Creating Value ...



... Delivering Solutions

Use of RMR to Improve Determination of the Bearing Resistance of Rock

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ASD Design

- σ_{v allowable} is a presumptive allowable bearing capacity
- Obtained from AASHTO Specs
- Based on a limiting settlement only (usually ½ to 1 ")
 - Shear failure of foundation

assumed to be not controlling

 $\sigma_{v \max} < \sigma_{v \text{ allowable}}$

The second se

LRFD Design

Service Limit State

 Compute displacements and compare to tolerable displacement

Strength Limit State

- Check sliding failure
- Check overturning (e)
- Check bearing failure

Controlled for soft, fractured rocks

Current LRFD Methodology

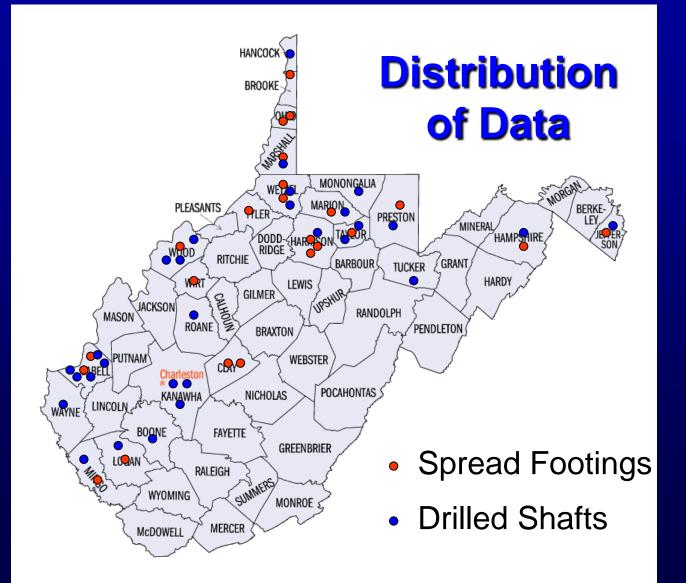
- 1. 10.6.3.5 allows flexibility in the method used
- 2. Many engineers use equation 10.8.3.5.4c-2
- 3. This is equivalent to the N_{ms} method that was presented in the old ASD specifications

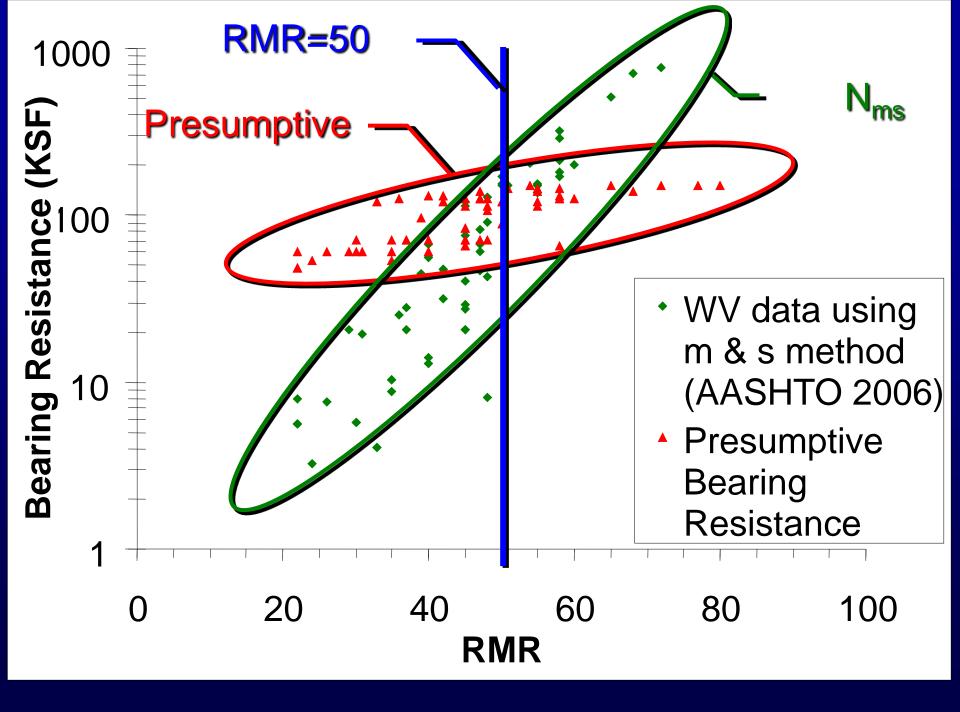
$$q_{n} = \left[\sqrt{s} + \sqrt{n\sqrt{s} + s} \right] q_{u}$$

