FLOW VISUALIZATION AROUND THE TWO PRISMATIC BODIES

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1. Introduction

Long-distance structures with high-drag cross-sections are used during the bridge constructions, the high-rise constructions and in other practical applications, and interference effect on the behavior nature of such structures in a wind flow is appeared at the close arrangement strongly [1]. In 2001 at the department of “Aerohydrodynamics” in NSTU aerodynamic and aeroelastic characteristics of the bridge span located across the river Tom in Kemerovo were investigated experimentally. The feature of the bridge situation was the fact that the not removed old bridge was located on the opposite sideriver at the angle of 15 degrees. In the course of studies it was obtained that the isolated bridge possessed sufficiently high aeroelastic stability and had the low values of the amplitudes of oscillations in the considered velocity range. However, when investigated bridge was located in the flow before the old one its oscillations were increased. This result is showing both scientific and practical interest because very intensive oscillations were possible at the particular relative positions of the structures. Besides, the intensive oscillations can not only postpone of the building process but also destroy the structure.

The revue of literature shows that considerable amount of data are available on the flow-induced oscillations of the bodies with circular cross-section. These bodies were investigated in the flow both in isolation and under interference condition. In the case of interference the cylindrical bodies with circular cross-sections were presented for the different configurations (tandem, side-by-side and staggered arrangements) and for the oscillating cylinders or not oscillating ones. Works for the prismatic bodies with the square or rectangular cross sections are presented lesser amount of data.

In the work of N. Mahir and D. Rockwell [2] it was noted that if the two identical circular cylinders located in the tandem arrangement had the transverse vibrations generated by a computer-controlled motor independently of each other, then for small longitudinal spacing of the cylinders of \( X=2.5D \) (\( D \) – cylinder diameter), the vortex formation did not occur the cylinders, and for large longitudinal spacing of the cylinders of \( X=5D \) different flow patterns around the cylinders occurred between them and depended on the excitation frequency of cylinders and the value of phase angle between the oscillating cylinders. R. Blevins in its work [3] showed, that when the oscillating circular cylinders were in tandem (one behind the other) there were little or no vortex shedding behind the upstream cylinder for center-to-center spacing up to about 3.9\( D \), and at spacing greater than 4\( D \), a vortex street formed behind each cylinder, more or less independently of the other cylinder. However, when the circular cylinders were in side-by-side arrangement, the center-to-center spacing between the cylinders (\( Y \)), which correspond to different flow patterns, take the following values: \( Y<1.4D \) – a single Karman vortex street formed behind the cylinder pair, \( Y>2D \) – a Karman vortex street appeared behind each cylinder. Investigating two identical prismatic bodies with the square cross-sections arranged in tandem in the stream, Huhe-Aode and al. [4] noted, that if the downstream cylinder oscillated sinusoidally in the transverse direction the dramatic change in flow pattern had been observed at the critical spacing of \( (X/D)_{crit}=2.5 \) – 3.0. If the spacing was less than critical the separated shear layers from the upstream cylinder reattached to the downstream cylinder and a quasi-steady twin-vortex region formed in the spacing between two cylinders, but if the spacing between the cylinders exceeded critical, the separated shear layers rolled strongly into the spacing before reattaching onto the downstream cylinder. The papers of S.J. Prise and al. [5] and
R. Ajith Kumar [6] demonstrate that oscillation of the upstream cylinder causes considerable modifications of the flow patterns around the two identical cylinders when the downstream cylinder is fixed in place. It was established that compared to a circular cylinders, a square cylinders had got a wider lock-in range and higher peak amplitude of vibration. With interference (when cylinders were located in tandem, side-by-side and staggered arrangements) the oscillatory amplitude was found to depend on the longitudinal and transverse spacing between the cylinders and also on the body geometry. Thus, there were both a decrease and an increase in the values of the amplitudes of vibrations, and under identical conditions the cylinders with the square cross-sections were found to exhibit higher amplitudes of vibration than the circular cylinder. The tandem arrangement was found to give rise to maximum magnification of vibratory amplitudes. It would be desirable to note that for the study of the aeroelastic characteristics of cylindrical bodies with the rectangular cross-sections located in the flow before the another fixed one is devoted the insignificant number of papers.

The purpose of this work is a study of the flow patterns around the two prismatic bodies with rectangular cross-sections and the estimation of the dependence of relative positions of the prisms on the change of the flow patterns and on the intensity of the oscillations.

It was noted in my early work that in the case of the two bodies in a tandem arrangement situated in a uniform flow the increase of oscillations of the prismatic body with the rectangular cross-sections located on an elastic suspension was possible when the fixed prismatic one of the same form was placed downstream. Also the most dangerous combinations of relative positions of the rectangular prisms when there were intensive oscillations were detected [7]. Investigations of the flow visualization have been carried out to study a nature of onset of similar oscillations.

Flow visualization is the useful tool for definition of a complete unsteady flow pattern and, generalities, for detection of unsteady flow characteristics. The unsteady flows can be visualized using the methods, which require introduction into the flow the small particles, which use dyes and smoke, and also optical and chemical methods [8]. In low-speed wind tunnels the flow visualization is carried out, mainly, by introduction of a smoke in the flow. At that «smoke» is the dispersion with very high concentration of exclusively small particles (tracers) [9].

