteristics are listed in Table 1. These figures show that both parameters have considerable influences to the higher amplitude rather than lower amplitude.

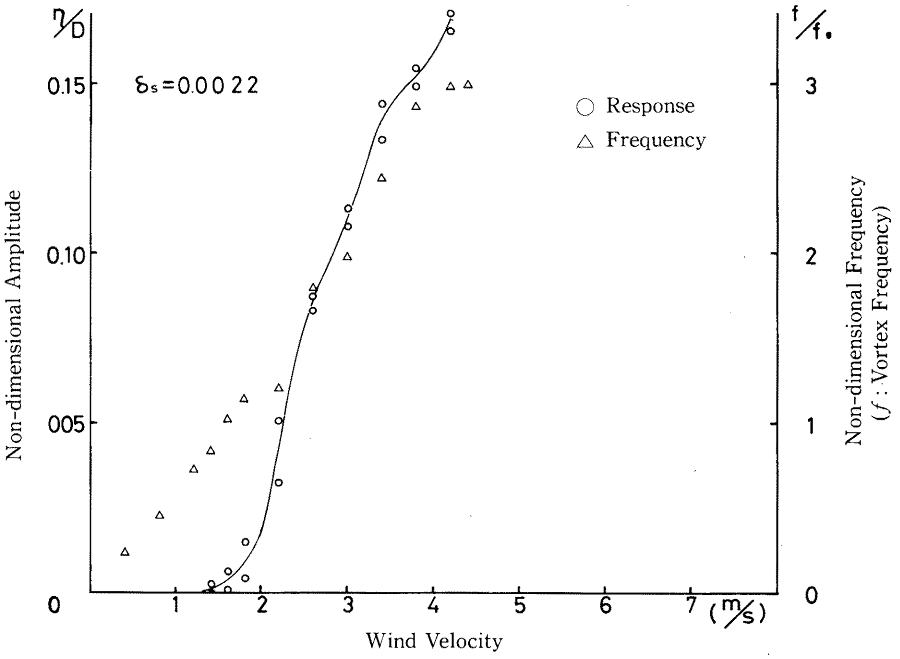

Fig. 10 **Responses and Vortex Frequencies in turbulent Flow by Grid II**

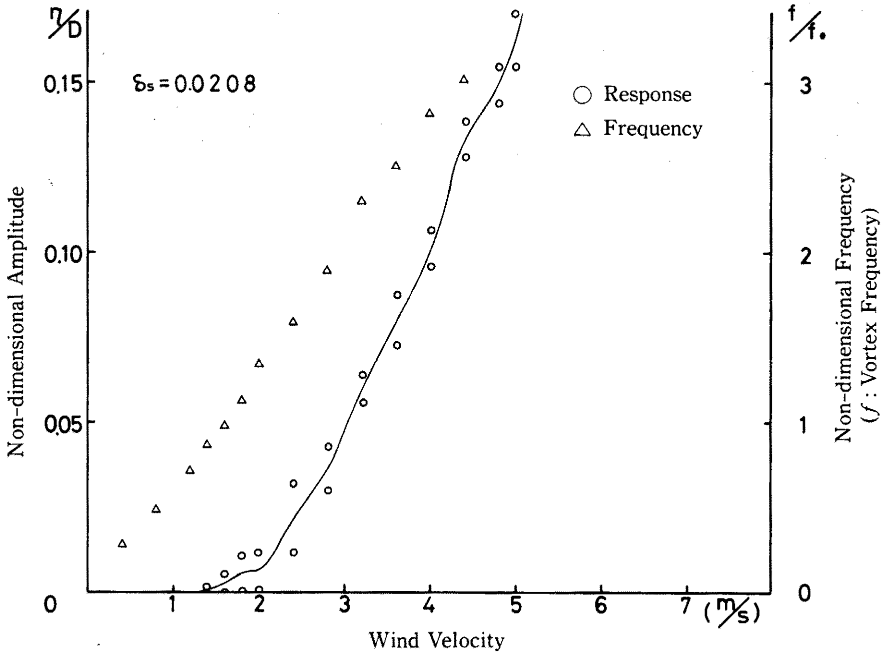