$$ASD \qquad Q_{ult} = N_{ms} C_{o}$$

$$\varphi q_{n} > \frac{V(1 + 6e)}{B(B)}$$

Comparison of Presumptive to N_{ms} Method based on RMR

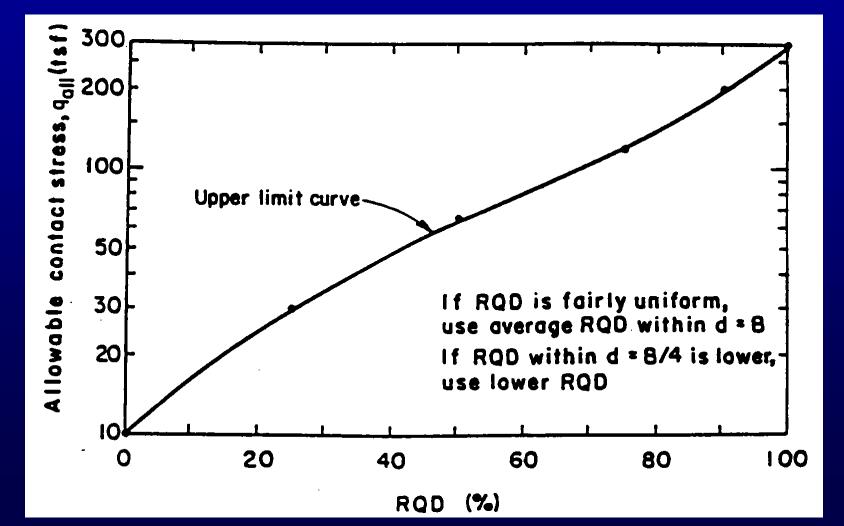




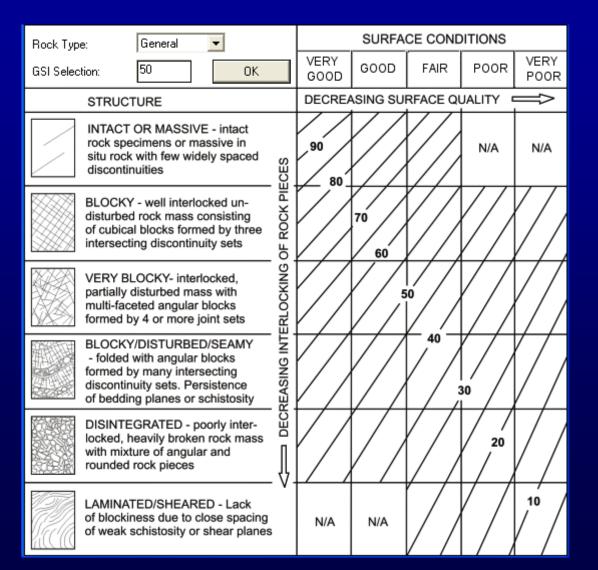
Presumptive (AASHTO 2006 Table 10.6.2.6-1 from NAVFAC DM-7)

		BEARING RES	STANCE (KSF)
TYPE OF BEARING MATERIAL	CONSISTENCY IN PLACE	Ordinary Range	Recommended Value of Use
Massive crystalline igneous and metamorphic rock: granite, diorite, basalt, gneiss, thoroughly cemented conglomerate (sound condition allows minor cracks)	Very hard, sound rock	120 to 200	160
Foliated metamorphic rock: slate, schist (sound condition allows minor cracks)	Hard sound rock	60 to 80	70
Sedimentary rock: hard cemented shales, siltstone, sandstone, limestone without cavities	Hard sound rock	30 to 50	40
Weathered or broken bedrock of any kind, except highly argillaceous rock (shale)	Medium hard rock	16 to 24	20
Compaction shale or other highly argillaceous rock in sound condition	Medium hard rock	16 to 24	20
Well-graded mixture of fine- and coarse- grained soil: glacial till, hardpan, boulder clay (GW-GC, GC, SC)	Very dense	16 to 24	20
Gravel, gravel-sand mixture, boulder-gravel mixtures (GW, GP, SW, SP)	Very dense Medium dense to dense Loose	12 to 20 8 to 14 4 to 12	14 10 6
Coarse to medium sand, and with little gravel (SW, SP)	Very dense Medium dense to dense Loose	8 to 12 4 to 8 2 to 6	8 6 3
Fine to medium sand, silty or clayey medium to coarse sand (SW, SM, SC)	Very dense Medium dense to dense Loose	6 to 10 4 to 8 2 to 4	6 5 3
Fine sand, silty or clayey medium to fine sand (SP, SM, SC)	Very dense Medium dense to dense Loose	6 to 10 4 to 8 2 to 4	6 5 3
Homogeneous inorganic clay, sandy or silty clay (CL, CH)	Very stiff to hard Medium stiff to stiff Soft	6 to 12 2 to 6 1 to 2	8 4 1
Inorganic silt, sandy or clayey silt, varved silt- clay-fine sand (ML, MH)	Very stiff to hard Medium stiff to stiff Soft	4 to 8 2 to 6 1 to 2	6 3 1

