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FATIGUE OF SLENDER LIGHT-WEIGHT STRUCTURES DUE TO WIND LOAD

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Summary. *One of the most important loads acting on slender light-weight structures is the effect of a wind stream. The wind action can be treated as a static or as a dynamic loading. Most of the lightweight pedestrian bridges, with a relatively narrow cross-section attacked by the wind, are loaded by a dynamic action of the wind. This kind of load exhibits a concurrent vortex shedding within the wake of the structure that can be treated as a stable oscillation having known the energy magnitude corresponding to the frequency. This phenomenon was first described by Strouhal who pointed out that the vortex shedding is describable in terms of a non-dimensional number* $St = Ns \cdot D/U$*. The importance of such number for structural design can be easily proved. Knowing the wind speed U and the aerodynamic diameter of the structure D (characteristic dimension of the structure projected on a plane normal to the wind flow), and of course the Strouhal number St of this structure, it is possible to calculate the frequency Ns of the vortex shedding and thus to know the frequency that must be avoided in order to prevent the structure from a resonant vibrations originating from the action of the wind. For the lifespan of the structure these oscillations lead to the high-cycle fatigue and thus problems with breaking of the wires in suspended cables and cracks in welds of structural connections. This article describes a method for obtaining basic input data for the fatigue analysis invoked by the action of the wind.*

1 INTRODUCTION

Wind load is one of the most important dynamic loads of slender light-weight structures, namely guyed masts and towers, cable-stayed and suspended bridges, pedestrian and pipe bridges. Both dimensions of the cross-section of the mast or tower, i.e. in the direction of the wind and transversely to the wind, are very close, which leads to strong wake behind the body and alternate vortex sheding. On the other hand, the bridge section dimension in the direction of wind is considerably greater than the transverse one, i.e. its behaviour is closer to so-called „airfoil“. In such case the vortex shedding occurs along the flown-around cross-section and the wake is not as strong as in the previous case.

The frequency of the vortex shedding of the body depends on the aerodynamic character of the body (cross-section, wind velocity and so-called Strouhal number). Provided that we know the Strouhal number for the particular cross-section, it is possible to determine the frequency or the range of frequencies close to the natural frequency where resonance might occur. High number of oscillations forming due to the vortex shedding may considerably lower the material strength (fatigue strength) or cause defects of the construction (breaking of wires of cables or rupture of welds)

The aim of the paper is to point out the possiblity how to obtain a convenient input data estimate for the computation of the structure analysis on fatigue due to wind load. The following characteristics must be determined: frequency, amplitude and duration of the wind effect, i.e. endurance range (e.g. peak-to-peak amplitude of forces) and their frequency and the duration of this load during the life-time of the structure. The duration of load may be obtained using meteorological measurement which determines distribution of the wind directions and their frequencies and velocities. Based on this data we can determine dominant direction and appropriate wind velocity, for which we can perform the numerical analysis.

2 DESCRIPTION OF THE MODEL

The analysis of wind effects on the cross-section of the structure is demonstrated on the cross-section of the prestressed RC pedestrian bridge. The problem is solved as a planar transient one, i.e. the response of wind load in time. The fluid part uses the Euler formulation of Navier-Stokes equations and the 'solid' phase is described using Lagrange formulation. The solution of the 2D problem of air flow uses an alternate stiffness (bending and torsion) from a whole structure geometrically non-linear model based on FEM. For the solid phase there were used PLANE 42 elements with the degree of freedom (DOF) UX, UY. The pedestrian bridge was suspended on cables, which were simulated using two elastic spring elements COMBIN14 which also supply torsion stiffness by placing the torsion spring COMBIN14 in the center of gravity of the cross-section, see fig. 1.

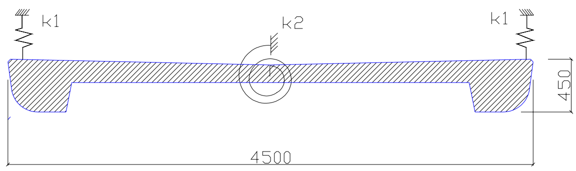

Fig. 1 deck section with stiffness location

The solution has four variants: var. a) – bridge deck suspended only by cables, i.e. only bending stiffness k_1 without the torque spring (twisting flexible model); var. b) – with torque spring k_2; and var. c) – using very stiff bridge cross-section (increasing value of Young modulus); var. d) – with rigid cross-section and fixed supports (i.e. totally stiff and not moving at all).

The fluid is modeled using FLUID141 elements assuming incompressible adiabatic flow and the estimated Re number (Re = 4 x 10^5) points out that the chosen laminar flow will be correct (transition region for an airfoil is approximately at Re = 5 x 10^5). In this case FLUID141 has UX, UY, VX, VY, PRES DOFs. The problem is solved using boundary conditions of free air stream, i.e. zero pressure on OUTLET boundary and zero transverse velocity on the other boundaries of the fluid, zero velocity vector on the surface of the cross-section, and stream velocity on INLET boundary was chosen to be $U = 20\ \mathrm{ms}^{-1}$. FEM model of the problem consists of approximately 30 000 elements and 15 600 nodes. Regarding the velocity of the air stream, time step for the transient analysis was chosen 0.01 sec as a compromise between exactness and computer time demands. On a PC with 3GHz CPU and 2GB RAM the analysis of the behaviour of the model for 10 seconds took approximately 9 hours.

