LOWER BOUND ANALYSIS OF SLOPES UNDER VARIABLE REPEATED DYNAMIC LOADS BY STRENGHT REDUCTION METHOD

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Stability of slopes against seismic loads has always been a great cause of concern in seismic regions. Pseudo-static, dynamic and mixture of Pseudo-Static and dynamic methods are utilized to evaluate the behaviour of slopes against earthquake loading. Common to all the aforementioned approach is that all of them suppose earthquake loads is imposed on the slope for one time only. In reality, slopes can be subjected to many earthquakes with different characteristics during their lifetime.

In order to investigate the behaviour of slope against repeated earthquake loading, two different approaches may be followed. The first way is to conduct a load-displacement nonlinear dynamic analysis, which in addition to being time consuming, is no trustable due to uncertainties in load characteristics. The second approach is to take advantage of shakedown limit theorems that directly attain a load domain under which, slope can be regarded to be safe and cease to develop further permanent deformation after a limited number of cyclic load imposition.

Shakedown limit theorems, similar to collapse limit theorems, have been developed in the form of lower and upper bound theorems. Ceradini (1980) developed the lower bound dynamic shakedown theorem and Maier and Koiter (1973, 1974) presented the upper bound dynamic shakedown theorem.

The first numerical shakedown solutions by finite element method and mathematical programming, is attributed to Maier (1969). Although shakedown approach has been used extensively in various fields of engineering, the first serious application of shakedown theory was conducted by Sharp and Booker (1984) to find the shakedown solution of road pavements under repeated wheel loading. Most of the works on shakedown limit of geotechnical structures have been devoted to pavement design under traffic loads. Hossain and Yu (1996) and Yu and Hossain (1998), extended the method of Bottero et al. (1980) which was used previously to find the limit loads of shallow footings, to shakedown problems. This method consists of finite element elastic analysis, finite element stress analysis and linear programming.

In seismic regions, slopes are subjected to variety of earthquake loading with different characteristics during their lifetime. In this regards, shakedown theory can be utilized for seismic stability of slopes. Arvin et al. (2012) and Askari et al. (2013) extended the method of Hossain and Yu (1996) to dynamic lower bound shakedown analysis and evaluated the safety of embankment and slopes under repeated seismic loads. In their study, variation of dynamic shakedown factor versus T_s/T_m is presented where T_s and T_m are the dominant period of slope and medium period of earthquake respectively. They showed that slopes might be stable under major earthquakes, but fail due to repetition of minor seismic loads.

In this paper, strength reduction method is employed to determine the safety factor of slopes against Dynamic repeated loads. An embankment and a slope, resting on bedrock are considered as model study. Sin loads with 0.15g intensity and different periods (T_m) are considered as imposed dynamic loads. Soil strength parameters (cohesion c, and internal friction angle ϕ) are reduced or increased by try and error so that slope reach the critical condition with respect to dynamic shakedown criterion.

Factor of safety (FS) against T_s/T_m for embankment and slope with ϕ=30°, γH/c=5 (γ is soil unit weight and H is the slope height), and damping ratio DR=0.05, are depicted in Fig 1. Results indicate that as T_s/T_m increases, first, FS value decreases and then increases. The minimum value of FS comes about $T_s/T_m=1$, when the slope and embankment undergo resonant. In addition, for all T_s/T_m. shakedown factor of safety of embankment is larger than the slope of the same geometrical properties. This finding is in contradiction to Pseudo-Static method which does not differentiate between embankment (with wide crest) and slope.

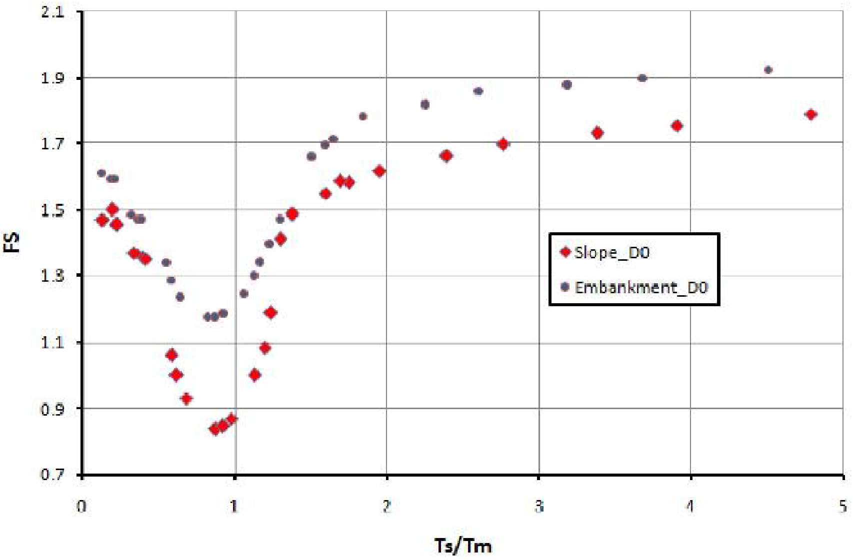

Figure 1. Shakedown factor of safety attained by strength reduction method against Ts/Tm for embankment and slope with ϕ=30°, γH/c=5 and DR=0.05

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