• Empirical correlation to RQD (AASHTO ASD 4.4.8.1.1)



Methods based on GSI



 Modified bearing resistance equations and bearing capacity factors (COE EM 1110-1-2908)

$$q_{ult} = 0.5 \ \gamma B N_{\gamma} + \gamma D N_{q}$$
(6-3)

$$N_{c} = 2 \ N \phi^{1/2} \ (N \phi + 1)$$
(6-2a)

$$N \gamma = N \phi^{1/2} \ (N_{\phi}^{2} - 1)$$
(6-2b)

$$N_{q} = N_{\phi}^{2}$$
(6-2c)

$$N_{\phi} = \tan^{2} \ (45 + \phi/2)$$
(6-2d)

 Empirical correlation of RMR to C and φf (Serafim and Pereira, 1983; Bieniawski, 1989) and General bearing resistance equation

$$Cohesion = C = 104 \times RMR \quad \text{(in PSF)}$$
$$Friction = \phi_f = 5 + \frac{RMR}{2}$$

$$q_n = c N_{cm} + \gamma D_f N_{qm} C_{wq} + 0.5 \gamma B N_{\gamma m} C_{w\gamma}$$



WINNER for RMR less than 50

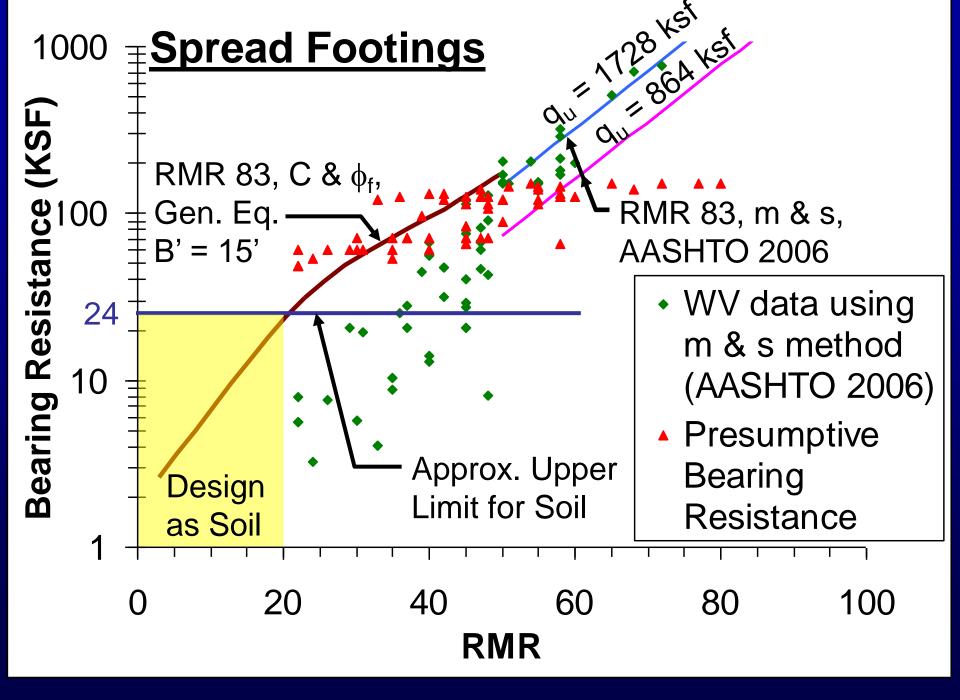
 N_{ms} method (AASHTO ASD 4.4.8.1.2) or m & s method (AASHTO 2006 10.8.3.5.4c-2)