Fig. 11 Responses and Vortex Frequencies in Turbulent Flow By Gird II

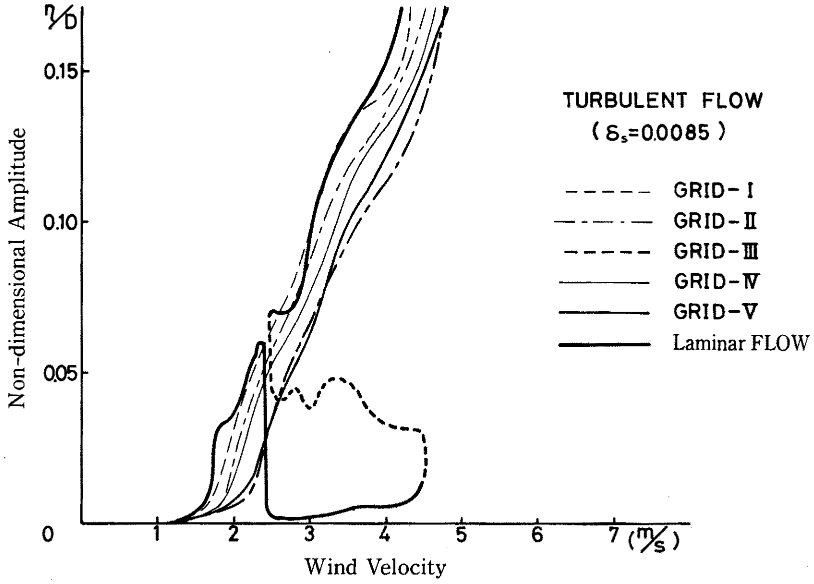

Fig. 12 Responses in Trubulent Flows by Grids.

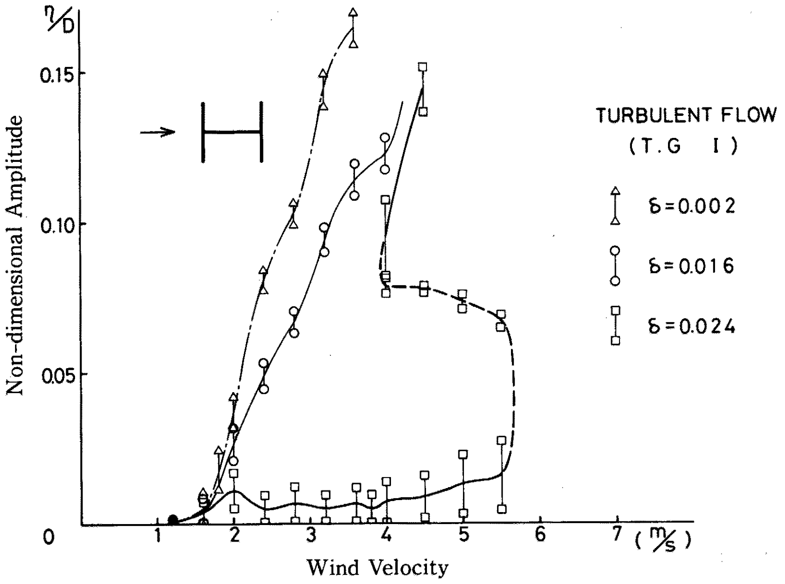

Fig. 13 Responses of H-shaped Section in Turbulent Flow by Grid I

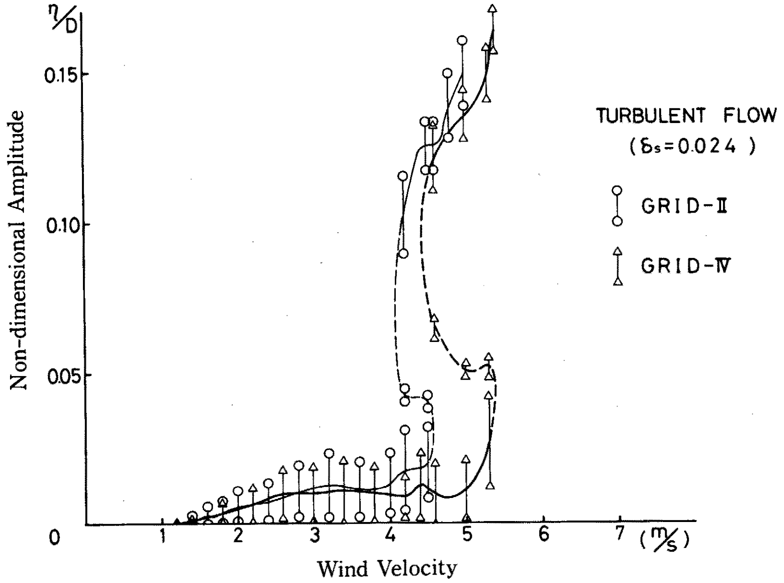

Fig. 14 Responses in Turbulent Flows by Grids.

