Geotechnical classification of weak and complex rock masses with the GSI system: Maintaining the geological particularities

V. P. Marinos
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• Vice President of the IAEG Engineering Geologist MSc, DIC, PhD
Outline

I. Introduction – Putting numbers to Geology
II. Rock mass characterization; a vehicle to translate Geology into Rock Engineering Design
III. Interaction between GSI and tectonism
IV. Interaction between GSI and weathering
V. Interaction between GSI and alteration
VI. Conclusions
I. Introduction – Putting numbers to Geology

- Despite the fact that significant advances have occurred within almost every area of geotechnical design, with arguably the greatest developments in rock engineering being in numerical modelling capability, to date similar levels of advance have not been achieved in improving characterization of the geological variability that exists in natural rock masses.

- Geological representativeness is key to achieving effective rock engineering design. This requires that reliable estimates be available of strength and deformation characteristics of the rock masses on which or within which engineering structures are to be created, be it a tunnel, a foundation or a slope cut.
I. ASSESSMENT OF GROUND IN THE DESIGN FOR ENGINEERING CONSTRUCTION

1. Geological data and conditions
2. Translation into an engineering geological description
3. Ground type properties

Environment (stress, groundwater, ...)

Selection of suitable geotechnical parameters and appropriate criteria

DESIGN
The use of empirical, analytical, numerical methods

CONSTRUCTION
Implementation of the design
Estimation of rock mass properties

- Laboratory testing
- In situ testing
- Back analysis
- Appropriate use of rock mass classifications
Rock mass characterization and classification; a vehicle to translate Geology into the design of Engineering Structures
THE ROCK MASS TYPE CHARACTERISATION IS A RESULT OF THE TOTAL GEOLOGICAL HISTORY (GEOLOGICAL MODEL)

**Genesis** is reflected on the quality of intact rock and inherent structures

**Tectonic evolution** reflects on mass structure (fabric) and quality of joints

**Palaeogeographical evolution** reflects on weathering and final fabric
With the development of extremely powerful microcomputers and of user-friendly software there was a higher demand for reliable input data related to rock mass properties required as input into numerical analysis or close form solutions for designing tunnels. This necessity led to the development of a different set of rock mass classification.

The GSI (Geological Strength Index) is such a classification.
II. Calculation of rock mass parameters using geotechnical classifications: Tight to direct engineering geology observation on the nature of the rock mass

1. Hoek-Brown failure criteria (Hoek et al, 2002)

\[
\sigma_1' = \sigma_3' + \sigma_{ci}(m_b \frac{\sigma_3'}{\sigma_{ci}} + s)^a
\]

\(\sigma_1', \sigma_3'\) = principal effective stresses at failure

\(\sigma_{ci}\) = Uniaxial compressive strength of the intact rock

\(D\): Disturbance Factor due to the excavation method or relaxation (0-1)

\[m_b = m_i \exp\left(\frac{GSI - 100}{28 - 14D}\right)\]

\[s = \exp\left(\frac{GSI - 100}{9 - 3D}\right)\]

\[\alpha = \frac{1}{2} + \frac{1}{6} \left(e^{-GSI/15} - e^{-20/3}\right)\]
Data entry stream for using the Hoek-Brown system for estimating rock mass parameters for numerical analysis.

- Geological observations
  - Descriptive input
    - Laboratory testing of intact rock samples
    - GSI Characterization
      - Hoek-Brown criterion - engineering properties of rock masses
      - Parameters required for numerical analysis
        - Verification and modification through in situ monitoring and back analysis
        - Numerical analysis of overstress and remedial measures
        - In situ stresses
        - Groundwater
        - Damage Factor
        - Excavation sequence

Hoek et al., 2013
GSI for jointed rock masses, *Hoek & Marinos 2000*

**GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS**
(Hoek and Marinos, 2000)

From the lithology, structure and surface conditions of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI = 35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.

