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VERTICAL VIBRATION OF COMPLEX AND SLENDER FOOTBRIDGE DUE TO STOCHASTIC CROWD-INDUCED EXCITATION

Jingru ZHONG
Research Assistant
Zhejiang University, China
zhongnrbuer@yahoo.com

Xu XIE
Professor
Zhejiang University, China
xiexu@zju.edu.cn

He ZHANG
Associate Professor
Zhejiang University, China
zjuzhanghe@zju.edu.cn

Summary

The principle aim of this paper is to study the crowd-induced vertical dynamic responses of the complex and flexible footbridges. Stochastic crowd flow of real traffic conditions is modelled with Monte-Carlo method and a numerical integration-based algorithm for structural vibration under crowd excitation is developed. Based on a real footbridge of complicated vibration modes, the crowd-induced acceleration responses are obtained, with the probabilistic characteristics of the peak acceleration being further studied. The calculation results indicate that the random crowd-induced peak response has a lognormal distribution, of which the average value is proportional to the increase of crowd density and the pacing frequency coherence. The algorithm for stochastic crowd loading and the analysis results provided can be valuable for reference in vibration assessment towards footbridges of complicated structural types.

Keywords: footbridge; pedestrian loading; stochastic crowd excitation; vertical vibration

1. Algorithm for crowd-induced vibration

As opposed to the fourier series model that has been widely used in current codes, this paper provides an algorithm for structural vibration under crowd excitation. The crowd-induced dynamic equation is described as formula 1, The numerical integration methodology is applied in the stochastic crowd-induced dynamic analysis, which is supposed to be much more widely applicable.

$$\boldsymbol{M}\ddot{\boldsymbol{u}}+\boldsymbol{C}\dot{\boldsymbol{u}}+\boldsymbol{K}\boldsymbol{u}=\boldsymbol{F}_{p,1}\left(x,t,f_1\right)+\boldsymbol{F}_{p,2}\left(x,t,f_2\right)+\ldots+\boldsymbol{F}_{p,n}\left(x,t,f_n\right) \tag{1}$$

Where ***M*** is the mass matrix; ***K*** is the stiffness matrix; ***C*** is the damping matrix. $\ddot{u}$ 、 $\dot{u}$ 、 u are the acceleration, velocity and displacement respectively. $\boldsymbol{F}_{p,n}$ here is the foot force vector of the $\boldsymbol{n}^{th}$ pedestrian.

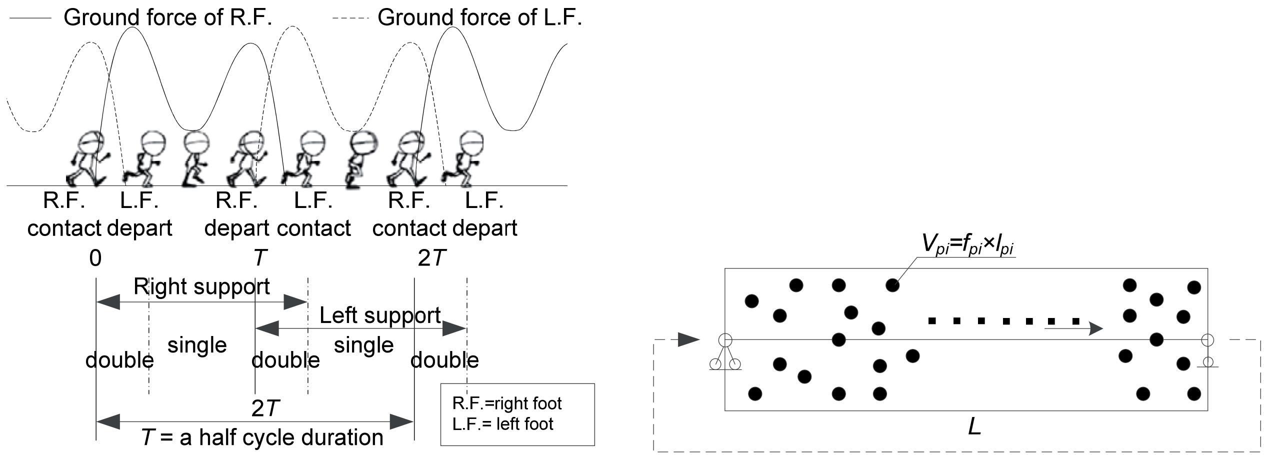


Fig. 1, a) Stepping process of a single pedestrian, b) Stochastic crowd model

The stochastic crowd model is developed, with certain key factors, such as pedestrian position, walking length, frequency,etc., of each person, being all considered as random variables. Force of the left and right foot for each pedestrian is defined as perfectly periodic point load moving alternatively (as shown in Fig. 1a) and the whole crowd excitation is consisted of foot force by every single pedestrian (as shown in Fig. 1b).

