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Whipping Effect of the Seismic Response of Unbraced Tied Arch Bridges

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Abstract

When a light roof structure is built atop a multi-story building, the roof structure will get much larger seismic forces than as if it is built directly on the ground. This is the so called whipping (or whip) effect, which has been well investigated and considered in building engineering. In bridge engineering, it is somewhat unnoticed because most bridges don't have important light structure members above deck level. However, when an unbraced arch is designed on a flexible substructure, the whipping effect on the arch could be very significant. This paper investigated this effect of two arch bridges on a High Speed Train (HST) project. The results showed the whipping factor is as high as 2.3 on these two bridges. Four design solutions to eliminate the whipping effect are analyzed and discussed. The findings of this paper call for attention of bridge engineers to the whipping effect during the design of this type of bridges.

Keywords: arch bridge; seismic response; whipping effect; high-speed train; bridge design.

1 Introduction

Back to 1930s to 1940s, Prof. Romeo R. Martel at California Institute of Technology and Prof. Merit P. White at University of Massachusetts investigated the seismic response of multi-story buildings. They found out that the shear force at the roof is much higher than the result of equivalent static method. They used an effectiveness factor C to denote the amplification of shear force along the height of the building. At the roof level, the C factor could be as big as 1.6 [1]

In 1943, Prof. Maurice A. Biot at University of Oklahoma proved the amplification of the roof structure analytically. He introduced the so called "whipping effect" (whip effect in his paper) to describe this phenomenon. [2]

During the past decades, the whipping effect has been thoroughly researched and controlled in building engineering. Nowadays, provisions have been written in building seismic design codes. American Society of Civil Engineering standard ASCE 7 section 12.8.3 [3] and Eurocode 8 Part 1 section 4.3.3.2.3 [4] distribute the horizontal shear force in vertical direction proportional to the elevation of each story. Story drift displacement is limited to protect each story from drifting damage in both ASCE 7 and Eucode 8. In the Chinese seismic design codes for buildings section 5.2.1 [5] , an additional shear force is added at the top story to capture the whipping effect, in addition to the height proportional distribution.

Unlike buildings that stack up stories vertically, bridges mainly stretch out spans horizontally. For most girder bridges, each span is virtually a heavy mass (deck and girder) at the top of columns that

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