Bearing Capacity of Rocks

Intact Rock Mass
A rock mass with joint spacing greater than 4 to 5 times the width of the footing. Local and General shear failure is associated to brittle and ductile rock respectively.
1. Theoretical pressure bulbs (10% intensity) below strip load on a medium of rock mass having low shear modulus.
# Jointed Rock Mass

<table>
<thead>
<tr>
<th>Joint</th>
<th>Description</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STEELY DIPPING JOINTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S &lt; B$</td>
<td>Compressive failure of individual rock columns. Near vertical joints serial</td>
<td>Eq. 8.5</td>
</tr>
<tr>
<td>$70 &lt; \alpha &gt; 90^\circ$</td>
<td>Closed Joints: General shear failure along well defined failure surfaces. Near vertical joint(s).</td>
<td>Eq. 8.1</td>
</tr>
<tr>
<td>$S &gt; B$</td>
<td>Open or Closed Joints: Failure initiated by splitting leading to general shear failure. Near vertical joint set(s).</td>
<td>Eq. 8.6</td>
</tr>
<tr>
<td><strong>JOINTED</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$20 &lt; \alpha &lt; 70^\circ$ or $S &gt; B$ if failure wedge can develop along joints</td>
<td>General shear failure with potential for failure along joints. Moderately dipping joint serial.</td>
<td>Eq. 8.3</td>
</tr>
<tr>
<td>Layered</td>
<td>Fractured</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>$0 &lt; \alpha &lt; 20$</td>
<td>$N/A$</td>
<td></td>
</tr>
<tr>
<td>Limiting Values of $H$ with respect to $B$ is dependent upon material properties</td>
<td>$S &lt; \ll B$</td>
<td></td>
</tr>
<tr>
<td>Thin Rigid Upper Layer: Failure is initiated by tensile failure caused by fracture of thin rigid upper layer.</td>
<td>General shear failure with irregular failure surface through rock mass. Two or more closely spaced joint sets.</td>
<td></td>
</tr>
</tbody>
</table>

For the layer case, $N/A$ is provided. Equations (6.3) apply for the fractured case.
FIGURE 16.1 Contd.
FIGURE 16.1 Surface footing—ultimate bearing capacity in case of: (a) open vertical joints, (b) intact rock, (c) tight vertical joints and (d) inclined set of tight joints, development of rupture zones with inclination of, (e) centrally located joint, (f) joint located at the edge of footing; other possible modes of failure of foundation rock (g) to (k), [Goodman (1989)].
General Shear Failure

\[ q_{ult} = cN_c + 0.5 \gamma BN_q + \gamma DN_q \]  \hspace{1cm} (6-12)

where

\[ q_{ult} = \text{the ultimate bearing capacity} \]

\[ \gamma = \text{effective unit weight (i.e. submerged unit wt. if below water table) of the rock mass} \]

\[ B = \text{width of foundation} \]

\[ D = \text{depth of foundation below ground surface} \]

\[ c = \text{the cohesion intercepts for the rock mass} \]

Local Shear Failure

\[ q_{ult} = cN_c + 0.5\gamma BN_q \]
• Compressive Failure:
  A case characterized by poorly constrained columns of poor rock.

\[ q_{quit} = 2c \tan (45 + \phi/2) \]

Splitting Failure

For widely spaced and vertically oriented discontinuities, failure generally initiates by splitting beneath the foundation.
The ultimate bearing capacity is given by:

For circular foundations

\[ q_{ult} = JcN_{cr} \]  \hspace{1cm} (6-6a)

For square foundations

\[ q = 0.85JcN_{cr} \]  \hspace{1cm} (6-6b)

For continuous strip foundations for \( L/B \leq 32 \)

\[ q_{ult} = JcN_{cr}/(2.2 + 0.18 \, L/B) \]  \hspace{1cm} (6-6c)
where

\[ J = \text{correction factor dependent upon thickness of the foundation rock and width of foundation.} \]

\[ L = \text{length of the foundation} \]

The bearing capacity factor \( N_{cr} \) is given by:

\[ N_{cr} = \frac{2N_{\phi}^2}{1+N_{\phi}} (\cot \phi) \left( \frac{S}{B} \right) \left( 1 - \frac{1}{N_{\phi}} \right) \]

