THE DYNAMIC EFFECT OF SURFACE WAVES ON SLOPE STABILITIES

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This study addresses the effect of Rayleigh surface waves on the dynamic behavior of a wedge-shaped slope. A two-dimensional model analysis shows that the superimposition of the reflected and incident waves may induce strong stress amplification and generate open cracks at the top of the slope. The analytical results are used to investigate the mechanism of slope failure caused by the 1978 Miyagi-ken-oki, Japan earthquake. Finally, the validity of conventional slope assessment criteria is discussed.

1. Introduction

The 1978 Miyagi-ken-oki, Japan earthquake caused one unique damage pattern at fill slopes in the residential areas of the city of Sendai: Only at the top of the slopes, crack openings were found (Fig.1; no cracks were generated on the slopes themselves). Surface waves may acquire an increasing preponderance at a great distance from the source, and therefore, in this case, considering the epicentral distance of 140 km, it may be more appropriate to assume that the damage was induced by Rayleigh surface waves that interacted with a wedge-shaped slope.

2. Two-dimensional wave analysis

Using the coordinate systems (Fig.2) and the method of Fourier transformations, we can evaluate quantitatively the interaction process and the effects of slope inclination on wave scattering (Fig.3). Figure 3(a) shows that the reflected amplitude increases with inclination nearly monotonically until 80°. When the incident and reflected Rayleigh waves are superimposed, at the position x_p (> 0) on the free surface those waves will be in phase with each other if a certain condition, derived from the phase shift in Fig.3(b), is satisfied [Fig.3(d)]. In this harmonic analysis, the induced normal stress becomes also maximum at x_p and hence will most easily generate tensile rupture around that position. Figure 3 suggests that the inclination 75° in Fig.1 is not particularly suitable for slopes: More energy is reflected and therefore the superimposition of the incident and the strong reflected Rayleigh waves may result in large tensile stress to be induced near the corner of the slope and cracks may be initiated and propagated.

3. Conclusions

The analytical investigation on the dynamic behavior of a wedge-shaped slope subjected to a Rayleigh wave has shown that the surface wave can be amplified at the top of the slope most significantly when the slope inclination is some 80°, but this amplification effect can be largely reduced by simply changing the angle to, say, 60° where much part of the incident wave energy is radiated in the form of body waves [Fig.3(c)]. Conventional slope assessment criteria, based on pseudo-static earthquake forces, may generally provide correct tendencies, but the results obtained in this study might assist in designing earthquake-resistant slopes more quantitatively and effectively. More detailed and quantitative discussion can be found in Uenishi (2005).

References

OYO Corporation. Miyagi-Ken-Oki, Japan earthquake, June 12, 1978, damage investigation report. OYO Corporation, Tokyo, 1978 (in Japanese).

Uenishi, K. The effect of Rayleigh surface waves on slope stabilities. Report of the Research Center for Urban Safety and Security, Kobe University, vol.9, 2005 (and references therein).

Keywords: Rayleigh wave, earthquake-induced slope failure, wave reflection and transmission, phase shift, critical slope inclination.

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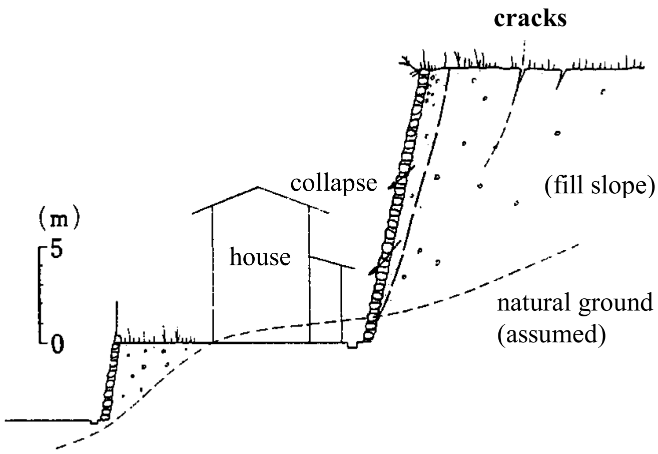


Figure 1. Typical failure of a fill slope in the Sendai city, induced by the 1978 Miyagi-ken-oki, Japan earthquake [modified from OYO Corporation (1978)].