<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>SURFACE CONDITIONS</th>
<th>DECREASING SURFACE QUALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTEGRAL OR MASSIVE</td>
<td>intact rock specimens or massive in situ rock with few widely spaced discontinuities</td>
<td>(N/A)</td>
</tr>
<tr>
<td>BLOCKY</td>
<td>well interlocked undisturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets</td>
<td>(90)</td>
</tr>
<tr>
<td>VERY BLOCKY</td>
<td>interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets</td>
<td>(70)</td>
</tr>
<tr>
<td>BLOCKY/DISTURBED/SEAMY</td>
<td>folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity</td>
<td>(50)</td>
</tr>
<tr>
<td>DISINTEGRATED</td>
<td>poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces</td>
<td>(30)</td>
</tr>
<tr>
<td>LAMINATED/SHEARED</td>
<td>Lack of blockiness due to close spacing of weak schistosity or shear planes</td>
<td>(10)</td>
</tr>
</tbody>
</table>

Note that the table does not apply to structurally controlled failures.
GSI for jointed rock masses,
*Hoek & Marinos 2000*

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</table>

**SURFACE CONDITIONS**

<table>
<thead>
<tr>
<th>VERY GOOD</th>
<th>GOOD</th>
<th>FAIR</th>
<th>POOR</th>
<th>VERY POOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>very rough, fresh, unweathered surfaces</td>
<td>rough, slightly weathered, iron-stained surfaces</td>
<td>smooth, moderately weathered and altered surfaces</td>
<td>slickensided, highly weathered surfaces with compact coatings or fillings</td>
<td>slickensided, highly weathered surfaces with soft clay</td>
</tr>
</tbody>
</table>

**DECREASING SURFACE QUALITY**

<table>
<thead>
<tr>
<th>90</th>
<th>80</th>
<th>70</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
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<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
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</tbody>
</table>

**DECREASING INTERLOCKING OF ROCK PIECES**

<table>
<thead>
<tr>
<th>90</th>
<th>80</th>
<th>70</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
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<tr>
<td>N/A</td>
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GSI for jointed rock masses,
*Hoek & Marinos 2000*

**SURFACE CONDITIONS**

**VERY GOOD**
Very rough, fresh unweathered surfaces

**GOOD**
Rough, slightly weathered, iron stained surfaces

**FAIR**
Smooth, moderately weathered and altered surfaces

**POOR**
Slickensided, highly weathered surfaces with compact coatings or fillings or angular fragments

**VERY POOR**
Slickensided, highly weathered surfaces with soft clay coatings or fillings

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**GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS**

(Hoek and Marinos, 2000)

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**SURFACE CONDITIONS**

- **VERY GOOD**
  - Very rough, fresh unweathered surfaces
- **GOOD**
  - Rough, slightly weathered, iron stained surfaces
- **FAIR**
  - Smooth, moderately weathered and altered surfaces
- **POOR**
  - Slickensided, highly weathered surfaces with compact coatings or fillings or angular fragments
- **VERY POOR**
  - Slickensided, highly weathered surfaces with soft clay coatings or fillings

**STRUCTURE**

- **INTACT OR MASSIVE**
  - Intact rock specimens or massive in situ rock with few widely spaced discontinuities
- **BLOCKY**
  - Well interlocked un-disturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets
- **VERY BLOCKY**
  - Interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets
- **BLOCKY/DISTURBED/SEAMY**
  - Folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity
- **DISINTEGRATED**
  - Poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces
- **LAMINATED/SHEARED**
  - Lack of blockiness due to close spacing of weak schistosity or shear planes

**DECREASING SURFACE QUALITY**

- **N/A**
  - N/A
- **10**
  - 20
- **30**
  - 40
- **50**
  - 60
- **70**
  - N/A
- **80**
  - N/A
- **90**
  - N/A
GSI for jointed rock masses

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VERY BLOCKY - interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets
GSI for jointed rock masses

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<td><strong>VERY GOOD</strong></td>
</tr>
<tr>
<td><strong>BLOCKY</strong> - well interlocked undisturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets</td>
<td><strong>GOOD</strong></td>
<td><strong>slightly weathered surfaces</strong></td>
</tr>
<tr>
<td><strong>VERY BLOCKY</strong> - interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets</td>
<td><strong>DECREASING</strong></td>
<td><strong>INTERLOCKING OF ROCK PIECES</strong></td>
</tr>
<tr>
<td><strong>BLOCKY/DISTURBED/SEAMY</strong> folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity</td>
<td><strong>N/A</strong></td>
<td><strong>N/A</strong></td>
</tr>
<tr>
<td><strong>DISINTEGRATED</strong> poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces</td>
<td><strong>N/A</strong></td>
<td><strong>N/A</strong></td>
</tr>
<tr>
<td><strong>LAMINATED/SHEARED</strong> Lack of blockiness due to close spacing of weak schistosity or shear planes</td>
<td><strong>N/A</strong></td>
<td><strong>N/A</strong></td>
</tr>
</tbody>
</table>

