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Progressive Failure Analysis of a Retaining Wall-Backfill System Based on Smeared Shear Band Technique

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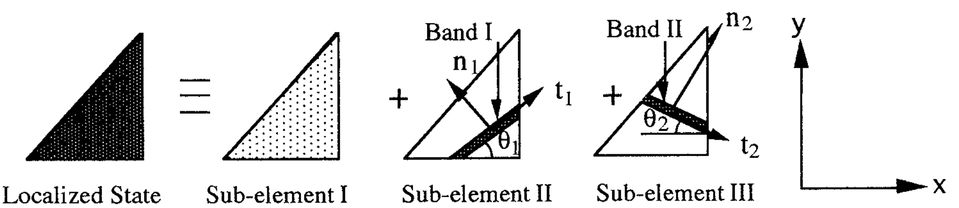
INTRODUCTION: When deformed sufficiently into the plastic range, deformation within granular materials such as sand tends to concentrate along bands called shear band resulting in non-uniform stress state. Hence the numerical analysis such progressively deforming material calls for the treatment of shear band within an element. Progressive failure analyses such as earth pressure analysis should take into account the effects of the incepted shear bands since earth pressure phenomenon is more likely to undergo shear band bifurcation as the plane strain condition is quite sensitive to the localized shearing. The primary objective of this research is to propose a numerical model for the seismic analyses of a retaining wall-backfill system that includes the effect of shear bands during deformation process of the backfill. In the analyses, the element under localized shearing is modeled incorporating two shear bands by extending the smeared shear band concept of Pietruszczak and Mroz (Ref. 1) where only one shear band was used.

FORMULATION: Once localized shearing takes place, the post bifurcation behavior can be idealized as pseudo-uniform deformation. Considering a triangular element, at the instant of inception of the shear bands, the element can be assumed to be composed of three sub-elements as shown schematically in Fig. 1. Such an element is called *cracked triangular element.* The strain rates generated inside each sub-element are also shown in the figure. The inclinations θ_1 and θ_2 of the two bands with the X axis are given by

$$\theta_1=\theta^1-\left(\frac{\phi}{2}+\frac{\pi}{4}\right); \qquad \theta_2=\theta^1+\left(\frac{\phi}{2}-\frac{3\pi}{4}\right) \tag{1}$$

where θ^1 is the angle from X axis to the major principal axis and ϕ is the angle of internal friction.



$$\dot{\varepsilon} = \dot{\varepsilon}^e + \dot{\varepsilon}_1^P + \dot{\varepsilon}_2^P$$

Fig. 1 Cracked Triangular Element with Two Shear Bands

Considering finite deformation within the band, the constitutive relations for the two bands in terms of rate of deformation tensors $\bar{\mathbf{d}}$ and Couchy's stress rate $\dot{\sigma}$ are given by the following relations in the {x,y} coordinate system.

$$\bar{\mathbf{d}}_1=\frac{1}{H}\left([I]-\frac{1}{H}[\bar{C}_1]\beta\delta_1^T\right)^{-1}[\bar{C}_1]\dot{\sigma} \tag{2}$$

$$\bar{\mathbf{d}}_2=\frac{1}{H}\left([I]-\frac{1}{H}[\bar{C}_2]\beta\delta_2^T\right)^{-1}[\bar{C}_2]\dot{\sigma} \tag{3}$$

in which $\mathbf{I}$ is the unit tensor, $[\bar{C}_1]$ and $[\bar{C}_2]$ are the compliance matrices; β is given by the expression

$$\beta=\{-2\sigma_{xy}, 2\sigma_{xy}, (\sigma_x-\sigma_y)\}^T \tag{4}$$

δ_1 and δ_2 are the transformation matrices defined by the orientation angles θ_1 and θ_2; H is the plastic modulus. Introducing the smearing factor ζ defined to be the ratio of the area of the shear band to the area of the element, the infinitesimal plastic strains in the two sub-elements can be expressed as

$$\dot{\varepsilon}_1^P=\zeta\bar{\mathbf{d}}_1; \qquad \dot{\varepsilon}_2^P=\zeta\bar{\mathbf{d}}_2 \tag{5}$$

