GSI: A GEOLOGICALLY FRIENDLY TOOL FOR ROCK MASS STRENGTH ESTIMATION

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ABSTRACT

This paper presents a review of the estimation of rock mass strength properties through the use of GSI. The GSI classification system greatly respects the geological constraints that occur in nature and are reflected in the geological information. A discussion is given regarding the ranges of the Geological Strength Index for typical rock masses with specific emphasis to heterogeneous rock masses.

1.0 INTRODUCTION

Reliable estimates of the strength and deformation characteristics of rock masses are required for almost any form of analysis used for the design of surface excavations. Hoek and Brown (1980a, 1980b) proposed a method for obtaining estimates of the strength of jointed rock masses, based upon an assessment of the interlocking of rock blocks and the condition of the surfaces between these blocks. This method was modified over the years in order to meet the needs of users who applied it to problems that were not considered when the original criterion was developed (Hoek 1983, Hoek and Brown 1988). The application of the method to poor quality rock masses required further changes (Hoek, Wood and Shah, 1992) and, eventually, the development of a new classification called the Geological Strength Index (Hoek 1994, Hoek, Kaiser and Bawden 1995, Hoek and Brown 1997, Hoek, Marinos and Benissi, 1998), extended recently for heterogeneous rock masses (Marinos and Hoek, 2000). A review of the development of the criterion and the equations proposed at various stages in this development is given in Hoek and Brown (1997).

2.0 ESTIMATE OF ROCK MASS PROPERTIES

The basic input consists of estimates or measurements of the uniaxial compressive strength (σ_{ci}) and a material constant (m_i) that is related to the frictional properties of the rock. Ideally, these basic properties should determined by laboratory testing as described by Hoek and Brown (1997) but, in many cases, the information is required before laboratory tests have been completed. To meet this need, tables that can be used to estimate values for these parameters are reproduced in Tables 1 and 2. Note that both tables are updated from earlier versions (Marinos and Hoek, 2000).

The most important component of the Hoek – Brown system for rock masses is the process of reducing the material constants σ_{ci} and m_i from their “laboratory” values to appropriate in situ values. This is accomplished through the Geological Strength Index GSI that is defined in Table 3.

GSI has been developed over many years of discussions with engineering geologists with whom E. Hoek has worked around the world. Careful consideration has been given to the precise wording in each box and to the relative weights assigned to each combination of structural and surface conditions, in order to respect the geological conditions existing in nature.

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Table 1: Field estimates of uniaxial compressive strength of intact rock.[3]

Grade*	Term	Uniaxial Comp. Strength (MPa)	Point Load Index (MPa)	Field estimate of strength	Examples
R6	Extremely Strong	> 250	>10	Specimen can only be chipped with a geological hammer	Fresh basalt, chert, diabase, gneiss, granite, quartzite
R5	Very strong	100 - 250	4 - 10	Specimen requires many blows of a geological hammer to fracture it	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, peridotite , rhyolite, tuff
R4	Strong	50 - 100	2 - 4	Specimen requires more than one blow of a geological hammer to fracture it	Limestone, marble, sandstone, schist
R3	Medium strong	25 - 50	1 - 2	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single blow from a geological hammer	Concrete, phyllite, schist, siltstone
R2	Weak	5 - 25	**	Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of a geological hammer	Chalk, claystone, potash, marl, siltstone, shale, rocksalt,
R1	Very weak	1 - 5	**	Crumbles under firm blows with point of a geological hammer, can be peeled by a pocket knife	Highly weathered or altered rock, shale
R0	Extremely Weak	0.25 - 1	**	Indented by thumbnail	Stiff fault gouge

* Grade according to Brown (1981).
** Point load tests on rocks with a uniaxial compressive strength below 25 MPa are likely to yield highly ambiguous results.

[3] Note that this table contains a few changes in the column of examples from previously published version.

Table 2: Values of the constant m_i for intact rock, by rock group[4]. Note that values in parenthesis are estimates. The range of values quoted for each material depends upon the granularity and interlocking of the crystal structure – the higher values being associated with tightly interlocked and more frictional characteristics.

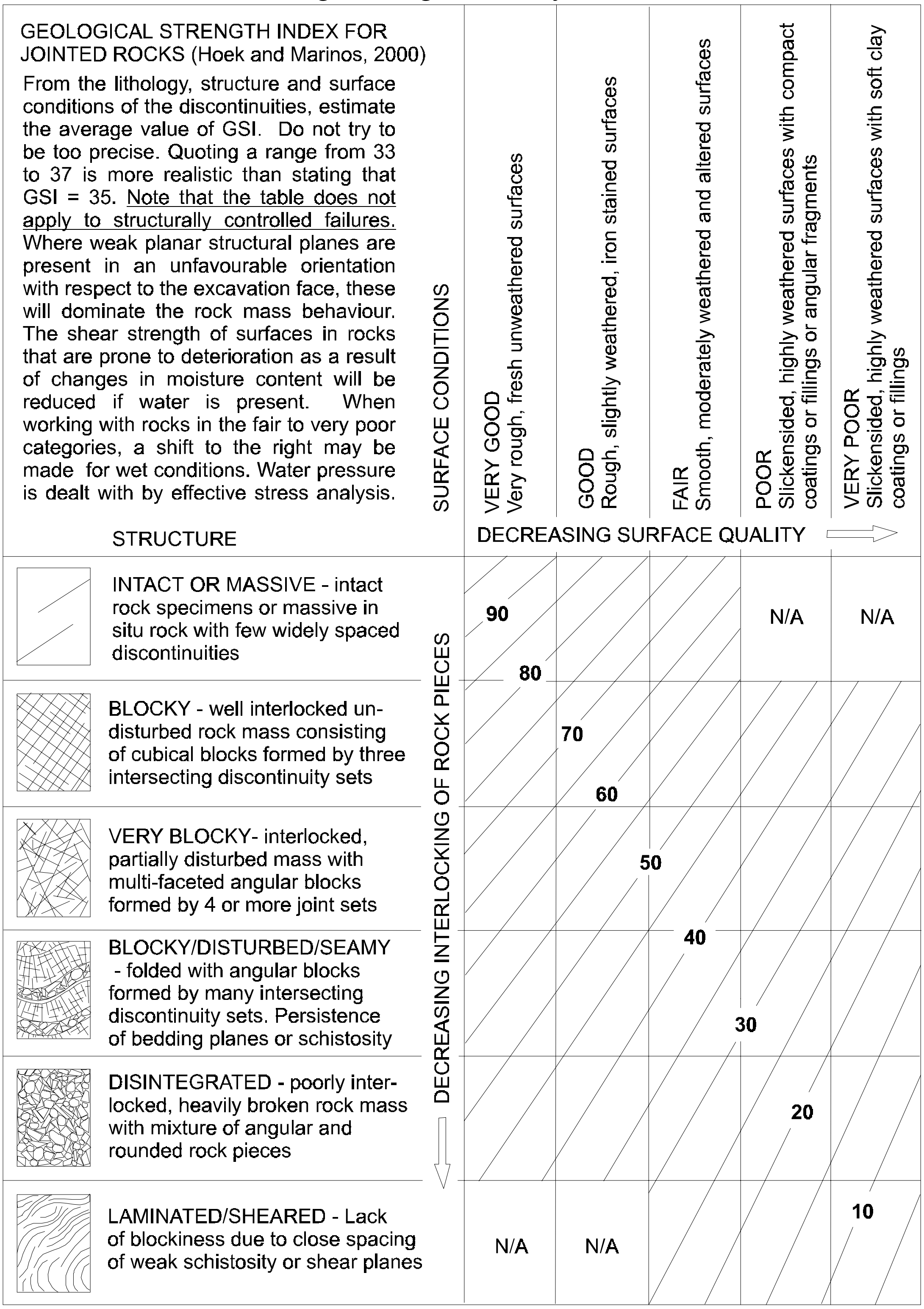
Rock type	Class	Group	Texture: Coarse	Texture: Medium	Texture: Fine	Texture: Very fine
SEDIMENTARY	Clastic		Conglomerates * Breccias *	Sandstones 17 ± 4	Siltstones 7 ± 2 Greywackes (18 ± 3)	Claystones 4 ± 2 Shales (6 ± 2) Marls (7 ± 2)
	Non-Clastic	Carbonates	Crystalline Limestone (12 ± 3)	Sparitic Limestones (10 ± 2)	Micritic Limestones (9 ± 2)	Dolomites (9 ± 3)
		Evaporites		Gypsum 8 ± 2	Anhydrite 12 ± 2	
		Organic				Chalk 7 ± 2
METAMORPHIC	Non Foliated		Marble 9 ± 3	Hornfels (19 ± 4) Metasandstone (19 ± 3)	Quartzites 20 ± 3	
	Slightly foliated		Migmatite (29 ± 3)	Amphibolites 26 ± 6	Gneiss 28 ± 5	
	Foliated**			Schists 12 ± 3	Phyllites (7 ± 3)	Slates 7 ± 4
IGNEOUS	Plutonic	Light	Granite 32 ± 3 Diorite 25 ± 5 Granodiorite (29 ± 3)			
		Dark	Gabbro 27 ± 3 Norite 20 ± 5	Dolerite (16 ± 5)		
	Hypabyssal		Porphyries (20 ± 5)		Diabase (15 ± 5)	Peridotite (25 ± 5)
	Volcanic	Lava		Rhyolite (25 ± 5) Andesite 25 ± 5	Dacite (25 ± 3) Basalt (25 ± 5)	
		Pyroclastic	Agglomerate (19 ± 3)	Breccia (19 ± 5)	Tuff (13 ± 5)	

* Conglomerates and breccias may present a wide range of m_i values depending on the nature of the cementing material and the degree of cementation, so they may range from values similar to sandstone, to values used for fine grained sediments (even under 10).