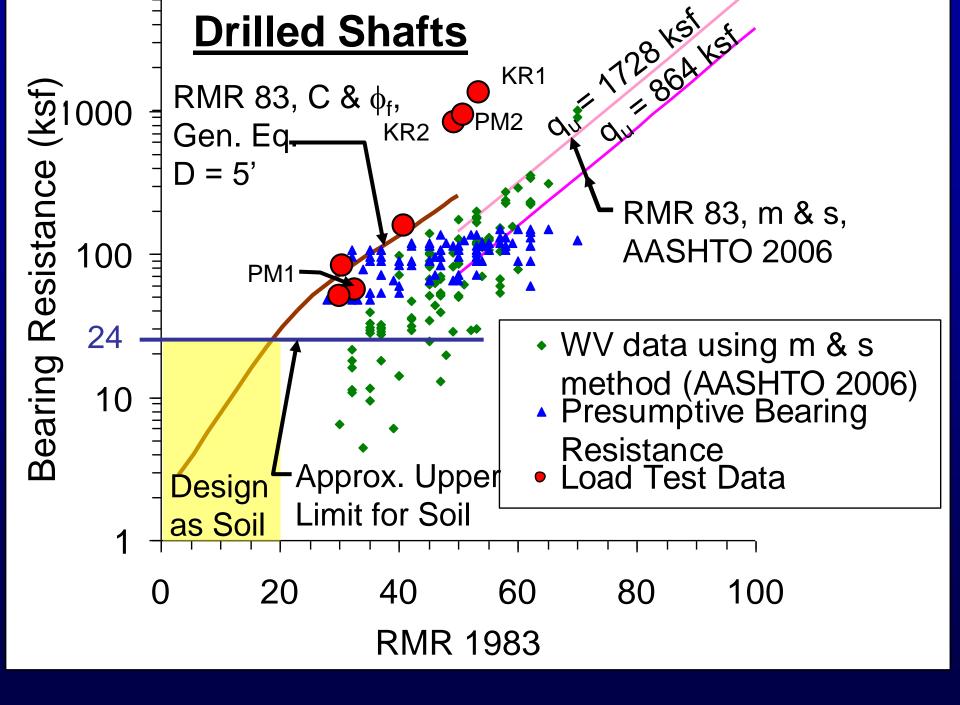
Rock Mass		RMR ⁽¹⁾	NGI ⁽²⁾	RQD ⁽³⁾			N _{ms} ⁽⁴⁾		
Quality	General Description	Rating	Rating	(%)	Α	В	C	D	Ε
Excellent	Intact rock with joints spaced > 10 feet apart	100	500	95-100	3.8	4.3	5.0	5.2	6.1
Very good	Tightly interlocking, undis- turbed rock with rough unweathered joints spaced 3 to 10 feet apart.	85	100	90-95	1.4	1.6	1.9	2.0	2.3
Good	Fresh to slightly weathered rock, slightly disturbed with joints spaced 3 to 10 feet apart	65	10	75-90	0.28	0.32	0.38	0.40	0.46
Fair	Rock with several sets of mod- erately weathered joints spaced 1 to 3 feet apart	44	1	50-75	0.049	0.056	0.066	0.069	0.081
Poor	Rock with numerous weathered joints spaced 1 to 20 inches apart with some gouge	23	0.1	25-50	0.015	0.016	0.019	0.020	0.024
Very poor	Rock with numerous highly weathered joints spaced < 2 inches apart	3	0.01	<25	Use q _u	_{ılt} for ar	n equiva	lent soi	l mass

$$q_n = \left[\sqrt{s} + \sqrt{n\sqrt{s} + s}\right] q_u$$

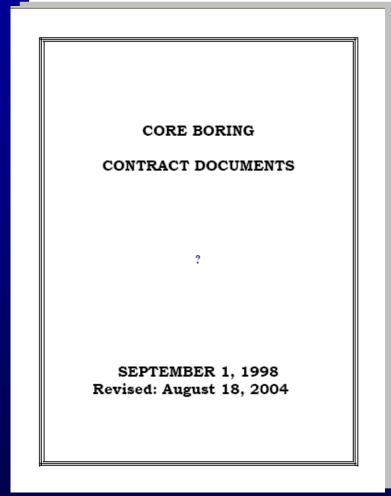


WINNER for RMR greater than 50





Implementation of RMR



Contract Documents

WEST VIRGINIA DEPARTMENT OF TRANSPORTATION DIVISION OF HIGHWAYS Material Controls, Soils and Testing Division DRILLER AND FIELD INSPECTOR HANDBOOK