Note that the table does not show the range of values for each category. The values are indicative and should be adjusted based on local conditions and experience.
GSI for jointed rock masses

Hoek and Marinos, 2000

GEOLOGICAL STRENGTH INDEX FOR JOINTED ROCKS

From the lithology, structure and surface conditions of the discontinuities, estimate the average value of GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI = 35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.

**STRUCTURE**

<table>
<thead>
<tr>
<th>Surface Conditions</th>
<th>Very Good</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Very Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very Blocky</strong></td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td><strong>Very Blocky</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Blocky</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Blocky/Disturbed/Seamy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Disintegrated</strong></td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Laminated/Sheared</strong></td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**DECREASING SURFACE QUALITY**

- Intact or Massive: intact rock specimens or massive in situ rock with few widely spaced discontinuities
- Blocky: well interlocked undisturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets
- Very Blocky: interlocked, partially disturbed mass with multi-faceted angular blocks formed by 4 or more joint sets
- Blocky/Disturbed/Seamy: folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity
- Disintegrated: poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces
- Laminated/Sheared: Lack of blockiness due to close spacing of weak schistosity or shear planes
GSI for jointed rock masses

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</thead>
<tbody>
<tr>
<td>VERY GOOD</td>
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</tr>
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- **LAMINATED/SHEARED**
  - Lack of blockiness due to close spacing of weak schistosity or shear planes

---

**LAMINATED/SHEARED**

Lack of blockiness due to close spacing of weak schistosity or shear planes
One of the key advantages of the Geological Strength Index is that the geological reasoning it embodies allows characterization to be made of a very wide range of rock masses and conditions, including both weak and complex situations, but always maintaining care to keep within valid applicability limits.
Definition of Rock Mass Type according to the scale of the project

- **Intact rock** - do not use GSI. Use Hoek Brown to check for tensile and shear failure.
- **Single joint** - do not use GSI. Model joint explicitly and use Hoek Brown for intact rock.
- **Sparsely jointed rock** - do not use GSI. Model joints explicitly and use Hoek Brown for intact rock.
- **Blocky rock mass with minimal anisotropy** - use GSI with caution.
- **Heavily jointed rock mass** - use of GSI is appropriate.

**Bench scale**

**Pit scale**

*H-B material: GSI is appropriate*
Bench scale slopes at Chuquicamata are obviously structurally controlled.

It can be argued that, on the scale of a 500 m high slope, the rock mass can be treated as “homogeneous” and that rock mass classification can be used to estimate the properties.

Photos E. Hoek
The overall failure will not be guided by rock mass anisotropy. Thus GSI is applicable.

Pindos mountain, Greece
Once a GSI has been selected, the system becomes highly quantitative. and GSI can be used as input into numerical analysis or closed form solutions.

Note that the GSI system is not intended as a replacement of the RMR or Q since it has no rock mass reinforcement capability

*Its only function is the estimation of rock mass properties*
Hoek-Brown criterion - Geotechnical parameters of rock mass through GSI, $\sigma_{ci}$, $m_i$

Equivalent $c'$, $\varphi'$ for MOHR COULOMB criterion:

$$c' = \frac{\sigma_{ci} [(1+2a)s + (1-a)m_b \sigma'_{3n}]^{a-1}}{(1+a)(2+a) \sqrt{1+\left(6am_b (s + m_b \sigma'_{3n})^{a-1}\right)}}$$

$$\varphi' = \sin^{-1}\left[\frac{6am_b (s + m_b \sigma'_{3n})^{a-1}}{2(1+a)(2+a) + 6am_b (s + m_b \sigma'_{3n})^{a-1}}\right]$$

where $\sigma'_{3n} = \sigma'_{3\text{max}}/\sigma_{ci}$

$s'_{3\text{max}}$ : the upper limit of confining stress over which the relationship between Hoek-Brown and Mohr-Coulomb criteria is considered

The geotechnical parameters can be calculated with the Windows program “RSdata”, that can be downloaded from www.rocscience.com.

