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ANALYSIS OF SLENDER BRIDGE STRUCTURE

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Abstract: *The following article presents the results of analysis of slender bridge structure to dynamic loads induced by movement of people. Further is emphasized the importance of modal analysis of structures thus the calculation of eigenfrequencies and modes of vibrations such as prediction of behaviour under dynamic load. In considering of large ratio between the weight of structure and pedestrians will not be discussed the type of loading causing adverse response of the structure in terms of first and second limit state. In this case the decisive criteria are on the part of pedestrians. Detailed examination and comparison with the criteria of comfort specified in the standards is not carried out in this paper. Attention is focused on the design of the computational model and method of application load representing the movement of people. Computational model of footbridge is designed to allow for variable load application in space and time. The same procedure can simulate the movement of small group of pedestrians that move in sync walking. The program system ANSYS was used for the analysis.*

Keywords: ***Footbridge, eigenfrequencies, vibrations modes, moving dynamic loads.***

1. Introduction

The paper deals with the analysis of the dynamic response of slender footbridges under human-induced dynamic loads. These loads are a frequently occurring and often dominant load for footbridges. Due to the development of new materials and advanced engineering technology slender footbridges are increasingly becoming popular to satisfy the modern transportation needs and the aesthetical requirements of the society. However these structures are always lively with low stiffness, low mass, low damping and low eigenfrequencies. As a consequence they are predisposed to vibration induced by human activities and can suffer weighty vibration and problems of serviceability particularly in the lateral direction. Weighty vibration and problems of serviceability can arise particularly in the lateral direction as pedestrians are more sensitive to the low-frequency lateral vibration than the vertical one.

This is a problem that has a lot of uncertain input factors. The effect of the influence of parameters on the mass and stiffness can be studied by methods of sensitivity analysis Kala (2009). Advanced is a method of global sensitivity analysis that allows us to analyze the higher order interaction effects Kala (2010).

2. Human-induced dynamic loads

The force transmitted by the foot on the pad was thoroughly examined and then expressed analytically. Treading force has a nonzero component in three orthogonal directions: longitudinal, lateral and vertical. The vertical component of stepping force is the most important. The course of stepping force in time is approximately periodic. The frequency of normal walking is in the range from 1.3 to 2.4 Hz. Two types of load's models depending on the time can found in the literature: deterministic and probabilistic. The first type is given by the force representing the weight of pedestrians. Value of force varies according to the periodic time-dependent functions. For one frequency of walking is one formulation of the load created. The second type is given by the randomization of input values such as weight and speed of pedestrian. The average weight of a person takes 70 kg. This force is transmitted by the foot on the pad in the value of changing the amplitude of the dynamic components of stepping force which is 18 kg.

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Three harmonic frequencies are defined in the paper Block & Schlaich (2002): f(1) = 2 Hz, f(2) = 4 Hz, f(3) = 6 Hz. Simple expression of dynamic force F(t) is:

$$F(t) = \alpha \cdot m_p \cdot g \cdot cos\omega(t) \quad (1)$$

where: α is a correction factor reflecting the difficulty of determining the vertical load and its diversity and its value is linearly dependent on the number of steps per second; m_p.g weight of pedestrian [N]; $\omega = 2\pi f_p$; f_p step frequency described in the paper Block & Schlaich (2002).

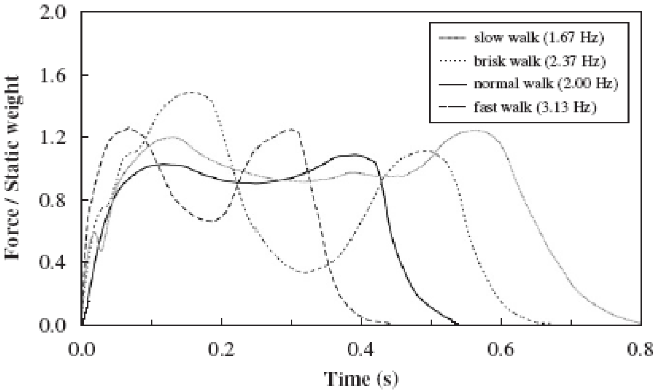

Fig. 1: Vertical force produced by one person taking one step.

Dynamic load is recommended for all types of footbridges by one pedestrian described in the paper Block & Schlaich (2002).

$$F\ (t) = 700 \cdot 0.257 \cdot sin\ (2\ \pi\ f_0)\ /\ t \quad (2)$$

where 700 [N] is the weight of one pedestrian; 0.257 dynamic coefficient; f_0 step frequency complying with the frequency of the footbridge.

