Sensitive study of numerical simulation of wedge failure

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outline

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Introduction

Plane cover area 26.36% in Taiwan

Hillside cover area 26.91% in Taiwan

High mountain cover area is 46.73% in Taiwan

Type of slope failure

- planner failure
- wedge failure
- circular failure
- topple failure
\[ N_a \sin \alpha + T'_a \cos \alpha + T'_b \cos \beta - N_b \sin \beta = P \cos \gamma \cos \theta \]
\[ N_a \cos \alpha + T'_a \sin \alpha + T'_b \cos \beta - N_b \sin \beta = P \cos \gamma \sin \theta \]

4 parameters are unknown, only 2 equation!!!

P: The resultant force P
\( N_a/N_b \): normal force of plane A/B
\( T'_a/T'_b \): shear stress perpendicular to I-line on plane A/B
\( \gamma \): the plunge of I-line
\( \theta \): parameters used to define direction of vector force P
\( \alpha \): the plunge of intersection line with plane A on plane I
\( \beta \): the plunge of intersection line with plane B

Nguyen, 2015 (modified from Lee, 1989)
Introduction—Rigid wedge method (RWM) (Hoek and Bray, 1974)

assumed the wedge is a rigid block and neglected the shear forces that perpendicular to l-line on two discontinuities $T_a'$ and $T_b'$. $T_a' = T_b' = 0$

$$N_a = \frac{W \cos \gamma \sin (\beta + \theta)}{\sin (\alpha + \beta)}$$
$$N_b = \frac{W \cos \gamma \sin (\alpha - \theta)}{\sin (\alpha + \beta)}$$

$$T_a' = C_a A_a + N_b \tan \varphi' = 0$$
$$T_b' = C_b A_b + N_a \tan \varphi' = 0$$

- $(\alpha - \theta)$ and $(\beta + \theta)$ are limited from 0° to 90°. otherwise it would be planar failure.
- $(\alpha + \beta)$ have to be restricted between 0° and 180°.
- $FS = \frac{\text{resist force}}{\text{driving force}} = \frac{T_a + T_b}{Wsiny}$

W: rock weight  
$N_a/N_b$: normal force of plane A/B  
$T_a'/T_b'$: shear stress perpendicular to l-line on plane A/B  
$T_a/T_b$: shear stress along l-line on plane A/B  
$\gamma$: the plunge of of l-line  
$\theta$: parameters used to define direction of vector force P  
$\alpha$: the plunge of intersection line with plane A on plane I  
$\beta$: the plunge of intersection line with plane B  
$\varphi'$: friction angle perpendicular to l-line on plane A/B

\[ T'_a = T'_b = T_a = T_b = T_{\text{max}} \]

\[ T'_a = C_a A_a + N_b \tan \varphi' \]

\[ T'_b = C_b A_b + N_a \tan \varphi' \]

\[ N_a = \frac{N_b D_3 + E_1 - E_3}{D_1} \quad , \quad N_b = \frac{D_1 (E_5 - E_2 - E_4) - D_2 (E_1 - E_2)}{D_1 D_4 + D_2 D_3} \]

\[ D_1 = \sin(\alpha - \theta) - R_a \tan \varphi \cos(\alpha - \theta) \quad , \quad E_1 = C_a A_a \cos(\alpha - \theta) \]

\[ D_2 = \cos(\alpha - \theta) + R_a \tan \varphi \sin(\alpha - \theta) \quad , \quad E_2 = C_a A_a \sin(\alpha - \theta) \]

\[ D_3 = \sin(\beta + \theta) - R_b \tan \varphi \cos(\beta + \theta) \quad , \quad E_3 = C_b A_b \cos(\beta + \theta) \]

\[ D_4 = \cos(\beta + \theta) + R_b \tan \varphi \sin(\beta + \theta) \quad , \quad E_4 = C_b A_b \sin(\beta + \theta) \]

\[ E_5 = W \cos \gamma \]

\[ FS = \frac{\text{resist force}}{\text{driving force}} = \frac{C_a A_a + C_b A_b + N_a \tan \varphi + N_b \tan \varphi}{W \sin \gamma} \]