\[ - N_{\phi} (\cot \phi) + 2N_{\phi}^{1/2} \]
Guideline properties of Rock Mass Classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>very good rock</td>
<td>good rock</td>
<td>fair rock</td>
<td>poor rock</td>
<td>very poor rock</td>
</tr>
<tr>
<td></td>
<td>RMR</td>
<td>80–100</td>
<td>60–80</td>
<td>40–60</td>
<td>20–40</td>
<td>&lt; 20</td>
</tr>
<tr>
<td></td>
<td>Q Value</td>
<td>&gt; 40</td>
<td>10–40</td>
<td>4–10</td>
<td>1–4</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Friction angle $\phi$ (°)</td>
<td>&gt; 45</td>
<td>35–45</td>
<td>25–35</td>
<td>15–25</td>
<td>&lt; 15</td>
<td></td>
</tr>
<tr>
<td>Cohesion (kPa)</td>
<td>&gt; 400</td>
<td>300–400</td>
<td>200–300</td>
<td>100–200</td>
<td>&lt; 100</td>
<td></td>
</tr>
<tr>
<td>SBP (MPa)</td>
<td>10</td>
<td>4–6</td>
<td>1–2</td>
<td>0.5</td>
<td>&lt; 0.2</td>
<td></td>
</tr>
<tr>
<td>Safe cut slope (°)</td>
<td>&gt; 70</td>
<td>65</td>
<td>55</td>
<td>45</td>
<td>&lt; 40</td>
<td></td>
</tr>
<tr>
<td>Tunnel support</td>
<td>none</td>
<td>spot bolts</td>
<td>pattern bolts</td>
<td>bolts + shotcrete</td>
<td>steel ribs</td>
<td></td>
</tr>
<tr>
<td>Stand up time for span</td>
<td>20 yr for 15 m</td>
<td>1 yr for 10 m</td>
<td>1 wk for 5 m</td>
<td>12 h for 2 m</td>
<td>30 min for 1 m</td>
<td></td>
</tr>
</tbody>
</table>
Allowable Bearing Stresses on Rock Masses

Note: Use maximum $q_a < q_u$ where $q_u =$ compressive strength of intact rock specimens

$$q_{ALLOWABLE} (MPa) \approx 1 + \frac{(RQD/16)}{1 - (RQD/130)}$$

Note: 1 MPa = 10 tsf

Peck, et al. (1974)
Approximation
In case of rock mass with favorable discontinuities, the net allowable bearing pressure may be estimated from:

\[ q_a = q_c \times N_j \]

Where \( q_c \) = average uniaxial compressive strength of rock cores

\( N_j \) = empirical coefficient depending on the spacing of the discontinuities

\[
N_j = \frac{3 + \frac{S}{B}}{10\sqrt{1 + 300(\frac{\delta}{S})}}
\]

\( \delta \) = thickness of discontinuity

\( S \) = spacing of discontinuities

\( B \) = width of footing

The above relationship is valid for a rock mass with spacing of discontinuities > 0.3 m, \( \delta < 10 \) mm (15 mm if filled with soil) and \( B > 0.3 \) m.
\[ N_j = \frac{3 + S/B}{10 \sqrt{1 + 300 \frac{S}{S}}} \]

**FIG. 2 - BEARING PRESSURE COEFFICIENT N_j**
Pile Foundations:

The allowable bearing capacity of socketed piles is given by:

\[ q_a = q_c \times N_j \times N_d \]

Where

\[ N_d = 0.8 + 0.2 \frac{h}{d} \]

\( h \) = depth of socket in rock

\( d \) = diameter of socket

Determination of Net Allowable Bearing Pressure from Pressuremeter Test:

\[ q_a = \frac{1}{3} \left[ \gamma D_f + K_d (P_l - \gamma D_f) \right] \]

Where \( q_a \) = allowable bearing pressure in t/m²

\( P_l \) = limit pressure determined by the Pressuremeter in t/m²

\( \gamma D_f \) = overburden pressure in t/m²
## Values of $K_d$

<table>
<thead>
<tr>
<th>Depth of footing</th>
<th>$K_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load at rock surface</td>
<td>0.8</td>
</tr>
<tr>
<td>Load at radius/width of foundation unit</td>
<td>2.0</td>
</tr>
<tr>
<td>Load at 4 times radius/width of foundation unit</td>
<td>3.6</td>
</tr>
<tr>
<td>Load at 10 times radius/width of foundation unit</td>
<td>5.0</td>
</tr>
</tbody>
</table>
Plate Load Test

FIG. 9 - ASSEMBLY FOR VERTICAL PLATE LOAD TESTS, USED AT TEHRI DAM SITE, UTTAR PRADESH.
Correction Factors : (Not required for RMR)

• Ground Water Table:
  (a) Rock with discontinuous joints with opening less than 1mm wide – 0.75
  (b) Rock with continuous joints with opening 1 to 5 mm wide filled with gouge – 0.7 to 0.5
  (c) Limestone/ Dolomite deposit with major cavities filled with soil – 0.66 to 0.5.

• Cavities: Major cavities inside limestone - 0.5

• Slope and orientation of joints:
  (a) Fair orientation of continuous joints in the slope – 1 to 0.5
  (b) Unfavorable orientation of continuous joints in slope – 0.5 to 0.33.
FIG. 3 - ROCK FOUNDATION PROBLEMS