Hoek, Carranza-Torres, Corkum, 2002
Empirical relations for the calculation of the Deformation Modulus of the rock mass $E_m$, through GSI, $\sigma_{ci}$, $E_i$

$$E_m (GPa) = \left(1 - \frac{D}{2}\right) \sqrt{\frac{\sigma_{ci} (MPa)}{100}} \times 10^{(GSI-10)/40} \quad \text{Hoek et al, 2002}$$

$$E_m = E_i \left[0.02 + \frac{1 - D / 2}{1 + e^{((60+15D-GSI)/11)}}\right] \quad \text{Hoek & Diederichs, 2006}$$

$E_m = $ Deformation modulus of the rock mass

$\sigma_{cm} = $ Uniaxial compressive strength of the rock mass

$\sigma_{ci} = $ Uniaxial compressive strength of the intact rock
Thus, the numerical “ID” of the “isotropic” rock mass for analysis
Typical values for Hoek and Brown parameters, constant $m_i$ and strength $\sigma_{ci}$, for typical rocks - formations

Carter and Marinos, 2020
Hoek - Brown parameters for different rock mass types

The usual projections - GSI values according to geological rules and characters of genesis and evolution for typical rocks - formations in combination with the Hoek and Brown parameters, constant $m_i$ and strength $\sigma_{ci}$.

Marinos and Carter, 2018
Hoek - Brown parameters for different rock mass types

Marinos and Carter, 2018
III. Interaction between GSI and Tectonism
Tectonic Shearing

a. The seamy rock mass type consisting of intercalated rock members of strikingly different competence which are differentially deformed (sheared, folded and faulted)

b. A chaotic rock mass comprising lensified hard rock bodies and boudinaged quartz or calcite lenses floating in a sheared soil-like environment.

*Scale of boxes: order of meter or few meters*
Moderately disturbed rock mass with sandstone and siltstone alternations in similar amounts

Tectonically disturbed sheared siltstone with broken deformed sandstone layers. These layers have almost lost their initial structure. Almost a chaotic structure

Degradation due to shearing and fissuring the original rock
Engineering geological evaluation in tunnelling – An example in flysch environment

<table>
<thead>
<tr>
<th>Geological conditions</th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Rock mass type</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Rock mass behaviour</td>
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</table>

Engineering Geological model in flysch
Engineering Geological Types of Flysch

- Complex rockmass
  - Alterations of competent-strong layers and incompetent-low strength
  - Profound bedding
  - Bedding thickness variety (cm to m scale)
  - Tectonic disturbance: transforms the initial structure and can produce tectonic mixtures

- Weak rockmass
  - Presence of clayey formations
  - Degradation due to shearing and fissuring
  - Weathering of silty-clayey members and susceptibility to slaking
  - Groundwater downgrades the quality of silty-clayey members

Flysch: Is not a rock. Is a formation. Rhythmic alternations of sandstone and pelitic (siltstones, silty or clayey shales). Associated with orogenesis, since it ends the cycle of sedimentation of a basin before the paroxysm folding process.

Tectonically strongly sheared siltstone or clayey shale forming a chaotic structure with pockets of clay. Thin layers of sandstone are transformed into small rock pieces. Ultimately the ground behavior is that of a soil.

It is not possible to detect specific zones of better or worst rock mass quality. Sandstone blocks have not particular geometry and persistence in space in such environment.

The area is consisted by sheared clayey-silty geomaterial where sandstone blocks are “floating.”

Tectonically deformed intensively folded/faulted siltstone or clay shale with broken and deformed sandstone layers forming an almost chaotic structure.

Chaotic mixture of siltstone flysch in a geological environment of a big thrust.

Legend:
- Thick sandstone beds with thin siltstone intercalations
- Siltstone and sandstone intercalations
- Greyey and reddish siltstones

Tamassos - Pindos Fault System

The Ionian zone is located on the right side of the cross-section.