** These values are for intact rock specimens tested normal to bedding or foliation. The value of mi will be significantly different if failure occurs along a weakness plane.

[4] Note that this table contains several changes from previously published versions, These changes have been made to reflect data that has been accumulated from laboratory tests and the experience gained from discussions with geologists and engineering geologists.

Table 3: Geological strength index for jointed rock masses.



Having defined the parameters σ_{ci}, m_i and GSI as described above, the next step is to estimate the mechanical properties of the rock mass. The procedure for making these estimates has been described in detail by Hoek and Brown (1997) it will not be repeated here. A spreadsheet for carrying out these calculations is given in Table 4 [5].

Table 4: Spreadsheet for the calculation of rock mass properties

Input:	sigci =	10	MPa	mi =	10		GSI =	30	
	Depth of failure surface or tunnel below slope =				25	m	Unit wt. =	0.027	MN/n3
Output:	stress =	0.68	MPa	mb =	0.82		s =	0.0004	
	a =	0.5		sigtm =	-0.0051	MPa	A =	0.4516	
	B =	0.7104		k =	3.95		phi =	36.58	degrees
	coh =	0.136	MPa	sigcm =	0.54	MPa	E =	1000.0	MPa
Calculation:									
									Sums
sig3	1E-10	0.10	0.19	0.29	0.39	0.48	0.58	0.68	2.70
sig1	0.20	1.01	1.47	1.84	2.18	2.48	2.77	3.04	14.99
ds1ds3	21.05	5.50	4.22	3.64	3.29	3.05	2.88	2.74	46.36
sign	0.01	0.24	0.44	0.62	0.80	0.98	1.14	1.31	5.54
tau	0.04	0.33	0.50	0.64	0.76	0.86	0.96	1.05	5.14
x	-2.84	-1.62	-1.35	-1.20	-1.09	-1.01	-0.94	-0.88	-10.94
y	-2.37	-1.48	-1.30	-1.19	-1.12	-1.06	-1.02	-0.98	-10.53
xy	6.74	2.40	1.76	1.43	1.22	1.07	0.96	0.86	16.45
xsq	8.08	2.61	1.83	1.44	1.19	1.02	0.88	0.78	17.84
sig3sig1	0.00	0.10	0.28	0.53	0.84	1.20	1.60	2.05	7
sig3sq	0.00	0.01	0.04	0.08	0.15	0.23	0.33	0.46	1
taucalc	0.04	0.32	0.49	0.63	0.76	0.87	0.97	1.07	
sig1sig3fit	0.54	0.92	1.30	1.68	2.06	2.45	2.83	3.21	
signtaufit	0.14	0.31	0.46	0.60	0.73	0.86	0.98	1.11	
Cell formulae:									
stress =	if(depth>30, sigci*0.25,depth*unitwt*0.25)								
mb =	mi*EXP((GSI-100)/28)								
s =	IF(GSI>25,EXP((GSI-100)/9),0)								
a =	IF(GSI>25,0.5,0.65-GSI/200)								
sigtm =	0.5*sigci*(mb-SQRT(mb^2+4*s))								
sig3 =	Start at 1E-10 (to avoid zero errors) and increment in 7 steps of stress/28 to stress/4								
sig1 =	sig3+sigci*(((mb*sig3)/sigci)+s)^a								
ds1ds3 =	IF(GSI>25,(1+(mb*sigci)/(2*(sig1-sig3))),1+(a*mb^a)*(sig3/sigci)^(a-1))								
sign =	sig3+(sig1-sig3)/(1+ds1ds3)								
tau =	(sign-sig3)*SQRT(ds1ds3)								
x =	LOG((sign-sigtm)/sigci)								
y =	LOG(tau/sigci)								
xy =	x*y	x sq =	x^2						
A =	acalc =	10^(sumy/8 - bcalc*sumx/8)							
B =	bcalc =	(sumxy - (sumx*sumy)/8)/(sumxsq - (sumx^2)/8)							
k =	(sumsig3sig1 - (sumsig3*sumsig1)/8)/(sumsig3sq-(sumsig3^2)/8)								
phi =	ASIN((k-1)/(k+1))*180/PI()								
coh =	sigcm/(2*SQRT(k))								
sigcm =	sumsig1/8 - k*sumsig3/8								
E =	IF(sigci>100,1000*10^((GSI-10)/40),SQRT(sigci/100)*1000*10^((GSI-10)/40))								
phit =	(ATAN(acalc*bcalc*((signt-sigtm)/sigci)^(bcalc-1)))*180/PI()								
coht =	acalc*sigci*((signt-sigtm)/sigci)^bcalc-signt*TAN(phit*PI()/180)								
sig3sig1=	sig3*sig1	sig3sq =	sig3^2						
taucalc =	acalc*sigci*((sign-sigtm)/sigci)^bcalc								
s3sifit =	sigcm+k*sig3								
sntaufit =	coh+sign*TAN(phi*PI()/180)								

[5] For an electronic version of this Excel spreadsheet, contact Evert Hoek <ehoek@attglobal.net>

2.1 Deep tunnels

For tunnels at depths of more than 30 m, the rock mass surrounding the tunnel is confined and its properties are calculated on the basis of a minor principal stress or confining pressure of $0 < \sigma_3 < 0.25\sigma_{ci}$, in accordance with the procedure defined by Hoek and Brown (1997).

For the case of “deep” tunnels, equivalent Mohr Coulomb cohesive strengths and friction angles can be calculated by means of the spreadsheet given in Table 4. Note that any depth greater than 30m can be used for this calculation. In addition, the deformation modulus E and the uniaxial compressive strength σ_{cm} of the rock mass can be estimated. Plots of these estimated values are given in Figures 1 to 4.

The uniaxial compressive strength of the rock mass σ_{cm} is a particularly useful parameter for evaluating potential tunnel squeezing problems. The following equation, obtained by a curve fitting process on the plots presented in Figure 4, gives a very close approximation of σ_{cm} for selected values of the intact rock strength σ_{ci}, constant m_i and the Geological Strength Index GSI :

$$\sigma_{cm} = (0.0034 m_i^{0.8})\sigma_{ci}\{1.029 + 0.025 e^{(-0.1 m_i)}\}^{GSI} \tag{1}$$

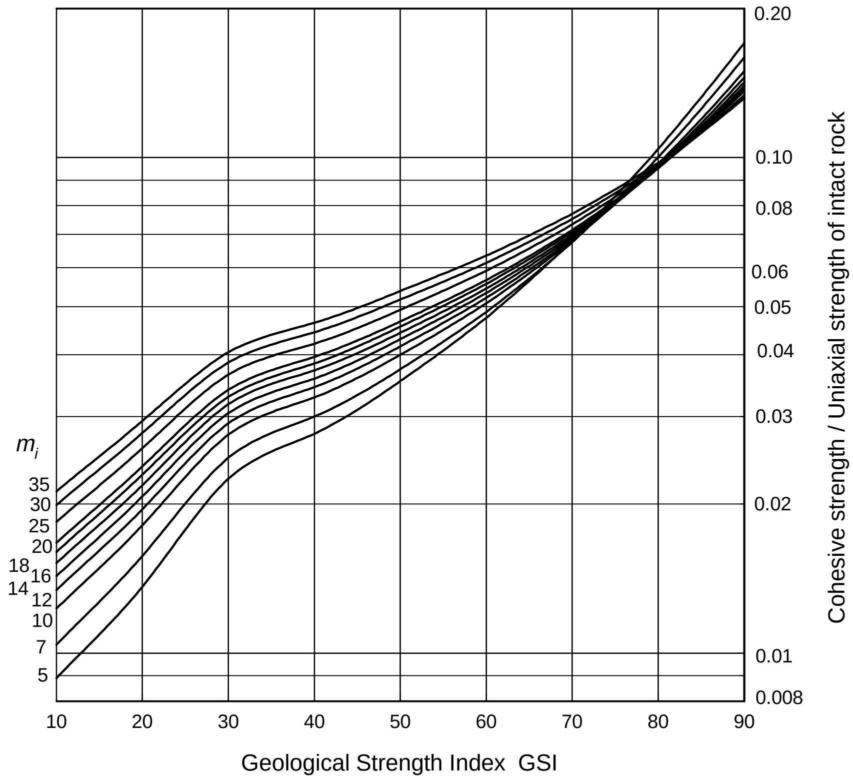


Figure 1. Relationship between ratio of cohesive strength to uniaxial compressive strength of intact rock c/σ_{ci} and GSI for different m_i values, for depths of more than 30m.