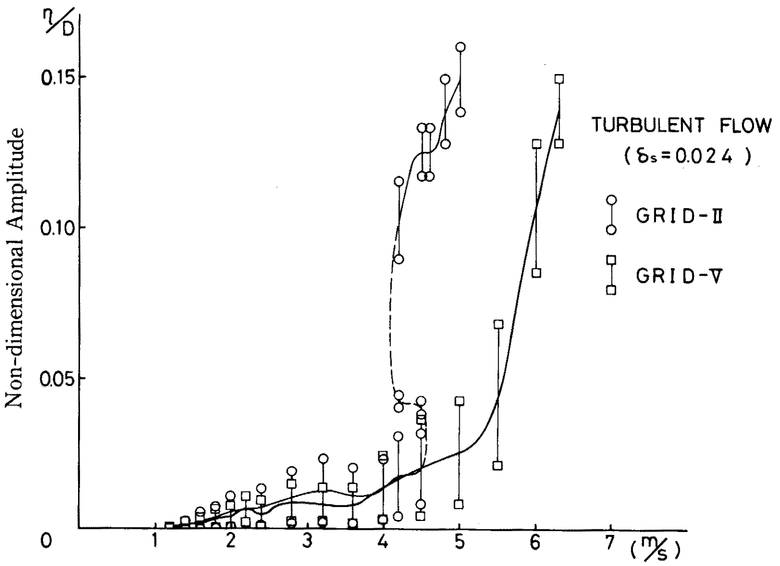

Fig. 15 Responses in Turbulent Flow by Grids

4. CONCLUDING REMARKS

The followings are the conclusions from the present investigation about the aerodynamic responses of H-shaped section cylinder.

(1) The maximum amplitudes in the region of first synchronization can be estimated by the proposed exponential form equations. These equations can be used by setting only the structural damping decrement.

(2) The aerodynamic responses occur at the region of synchronization with harmonics. The conventional consideration has explained the aerodynamic responses of bluff bodies as the two type phenomena which are the vortex excited and the galloping oscillations, but the results from the present investigations supersede the conventional consideration and the two type phenomena are essentially same mechanisms, the differences bwtween two phenomena are dependent only on the order of synchronization. But the lower amplitude responses in higher wind velocity has wake vortex frequency of Strouhal component.

(3) The weak synchronization appears in the responses in turbulent flows. This means that the response mechanism in both laminar and turbulent flows is almost equal. It is considered that the fluctuation of wind velocity in turbulent flow makes weak the synchronization. The structural damping decrement does not influence to the responses of the first synchronization in turbulent flow as strongly as that in laminar flow.

(4) The scale and the intensity of turbulent flow considerably influences to the responses in turbulent flow.

(5) The causes of the accidents by the wind induced oscillation is not always by the vortex excited oscillations (first synchronization) in laminar flow but there is the possibility by the weak synchronization in turbulent flow, for the value of amplitude in the turbulent flow is almost equal to that in laminar flow corresponding to the wind velocity of first synchronization. This means that it needs in design of hanger with bluff bodies to consider the aerodynamic characteristics in both laminar and turbulent flows.

5. REFFRENCES

1) Parkinson, G.V. and Smith, J.D., "The square prism as an aeroelastic nonlinear oscillator", Quart. Journ, Mech. and Applied Math., Vol. 18, Pt. 2, 1964.
2) Hino, M. and Kaneko, D., "Interaction between an oscillating plate and shedding vortices", Proc. JSCE, No. 193, 9. 1971.
3) Kubo, Y., "Wind forces acting on H-shaped sections", Annual Report of Civil Eng. Faculty of Univ. of Tokyo, No. 9, 1972.
4) Yoshimura, T., Nakamura, Y., Yoshimura, T. and Mizuta, Y., "On the aerodynamic stability of slender bridge-hanger", Proc. JSCE, NO. 230, 10, 1974.