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Effect of Slip Width on the Permanent Displacement of Earth Slopes

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ABSTRACT: Newmark's sliding block method is commonly used for estimating earthquake-induced permanent displacement of earth slopes and embankments. Since this method is a simplified dynamic analysis procedure with acceptable accuracy, it has received considerable attention among the geotechnical practitioners. However, it has some shortcomings such as neglecting system response and sliding mass rotation. Hence, researchers have proposed modified procedure to enhance the realistic features of this method. The effect of sliding mass rotation, which sets the block in a gentler condition, was previously considered by continuous increment of yield acceleration. Since the sliding mass is three dimensional in reality, smaller permanent displacement is expected when the width of block is accounted for. In this paper, width of the rotating-sliding mass is taken into account in the coupled and decoupled solution of sliding block equations. The results show that the width of the slip zone is effective on the resulting displacements. With a constant slip length, whatever slip width is reduced, yield acceleration increases and consequently difference between the modified decoupled (or modified coupled) and decoupled (or coupled) increases.

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1- Introduction

Evaluation of earthquake-induced deformation of earth embankments and slopes is a matter of high importance for geotechnical engineers. Numerical and analytic methods could be used to calculate the permanent displacement of earth slopes. Since numerical methods with an appropriate constitutive model commonly need many soil parameters, engineers might be more interested to use analytic and semi-analytic methods. Among such methods, the rigid block method proposed by Newmark [1] and the subsequent methods developed based on has the most applications. In the initial form of the rigid block method, the effects of system response and rotation are not considered. Thereafter, the subsequent analyses considered the system response in the calculation of displacement through the coupled and the decoupled procedures. Contrary to the decoupled assumption of system response and sliding, the dynamic response of the sliding mass and the permanent displacement are modeled together in the couple method so that the effect of plastic sliding displacement on the ground motions is taken into account. Geometrically, downward movement of the sliding mass tries to stabilize the block; thereby increasing the yield acceleration. Such modification was initially proposed and formulated by Stamatopoulos [2] for the sliding block method and implemented within a decoupled analysis by Baziar et al. [3].
The modified acceleration, presented by Stamatopoulos [2], is

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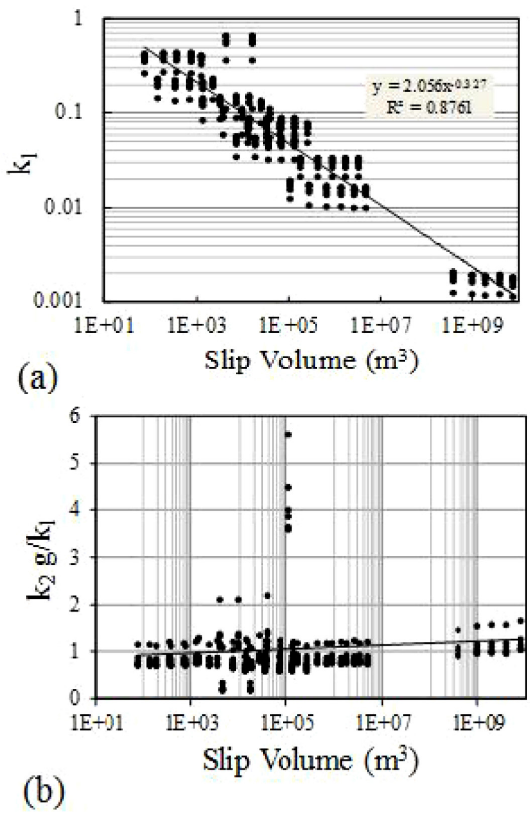

Fig. 1. Variations of constant coefficient versus slip volume (a) k_1 (b) k_2

based on constant width of the rotating-sliding mass during rotation. This assumption is not true, because width of the rotating-sliding mass is changing in reality. In this paper, the relationships proposed by Stamatopoulos [2] are modified with considering different width of the rotating-sliding.

2- Methology

One of the limiting assumptions in the Newmark analysis is the role of downward movement of the sliding mass on the increment of yield acceleration. Stamatopoulos [2] assumed that mass failure is like a chain and this chain moves along the slip surface. The width of chain was considered constant in the Stamatopoulos [2] approach. With modifying Stamatopoulos's equations, Eq. (1) will obtain:

$$a_c = a_{c_0} + \frac{2sk_1}{1+\sqrt{1+sk_2}} \qquad (1)$$

where k_1 and k_2 are constant coefficients, a_{c0} is initial critical acceleration, s is slope permanent displacement and a is modified critical acceleration. The examples considered by Stamatopoulos [2] were also used for calculation of k_1 and k_2. But slip width was considered variable. Fig. 1 was plotted from the calculation results for the coefficients.

According to Fig. 1-b, $k_2 = k_1/g$ and k_1 is:

$$k_1 = \frac{2.1}{V_t^{\,0.33}} \qquad (2)$$

where V_t is volume of sliding zone in cubic meter.

