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Dynamic Analysis of the Structure Exposed to the Moving Periodic Force and Viscoelastic Models of the Human Body

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Abstract: Submitted paper is focused on dynamic analysis of the footbridge structure, which is represented by the simply supported beam. The continuous beam model was discretized by the FEM to MDOF system and loaded by pedestrians, walking across the structure. Two states of loading are considered in this paper. Firstly, it is the mathematical description of pedestrian's ordinary traffic, where each pedestrian is randomly generated by the Monte Carlo method. Secondly, the movement of single pedestrian, simplified by viscoelastic models, is introduced.

Introduction

The human induced vibration is phenomenon, which designers and structural engineers must take into account during the design of footbridges, grandstands etc. It is essential namely at the structures with some of the natural frequencies inside the range $\langle 1\,\mathrm{Hz}; 3\,\mathrm{Hz}\rangle$, which is typical frequency interval of human walking or running. It means, that the resonance between pedestrians and structure can occurs.

DLF model of pedestrian's ordinary traffic

This is special type of live load induced by humans. Pedestrians walk with random pacing frequencies and with random incoming time during the ordinary traffic. It is significant at structures with very dense traffic, e.g. at footbridges near the underground stations etc. The ordinary traffic of pedestrians has been considered as stochastic process, where each of these pedestrians is simplified by the periodic force defined as

$$P(t) = G + \sum_{j=1}^{N} G\,\alpha_j\,\sin\left(j\,\omega_p\,t - \phi_j\right). \tag{1}$$

where G is static weight of pedestrian, α_j is the dynamic loading factor of j-th harmonic element (DLF), ω_p is circular frequency associated with velocity of motion and ϕ_j is phase shift of j-th harmonic element. *Bachmann's* DLF model was used for the mathematical description of pedestrian. The appropriate multipliers α_j and phase shifts ϕ_j are summarized e.g. in [2].

The Monte Carlo method was used for numerical simulations of ordinary traffic, where number of pedestrians N, velocity of motion v_p (pacing frequency f_p), weight of pedestrians m_p and individual time of incoming τ_p were generated from the uniform distribution of probability. The script, created in MATLAB, can be briefly described by next steps: Set up input param. $\rightarrow$ assembling of struct. matrices $\rightarrow$ generating of random pedestrians (v_p, m_p, N) $\rightarrow$ assembling of right sided vector $\rightarrow$ numerical integration of diff. eq. (Newmark-β) $\rightarrow$ data visualization.

Viscoelastic models of single pedestrian

By using this approach, it was considered, that the human body is replaced by the Kelvin-Voigt element with 1 or 2 degrees of freedom. These models, visualized in Fig. 1, are described by the stiffness and

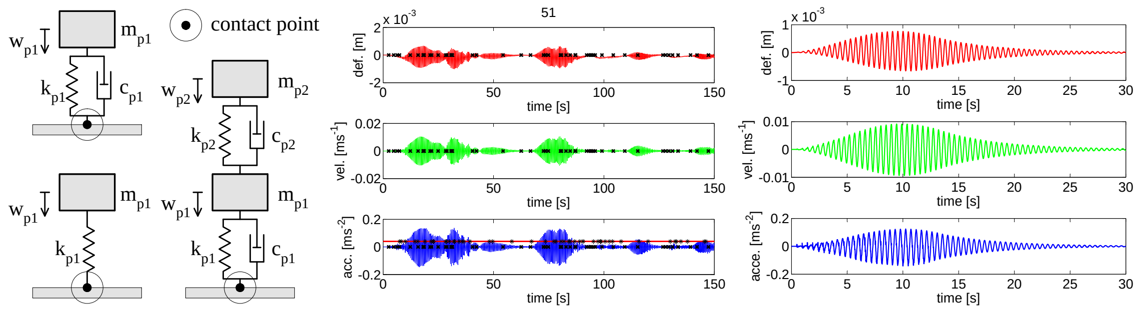

Fig. 1: Viscoelastic models, one realization of ordinary traffic and response of the structural midpoint-viscoelastic model.

viscous parameters, which can be found out hardly. Nevertheless someone is able to find the data in the literature. The viscoelastic parameters of the human body were studied and measured e.g. by *Farah*, *Brownjohn* etc. It was also considered, that model is moving with constant velocity v_p over the structure.

Solution of this problem was carried out separately for the viscoelastic element and for the structure (decoupled problem). Complications with activation of the pedestrian's passive model were solved by using the approximation of trajectory of the centre of gravity (CoG), which was used as input excitation signal for contact point between Kelvin's element and the structure. The algorithm of solution can be written as:

response of K-V model to kinematic exc. $\rightarrow$ calculation of contact force $\rightarrow$ calculation of the response of the structure $\rightarrow$ correction of CoG trajectory by computed deflections $\rightarrow$ back at the beginning of the loop.

Summary

New approaches to modeling of pedestrian's ordinary traffic and movement of single pedestrian have been presented in this paper. The ordinary traffic was simulated by the Monte Carlo method and each of random pedestrians was simplified by DLF *Bachmann's* model. Vibration induced by single pedestrian was described by viscoelastic model with kinematic excitation. The investigated structure was the simply supported beam, which is based on the real structure across Opatovska street in Prague. The numerical results of dynamic analysis are summarized in Fig. 1.

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