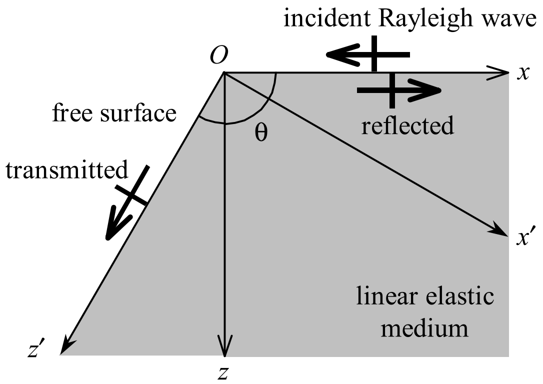
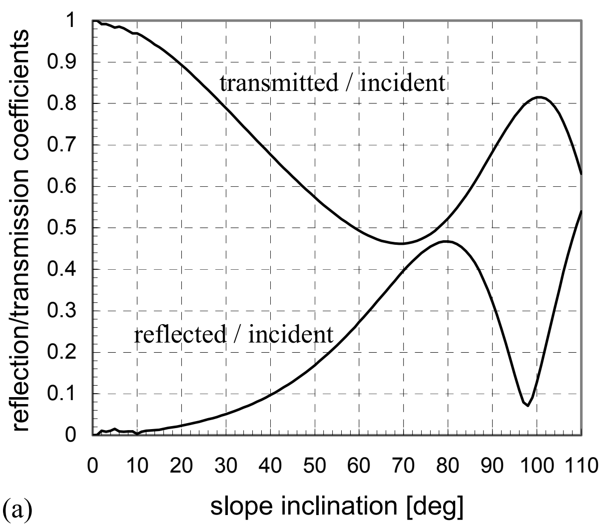
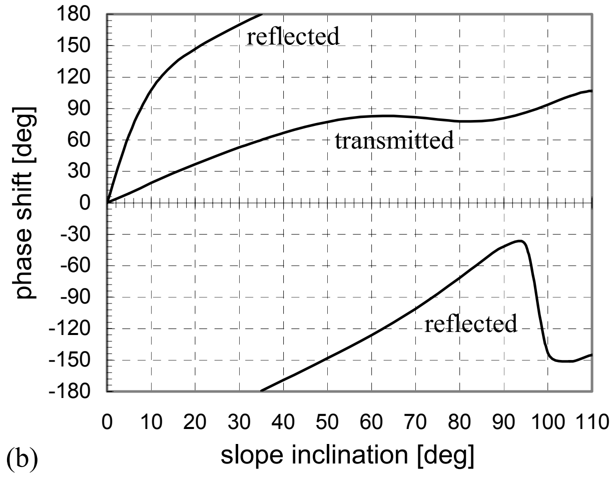
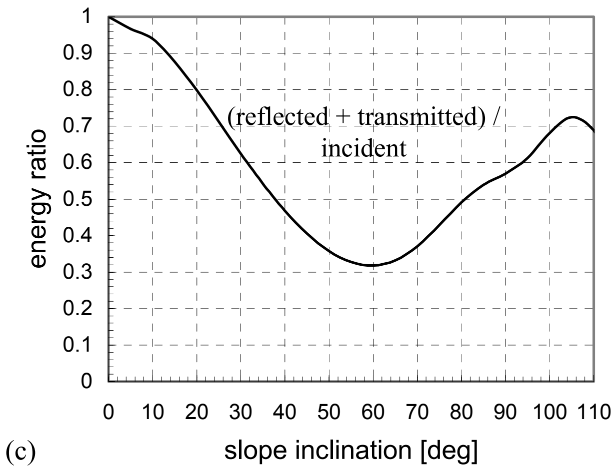


Figure 2. The two Cartesian coordinate systems employed in the analysis. The slope inclination is (180 − θ) degrees.







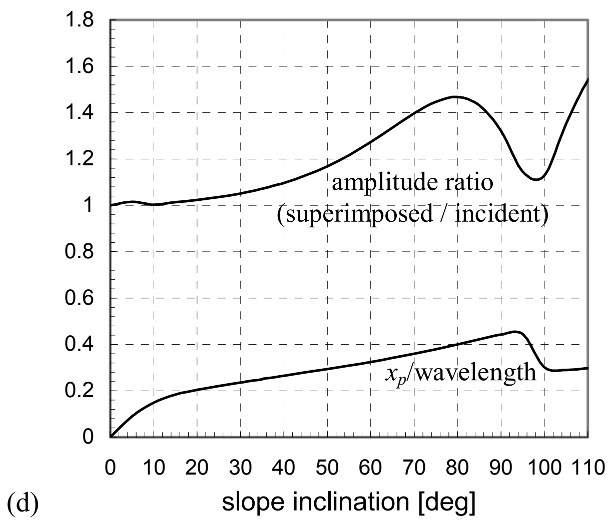


Figure 3. The effect of slope inclination on wave reflection and transmission: (a) amplitude ratios, (b) phase shift, (c) total energy and (d) the position x_p where the incident and reflected waves are in phase with each other and therefore the superimposed amplitude becomes maximum. Poisson's ratio 0.25; plane strain conditions.