2. Experimental arrangements

In this work the flow was visualized using “smoking wire method” developed as far back as the 50th years by Rasped and Moor [8]. During the experiment a nichrome wire of 0.6 mm was situated in the wind tunnel vertically. Drops of a glycerin applied on the wire evenly exhaled as a consequence of electric heating of the wire and formed a smoke surface or discrete lines of a smoke stream.
The experiments were carried out in a subsonic open-jet wind tunnel T-503 at the industrial aerodynamics laboratory of NSTU. Two types of the rectangular prisms were used for the experiments; the prism located on an elastic suspension with 8 springs had a cross flow vibration and was named as the section model, and the prism placed quiescently was named as the fixed prism. All the prisms had a rectangular cross sections with aspect ratio of $H/B = 3/2$ thus a height ($H$) of the prism was 60 mm. During the experiments the fixed prism was situated in parallel with the section model before or behind it and spacing was changed in longitudinal and transverse directions between the two bodies (fig. 1).

Natural frequency of the section model was about 2 Hz. The flow was visualized at a low freestream velocity ($\sim1\,\text{м/с}$) because a flow visualization of the vibrating section model at high freestream velocity was complicated by diffusion of the smoke stream. Images of the smoking wire visualization were acquired using a Panasonic DS1 model digital video camera. The digital video camera was situated transversely to streamline on one axis with the vibrating prism. For an ability of video filming of the flow visualization process perpendicularly to streamline direction one of the end plates was made from a transparent material (plexiglass), and second was non-transparent (black). For an achievement of a necessary contrast the plane of the flow visualization was brightened in parallel with streamline by a “light knife”, and background was occulted.

### 3. Results and discussion

The results of the research work show that the flow patterns around the investigating prisms were changed when the relative positions of the prisms were varied. All flow patterns around the prisms can be classified in to four types:

**Type 1** – a single vortex street is formed behind the prisms and the vortex formation does not occur between the prisms (fig. 2). In this case the longitudinal spacing between the beams, when this pattern was invariable, depended on the flow direction. Thus, of the fixed prism was placed before the downstream section model and the spacing between the two prisms was $|X/H|<4$ there was the flow pattern of $1b$ type. When the fixed prism was situated in a wake from the upstream section model and the spacing between these two prisms had less value ($|X/H|<2$) there was the flow pattern of $1a$ type.

![Type 1](image)

**Fig 2.** Photographs and diagrams of the first type of the flow patterns.

**Type 2** – separated shear layers from the upstream prism roll into the spacing between the prisms and break about a forward side of the downstream prism (fig. 3). This type of the flow patterns formed when the fixed prism was situated in the wake from the upstream section model of the prism and at the same time the longitudinal and transverse distances between the prisms were $|X/H|=2–3.5$ and $|Y/H|<1$ respectively.
Type 3 – in side-by-side arrangements the shear layers separate from the topping surface of the vibrating prism and from the bottom of the fixed prism and the vortex formation does not occur in the spacing between the prisms ($|Y/H|<3$) (fig. 4). This type also formed when the longitudinal coordinate had small departure from the zero mark ($|X/H|<1$).

Type 4 – the vortex street forms behind each prism independently of the other prism (fig. 5). This type of the flow patterns depend on the relative position of the investigated rectangular prisms, in this case just as for the flow patterns of the first type the longitudinal spacing depend on the flow direction. So at the configuration when the fixed beam was placed directly in a wake from the vibrating one and the spacing in the longitudinal direction was $|X/H|>3.5$ the $4a$ flow pattern appeared. If the fixed prism was situated before the upstream section model directly at the longitudinal distance of $|X/H|>4$ there was the flow pattern of $4d$ type. When configuration of “side-by-side” was examined (when the fixed prism was arranged in the flow under the section model at
the distance of \(|Y/H|>3\) in the transverse direction) the 4b flow pattern was observed. The flow structure of 4c type appeared at the staggered arrangements of the beams and in this case the section model was situated in the flow before the fixed prism. The 4f flow pattern was observed also at the staggered only the section model was placed in a wake from the fixed one.

Fig. 6 Area of isolines of amplitudes of the oscillating section model

All presented types of the flow patterns have been combined with the area of isolines of amplitudes of the oscillating section model which was showed in the paper [3]. It is possible to see that when the fixed prismatic body was placed before the downstream section model there were first and fourth flow patterns, however when the fixed prism was situated in the wake from the section model there were all presented types of the flow patterns (fig.6). In this case the flow visualization results show that when the section model had the highest amplitude vibrations \(A_{\text{max}} \sim 0.5H\) the flow patterns became the following types – 1 (the fixed prism was arranged in a wake from the upstream section model), 2 and 4 (except for configuration when the prisms were in tandem). When the vibrations of the section model were absent or had small oscillations intensity \(A_{\text{max}} < 0.3H\) the flow patterns became the type 1 (only when the fixed prism was arranged before the section model), type 3 and type 4 (only in side-by-side arrangements of the prisms).

Thus it is possible to note that the interference effect of the fixed cylinder with the rectangular cross-section consists in the flow patterns changes of the identical spring-mounted cylinder with the rectangular cross-section (in comparison with the flow pattern around the isolated cylinder with the rectangular cross-section) and in a nature and intensity changes of oscillations of this cylinder. These changes depend not only on the longitudinal and transverse spacing between the prismatic bodies but also on the flow direction.

4. Conclusions

The results presented in this paper show that there are four types of the flow patterns around the two prismatic bodies with rectangular cross-sections situated in a uniform flow. The systematization of the flow patterns is given according to the relative positions of the rectangular prisms and to the magnitudes of the oscillation amplitudes of the spring mounted prismatic body.
Thus, the types 2, 4b, 4c and 4f are the most dangerous because the amplitude magnitudes of the oscillating section model of the prismatic body may reach high values.

REFERENCES