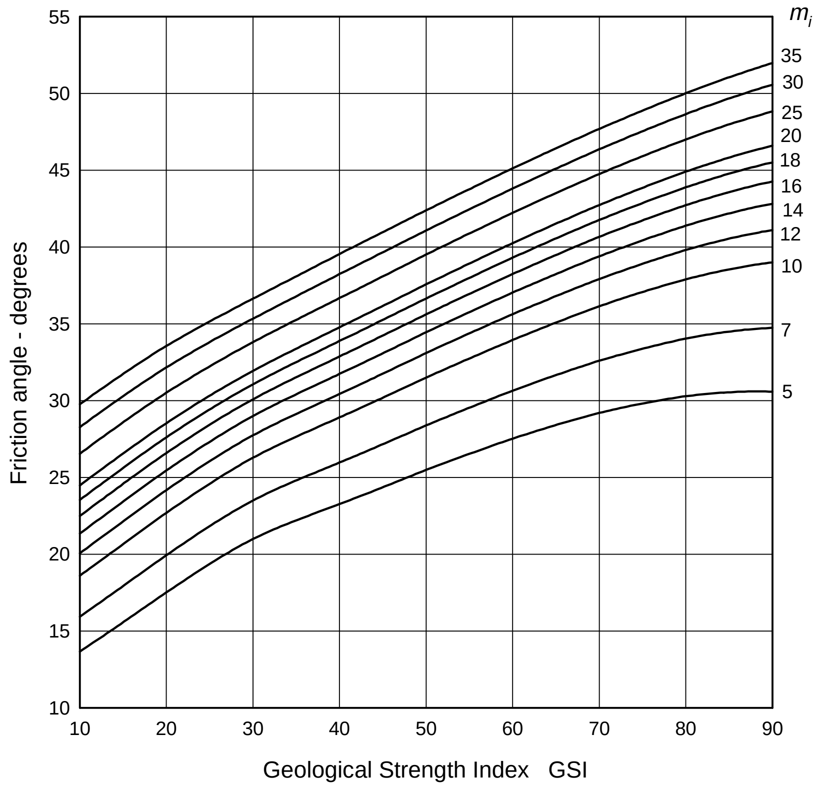


Figure 2. Friction angle ϕ for different GSI and m_i values, for depths more than 30m.

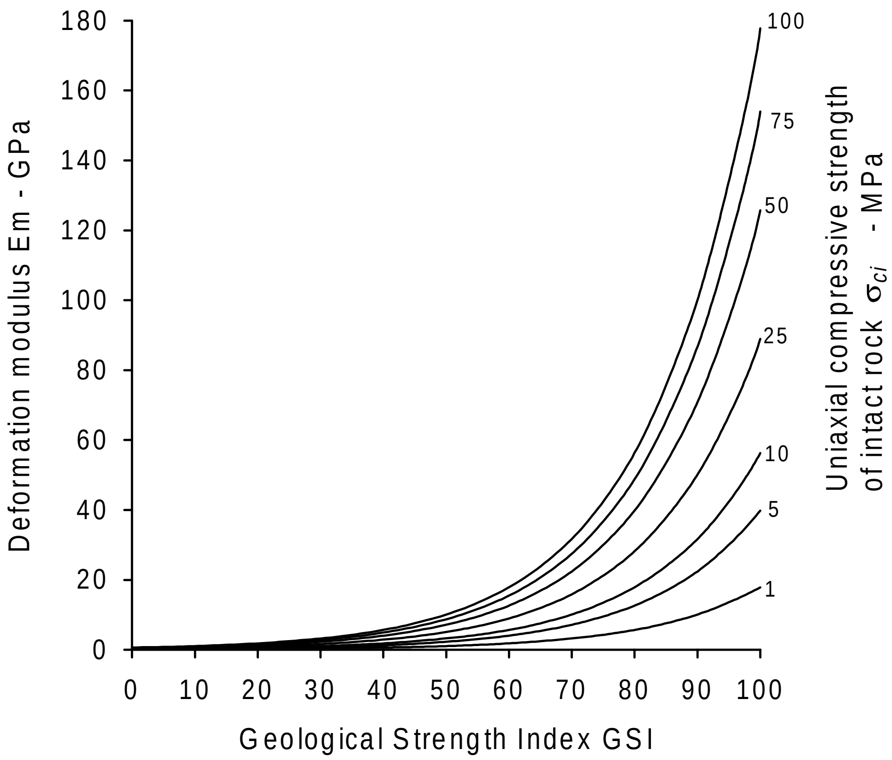


Figure 3. Rock mass Deformation modulus *E* versus Geological Strenth Index *GSI*.

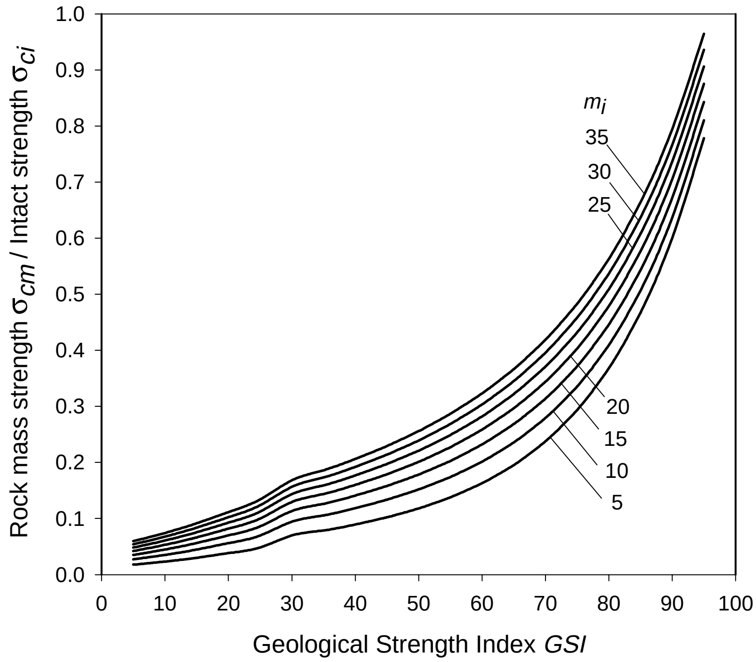


Figure 4. Relationship between rock mass strength σ_{cm}, intact rock strength σ_{ci}, constant m_i and the Geological Strength Index *GSI*, for depths of more than 30m.

2.2 Shallow tunnels and slopes

For shallow tunnel and slopes in which the degree of confinement is reduced, a minor principal stress range of $0 < \sigma_3 < \sigma_v$ is used, where σ_v = depth x unit weight of the rock mass. In this case, depth is defined as the depth below surface of the tunnel crown or the average depth of a failure surface in a slope in which a circular type can be assumed, i.e. where the failure is not structurally controlled.

In the case of shallow tunnels or slopes, the spreadsheet presented in Table 4 allows the user to enter the depth below surface and the unit weight of the rock mass. The vertical stress σ_v calculated from the product of these two quantities is then used to calculate the rock mass properties.