2. Numerical case study

A real footbridge of irregular steel arch structure with complicated vibration modes is studied as a case (shown in Fig. 2a). Field experiment including modal test and pedestrian-excited vibration test is conducted at first and then a specific comprison between the results of test and simulated analysis is put forward for attesting the accuracy, stability and convergence of this algorithm (shown in Fig. 2b).

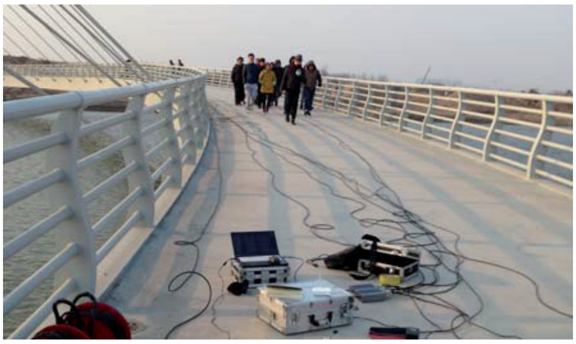
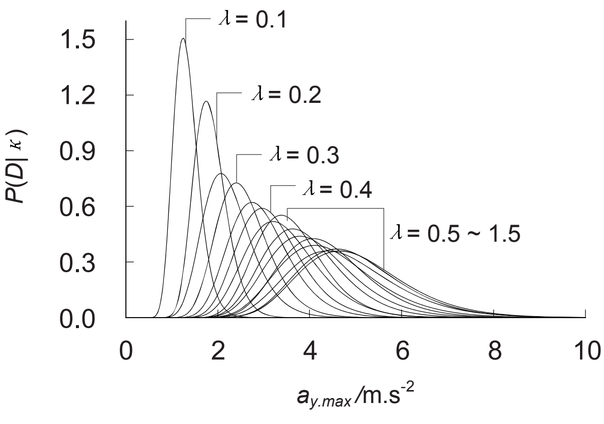



Fig.2, a) Photograph of the footbridge study case, b) Photograph of field experiment

The destribution of the peak vertical acceleration responses, alongside with the effects of density of people and pacing frequency is described in detail. To investigate the probability character of the vertical peak acceleration, Kolmogorov–Smirnov test is adopted to serve as a goodness of fit test. It is obtained that the peak acceleration due to stochastic crowd model follows the lognormal distribution, of which the average value is proportional to the increase of crowd density and the pacing frequency coherence. Fig. 3 shows the fitted lognormal density curves with regard to different pedestrian densities and pacing frequency.



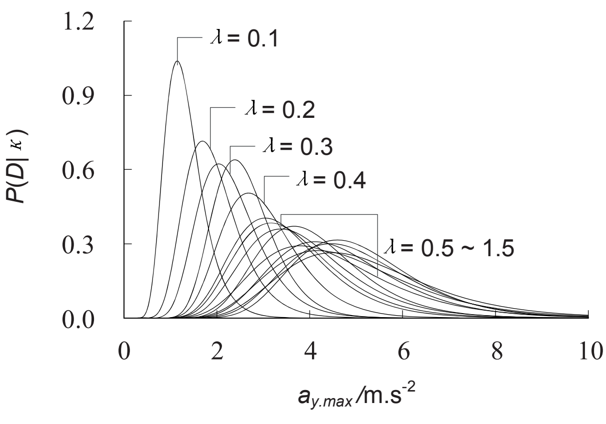


Fig.3, a) Fitted lognormal density functions, a) average pacing frequency of 1.75Hz, b) average pacing frequency of 2.18Hz

The results provided can be valuable for reference in vibration assessment towards footbridges of complicated structural types. Besides, the crowd excitation in this method is generated randomly by the Monte-Carlo method and does not consider the human-structure interaction. The effect of this aspect need to be investigated in further studies.