9th International Congress on Civil Engineering, May 8-10, 2012
Isfahan University of Technology (IUT), Isfahan, Iran

Stability criterion for lateral vibration of footbridges

Mohammad Jafari [1], Amir Keyvan Ghorbani-Tanha [2], Mehdi Yazdani[3]

1- M.Sc student, University of Tehran
2- Assistant professor, University of Tehran
3- M.Sc student, University of Tehran

Mohammad_jafari@ut.ac.ir

Abstract

Annoying human-induced lateral vibrations introduces a serviceability limit state that must be considered in the design of footbridges and it is often conquered by increasing the structural damping. To quantify the amount of damping needed in each frequency there is a need for a decisive factor which can predict whether the bridge is going to be unstable or not. Employing human-induced lateral force model introduced by Nakamura, a discussion is then presented on an energy balancing method in which the energy entered into the system as a result of pedestrians walking on the bridge, is compared with the energy dissipated through inherent structural damping. From the results a serviceability criterion is proposed. The pedestrian Scruton number is introduced as an instability criterion and is assessed for some footbridges and compared with criteria proposed by others. It is shown that the bridge instability can be well predicted by the proposed criterion.

Keywords: Lateral stability, Dynamic interaction, Lateral vibrations.

1. INTRODUCTION

With modern structural design and more slenderness, footbridges need to fit the serviceability purposes, so the pedestrian can feel comfortable in normal vibration conditions. This situation has led to several proposed approaches into the issue and many researchers have been attracted to the field in recent years. In addition, since the pedestrian-excited vibrations of the London Millennium Bridge in June 2000, there has been considerable interest in bridge vibrations caused by the movement of people. A report in 1972 quoted by Bachmann and Ammann [1] in their book described how a new steel footbridge had experienced strong lateral vibration during an opening ceremony with 300–400 people. They explained how the lateral sway of a person's centre of gravity occurs at half the walking pace. Since the footbridge had a lowest lateral mode of about 1.1Hz, the frequency of excitation was very close to the mean pacing rate of walking of about 2 Hz. Thus, in this case an almost resonating vibration occurred [1].

This paper presents a criterion for footbridge lateral instability. The simplicity of the criterion allows it to be used in early footbridge design stages. Finally the criterion is compared with other proposed criteria.

2. Mechanism of lateral excitation and background of proposed approaches

Fujino et al [2] described observations of pedestrian-induced lateral vibration of a cable stayed footbridge. It was found that, when a large number of people were crossing the bridge, lateral vibration of the bridge deck at 0.9Hz could build up. They concluded that lateral deck movement encourages pedestrians to walk in step and that synchronization increases the human force and makes it resonate with the bridge deck. After the millennium footbridge excessive lateral vibrations, a model for bridge lateral vibration was proposed by Dallard et al [3]. The key result of Dallard's work is an observation that pedestrian act like a negative damping. Thus they formulate a model based on that assumption, where the correlated lateral force per person αF_i is proportional to local lateral bridge velocity V_{local}, i.e., $\alpha F_i = kV_{local}$. The proportionality constant k was measured empirically to be about 300 kg/s. The primary disadvantage of their model is that the response obtained from the model is unrestrained and it can grow infinitely. Using Dallard's laboratory experiment results, a later paper by Newland [4] proposed a criterion for footbridge lateral instability due to the human induced vibration. For the modal mass of the pedestrians, he assumed that only some fraction of the population β lock into sync the bridge. The criterion proposed by Newland has the same disadvantage