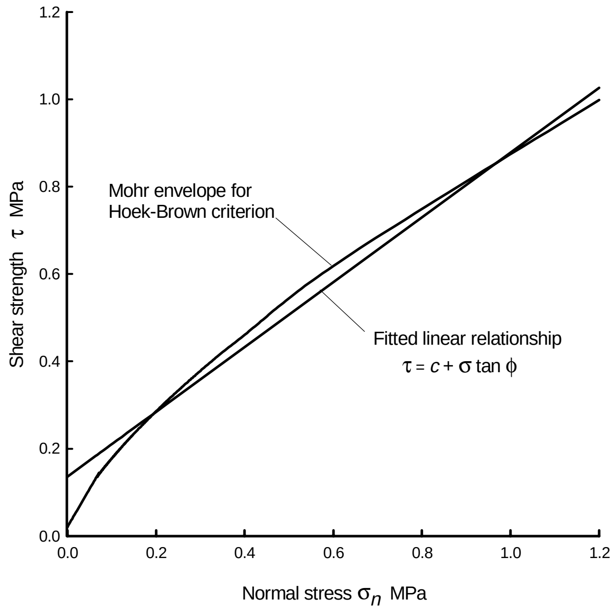


Figure 5. Mohr envelope for Hoek Brown criterion and fitted linear relationship for the normal stress range $0 < \sigma_n < \sigma_v$ where σ_v = depth x unit weight. As shown in the spreadsheet in Table 4, the friction angle ϕ = 36.6° and the cohesive strength c = 136 kPa for σ_{ci} = 10 MPa, m_i = 10, *GSI* = 30 and a depth below surface of 25 m.

3.0 TYPICAL RANGES OF GSI FOR VARIOUS ROCK MASSES

The strength of a jointed rock mass depends on the properties of the intact rock pieces and also upon the freedom of these pieces to slide and rotate under different stress conditions. This freedom is controlled by the geometrical shape of the intact rock pieces as well as the condition of the surfaces separating the pieces. Angular rock pieces with clean, rough discontinuity surfaces will result in a much stronger rock mass than one which contains rounded particles surrounded by weathered and altered material, or sheared flakes of the initial rock.

Note that the Hoek and Brown criterion and indeed any of the other published criteria that can be used for this purpose, assume that the rock mass behaves isotropically. In other words, while the behaviour of the rock mass is controlled by movement and rotation of rock elements separated by intersecting structural features such as bedding planes and joints, there are no preferred failure directions.

This failure criteria should not be used when the rock mass consists of a strong blocky rock such as sandstone, separated by clay coated and slickensided persisting bedding surfaces. The behaviour of such rock masses will be strongly anisotropic and will be controlled by the fact that the bedding planes are an order of magnitude weaker that any other features. In such rock masses the predominant failure mode will be planar or wedge slides in slopes, or gravitational falls of wedges or blocks of rock defined by the intersection of the weak bedding planes with other features which act as release surfaces in tunnels. However, if the rock mass is heavily fractured, the continuity of the bedding surfaces will be disrupted and the rock may behave as an isotropic mass.

This GSI Index is based upon an assessment of the lithology, structure and condition of discontinuity surfaces in the rock mass and it is estimated from visual examination of the rock mass exposed in surface excavations such as roadcuts, in tunnel faces and in borehole core.

The Geological Strength Index, by the combination of the two fundamental parameters of geological process, the blockiness of the mass and the conditions of discontinuities, respects the main geological constraints that govern a formation and is thus both a geologically friendly index and practical to assess.

The petrographic characteristics of each and every rock do not however allow all the combinations that can be derived from the GSI charts to exist. A limestone mass, for instance, can not present “poor” conditions in discontinuities or a thin bedded sequence of rock cannot be better than “seamy” in a folded geological environment; a siltstone or clayshale cannot present better conditions in the discontinuities than “fair”.

In order to give the most probable range of GSI values for rock masses of various rock types that most usually occur in nature, a series of indicative charts are presented in tables 5 to 13. Deviations may certainly occur but these are the exceptions. From the charts it can be seen:

- *Sandstones*: A typical rock mass varies in the majority of cases between 45 and 90, but if tectonically brecciated from 30 to 45. It is understood that in all cases weak interlayers do not interfere and that in a typical sandstone no clayey or gypsiferous cement is involved; if yes the GSI values may move to the right of the chart.
- *Silstones, clayshales*: Siltstones and claystones may be homogeneous with no discontinuities other than bedding planes, if they are of recent geological age and have not suffered from major tectonic effects. In these cases the GSI classification is not applicable and its use, even approximately, is not recommended. In these cases laboratory testing is to be applied. However GSI may be applied when siltstones exhibit joints and shears (common deformational features in orogenetic belts, etc). In shales, either silty or clayey, the role of weak schistosity planes is in that case more pronounced, which cannot however induce an anisotropic character to the mass, as they are developed in thin discontinuous flake-like sheets. By their nature the condition of discontinuities will usually be poor, and it cannot be classified beyond the fair type, even in extreme cases. In many cases siltstones and clayshales are present as thin interlayers (e.g. of few millimetres of thickness) between stronger rocks; in that case a downgrading of the rock mass towards the right part of the chart is brought about, unless other unfavourable situations arise from instability on preferred failure orientations.
- *Limestones*: Limestones in term of bedding may be massive, bedded, thin bedded (few to 10-20cm thickness of beds). Jointing from the tectonic history is added. In all cases the surface of discontinuities is mainly “good” and can hardly be “fair”. The thin bedded type is more keen to differential movement of beds during folding thus lower GSI values are expected. In this type the many intersecting discontinuity sets diminish the role of the persisting orientations of the bedding planes, making GSI applicable. In the chart of Table 7 the limestone series with thin interlayers or films of clayey, marly or silty nature is of course not considered.
- *Granite*: The range shaded in the chart is considered for sound or non significantly weathered granite. Thus there is no remarkable decrease of the surface condition or the interlocking of the rock pieces with fracturing. In case of weathered granite, care has to be taken in the assignment of GSI values, owing to the enhanced heterogeneity that usually arises at the scale of the excavation, especially where

poorly interlocked rock masses with smooth planes (e.g. GSI of 30-35) may transpass irregularly to engineering soils (arrenites).

- *Ultrabasic rocks (ophiolites)*: In ophiolithic rocks (mainly peridotites, diabases) the characteristic is that, even where they are sound, their discontinuities may be coated by weak minerals that originate from alteration or dynamic metamorphosis. So they decline a bit to the right in the GSI chart comparing to a sound granitic mass. Ophiolites are often transformed to serpentinites which along with the tectonic fatigue may produce very weak masses.
- *Gneiss*: Compared to sound granitic masses a slight displacement of the assigned range downward and to the right of the GSI chart may be seen. Same comments as for the granite apply when gneiss is weathered.
- *Schists*: They vary from strong micaschists and calcitic schist types to weak chloritic, talcic schists and phyllites. The persisting schistosity planes and their usually "poor" surface conditions restrain the range of GSI values.

It is strongly underlined that the shaded areas illustrated in the charts are indicative and should not be used for design purposes as deviations may occur. But even for indicative cases or for rough approaches the use of mean values is not, again recommended. For design purposes it is obviously necessary to base the assessment on detailed site inspection and evaluation of all geological data derived from site investigation.

4.0 HETEROGENEOUS ROCK MASSES

The design of tunnels and slopes in heterogeneous rock masses such as *flysch* presents a major challenge to geologists and engineers. The complex structure of these materials, resulting from their depositional and tectonic history, means that they cannot easily be classified in terms of widely used rock mass classification systems.

Flysch consists of alternations of clastic sediments that are associated with orogenesis. It closes the cycle of sedimentation of a basin before the "arrival" of the poroxysmic folding process. The clastic material derived from erosion of the previously formed neighbouring mountain ridge. Flysch is characterised by rhythmic alternations of sandstone and fine grained (pelitic) layers. The fine grained layers contain siltstones, silty shales and clayey shales. The thickness of the sandstone beds range from centimetres to metres. The siltstones and schists form layers of the same order but bedding discontinuities may be more frequent, depending upon the fissility of the sediments.

Different types of alternations occur in the flysch series: e.g. predominance of sandstone, or typical sandstone/siltstone alternations, or predominance of siltstone. The overall thickness of the formation has often been reduced considerably by erosion or by thrusting. In fact, the formation is often affected by reverse faults and thrusts. This, together with consequent normal faulting, results in a significant degradation of the geotechnical quality of the flysch rock mass. Thus, sheared or even chaotic rock masses can be found at the scale of a typical engineering design.

