60 years of Pressuremeter
International Symposium for the 60th Anniversary of the pressuremeter
May 1 - 2, 2015

Numerical modeling of cylindrical cavity expansion in rock mass based on the Hoek-Brown yield criterion

Sami Hamdi (Researcher - UCL)
Alain Holeyman (Professor - UCL)

Presented by Sami Hamdi (✉️ sami.hamdi@uclouvain.be)
Outline

1. Rock masses Modeling
   - Hoek-Brown (H-B) yield criterion
   - Extended Drucker Prager (EDP) yield criterion
   - Parameters for EDP yield criterion

2. Numerical axisymmetric modeling
   - Triaxial tests and cylindrical cavity expansion
   - Comparison with Lamé’s solution

3. Experimental validation
   - Comparison with pressuremeter tests
   - Comparison with Pressiorama® chart

4. Conclusions
**Rock masses Modeling**

- Hoek-Brown yield criterion

\[ \sigma_1 = \sigma_3 + \sigma_{ci} \left( m_b \frac{\sigma_3}{\sigma_{ci}} + s \right)^{\alpha} \]

- \( \sigma_1 \): major effective principal stress
- \( \sigma_3 \): minor effective principal stress
- \( \sigma_{ci} \): unconfined compressive strength of the intact rock
- \( m_b \): reduced value of the material constant \( m \)
- \( m_i, \alpha, s \): material constants

**Figure 1** Hoek–Brown yield criterion

- Hoek-Brown parameters
  - \( \sigma_{ci} = 52 \text{ MPa} \)
  - GSI = 40
  - \( m_i = 40 \)
  - \( D = 0 \)
Rock masses Modeling

- Extended Drucker-Prager yield criterion

\[ F(p, q) = aq^b - p - p_t \]

\[ q = \sqrt{\frac{3}{2} S : S} \]

\[ p = \frac{1}{3} \text{trace}(\sigma) \]

\[ \sigma = \begin{bmatrix} \sigma_3 & 0 & 0 \\ 0 & \sigma_3 & 0 \\ 0 & 0 & \sigma_1 \end{bmatrix} \]

\[ S = \frac{1}{3} \begin{bmatrix} \sigma_3 - \sigma_1 & 0 \\ 0 & \sigma_3 - \sigma_1 \\ 0 & 0 & 2\sigma_1 \end{bmatrix} \]

Figure 2 Extended Drucker-Prager yield criterion
Rock masses Modeling:

- Parameters calculation of the EDP yield criterion

\[
p = \frac{\sigma_{ci}}{6\eta^2} \left( m_b (3 - \eta) + \sqrt{m_b^2 (3 - \eta)^2 + 36.\eta^2} \right)
\]

\[
q = \frac{\sigma_{ci}}{6\eta} \left( m_b (3 - \eta) + \sqrt{m_b^2 (3 - \eta)^2 + 36.\eta^2} \right)
\]

**H-B parameters**
- \( \sigma_{ci} \)
- \( GSI \)
- \( D=0 \)
- \( m_i \)

**EDP parameters**
- \( a = \frac{p \eta_B + q \eta_B}{q \eta_B} \)
- \( b = \frac{p \eta_C + q \eta_C}{q \eta_C} \)
- \( p_t = \frac{s \sigma_{ci}}{m_b} \)

**Figure. 3**
Yield criterion in p-q plane with H-B and EDP
Rock masses Modeling

- Numerical triaxial tests

### St-Peter sandstone parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{ci}$</td>
<td>52 MPa</td>
</tr>
<tr>
<td>GSI</td>
<td>40</td>
</tr>
<tr>
<td>$m_i$</td>
<td>17</td>
</tr>
<tr>
<td>$D$</td>
<td>0</td>
</tr>
<tr>
<td>$a$</td>
<td>0.035</td>
</tr>
<tr>
<td>$b$</td>
<td>1.16</td>
</tr>
<tr>
<td>$p_t$</td>
<td>33 kPa</td>
</tr>
<tr>
<td>$E$</td>
<td>4 GPa</td>
</tr>
<tr>
<td>$\nu$</td>
<td>0.33</td>
</tr>
</tbody>
</table>

- Cylindrical cavity expansion

**Figure. 4**. Comparison between yield points obtained by numerical triaxial compression tests and the theoretical H-B yield criterion.

**Figure. 5**. Cylindrical cavity expansion in rock mass.

**Figure. 6**. Numerical modeling of the cylindrical cavity expansion.
Numerical axisymmetric modeling

- Comparison with Lamé’s solution

\[
\sigma = \sigma_0 + (P - \sigma_0) \left( \frac{r_0}{r} \right)^2 \\
\sigma = \sigma_0 - (P - \sigma_0) \left( \frac{r_0}{r} \right)^2
\]

H-B yield criterion

\[
P_{Yield} = \sigma_0 + \frac{\sigma_{ci}}{8} \left( -m_b + \sqrt{m_b^2 + 16s + 16m_b} \right)
\]

Figure 7: Comparison of radial and circumferential stresses with elastic analytical.

Figure 8: Radial plastic strain at the cavity wall vs. applied pressure (ABAQUS).
Experimental validation

- Comparison avec pressuremeter test performed in St-Peter sandstone

**Figure. 9** Comparison between pressuremeter tests and present study

**Figure. 10** Normalized probe volume variation as a function of the applied pressure for weathered gneiss and for St-Peter sandstone
Experimental validation

- Comparison with Pressiorama® chart (weathered gneiss)

- Moderately weathered Gneiss [GSI=30]
- Highly weathered Gneiss [GSI=20]
- Completely weathered Gneiss [GSI=10]
- St-Peter sandstone

Figure 11 Pressiorama® $[E_m/P_{LM}, P_{LM}]$ “spectral” diagram ranging from soils to rocks (after Baud et Gambin 2013)
Conclusions

Extended Drucker-Prager (EDP) yield criterion allows a reasonable modeling of rock mass behavior based on the Hoek-Brown yield criterion Extended.

The proposed numerical model of cylindrical cavity expansion in rock mass gave good results compared to pressuremeter tests performed in St-Peter sandstone.

Good agreement with Pressiorama® chart for weathered gneiss.

During pressuremeter tests in rock masses, a small incremental pressure is needed in order to identify the yielding pressure.

The Limit pressure \( (P_L) \) is very high: revision of doubling of the probe volume criterion should be considered in the case of pressuremeter tests performed in rock masses.