Inspector Handbook

RMR

rock mass strength

- q_u • RQD
- Spacing
- Condition
- Water

	PARAME						NGES C	F VAL	JES			
	Strength of	Point load strength index	>175 ksf	>175 ksf 85 to 175		45 to 85 ksf	20 to 45 ksf	COI			e – uniaxial is preferred	
1	intact rock material	Uniaxial compressive strength	>4320 ksf	216 to 432 ksf	20	1080 to 2160 ksf	520 to 1080 ksf	21 to 52	5 0 ksf	70 to 215 ksf	20 to 70 ksf	
	Relative Ratir	ıg	15	1	12	7	4		2	1	0	
	Drill core qual	ity RQD	90% to 100%		75%	6 to 90%	50% to	o 75%	25%	6 to 50%	<25%	
	Relative Ratir	Ig	20			17		13		8	3	
3	Spacing of joi		>10 ft		3 1	to 10 ft	1 to	3 ft	2 in.	to 1 foo		
	Relative Ratin	Ig	1	30		25		20		10	5	
4	Condition of jo		 Not continuo No separati Hard joir 	rough surfaces • Not continuous		htly gh acces paration 05 in d joint l rock 20	 Slight rough surfac Sepan <0.05 Soft jo wall ro 	ces ration in pint	- or - • Go in. t - or • Joi 0.05	ed faces uge <0.2 hick - nts open 5 to 0.2 in ntinuous	open >0.2 in. • Continuous joints	
		ig	23			20	12			0	0	
5	Ground water conditions (use one of the three evaluation criteria as appropriate	Inflow per 30 ft tunnel length	None	e	<	:400 gallor	ıs/hr	s/hr 400 to gallo		>2	2000 gallons/hr	
	to the method of exploration)	Ratio= joint water pressure/ major principal stress	0	0		0.0 to 0.		0.2	to 0.5		>0.5	
		General Conditions	Completely Dry		ſУ	Moist on (interstiti water)				r	Severe water problems	
	Relative Ratir	ıg	10			7			4		0	

Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

Unconfined Compression Strength

HCSI – Hardness and Compressive Strength Index

HCSI	Field Test	RMR
0	Indented by Thumb Nail	0
1	Crumble under firm blows with point of geological pick. Can be peeled by a pocket knife.	1
2	Can be peeled by a pocket knife with difficulty. Shallow indentations made by firm blow of geological pick.	2
3	Cannot be scraped or peeled with a pocket knife. Specimen can be fractured with single firm blow of hammer end of geological pick.	4
4	Specimen requires more than one blow with hammer end of geological pick to fracture it.	7
5	Specimen requires many blows of hammer end of geological pick to fracture it.	12
6	Specimen can only be chipped with geological pick.	15

Unconfined Compression Strength

 Uniaxial compression tests of laboratory specimens

 Point load tests conducted in the field or laboratory





RMR

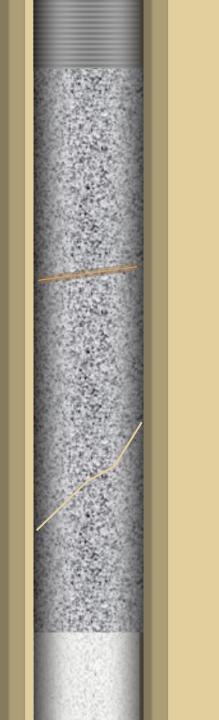
rock mass strength

- qu • RQD
- Spacing
- Condition
- Water

		PARAME						NGES	OF VAL	UES		
		Strength of	Point load strength index	to		5 ksf	45 to 85 ksf	20 to 45 ks	со		ow range - sive test is	- uniaxial preferred
	1	material	Uniaxial compressive strength	>4320 ksf	210 to 432 ksf	20	1080 to 2160 ksf	520 to 1080 ksf	21 to 52	5 0 ksf	70 to 215 ksf	20 to 70 ksf
		Relative Rating	g	15		12	7	4		2	1	0
	2	Drill core quali	ty RQD	90% to 100%		75%	% to 90%	50% 1	to 75%	25%	6 to 50%	<25%
L		Relative Rating	g	20	20		17		13		8	3
:	3	Spacing of join		>10 ft		3	to 10 ft	1 to	o 3 ft	2 in.	to 1 foot	<2 in.
L		Relative Rating	g	30			25		20		10	5
	4		 Very rough surfaces Not continuou No separatio Hard join wall rock 		ous on nt k	rou sur • Ser <0. • Har	gh faces paration 05 in rd joint I rock	 Sligh roug surfa Sepa <0.00 Soft wall re 	h aces aration 5 in joint ock	- or - • Go in. t - or • Joi 0.05	ed faces uge <0.2 hick - nts open 5 to 0.2 in. ntinuous	
		Relative Rating	9	25		20			12			0
:	5	Ground water conditions (use one of the three evaluation criteria as appropriate	Inflow per 30 ft tunnel length	None	e <40		<400 gallon			400 to 2000 gallons/hr		000 gallons/hr
		to the method of exploration)	Ratio= joint water pressure/ major principal stress	0			0.0 to 0.2	2	0.2	to 0.5		>0.5
			General Conditions	Completely Dry		ry	Moist onl (interstitia water)		moo	er under derate ssure	s	evere water problems
	Relative Rating			10			7			4		0