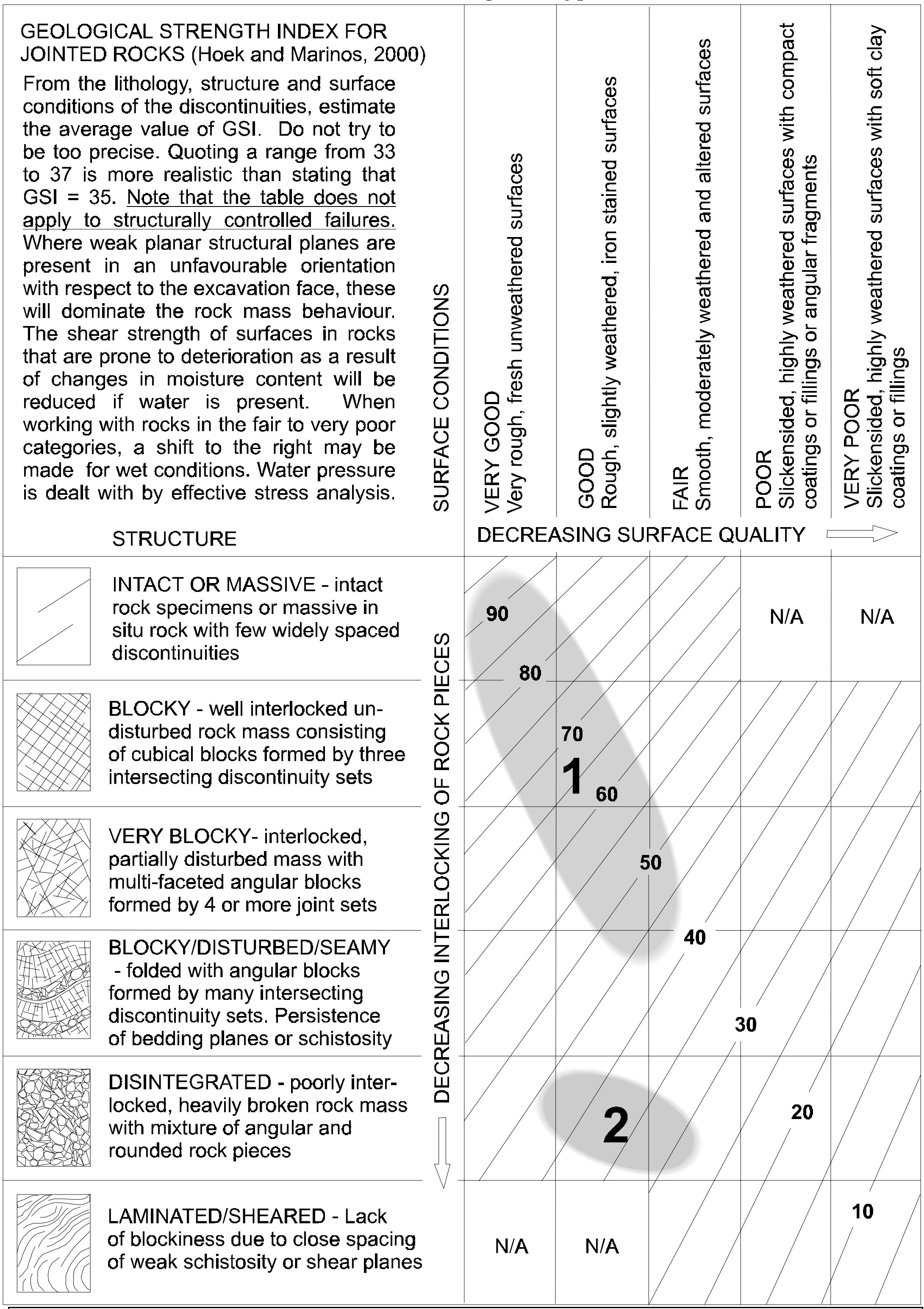
The determination of the Geological Strength Index for these rock masses, composed of frequently tectonically disturbed alternations of strong and weak rocks, presents some special challenges. However, because of the large number of engineering projects under construction in these rock masses, some attempt has to be made to provide better engineering geology tools than those currently available. Hence, in order to accommodate this group of materials in the GSI system, a chart for estimating this parameter has been developed recently (Marinos and Hoek, 2000) and is presented in Table 12.

4.1 Selection of σ_{ci} and m_i for flysch

In addition to the GSI values presented in Table 12, it is necessary to consider the selection of the other "intact" rock properties σ_{ci} and m_i for heterogeneous rock masses such as flysch. Because the sandstone layers or usually separated from each other by weaker layers of siltstone or shales, rock-to-rock contact between blocks of sandstone may be limited. Consequently, it is not appropriate to use the properties of the sandstone to determine the overall strength of the rock mass. On the other hand, using the "intact" properties of the siltstone or shale only is too conservative since the sandstone skeleton certainly contributes to the rock mass strength.

Therefore, it is proposed that a 'weighted average' of the intact strength properties of the strong and weak layers should be used. Suggested values for the components of this weighted average are given in Table 13.

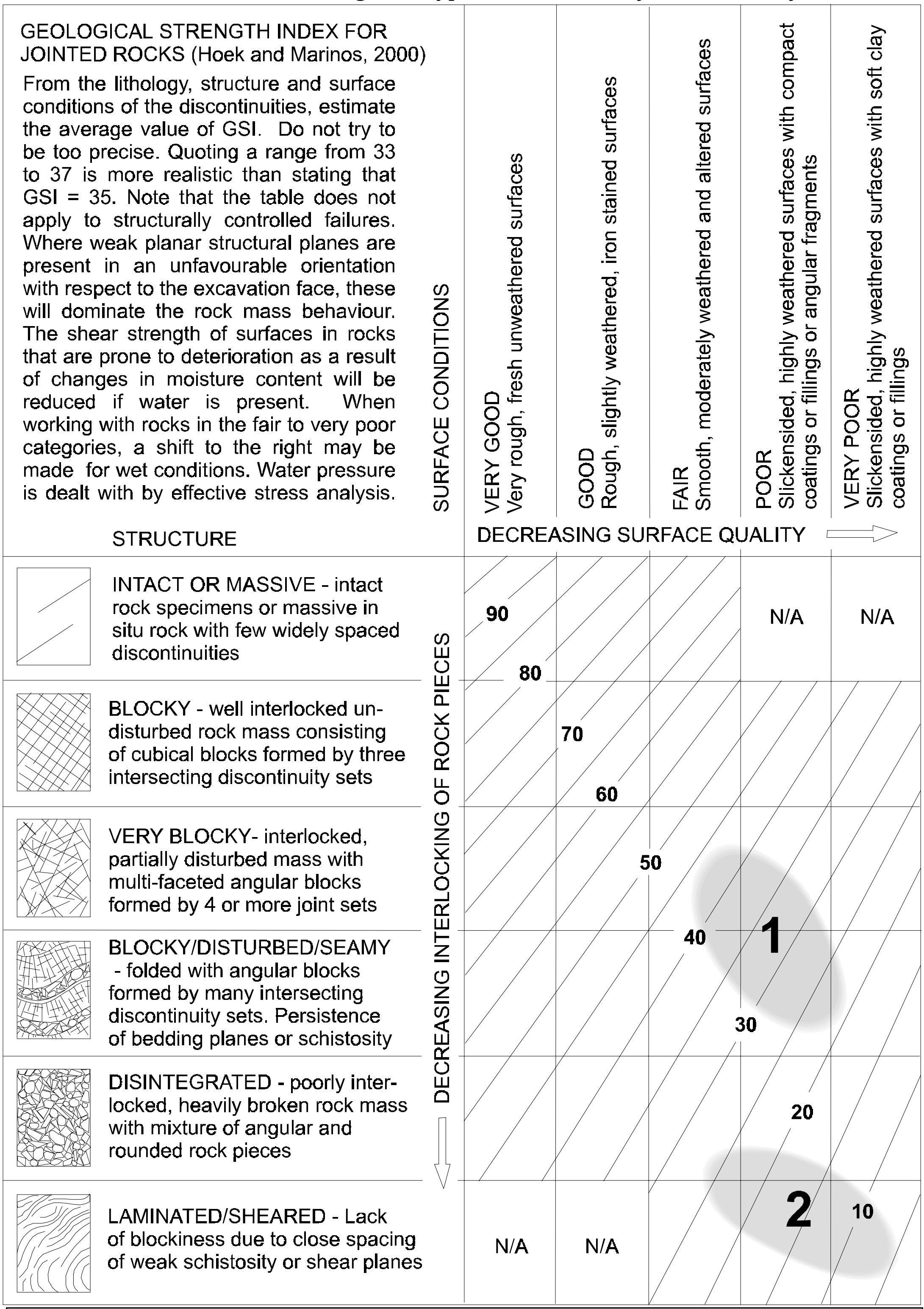
Table 5: Most common GSI ranges for typical sandstones.*



WARNING:
The shaded areas are indicative and may not be appropriate for site specific design purposes.
Mean values are not suggested for indicative characterisation; the use of ranges is recommended

1. Massive or bedded (no clayey cement present)
2. Brecciated (no clayey cement present)

Table 6: Most common GSI ranges for typical siltstones, claystones and clay shales.*