3 RESULTS DISCUSION AND CONCLUSIONS

Two dimensional models for the analysis of foot bridge under the action of wind has been proposed and analyzed. Four variants of deck and suspension stiffness were taken into consideration. Computational fluid dynamics analyses with Fluid-structure interaction were solved. Euler solution of fluid field is depicted on figures 2 and 3.

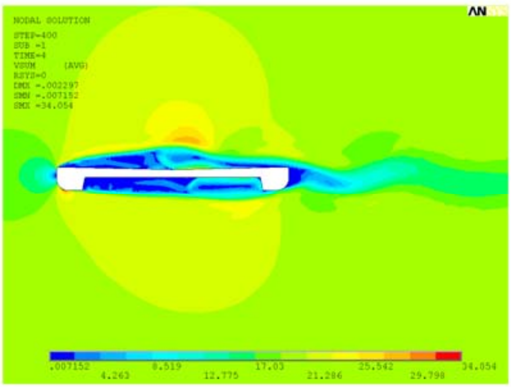

Fig. 2 Var. *a* velocity field, $t = 8$ s

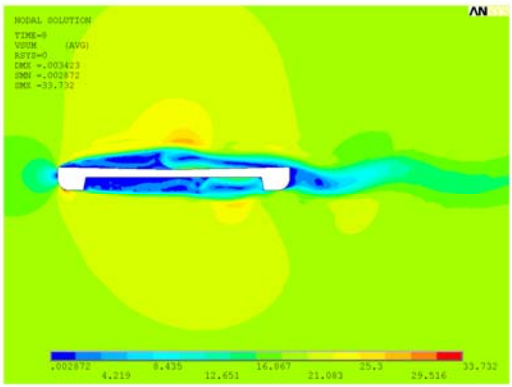

Fig. 3 Var. *d* velocity field, $t = 8$ s

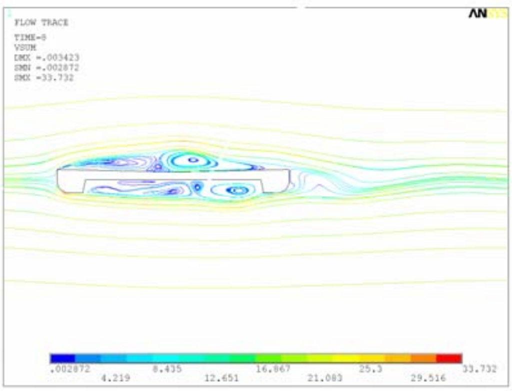

Fig. 4 Var. *a* velocity field, $t = 8$ s

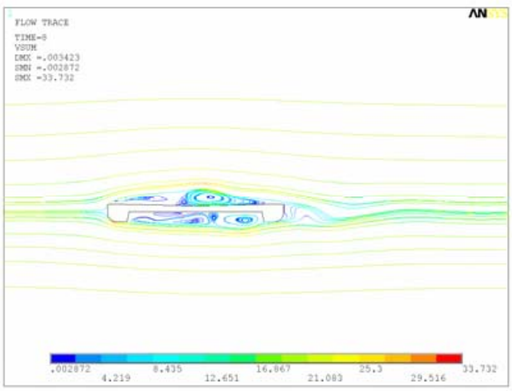

Fig. 5 Var. *d* velocity field, $t = 8$ s

Part perpendicular to unavoid stream of wind action resultant f_y in time interval 0 to 10 seconds was the main result. From these diagrams the Strouhal number for the section with various rigidity were derived. Second main result part was bridge deck displacement on windward u_1 and leeward u_2 side. The results of all variants are included in table 1.

Variant No.	Displacement [mm]		Cross wind force [N/m]		Strouhal number
	u_1	u_2	min	max	
a	± 2,3	± 2,3	- 72	+ 260	0,115
b	$\pm 5.10^{-2}$	$\pm 5.10^{-2}$	- 43	+ 248	0,102
c	$+ 1{,}3.10^{-5}$ $- 3{,}7.10^{-5}$	$+ 1{,}3.10^{-4}$ $- 3{,}7.10^{-4}$	- 43	+ 232	0,097
d	0	0	- 43	+ 244	0,095

Table 1: Analysis results

It is clearly seen, by applying torsional stiffness deck section become stabilized and displacements approach to zero.
Really, to describe the complete behaviour of a bridge under wind action should be used three-dimensional model, by considering bridge deck with self weigh stabilizing effect and suspended cable instead of analyzing just a single cross section of the bridge. Although the use of two-dimensional model describe above implies a simplified point of view it's on the top of accuracy in up-to-date numerical simulation techniques.

Acknowledgement

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