The Pindos zone is located on the left side of the cross-section.
**New GSI chart for Flysch**

Use it only for isotropic rock mass behaviour

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**Marinos 2017**
It is extremely difficult to take a sample of an "intact" core and a representative specimen of rock as well as to prepare laboratory specimens.
Steel set yielding due to the overstressed tunnel support section

Shotcrete failure

Steel set bending

Tunnel deformation for 4 different tunnel covers (modified from Marinos and Hoek, 2000).

\[ \sigma_{cm}/\sigma_o = \text{rock mass strength}/\text{in situ stress} \]
IV. Interaction between GSI and Weathering
Indicative example of how weathering degree (W-I to W-V) affects GSI

<table>
<thead>
<tr>
<th>GEOSPHERICAL STRENGTH INDEX (GSI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E. Hoek, P. Marinos, 2000)</td>
</tr>
<tr>
<td>From the lithology, structure and surface conditions of the discontinuities, estimate the average value GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI = 35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>SURFACE CONDITIONS OF DISCONTINUITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTACT OR MASSIVE</td>
<td>VERY GOOD</td>
</tr>
<tr>
<td>Intact rock specimens or massive in situ rock with few widely spaced discontinuities</td>
<td></td>
</tr>
<tr>
<td>BLOCKY</td>
<td>GOOD</td>
</tr>
<tr>
<td>Very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal intersecting discontinuity sets</td>
<td></td>
</tr>
<tr>
<td>VERY BLOCKY</td>
<td>FAIR</td>
</tr>
<tr>
<td>Interlocked, partially disturbed rock mass with multi-faceted angular blocks formed by four or more discontinuity sets</td>
<td></td>
</tr>
<tr>
<td>BLOCKY/DISTURBED/SEAMY</td>
<td>POOR</td>
</tr>
<tr>
<td>Folded with angular blocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity</td>
<td></td>
</tr>
<tr>
<td>DISINTEGRATED</td>
<td>VERY POOR</td>
</tr>
<tr>
<td>Poorly interlocked, heavily broken rock mass with mixture of angular and rounded rock pieces</td>
<td></td>
</tr>
<tr>
<td>LAMINATED/FOLIATED/SHEARED</td>
<td>N/A</td>
</tr>
<tr>
<td>Laminated or foliated and tectonically sheared weak rock mass. Foliation prevails over any other discontinuity set, resulting in complete lack of blockiness (this drawing scale is not compared with the other's drawing scales)</td>
<td></td>
</tr>
</tbody>
</table>

Note: The position of projected grey areas are indicative.
Basic engineering geological consideration

Focuses on the:

- foliated structure
- tectonic disturbance
- weathering degree
- presence of shear zones

