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A note on the wave-passage effects in out-of-plane response of long structures to strong earthquake pulses

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ABSTRACT

Elementary consequences of the wave-passage effects are described for out-of-plane response of long structures, excited by SH wave earthquake ground motion pulses propagating along their longitudinal axis. For the passage times in the range of 0.005–0.10 s, the maximum column drifts can increase several folds due to the combined action of out-of-plane and torsional response. Because most of the seismic wave energy do not arrive at a site vertically, the common engineering assumption that it does, leads to nonconservative response estimates.

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1. Introduction

The traditional response spectrum describing the structural response to strong earthquake ground shaking is based on onedimensional vibrational formulation of the linear response of a single-degree-of-freedom (SDOF) system [1-4], in which the ground and the SDOF are interconnected at a point, and only the horizontal component of ground motion is considered. According to this model, the contributions to the response resulting from wave passage along the finite dimensions of the foundation, and from the three-dimensional nature of strong motion (three translations and three rotations), are all ignored. This simplification can lead to reasonably realistic estimates of response when the earthquake excitation consists of long waves—long relative to the plan dimensions of the structure [5]-but when excitation involves short waves, vibrational formulation ceases to provide realistic description of the response, and wave-propagation methods of solution must be used. This is because for strong ground motion pulses in the near field, damage can and will occur during the first wave travel from foundation towards roof, well before the interference of incident motions, which had time to form the mode shapes in the structure (viewed from the vibrational point of view), and well before the occurrence of first maximum of the relative response of the equivalent degree of freedom.

Extensions and generalizations of the response-spectrum method have been proposed to account approximately for the wave passage and differential motions along the base of long structures, but these approximations, which are based on the Taylor series extrapolations of long-wave motions, cease to be valid

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for short-wave excitations. Examples of such extensions are described in several studies involving differential strong motion [6–8] and the strength-reduction factors [9–11]. This paper also examines how the classical response-spectrum method can be extended to apply for physical conditions that are well beyond its original formulation.

The role of simultaneous action of all six components of ground motion (three translations and three rotations; [12–17]) is still rarely considered in engineering design [18–20], even though it has been 75 years since the response-spectrum method was formulated and about 40 years since it became the principal tool in engineering design [21]. Simultaneous action of all those six components of motion is not considered in this paper. We consider only the out-of-plane horizontal displacements associated with passage of SH and Love waves. Nevertheless, it is hoped that the present work will help in further understanding of wave-passage effects.

The consequences of non-vertical wave incidence and of the associated wave-passage effects [22] on the torsional response of symmetric structures [23], out-of-plane response of long structures [24], bridges [25], and rigid foundations [26] have been studied previously. The purpose of this brief note is to extend this type of analysis to a stiff long structure supported by equally spaced columns, on individual foundations, for transient ground motions, which are characteristic of the near fault large displacement pulses and permanent displacements, and which arrive with large initial velocities [20].

We consider the response of a long, rigid mass supported by multiple columns and excited by a ground motion pulse in an outof-plane horizontal direction (Fig. 1). This model has two degrees of freedom (translation in the *y* direction and torsion about the *z* axis), and it is analogous to the one studied by Trifunac and Gičev [8], excited by SH and Love waves propagating along the longitudinal

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