Modelling Aeroelastic Response of Bridge Decks using Discrete Vortex Method

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Abstract

Two–dimensional viscous incompressible flow past bridge deck-like bluff bodies are simulated using the Discrete Vortex Method. Interaction between fluid and a solid as well as motion of the solid has been incorporated into the simulation. Wind tunnel tests have been preformed to verify the numerical results. The simulations cover long range of different boundary condition sets in order to indicate the worst and the best configurations. This paper contains original results obtained by the authors as well as refers to results from the literature.

Keywords: aeroelastic instability, flutter, computational bridge aerodynamics, discrete vortex method, turbulent flow, wind tunnel tests

1. Introduction

The aim of this research is to propound a modified version of Discrete Vortex Method intended to model dynamic interaction between a light bridge deck and wind. Limitation the problem to one particular case let develop a useful engineering tool and verify it in a wind tunnel experiment.

2. Problem description

Nowadays aeroelastic instabilities caused by dynamic wind loads seem to be one of the main restrictions for height and span of buildings. Rising awareness of the phenomena has resulted in more beautiful, more useful and more economical structures for the last decades. Undoubtedly the ability to erect such structures are the sign of the times we live (Fig. 1).

Figure 1: Examples of modern structures: a) Burj Khalifa, Dubai, 2010; b) New Little Belt Bridge, Nye Lillebæltsbro, 1970; c) Øresund Bridge, Sweden/Denmark, 2000; d) Juscelino Kubitschek Bridge, Brazil, 2002; e) International Finance Centre, Honk Kong, 2003

New methods of analysing structure behaviour under wind action are being developed continually. This paper focuses on aeroelastic response of long span bridge decks (Fig. 2). Such decks are prone to developed flutter in their central parts. The most spectacular bridge collapse due to flutter happened to Tacoma Narrows Bridge (USA) in 1940. The latest flutter of a big bridge with an amplitude above 1m was observed in Volgograd (Russia) in 2010. The bridge did not collapsed but was closed until necessary rebuilding was done. Both examples show how important is the ability to predict an aeroelastic response of a bridge structure.

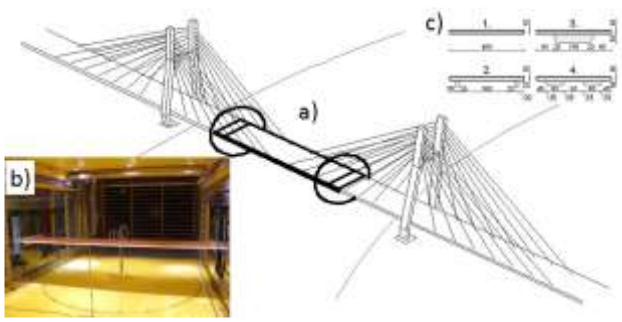

Figure 2: a) central part of a bridge deck under investigation; b) aeroelastic model in a wind tunnel; c) cross–sections of the deck under investigation

Discrete Vortex Method (DVM) has been used for prediction the response. DVM has been applied to solve structural engineering problems since rapid progress in computer technology [4]. Although it has proved its ability to model turbulent flows past solid bodies, there is still lack of commercial computer programs available for engineering use. A pioneer computer program based on DVM algorithms is being developed at the Department of Structural Mechanics of Lublin University of Technology with cooperation with Wind Engineering Laboratory at Cracow University of Technology.

3. Discrete Vortex Method

DVM is a numerical method developed for solving the Navier–Stokes equation (N–S) based on the Lagrangian model of a particle tracing [1,2]. In DVM the N–S equation is solved by direct simulation of a physics phenomena. A finite mesh known form the finite element method or the finite volume method is not used in DVM.

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Assuming a homogeneous fluid we can write the N-S equation in the form (1):

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = -\nabla p + \frac{1}{\mathrm{Re}}\Delta \mathbf{u} \tag{1}$$

where: **u** – velocity field, p – pressure field, Re – Reynolds number, t – time.

The equation (1) is decomposed by calculation the rotation of the vector **u**, which gives the vorticity transport equation (2)

$$\frac{\partial \boldsymbol{\omega}}{\partial t} + (\mathbf{u} \cdot \nabla)\boldsymbol{\omega} = \frac{1}{\mathrm{Re}}\Delta \boldsymbol{\omega} \tag{2}$$

where: $\boldsymbol{\omega} = \nabla \times \mathbf{u}$ is a vorticity field of the flow.

The equation (2) is composed with two parts: advection (3) and diffusion (4) part.

$$\frac{\partial \boldsymbol{\omega}}{\partial t} + (\mathbf{u} \cdot \nabla)\boldsymbol{\omega} = 0 \tag{3}$$

$$\frac{\partial \boldsymbol{\omega}}{\partial t} = \frac{1}{\mathrm{Re}}\Delta \boldsymbol{\omega} \tag{4}$$

The separation lets us treat fluid flow as two simultaneous phenomena: advection and diffusion and it is known as the *Split Algorithm*. It is the core idea for computer simulation of a fluid flow in DVM.

The authors introduce to the classical DVM: (i) vortex particle aging, (ii) simplified methods of boundary vorticity shedding.

4. Wind tunnel experiment

An experiment in a wind tunnel was carried out in order to verify numerical results (Fig. 2). An aeroelastic sectional model of a bridge deck was crated and tested against an incoming air stream. Finally 48 different configuration were tested, most of them were modelled numerically.

5. Results

Computer simulation output is compared with the experiment data and results obtained with other researchers [3]. In most cases good agreement between numerical simulations and experimental data is stated.

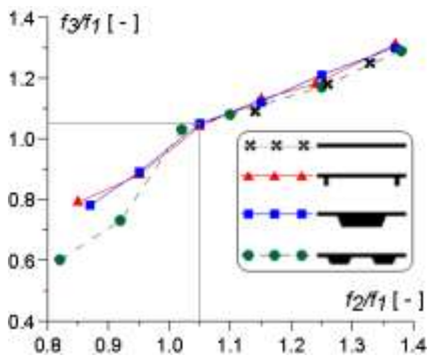

Figure 3: Relation between characteristic frequencies of the aeroelastic system: f_1, f_2 – frequency of free vibrations of the system vertical and rotational respectively, f_3 – dominant flutter frequency

Except direct output such as: accelerations, velocities and displacements of the model other conclusions about flutter are included. The most and less sensitive configurations to aeroelastic instabilities are indicated. A simple formula for dominant flutter frequency has been given. The transition of flutter form has been noticed for different configuration of the model suspension.

Figures from 3 to 5 presents chosen output of the work.

Figure 4: Exemplary snapshots of numerical simulations [3].

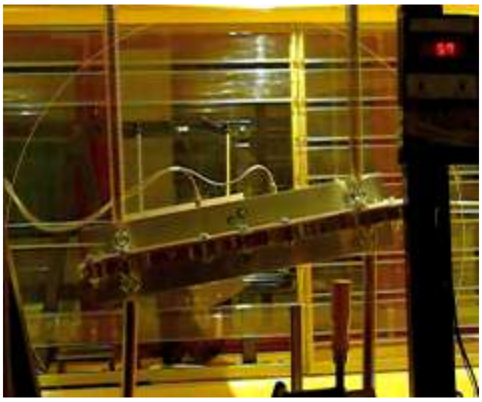

Figure 5: Exemplary snapshots of wind tunnel simulations.

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