19

Table 10.4.6.4-1 Geomechanics Classification of Rock Masses



RQD

Record for each core run

For stratum thinner than core run length - record the RQD separately for stratum

Assign points for RQD according to AASHTO LRFD, Table 10.4.6.4-1

RMR

rock mass strength

- q_u
 RQD
- Spacing
- Condition
- Water

		PARAME	TER				RAI	NGES	OF VAI	LUES			
		Strength of	Point load strength index Uniaxial	>175 ksf	85 to 175	<u>5 ksf</u>	45 to 85 ksf 1080	20 to 45 ks 520	f CO		ow range – sive test is 70		
	1	material	compressive strength	ksf	to 432 ksf	20	to to 2160 108 ksf ksf		to		to 215 ksf	to 70 ksf	
		Relative Ratin	g	15	15 1		7	4		2	1	0	
	2	Drill core quali	ty RQD	90% to 100%			% to 90%	50% 1	to 75%	25%	% to 50%	<25%	
L		Relative Ratin	g	20			17		13		8	3	
	3	Spacing of joir		>10 ft		3	to 10 ft	1 to	o3ft	2 in.	to 1 foot	<2 in.	
	-	Relative Ratin	g	30			25		20		10	5	
					ugh rough ro			 Sligh rougl surfa 	h	• Slic sid sur		 Soft gouge >0.2 in. thick 	
	4	Condition of jo	Not continuous		continuous<0.05 in<0.05 i• No separation• Hard joint wall rock• Soft joi wall rock• Hard joint• Hard joint			joint	in. t - or • Joi 0.05	nts open 5 to 0.2 in. ntinuous	 or - Joints open >0.2 in. Continuous joints 		
		Relative Ratin	g	25	25 20		20		12		6	0	
	5	Ground water conditions (use one of the three evaluation criteria as	Inflow per 30 ft tunnel length	None	e <4		<400 gallor	is/hr		400 to 2000 gallons/hr		00 gallons/hr	
		appropriate to the method of exploration)	Ratio= joint water pressure/ major principal stress	0			0.0 to 0.	2	0.2	2 to 0.5		>0.5	
			General Conditions	Completely Dry		ry	Moist on (interstiti water)		ma	er under oderate essure		Severe water problems	
		Relative Ratin	10			7			4		0		

Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

Fracture Spacing

Estimate average fracture spacing for core run or identified stratum (which ever is smaller)

length of identified interval

Average spacing =

number of discontinuities in interval

Assign point value in accordance with AASHTO LRFD Table 10.4.6.4-1

RMR

rock mass strength

- q_u
- RQD
- Spacing

Condition

Water

	PARAME	ETER					NGES OF	VAL	UES		
1	Strength of intact rock	Point load strength index Uniaxial	>175 ksf >4320	216	5 ksf 60	45 to 85 ksf 1080	20 to 45 ksf 520		mpress	ow range – sive test is 70	
	material	compressive strength	ksf	to 432 ksf		to 2160 ksf	to 1080 ksf	to 52	0 ksf	to 215 ksf	to 70 ksf
	Relative Ratir	ng	15	15 1		7	4		2	1	0
2	Drill core qual	lity RQD	90% to 100%			6 to 90%	50% to	75%	25%	% to 50%	<25%
	Relative Ratir	ng	20			17		13		8	3
3	Spacing of joi		>10 ft		3	to 10 ft	1 to 3		2 in.	to 1 foot	<2 in.
	Relative Ratir	ng	30			25	2	20		10	5
4	Condition of jo	pints	rough surfaces • Not continuous		• Sep <0. • Hai	gh faces	 Slightly rough surface Separa <0.05 i Soft joi wall roc 	es ition n nt	sid sur - or - • Go in. t - or • Joi 0.05	faces uge <0.2 hick - nts open 5 to 0.2 in. ntinuous	 Soft gouge >0.2 in. thick or - Joints open >0.2 in. Continuous joints
	Relative Ratir	ng	25		20			12		6	0
5	conditions (use one of the three evaluation criteria as	Inflow per 30 ft tunnel length	None	one		<400 gallor	is/hr		o 2000 ons/hr	>20	00 gallons/hr
	appropriate to the method of exploration)	Ratio= joint water pressure/ major principal stress	0			0.0 to 0	2	0.2	to 0.5		>0.5
		General Conditions	Completely Dry		ſy	Moist on (interstiti water)		mod	Water under moderate pressure		evere water problems
	Relative Ratir	ng	10			7			4		0

Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

Fracture Condition

Different sub-categories

- Discontinuity length
- Separation
- Surface roughness
- Infilling joint material
- Joint weathering

Fracture Condition

Parameter			Ratings	;			
Discontinuity length (feet)	< 3 5	3-10 4	10-30 2	30-65 1	>65 0		
Separation (inches)	None 5	<0.005 4	0.005-0.05 3	0.05-0.2 1	>0.2 0		
Roughness	Very rough 5	ough rough		Smooth 1	Slickensided 0 oft filling		
Infilling		Harc	l filling	So	oft filling		
Infilling (inches)	None 5	<0.2 4	>0.2 3	<0.2 2	>0.2 0		
Weathering	None	Slightly	Moderate	Highly	Decomposed		
	5	4	2	1	0		

Sub: Discontinuity Length

 Estimate based on exposed outcrops and site geology

• Compare with adjacent boreholes

 Use default value of 2 where this parameter is hard to estimate

Sub: Discontinuity Separation

 Observe core in split core barrel prior to removal



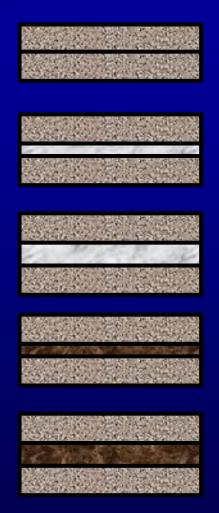
Sub: Roughness

- Very rough : discontinuity surface angular, amplitude > 0.2"
- Rough : amplitude < 0.2"
- Slightly rough : undulating surface, amplitude < 0.2
- Smooth discontinuities : planer surface
- Slickensided : discontinuity shows visible polishing



Sub: Infilling

- None
- Hard , thickness < 0.2"
- Hard , thickness > 0.2"
- Soft , thickness < 0.2"
- Soft , thickness > 0.2"



Hard and soft infilling as previously described

Sub: Weathering

Term	Description	Points
Decomposed	Original minerals decomposed to secondary minerals Original rock fabric not apparent Material can be easily broken by hand	0
Highly Weathered	Original minerals almost entirely decomposed to secondary minerals Although original fabric maybe intact Material can be granulated by hand	1
Moderately Weathered	More than half of the rock is decomposed	2
Slightly Weathered	Rock is discolored and noticeably weakened, but less than half is decomposed.	4
Unweathered	Rock shows no discoloration, loss of strength, or other effect of weathering/alteration	5

RMR

rock mass strength

- q_u
- RQD
- Spacing
- Condition

• Water -

		PARAME	ETER				RAI	NGES	OF VA	ALUES		
		Strength of	Point load strength index	>175 ksf	ksf 85 to 175 ks		45 to 85 ksf	20 to 45 ks	0		ow range - sive test is	- uniaxial preferred
	1	intact rock material	Uniaxial compressive strength	>4320 ksf	216 to 432 ksf	20	1080 to 2160 ksf	520 to 1080 ksf	t	215 to 520 ksf	70 to 215 ksf	20 to 70 ksf
		Relative Ratir	g	15	1	12	7	4		2	1	0
	2	Drill core qual	ity RQD	90% to 100%		75%	5 to 90%	50%	to 75%	% 25%	% to 50%	<25%
L		Relative Ratin	g	20			17		13		8	3
	3	Spacing of joi		>10 ft		3 1	to 10 ft	1 t	to 3 ft	2 in.	to 1 foot	<2 in.
		Relative Ratin	g	30			25		20		10	5
	4	Condition of jo	pints	 Not continuo No separati Hard joir 	rough surfaces • Not continuous • No		htly gh aces aration 05 in 05 in d joint rock		gh aces aration)5 in joint	sid sur - or - • Go in. t - or • Joi 0.05	faces uge <0.2 hick - nts open 5 to 0.2 in. ntinuous	 Soft gouge >0.2 in. thick or - Joints open >0.2 in. Continuous joints
		Relative Ratir	g	25			20		12		6	0
	5	Ground water conditions (use one of the three evaluation criteria as	Inflow per 30 ft tunnel length	None <400 gallons/h 0 0.0 to 0.2 Completely Dry Moist only (interstitial water)		is/hr		0 to 2000 allons/hr	>20	00 gallons/hr		
		appropriate to the method of exploration)	Ratio= joint water pressure/ major principal stress				0.0 to 0.	2	0.	.2 to 0.5		>0.5
			General Conditions			ry	(interstitia		m	iter under ioderate ressure	r S	Severe water problems
		Relative Ratir	g	10			7			4		0

Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

Ground Water

- For bearing resistance determination: base on anticipated service conditions.
- Parameter may change from that observed during the field investigation.
- Record all 5 components of the RMR
- Allows correction of the RMR values based on the final design configuration and use.