3- Results

In this study, a computer code was written in time domain to capture the displacement time using Newmark [4] and Rathje and Bray [5] equations for rigid block, coupled and decoupled analysis. The modified critical acceleration (Eq. (1)) was combined with the equations provided by Newmark [1] and Rathje and Bray [5]. These equations were solved by using the time stepping method developed by Newmark [1] and also the central difference method. The earthquake motions YBI and TAP recorded from 1989 Chi Chi and 1994 Northridge earthquake were first scaled to MHA = 0.4g and used in the analyses.

The rigid block, coupled and decoupled permanent displacements shown in Fig. 2 were calculated based on the formulations of Newmark [1] and Rathje and Bray [5] which ignore the effect of slip width. Moreover, the modified-rigid block, modified-coupled and modified-decoupled were calculated based on the equations modified for the width of slip surface. There would be an opportunity to compare the permanent displacements obtained from the original and

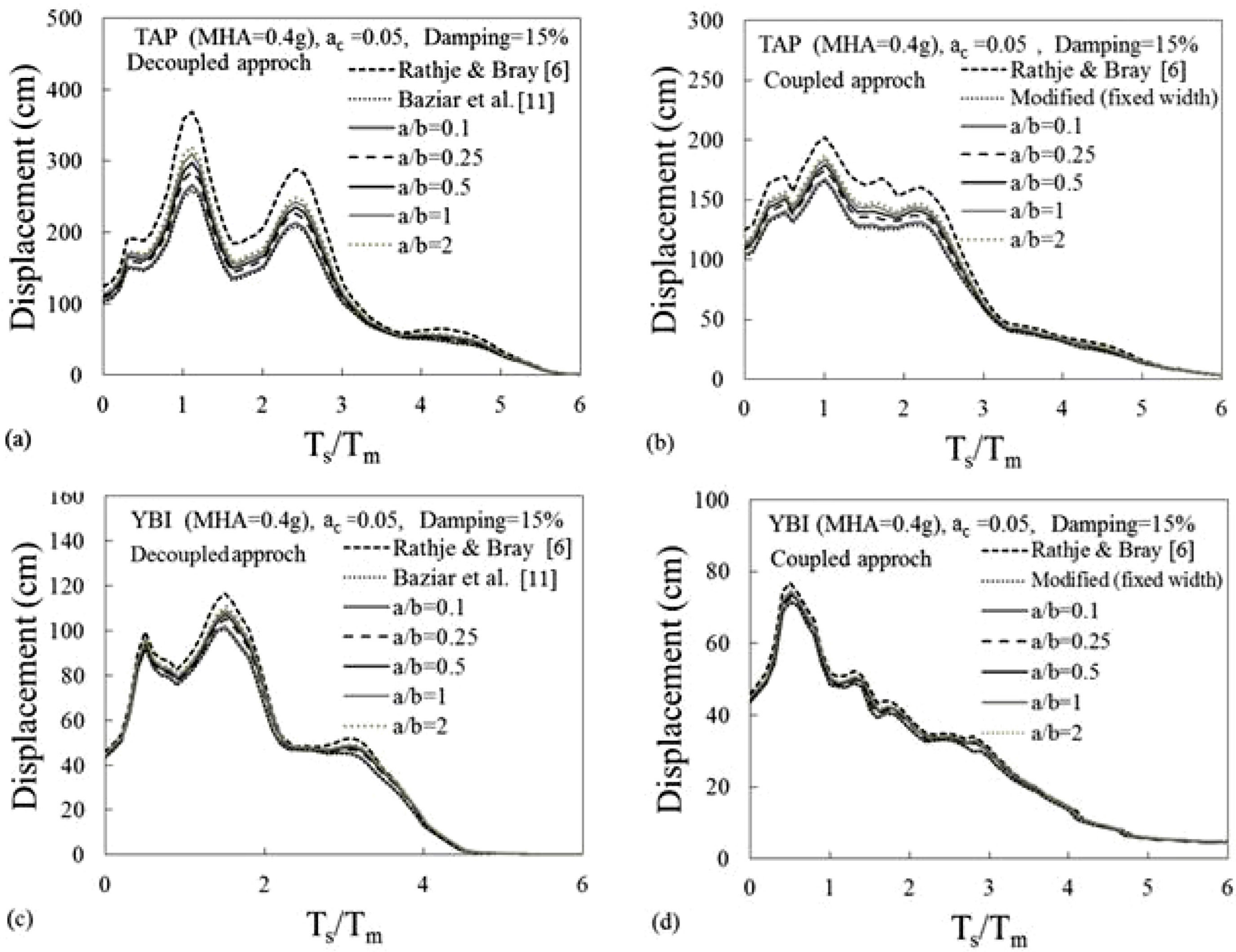

Fig. 2. Displacement difference versus period ratio for various ratio of slip width to slip length for: (a) TAP, decoupled approach; (b) TAP, coupled approach; (c) YBI, decoupled approach; (d) YBI, coupled approach

mentioned analyses and to evaluate the effect of slip width on the resultant displacements. Fig. 2 compares rigid block, modified rigid block, decoupled, modified decoupled, and coupled analyses using YBI and TAP records for two different sliding lengths and k_y=0.05g.

4- Conclusion

The results show that the width of the slip zone is effective on the resulting displacements. With a constant slip length, whatever slip width is reduced, yield acceleration increases and consequently difference between the modified decoupled (or modified coupled) and decoupled (or coupled) increases.

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