Gneissic rock masses categorized in rock mass types according to key engineering geological characteristics that define the rock mass behaviour.
<table>
<thead>
<tr>
<th>GRADE SCALE (ISRM)</th>
<th>TERM</th>
<th>Description</th>
<th>$\sigma_\alpha$ reduction factor (After Stacey and Page, 1986)</th>
<th>GSI notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>Residual soil</td>
<td>Soil derived from in situ weathering (100% soil) (from grades IV, V)</td>
<td>N/A (advise soil mechanics testing)</td>
<td>N/A (advise soil mechanics testing)</td>
</tr>
<tr>
<td>V</td>
<td>Completely weathered</td>
<td>All rock material is decomposed and/or disintegrated to soil (less than 30% rock of grades I, II, III). The original mass structure is still visible. Shearing can be affected through matrix.</td>
<td>0.001-0.004</td>
<td>Area where GSI is marginally applicable. The structure has been severely disturbed and the interlocking between the fragments has been lost. Clayey-sandy zones follow the original structure and rock fragments are not interlocked. Joint condition is Very Poor.</td>
</tr>
<tr>
<td>IV</td>
<td>Highly weathered</td>
<td>More than a half of the rock material is decomposed and/or disintegrated to a soil (30% to 50% rock of grades I, II, III). Severe weathering along the surfaces. Fresh or discoloured rock is present either as a discontinuous framework or as corestones. The rock material is friable. Corestones still affect shear behaviour of the rock mass.</td>
<td>0.04</td>
<td>The structure has been highly disturbed and the interlocking between the fragments has been highly loosened. Clayey and sandy products are filling all the discontinuities. Joint condition is Very Poor. The GSI shifts down and right in the chart.</td>
</tr>
<tr>
<td>III</td>
<td>Moderately weathered</td>
<td>Less than half of the rock material is decomposed and/or disintegrated to a soil (50% to 90% rock of grades I, II, III). High to severe weathering along the surfaces. Fresh or discoloured rock is present either as a discontinuous framework or as corestones. The rock material is not friable. The structure is locked.</td>
<td>0.1</td>
<td>The interlocking between the fragments has been considerably loosened. Weathering coatings and fragments are filling principle discontinuities (e.g. gneissic bands) and other joints. Joint condition is Poor. The GSI shifts to the poorer structure (e.g. from Very Blocky to Blocky/Disrupted and to the right in the chart).</td>
</tr>
<tr>
<td>II</td>
<td>Slightly weathered</td>
<td>Discolouration indicates weathering of rock material and discontinuity surfaces (&gt;90% rock of grades I, II, III). All the rock material may be discoloured by weathering and may be somewhat weaker than its fresh condition.</td>
<td>0.4</td>
<td>The structure is not changed but the quality of the discontinuity surfaces is (shift to the right). The GSI is reduced to Fair conditions.</td>
</tr>
<tr>
<td>I</td>
<td>Fresh</td>
<td>No visible sign of rock material weathering (100% rock); perhaps slight discolouration on major discontinuity surfaces</td>
<td>1.00</td>
<td>Fresh rocks are generally massive (Intact to Very blocky). Joint condition is Very Good (very rough) to Good (rough). Blocks and surfaces are strongly interlocking. Rock mass may be even more fractured but only in depth (along a fault zone) where weathering has not been favored. In surface, a fractured rock mass is rarely fresh.</td>
</tr>
</tbody>
</table>
Geotechnical characterization: A GSI chart for gneissic rock masses

The chart maintains the basic structures the surface conditions of joints are replaced by the weathering grades (ISRM, 1981).

Calibration and substitution of the straight lines of the fundamental chart with curved lines, bended to the left side of the chart.

As weathering degree increases bending is increased as well.
V. Interaction between GSI and alteration
V. Interaction between GSI and alteration

GEOLOGICAL STRENGTH INDEX (GSI) (E. Hoek, P. Marinos, 2000)

From the lithology, structure and surface conditions of the discontinuities, estimate the average value GSI. Do not try to be too precise. Quoting a range from 33 to 37 is more realistic than stating that GSI=35. Note that the table does not apply to structurally controlled failures. Where weak planar structural planes are present in an unfavourable orientation with respect to the excavation face, these will dominate the rock mass behaviour. The shear strength of surfaces in rocks that are prone to deterioration as a result of changes in moisture content will be reduced if water is present. When working with rocks in the fair to very poor categories, a shift to the right may be made for wet conditions. Water pressure is dealt with by effective stress analysis.

Note: The position of projected grey areas are indicative.
Geological Model in Ophiolitic complex

• A sequence of mafic (basic) and ultramafic (ultrabasic) rocks
• More or less serpentinised and metamorphosed, occurring in the Alpine chains.
• Ophiolites are at present considered as pieces of the oceanic crust generated at an oceanic ridge and the upper mantle of an ancient ocean, thrust up on the continental crust during mountain building.
This geometry is highly disturbed:

- occur mainly in tectonic zones with superposition of numerous overthrusts.
- metamorphism changes the initial nature of the rock
- the high serpentinisation and the tectonic shearing degree make it difficult to recognize the original nature and texture

(details in Pollino et al. 1990 in Mercier and Vergely 1999)
Engineering Geological Types in Ophiolitic complex

Main Characteristics: Tectonism + Serpentinization

Transformation of ferromagnesian minerals, olivine in particular, to serpentine – a lattice mineral of either fibrous or laminar form.

originally compact, relatively soft and more easily sheared by tectonic processes.

Complex rockmass
- Serpentinisation: Irregular and in any depth
- Complexity in the identification of certain zones of different quality
- Tectonic alternations with other formations like clayey shales with certs

Weak rockmass
- Serpentinization – folliation – clay presence
- Tectonical disturbance: Brecciated– schistosed– sheared
Rock Mass Type I (Peridotites, gabbros)

massive, with only a few widely spaced discontinuities, even close to the surface in tectonically quiet areas or in zones of “tectonic shadow”.