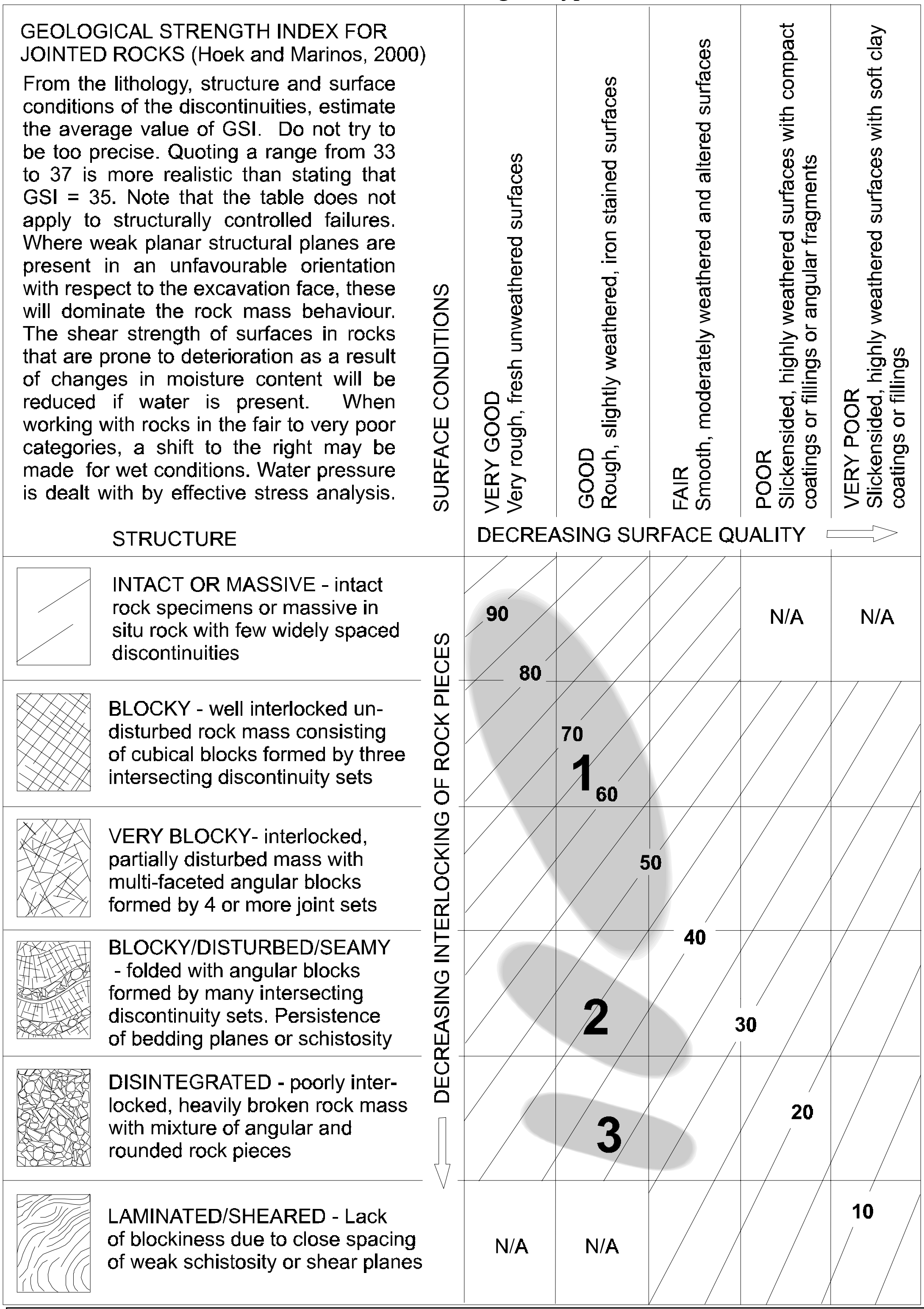


*<u>*WARNING*</u>:
The shaded areas are indicative and may not be appropriate for site specific design purposes. Mean values are not suggested for indicative characterisation; the use of ranges is recommended

1. Bedded, foliated, fractured
2. Sheared, brecciated

These soft rocks are classified by GSI as associated with tectonic processes. Otherwise, GSI is not recommended. The same is true for typical marls.

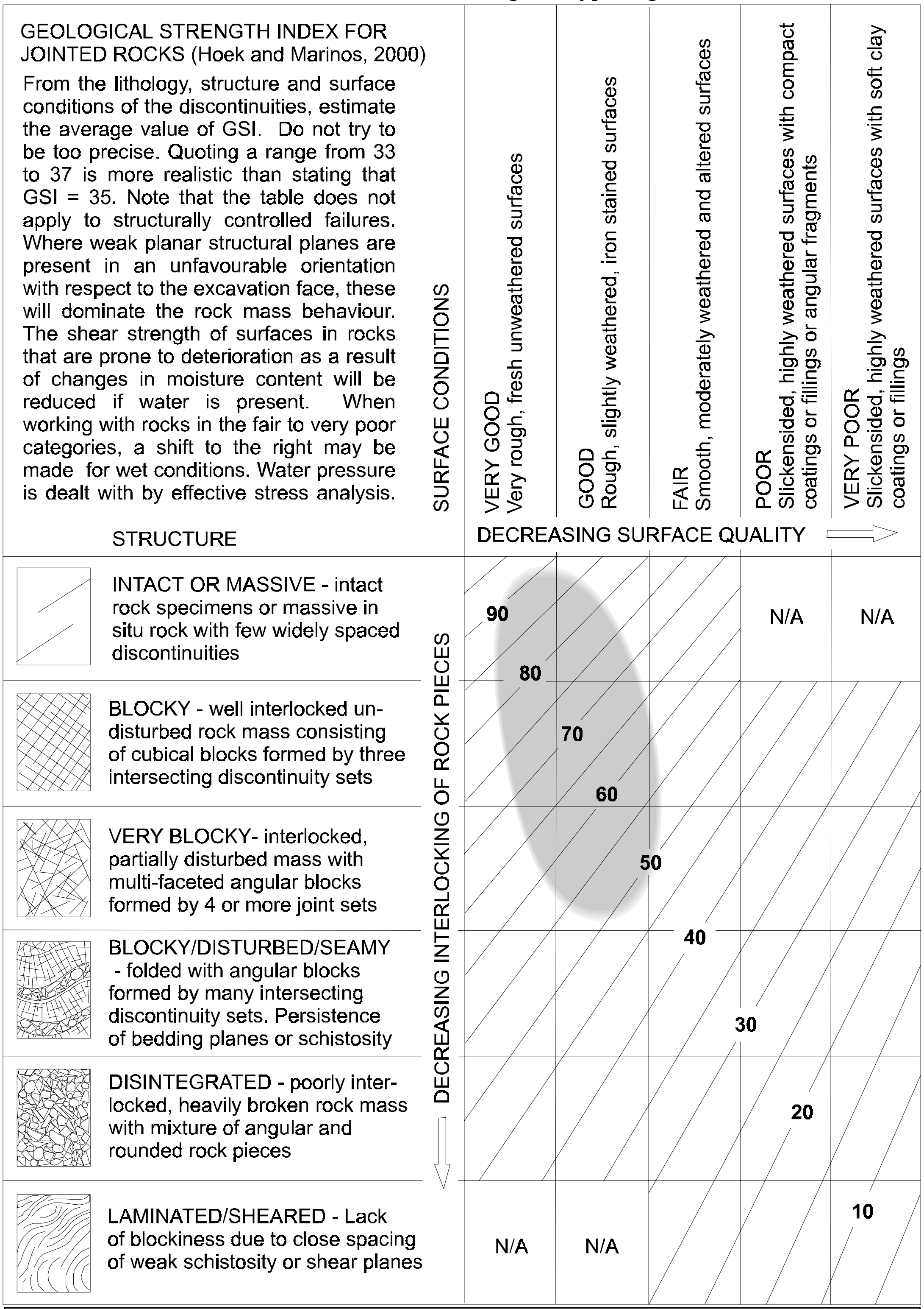
Table 7: Most common GSI range of typical limestone.*



WARNING:
The shaded areas are indicative and may not be appropriate for site specific design purposes.
Mean values are not suggested for indicative characterisation; the use of ranges is recommended

