Study of A Monumental Stair Susceptible to Excessive Vibrations Due to Human Movements

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Abstract

Excessive vibrations of monumental stairs can become a major serviceability issue. It is, therefore, important for structural engineers to be able to predict the behavior of these systems as accurately as possible. Inaccuracies in the response prediction can result in a structure with excessive vibrations or great unnecessary costs in terms of material consumption, particularly steel, which is against one of the main goals of sustainability in construction. To evaluate the accuracy of response prediction using a Finite Element computer analysis, this paper presents a study of a monumental stair susceptible to excessive vibrations due to human movements. The stair responses due to the ascent and descent at its first sub-harmonic of fundamental frequency were computed and compared with those from the measurement. Conclusions were made in regards to the computer modeling of the structure and its effectiveness in walk response prediction.

Keywords: Monumental stairs; vibration serviceability; modal test; walk excitation; experimental evaluations; Finite Elements Analysis; response prediction.

1 Introduction

Recent trend in the design of lightweight and slender monumental stairs by architects have made the vibration serviceability an important issue in the design of this class of structures [1-5].

Kim, et al. [6] studied the serviceability performance of steel and reinforced concrete stairs. Six mock-up stairs were constructed and tested. All stairs had very high natural frequencies and were not susceptible to large vibrations from human movements. The tests on the stairs confirmed that, in general, cast-in-place concrete systems exhibited better vibration serviceability than steel stairs. They also found that vibrations were larger when people ascended the stairs than when they descended, which is not consistent with other reported studies. They also noted that steel stairs had much larger vibration levels than their reinforced concrete counterparts.

There have also been several publications on the design of monumental stairs using Finite Element analysis only (without any vibration measurements) as mentioned below. Arbitrio [1] briefly discussed the design of a stair and vaguely explained its vibration analysis using the shell elements in the SAP2000 structural analysis software [7]. Huntington and Mooney [2] presented their study of the excessive vibrations of a 11,89m long steel stair. They conducted a Finite Element Analysis of the structure but did not provide any details of their work. They also reported the application of tuned mass dampers (TMD) to correct the excessive stair vibrations without providing much details.

Howes and Gordon [3] discussed the details of two sets of stairs for the Art Gallery of Ontario, located

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