A Recommendation to the Application of Directional Combination Rules for the Seismic Responses in Bridge Design

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Summary

It is well known that the seismic forces applied in orthogonal directions should be combined to achieve the maximum seismic response of bridges. However, design codes do not give detail instruction to process the concurrent responses of seismic excitations when combined with other load effects in design. This leaves a few different algorithms by engineers' own judgments when doing the load combinations in the bridge design. This paper investigated these algorithms and compared their distinctive differences in design process. Based on the fact that both orthogonal seismic waves can shake the bridge site simultaneously, a revised 30% rule is recommended in this paper to estimate the reasonable concurrent responses. This revised 30% rule essentially treats excitations in orthogonal directions as normal load cases and applies 1.0, 0.3 load factors to them in one scenario and 0.3, 1.0 factors in another, just like the same pattern we do with other load cases. Then, seismic responses can be combined with all concurrent responses from other loads cases using the load combination factors defined in the codes.

Keywords: Bridge, Design, Seismic, and Combination.

1. Introduction

When a structure is subjected to seismic risks, it should be designed to resist earthquake motions equally (preferably) from all possible directions. A structural design based on accounting for the orthogonal earthquake effects separately may result in insufficient member dimensions, as an unfavourable internal force distribution in the structural elements would usually develop under the combined effects of an earthquake motion. Many studies investigated the bi-directional effects using several methods of analysis. As a common approach, the square-root-of-sum-of-squares (SRSS) procedure is based on the assumption that the actions on an element affected by earthquake excitations in two directions are combined [1]. Cili et al. [2] proposed a way of analysis for the multi-directional effects of earthquakes using the characteristics of the selected earthquakes. The 30% and 40% rules are simplified approximations to the SRSS (square root of the sum of squares) method. Menun and Der Kiureghian [3] presented a response spectrum rule for combining the contributions from three orthogonal components of ground motion to the maximum value of a response quantity. This is called the CQC3 (complete quadratic combination in three directions) rule which also offers the most critical orientation of the ground motion components.

Nowadays, the outcomes of these studies have been included in most seismic design codes [4 to 7]. After examining these codes, it is still not quite clear how exactly the seismic responses in different directions should be combined in real design practice. All design codes require combining seismic responses with other primary loads such as dead load and live load. None of these codes give instructions to process the concurrent forces (such as concurrent moment and compression forces in columns) excited by earthquakes from different directions in the load combinations. Designers have to use their own judgments to combine concurrent forces. At some scenarios, a same project may get different design forces by designers and checkers using their own interpretations. This doesn't seem normal after decades of efforts in the researches and practices of seismic design. As design codes, there should be clearer specifications to guide engineers in this work.

https://doi.org/10.2749/222137816819258708
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