1. Massive
2. Thin bedded
3. Brecciated

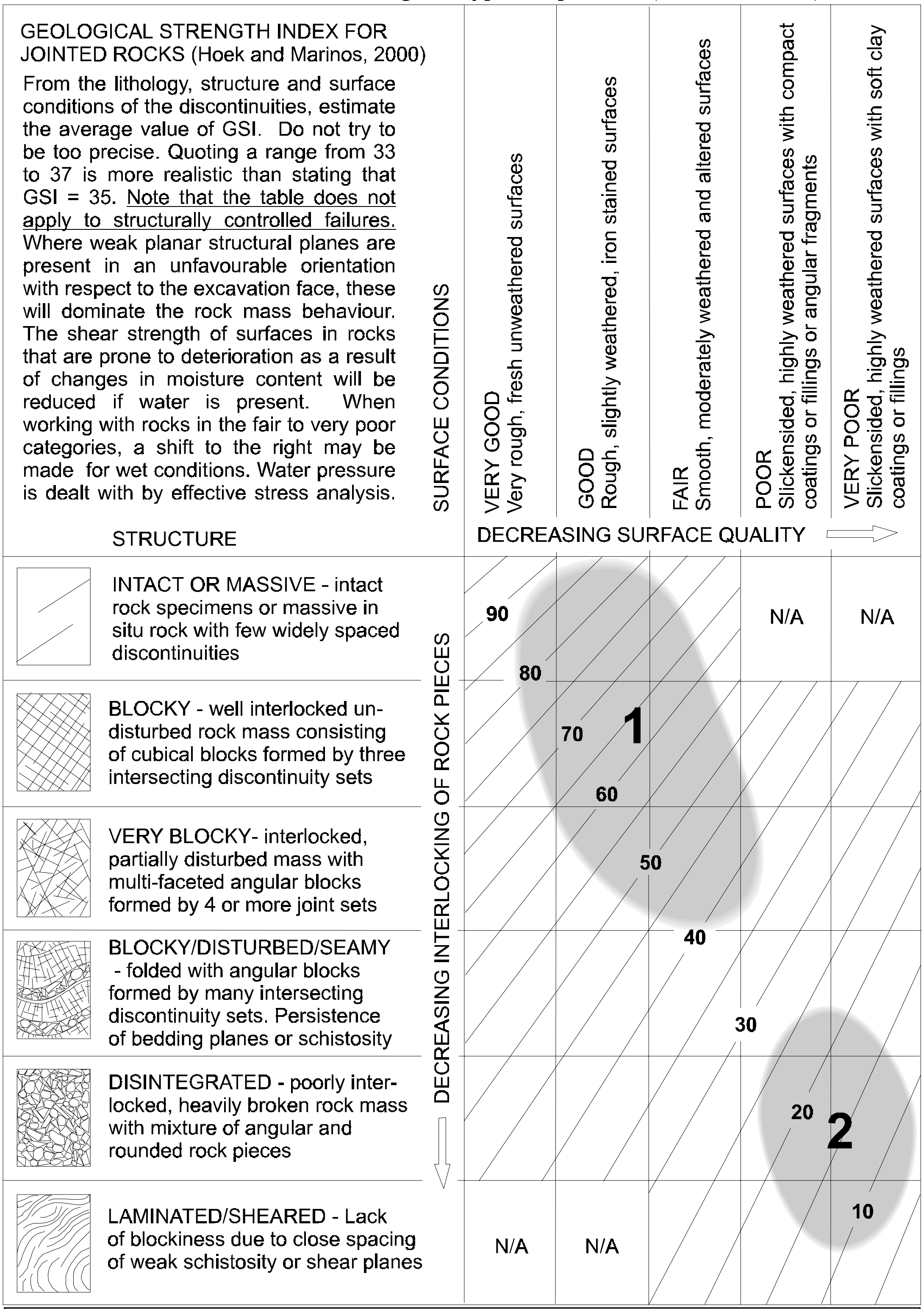
Table 8: Most common GSI range for typical granite.*



*<u>*WARNING*</u>:
The shaded areas are indicative and may not be appropriate for site specific design purposes.
Mean values are not suggested for indicative characterisation; the use of ranges is recommended

Only fresh rock masses are shown. Weathered granite may be irregularly illustrated on the GSI chart, since it can be assigned greatly varying GSI values or even behave as an engineering soil.

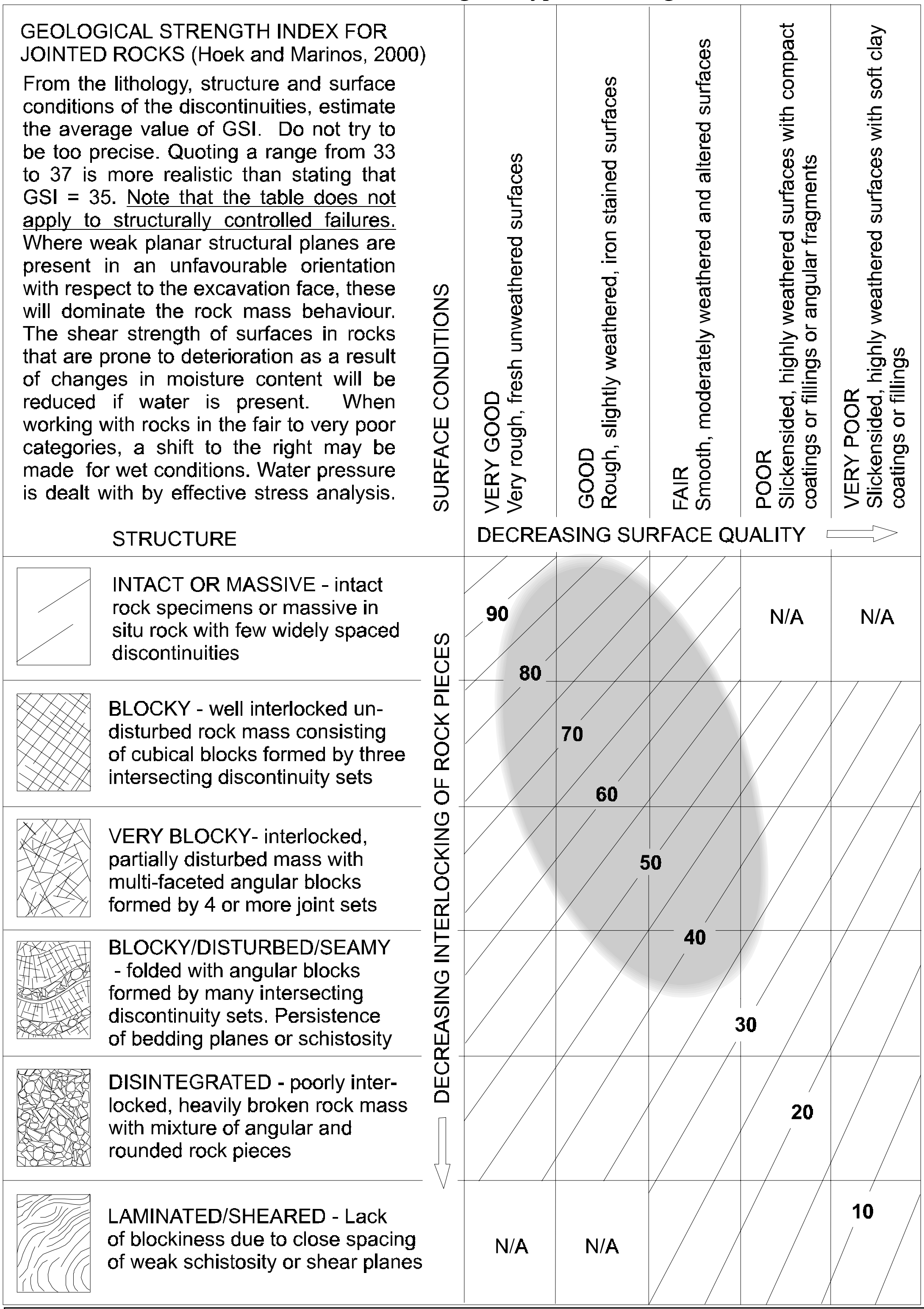
Table 9: Most common GSI range for typical ophiolites (ultrabasic rocks).*



*<u>*WARNING*</u>:
The shaded areas are indicative and may not be appropriate for site specific design purposes. Mean values are not suggested for indicative characterisation; the use of ranges is recommended

