THE ROLE OF TOPOGRAPHIC AMPLIFICATION IN SEISMIC SLOPE INSTABILITIES

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The seismic instability of earth slopes is among the most challenging seismic hazards which is placed in the category of inertial instabilities in the context of slope stability analysis. There are two main groups of analysis which are popular among engineers, pseudostatic and permanent deformation analysis. The pseudostatic approach has a number of attractive features including a simple and straight forward nature. Nonetheless, representation of the complex, transient, dynamic effects of the seismic load by a single constant unidirectional pseudostatic coefficient is among its most notable drawbacks (Kramer, 1996). Based on the landmark works of Newmark (1965) and Makdisi and Seed (1978), permanent-deformation analysis of soil slopes has become more common during the recent past decades. Newmark used a procedure using the analogy of a sliding block on an inclined plane. Comprehensive discussions of this procedure and its application in engineering practice have been presented by many researchers, such as Ambraseys and Srbulov (1995), Kramer and Smith (1997) and Bray and Travasarou (2007).

It is worth mentioning that all of the classic procedures of evaluation of dynamic slope stability were developed only to account for the effect of SV waves. However, most of the times Rayleigh waves are generated near soil slopes due to topographic effects on seismic wave propagation. This event can greatly amplify the induced accelerations and velocities on the surface of the slope and accordingly increase the potential for larger instabilities (Ashford and Sitar, 2002). The generated surface waves can significantly affect the response of soil slopes subjected to seismic waves, and the super imposition of the reflected and incident waves may also produce open cracks in the top surface of the slope (Uenishi, 2010). This paper addresses the effect of surface Rayleigh waves combined with SV body waves generated by an earthquake and their interactions with a soil slope.

If the influence of Rayleigh waves on dynamic response of soil slopes is to be considered, significance of the frequency-dependent nature of these waves arises. Sliding block procedure, as originally proposed, assumes that the potential failure mass is rigid, neglecting the compliance behaviour of actual slopes- they act non-rigid during earthquake shakings. Their dynamic response is influenced by a number of their inherent properties including geometry and stiffness, and also by characteristics of the input motion, such as its amplitude and frequency content (Kramer, 1996). A slope composed of stiff soil or subjected to a low-frequency input motion, is exposed to long wavelengths, resulting in nearly in phase motions throughout the potential failure mass (Figure 1.a). On the other hand, if the slope is made of softer soils or is subjected to a high-frequency input motion, short wavelengths are propagated inside of the sliding mass and out of phase motions occur (Figure 1.b).

The importance of the input motion and its frequency content has been indicated in some predictive relationships for the permanent deformation of embankments due to seismic loadings, including the expression proposed by Yegian et al. (1991). In this paper, a numerical finite element large-scale model is used which is verified with the results obtained by a physical small-scale shaking table test on a sandy soil slope (Jafarzadeh *et al.*, 2014). A discussion is presented on the importance of Rayleigh waves near soil slopes on their dynamic behaviour. As it is shown in Figure 2, effects of Rayleigh wave generation is more pronounced when a given slope is subjected to an incident motion with a lower dominant frequency.

The reason behind this phenomenon is the fact that there is an effective depth to which surface waves (e.g. Rayleigh waves) are transpired, and this depth is proportional to the wavelength of the input motion. This finding compares well with the expression developed by Yegian *et al.* (1991). In this regard, the concept of "effective depth of surficial amplification" is introduced.

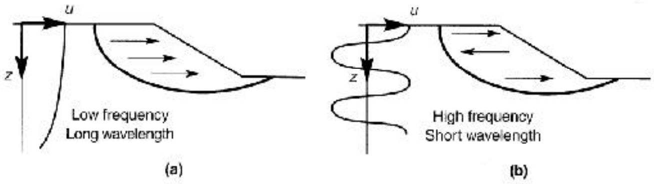

Figure 1. Effect of frequency on motions induced in slopes. (a) Long wavelength associated with low-frequency motion and (b) short wavelength associated with high-frequency motion (Kramer, 1996)

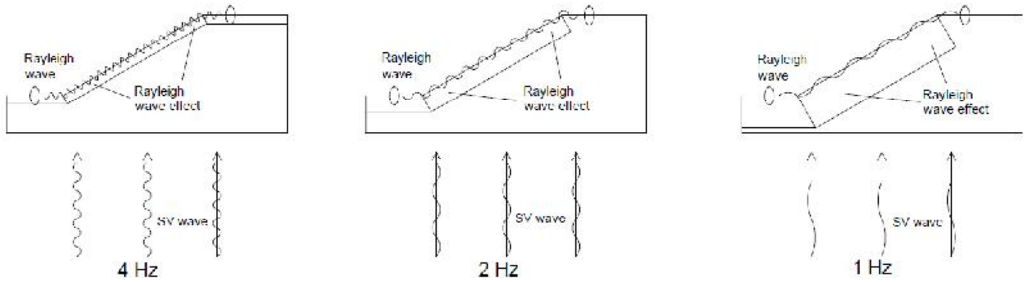

Figure 2. Influence of the frequency content of the incident motion on effective depth of reflected Rayleigh waves near soil slopes

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