W: rock weight

\( N_a/N_b \): normal force of plane A/B

\( T'_a/T'_b \): shear stress perpendicular to I-line on plane A/B

\( T_a/T_b \): shear stress along I-line on plane A/B

\( \gamma \): the plunge of I-line

\( \theta \): parameters used to define direction of vector force P

\( \alpha \): the plunge of intersection line with plane A on plane I

\( \beta \): the plunge of intersection line with plane B

\( \varphi' \): friction angle perpendicular to I-line on plane A/B

\( C_a/C_b \): cohesion of material on plane A/B
Introduction (Nguyen, 2018)

\[ T' = RT_{\text{max}}(R=0-1) \]

\[ T'_a = R(C_a A_a + N_b \tan \varphi') \]
\[ T'_b = R(C_b A_b + N_a \tan \varphi') \]

\[ N_a = \frac{N_b D_3 + E_1 - E_3}{D_1}, \quad N_b = \frac{D_1(E_5 - E_2 - E_4) - D_2(E_1 - E_2)}{D_1 D_4 + D_2 D_3} \]

\[ D_1 = \sin(\alpha - \theta) - R_a \tan \varphi \cos(\alpha - \theta) \]
\[ D_2 = \cos(\alpha - \theta) + R_a \tan \varphi \sin(\alpha - \theta) \]
\[ D_3 = \sin(\beta + \theta) - R_b \tan \varphi \cos(\beta + \theta) \]
\[ D_4 = \cos(\beta + \theta) + R_b \tan \varphi \sin(\beta + \theta) \]
\[ E_1 = R_a C_a A_a \cos(\alpha - \theta) \]
\[ E_2 = R_a C_a A_a \sin(\alpha - \theta) \]
\[ E_3 = R_b C_b A_b \cos(\beta + \theta) \]
\[ E_4 = R_b C_b A_b \sin(\beta + \theta) \]
\[ E_5 = W \cos \gamma \]

\[ F_S = \frac{\text{resist force}}{\text{driving force}} = \frac{C_a A_a + C_b A_b + N_a \tan \varphi + N_b \tan \varphi}{W \sin \gamma} \]

W: rock weight
\( N_a/N_b \): normal force of plane A/B
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\( \varphi' \): friction angle perpendicular to I-line on plane A/B
\( C_a/C_b \): cohesion of material on plane A/B
Motivation

• Because RWM and MSSM provide factor of safety upper and lower boundary, they show the lowest and highest shear stress which is perpendicular to I line. It also mean different deformable condition of wedge block. RWM regard the wedge block as rigid block and MSSM regard the wedge as the most deformable block. Therefore, this study want to know what kind of deformable condition is suitable for RWM and MSSM on different dihedral angle
Method-Flac 3D

• FLAC3D (Fast Lagrangian Analysis of Continua in 3 Dimensions)
• A numerical modeling code for advanced geotechnical analysis of soil, rock, and structural support in three dimensions
• Use finite-difference methods (FDM) to get solution.
• The calculation cycle repeats over-and-over until a steady-state solution has been achieved (i.e., the maximum unbalanced force is small compared to the total applied forces)
Method-Flac3D

1. Generate grid, construct desire shape
2. Define material properties
3. Specify boundary and initial condition

Make initial stress balance

Set new condition which you want to simulate

calculate

Construct analysis model

Simulate and get solution
Preliminary result

**FS-dip angle of intersection line**

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P = W$</td>
<td>530 T</td>
</tr>
<tr>
<td>$C_a = C_b$</td>
<td>0</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0 degrees</td>
</tr>
<tr>
<td>$\varphi_a = \varphi_b$</td>
<td>45 degrees</td>
</tr>
</tbody>
</table>

Set $\alpha = \beta$, dihedral angle = $180 - (\alpha + \beta)$
Preliminary result

- $T' = RT_{max}$
- (R=0-1)

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>P=W</td>
<td>530 T</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>15 degrees</td>
</tr>
<tr>
<td>$C_a = C_b$</td>
<td>0</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0 degrees</td>
</tr>
<tr>
<td>$\varphi_a = \varphi_b$</td>
<td>45 degrees</td>
</tr>
</tbody>
</table>

Set $\alpha = \beta$, dihedral angle=180-($\alpha + \beta$)
Preliminary summary

1. When plunge of sliding wedge is small, FS has larger difference between RWM and MSSM.

2. When plunge of sliding wedge is fixed and dihedral angle is small, if we increase shear stress which is perpendicular to I-line a little from zero, the influence is very significant.
Future work

• Construct model by using Flac3D.
• Set different deformation to get solution.
Thanks for listening