An Evaluation of Human Bouncing Force Excitation

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Abstract

Modern architectural designs have resulted in floors with large open areas and long-span structural systems which can be susceptible to excessive vibrations due to human movements. This problem particularly becomes more important when the occupants engage in rhythmic activities such as bouncing. Bounce is defined as rhythmic up and down movements of people in which the person's feet do not leave the floor. This paper presents an experimental study to evaluate the exerted bounce force by measuring the applied ground reaction forces (GRF) by a group of individuals on a force platform. Two bounce force levels for design purposes at 75% and 95% probability of exceedance are considered based on the required level of conservatism. Using the developed forcing function equations, closed forms are obtained for the dynamic load factors and are compared with the linear regression of the dynamic load factors, considering a Gaussian Distribution, which showed they are more conservative for most harmonics.

Keywords: bouncing force; vibration serviceability; excessive vibration; human movements; Finite Element analysis; response prediction; dynamic load factor; Fourier coefficient.

1 Introduction

Bouncing or bobbing is a rhythmic up-and-down movement of people in which the person's feet do not leave the floor. This movement is generally associated with dancing or aerobic exercises. There have been several instances of structures subjected to such activities that resulted in vibration serviceability issues. These include excessive movements of a stadium in the UK during a pop concert [1], large vibrations at the Nuremberg soccer stadium in Germany [2], and Maracanã stadium in Brazil [3] during soccer matches due to the audience's rhythmic bouncing actions. Large vibrations due to aerobic exercises also resulted in the evacuation of a residential-commercial building in Seoul, South Korea [4]. Therefore, it is important for the structural designer to be able to predict the structural behavior subjected to people's bouncing forces within an acceptable range. Several research studies on the measurement of the bounce ground reaction force (GRF) are available in the literature. Yao et al. [5] used a movable platform to measure the bounce force generated by an individual. They found that the subject could not follow the metronome beat when the bouncing frequency was close to the platform's natural frequency causing large movements of the platform. Duarte and Ji [6] conducted a study in which a number of individuals bounced on two simply supported reinforced concrete beams. From the response of the beams, they computed the first four Fourier Coefficients or Dynamic Load Factors (DLF) of the forcing functions. They reached the conclusion that people can bounce with coordination between 1,0 and 3,1 bps (bounces per second). They came up with a linear relationship between the first harmonic of DLF (α_1) and the bounce frequency using a regression analysis of the measured data.

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