1. Fresh
2. Serpentinised with brecciation and shears

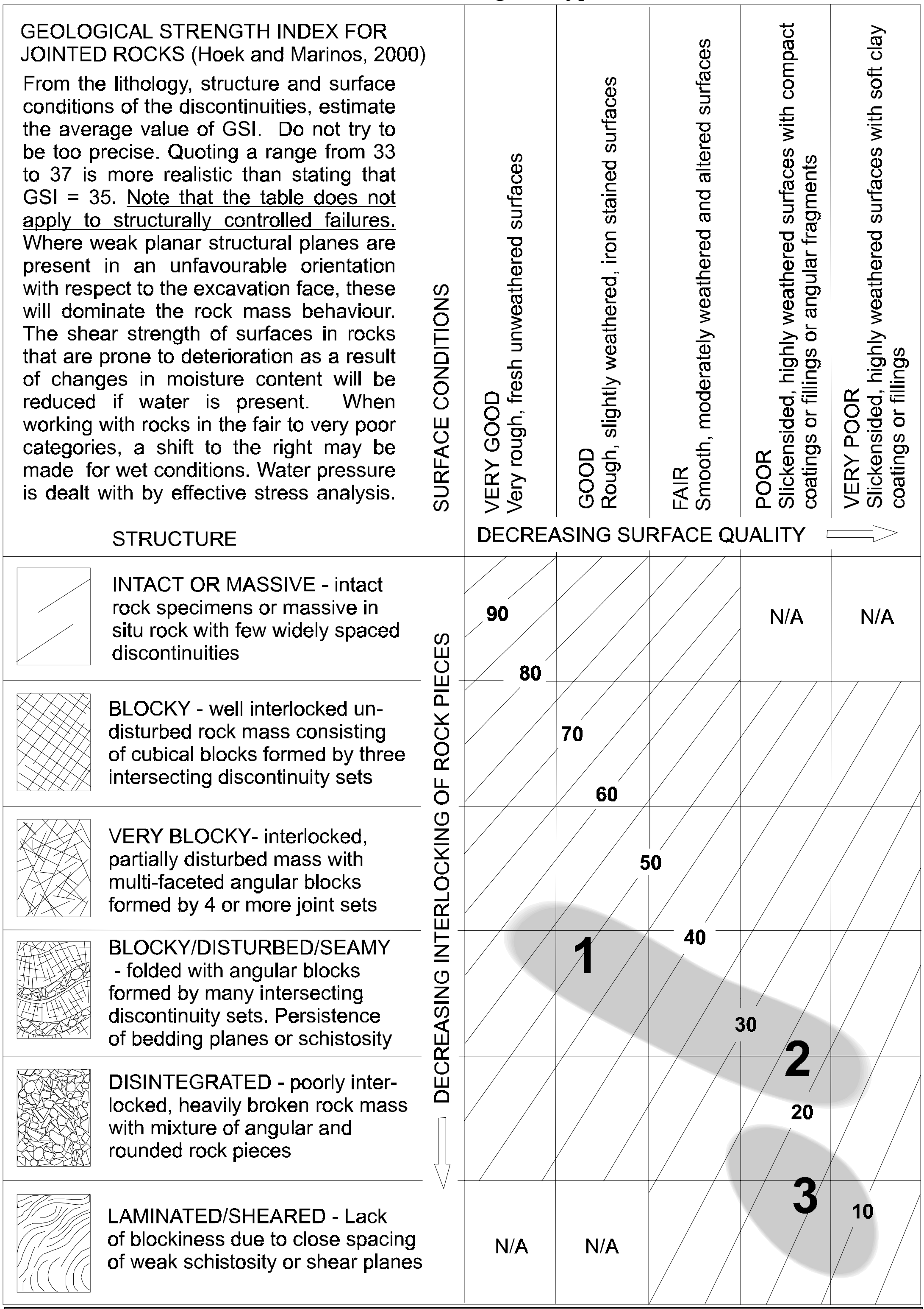
Table 10: Common GSI range for typical sound gneiss.*



*<u>*WARNING*</u>:
The shaded areas are indicative and may not be appropriate for site specific design purposes.
Mean values are not suggested for indicative characterisation; the use of ranges is recommended

Sound gneiss. Shaded area does not cover weathered rockmasses.

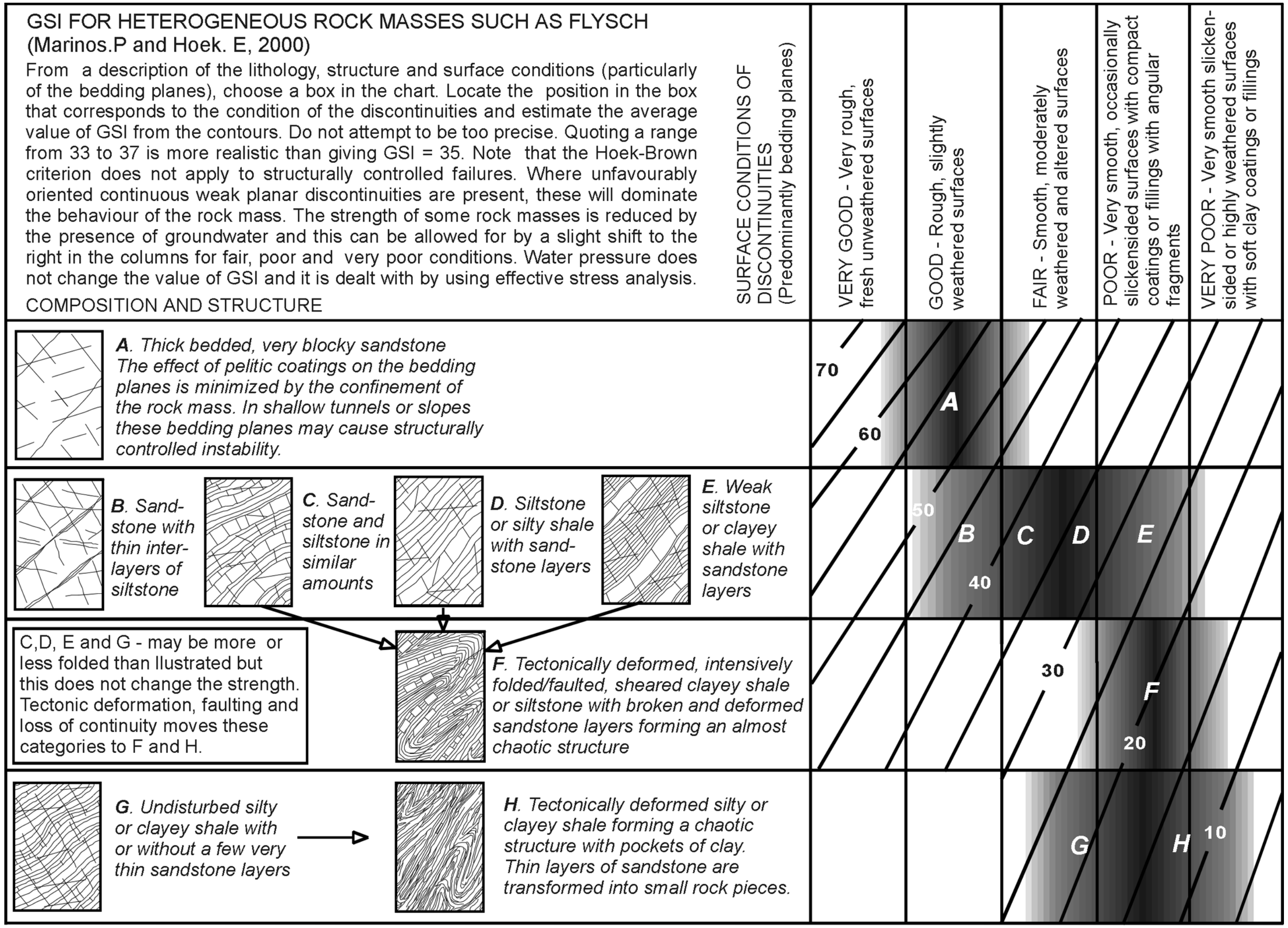
Table 11: Common GSI range for typical schist.*



*<u>*WARNING*</u>:
The shaded areas are indicative and may not be appropriate for site specific design purposes. Mean values are not suggested for indicative characterisation; the use of ranges is recommended

1. Strong (e.g. micaschists, calcitic schists)
2. Weak (e.g. chloritic schists, phyllites)
3. Sheared schist

Table 12. GSI estimates for heterogeneous rock masses such as flysch.



: Means deformation after tectonic disturbance

Table 13: Suggested proportions of parameters σ_{ci} and m_i for estimating rock mass properties for flysch (Marinos, P., Hoek, E., 2000).

Flysch type see Table 12	Proportions of values for each rock type to be included in rock mass property determination
A and B	Use values for sandstone beds
C	Reduce sandstone values by 20% and use full values for siltstone
D	Reduce sandstone values by 40% and use full values for siltstone
E	Reduce sandstone values by 40% and use full values for siltstone
F	Reduce sandstone values by 60% and use full values for siltstone
G	Use values for siltstone or shale
H	Use values for siltstone or shale

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