- Condition of the joints has good to very good quality
- GSI >65.
- $\sigma_{ci} = 100-250$ MPa
Rock Mass Type II
(Serpentinised Peridotites)

- Serpentinisation is limited along the surface of discontinuities.
- The initial rough conditions of the joints are dramatically reduced to poor or very poor with coatings of smooth and slippery minerals such as serpentine or even talc.
- GSI: 40 - 65.
- $\sigma_{ci} = 100-250$ MPa
Detect the Rock Mass Types

Rock Mass Type III
Highly serpentinised ophiolite or serpentinite

- serpentinisation process often affects and disintegrates parts of the rock, not only contributing to lower GSI values but also reducing the intact strength values
- Fair quality peridotite with discontinuities of low frictional properties due to the presence of films of seprentinised material
- GSI: 30 - 45.
- \( \sigma_{ci} = 45\text{–}60 \text{ Mpa} \) (The influence of "schistosity" results in a significant reduction in the strength \( \sim 30\% \))
Detect the Rock Mass Types

Rock Mass Type IV (Sheared foliated serpentinites)

- Lack of blockiness: allows the rock to disintegrate into slippery laminar pieces and small flakes of centimetres or millimetres in size.
- Completely disintegrated peridotite with loss of blockiness and presence of clayey sections
- GSI: 15-25
- $\sigma_{ci} = 5$-20 MPa
Projection of GSI values in a ophiolitic complex.

Main characteristics of the rock masses:
- **Serpentinisation** as a change in both in the characteristic of the discontinuities but in some cases also in the structure
- **Shearing of the rock masses** leading to the change of structure
Serpentinised peridotite: A case of raveling - Support

- Light forepole umbrella (75 or 100 mm diameter pipes).
- Pre-grouting an umbrella in the rock mass over the forepoles: increase the cohesive strength of the rock mass.
- Stabilisation: installation of a double forepole umbrella and by extensive grouting through the forepoles and also through horizontal holes drilled through the muckpile.
Yielding primary support (sliding joints in steel sets and gaps in shotcrete) in very weak serpentinite (type IV) in areas of thick cover, 220m, GSI 15-20, $\sigma_{ci}$ 8MPa and $m_i$ 10.
But let say that the approaches we apply, associated with an appropriate factor of safety, based on the degree of uncertainties, are satisfactory, provided they are not erroneous.

It is then obvious why THE GEOLOGICAL JUDGMENT must be always present and why is so important.
VI. Conclusions 1

Rock engineers have to work within the limitations of available technology and some of the most severe limitations are associated with the estimation of rock mass properties.

Efforts to overcome have resulted in tools such as the GSI classification which, at this moment, can be regarded as interim solutions. These efforts have been in most cases useful since there are very few practical alternatives available.
VI. Conclusions 2

- The GSI classification and the associated Hoek-Brown failure criterion being **empirical tools** should be used interactively during design and the input parameters should be adjusted and refined as **back analysis** information from actual field behaviour becomes available.

- In some cases it may be necessary to develop **project specific GSI charts** in order to permit classification of rock masses that have not been adequately covered in published papers.

- Indeed such a form of rock mass characterization as the GSI, has considerable potential for use in rock engineering because it permits the manifold aspects of rock to be quantified **enhancing geological logic even in extremely heterogeneous and complex geological formations**.
VI. Conclusions 3

We look forward to the time when these numerical tools will allow us to at least calibrate better if not replace some of the empirical methods, such as the GSI classification and the Hoek-Brown criterion that we use today.

E. Hoek & P. Marinos, EUROCK 2009, Dubrovnik

“...My long term hope is that numerical tools such as the Synthetic Rock Mass and its off-shoots will eventually enable us to replace classification type approaches or at least to calibrate these classifications. It may be a while before these hopes can be realized...”

Hoek, personal communication
Thank you
References


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- Marinos V. 2007. Geotechnical classification and engineering geological behaviour of weak and complex rock masses in tunneling, Doctoral thesis, School of Civil Engineering, Geotechnical Engineering Department, National Technical University of Athens (NTUA), Athens. (In greek)
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