Analysis of footbridge, described in this paper, is carried out by load of pedestrians expressed by the equations (3) and (4). Equations express two perpendicular components of stepping force. The dominant component of stepping force is given by equation (3) and smaller component perpendicular to the direction of walking is given by equation (4).

$$F(t) = 700 + 180 \cdot sin(2\ \pi\ f\ t) \quad (3)$$

$$F(t) = 45 \cdot sin(2\ \pi\ f\ t) \quad (4)$$

3. Description of the bridge structure

Construction of footbridge is designed as a suspended. Total length of the footbridge is 84 m and height of pylons is 16 m. The slack of the main supporting cable is 13 m. The roadway is 3 m width and is composed of runners 200 mm high which strengthen plate of roadway 8 mm thick. Surface coarse is made of poured resin with fill of thickness of 12 mm.

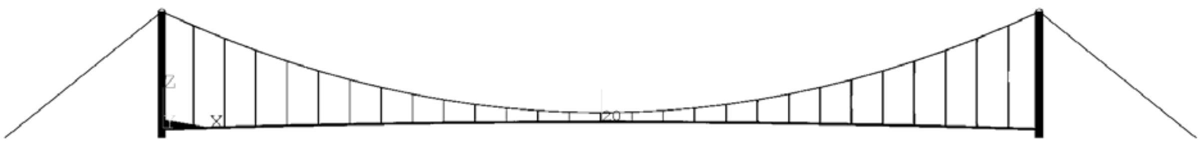

Fig. 2: One span suspended footbridge with 84 m long deck.

4. Eigenfrequencies and mode vibrations

Eigenfrequency and corresponding eigenvector are important dynamic properties. They describe the behaviour of structure under dynamic load. Three basic eigenvector are: bending, torsional and longitudinal. There are also combinations of shapes such as torsion-bending wave shape. Eigenfrequencies found in the frequency range of human walking are in the case of load by moving people for the structure dangerous. It means occurrence of vibrations of structure by movement certain number of people in sync walking.

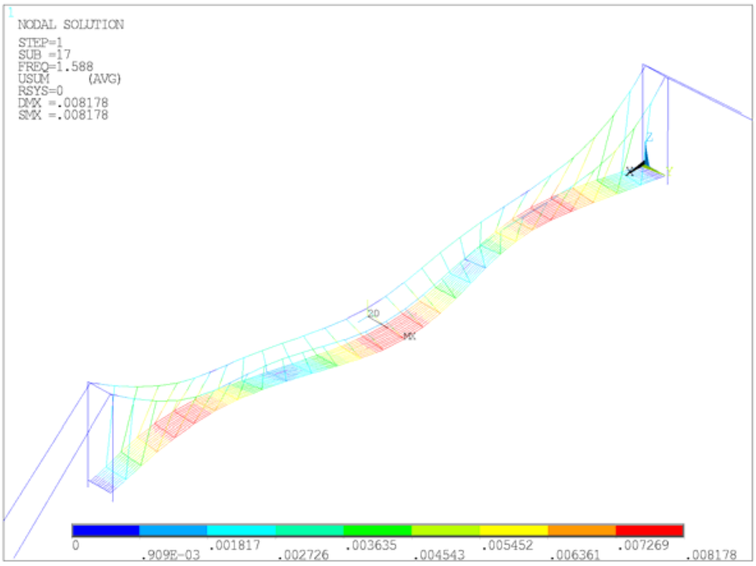

Fig. 3: Eigenvector according to f = 1.588 Hz.

5. Dynamic response of the bridge structures on single pedestrian load

The frequency step was chosen according to the bending frequency of the structure. The force representing pedestrian was moved by 10 cm and by 5 cm. Densification of finite elements was performed on runners which are distant 60 cm from the midline of the roadway on both sides. The load corresponding to the intensity of stepping force in the time is applied to the nodes on these runners. The frequency was selected to the higher bending eigenfrequency of the structure. Evaluation of the response of the structure is performed in chosen nodes for the time of the load. This means the time required to pass the footbridge. Evaluated sites are in the mid-range and in the quarter of span of the roadway. The graphs Fig. 4 and Fig. 5 present the response of the structure in a selected point on the load of a pedestrian as defined in equation (3). Load is allocated to individual points along the roadway in the selected time step and corresponds to walking speed. The graphs on the left side of Fig. 4 and Fig. 5 describe the displacement of the point in time and the graphs on the right side of Fig. 4 and Fig. 5 acceleration of the point in time. The difference between Fig. 4 and Fig. 5 is given by the density of roadway finite element mesh. Fig. 5 presents finer mesh.