RMR

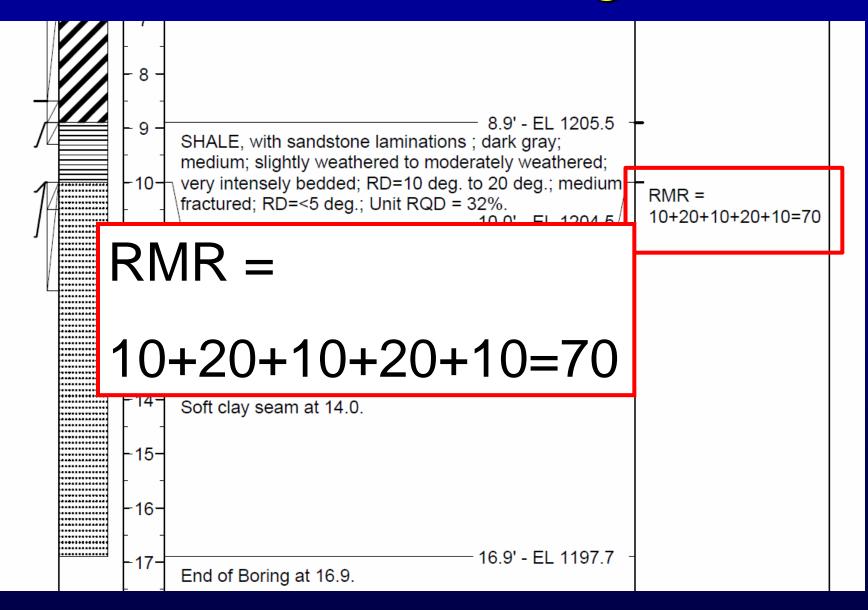
rock mass strength

- q_u
- RQD
- Spacing
- Condition
- Water

		PARAME	ETER				RAI	NGES O	F VAL	UES		
		Strength of	Point load strength index	>175 ksf	85 to 175	5 ksf	45 to 85 ksf	20 to 45 ksf			ow range – sive test is	
	1	intact rock material	Uniaxial compressive strength	>4320 ksf	216 to 432 ksf	20	1080 to 2160 ksf	520 to 1080 ksf	21 to 52	5 0 ksf	70 to 215 ksf	20 to 70 ksf
		Relative Ratin	ıg	15	1	12	7	4		2	1	0
	2	Drill core qual	ity RQD	90% to 100%		75%	6 to 90%	50% to	75%	25%	% to 50%	<25%
		Relative Ratin	Ig	20			17		13		8	3
	3	Spacing of joi		>10 ft		3 1	to 10 ft	1 to		2 in.	to 1 foot	<2 in.
l		Relative Ratin	Ig					20		10	5	
	4	Condition of jo	rough surfaces • Not continuous		 Sep <0.0 Han 		 Slightl rough surfac Separ <0.05 Soft jo wall roo 	es ation in int	sid sur - or - • Go in. t - or • Joi 0.05	faces uge <0.2 hick - nts open 5 to 0.2 in. ntinuous	 Soft gouge >0.2 in. thick or - Joints open >0.2 in. Continuous joints 	
		Relative Ratir	ıg	25			20		12	6		0
5	5	Ground water conditions (use one of the three evaluation criteria as appropriate	Inflow per 30 ft tunnel length	None	0 0.0 Completely Dry Mo		:400 gallor	ıs/hr	400 to 2000 gallons/hr		>20	00 gallons/hr
		to the method of exploration)	Ratio= joint water pressure/ major principal stress	0			0.0 to 0.	2	0.2	to 0.5		>0.5
			General Conditions	Complete			Moist on (interstitia water)		mod	r unde derate ssure		evere water problems
		Relative Ratin	ıg	10			7			4		0

Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

Method for Recording RMR



5)

Conclusions

- The Nms method of bearing resistance determination greatly under estimates the bearing resistance of rocks with RMR<50
- An alternate procedure for estimating bearing resistance of rocks with RMR<50 shows better correlation to past successful practice

Conclusions

- Use of RMR methods requires consistent implementation of the RMR in the field
- Additional guidance On RMR determination is helping provide more consistent and less conservative estimates of bearing resistance