Substituting Eqs. (2) and (3) into Eq. (5) and then using Fig. 1 the constitutive equation takes the form

$$\dot{\varepsilon} = \{([I] - \frac{1}{H}[\bar{C}_1]\beta\delta_1{}^T)^{-1}[\bar{C}_1] + ([I] - \frac{1}{H}[\bar{C}_2]\beta\delta_2{}^T)^{-1}[\bar{C}_2] + \frac{H}{\zeta}[C^e]\}\frac{\zeta}{H}\dot{\sigma} \qquad (6)$$

in which C^e is the elastic part of the compliance matrix obtained using Young's modulus E and Poisson's ratio ν. Eq. (6) completes the cracked element formulation named here as *Coupled Shear Band Method* .

ANALYSES AND RESULTS: An experimental model on earth pressure (Ref. 2) has been simulated in the analyses. Wilson's theta method is used in the time incremental procedure to calculate the dynamic increment. Analyses are completed using two constitutive models, one using the conventional method (Ref. 3) assuming the continuity of stress and the other using the *Coupled Shear Band Method* discussed above.

Defining the active state as that stage when the backfill forms a clear failure wedge of Rankine type, the coefficient of the dynamic active thrust, K_{AE} and the relative height of the point of application of the resultant, $(h / H)_{AE}$ have been calculated. In Figs. 2a and 2b, K_{AE} and $(h / H)_{AE}$ respectively have been plotted as functions of the acceleration level. It can be observed from the figures that the results obtained from the new method are more close to the experimental results than those of the conventional method.

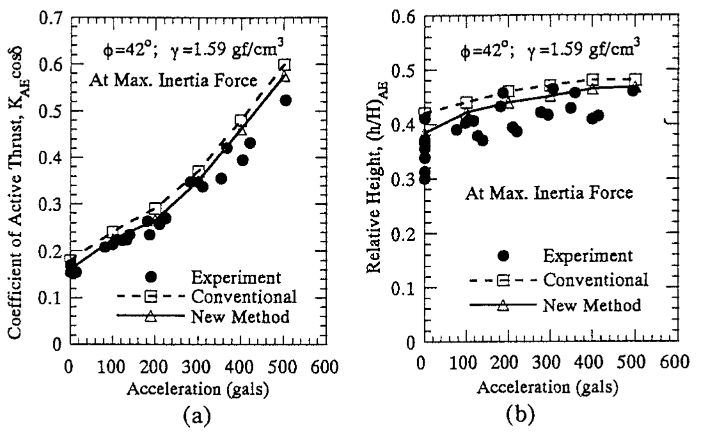


Fig. 2 Variation of K_{AE} and $(h / H)_{AE}$ with Acceleration

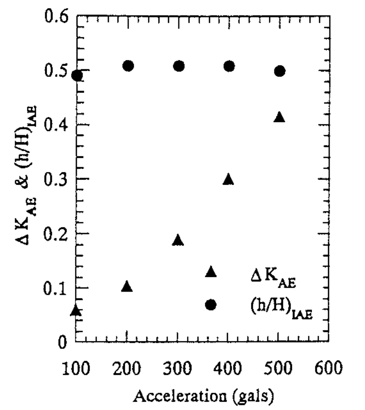


Fig. 3 Dynamic Increment Vs. Accn.

The point of application of the dynamic increment, $(h / H)_{IAE}$ has been calculated by using the results obtained from the developed numerical model. Fig. 3 shows the values of $(h / H)_{IAE}$ and the corresponding active coefficient, ΔK_{AE} at various acceleration levels. It can be observed from the figure that with increasing acceleration the dynamic increment of the active coefficient increases non linearly, however, the relative height of it's point of application fluctuates between the value of 0.49 to 0.51, the mean value of which coincides with Ichihara and Matsuzawa's recommendation (Ref. 2).

FINAL REMARKS: The *coupled shear band* formulation presented here can capture the progressive deformation characteristics of the backfill better than do the conventional method of analyses. The deviation of the results from the experimental ones at the higher acceleration level may be due to the assumption of perfect bonding at the interface which cease to remain valid when acceleration level increases (Ref. 4).

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