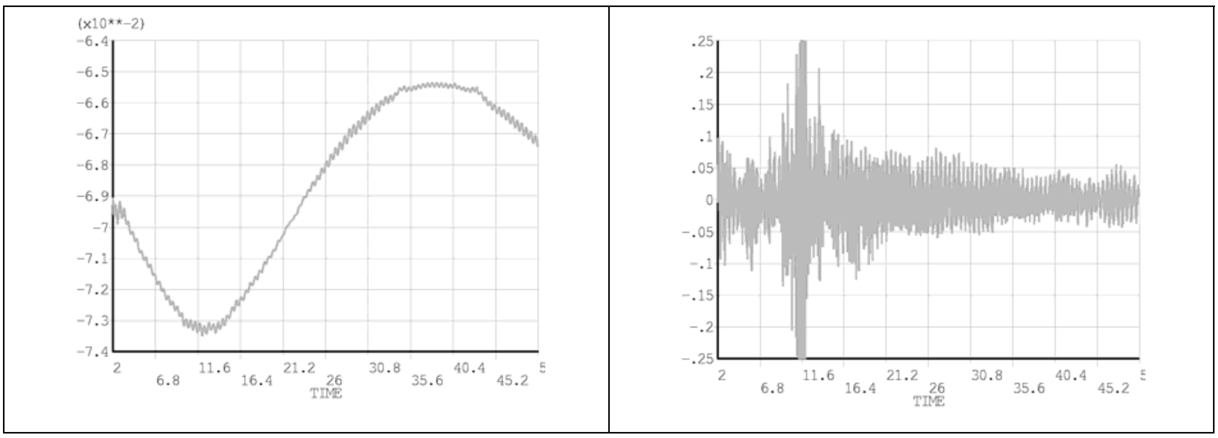

Fig. 4: Vertical displacements U_z, vertical acceleration, near L/4.

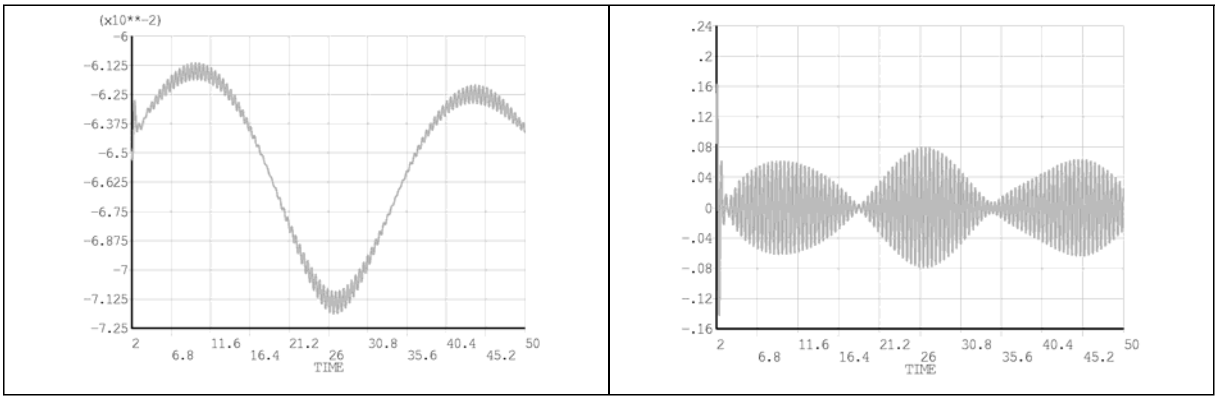

Fig. 5: Vertical displacements U_z, vertical acceleration, mid span.

6. Conclusions

The response of the footbridge on the movement of pedestrians was solved for the motion simulation by 1 and 2 pedestrians. Stepping force was expressed in two variants. In the first variant the stepping force is represented only by its dominant vertical component. In the second variant is added also lateral component of stepping force. Walking speed was chosen according to the eigenfrequency of 2.1 Hz which corresponds to the bending shape with three vertical antinode loops along the roadway. The results show that the structure vibrated under load of pedestrians in sync walking. The selected point achieves the maximum acceleration 0.45 ms^{-2} and threshold, defining the acceptable comfort for such a structure, is according to Eurocode 0.7 ms^{-2}. Thus there is some distortion of walking comfort but not fatal.

The second aim of this paper was to present the influence of discretization of the computational model on the results analysis of dynamic load. It is recommended to use a finer division in compiling the computational model and its subsequent discretization namely approximately to the maximum element length 50 mm.

Acknowledgement

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