Creating Value ...

... Delivering Solutions

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

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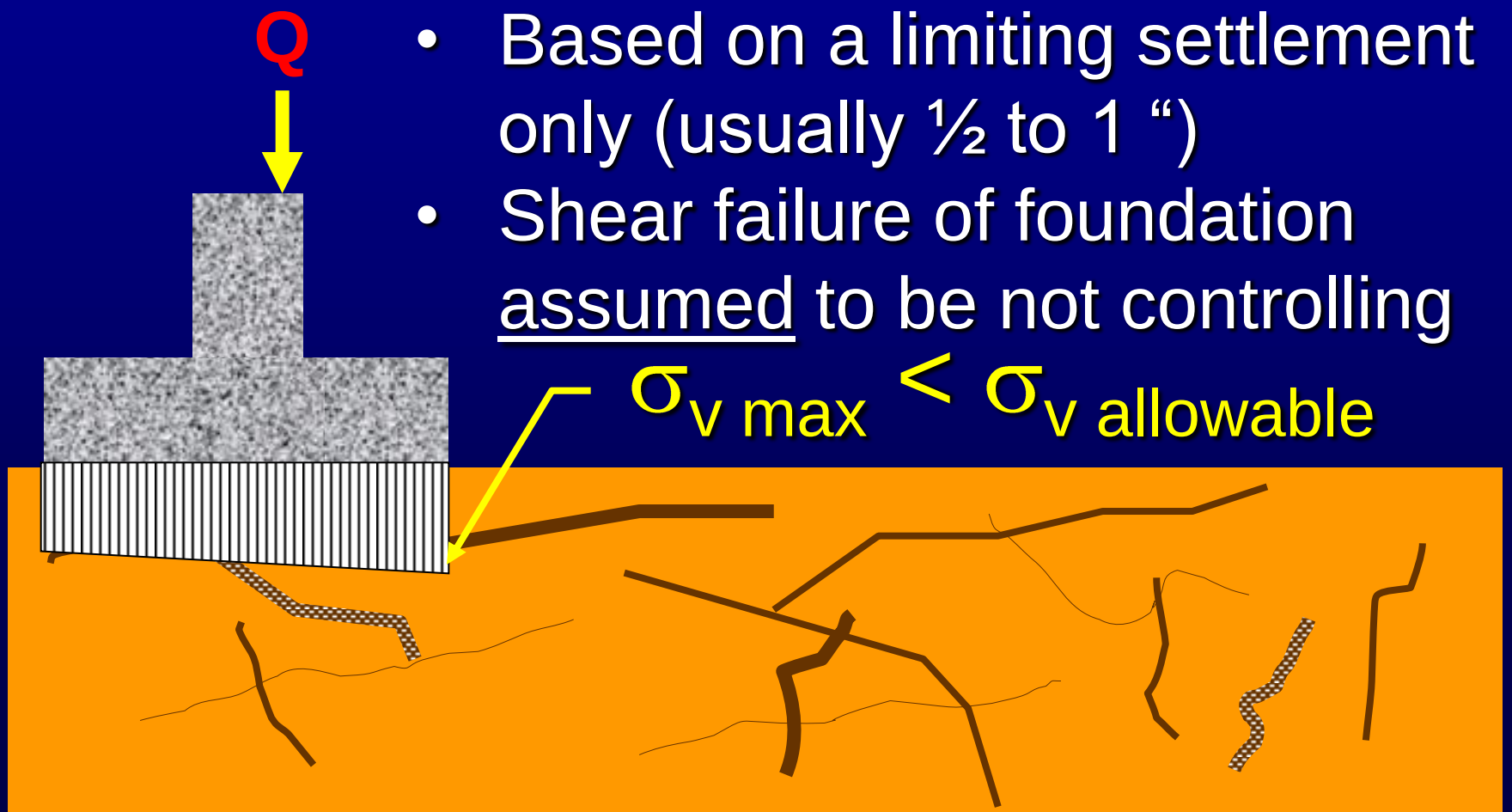
Baker

ASD Design

- $\sigma_{v\ allowable}$ is a presumptive allowable bearing capacity
- Obtained from AASHTO Specs
- Based on a limiting settlement only (usually ½ to 1 “)
- Shear failure of foundation <u>assumed</u> to be not controlling

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



LRFD Design

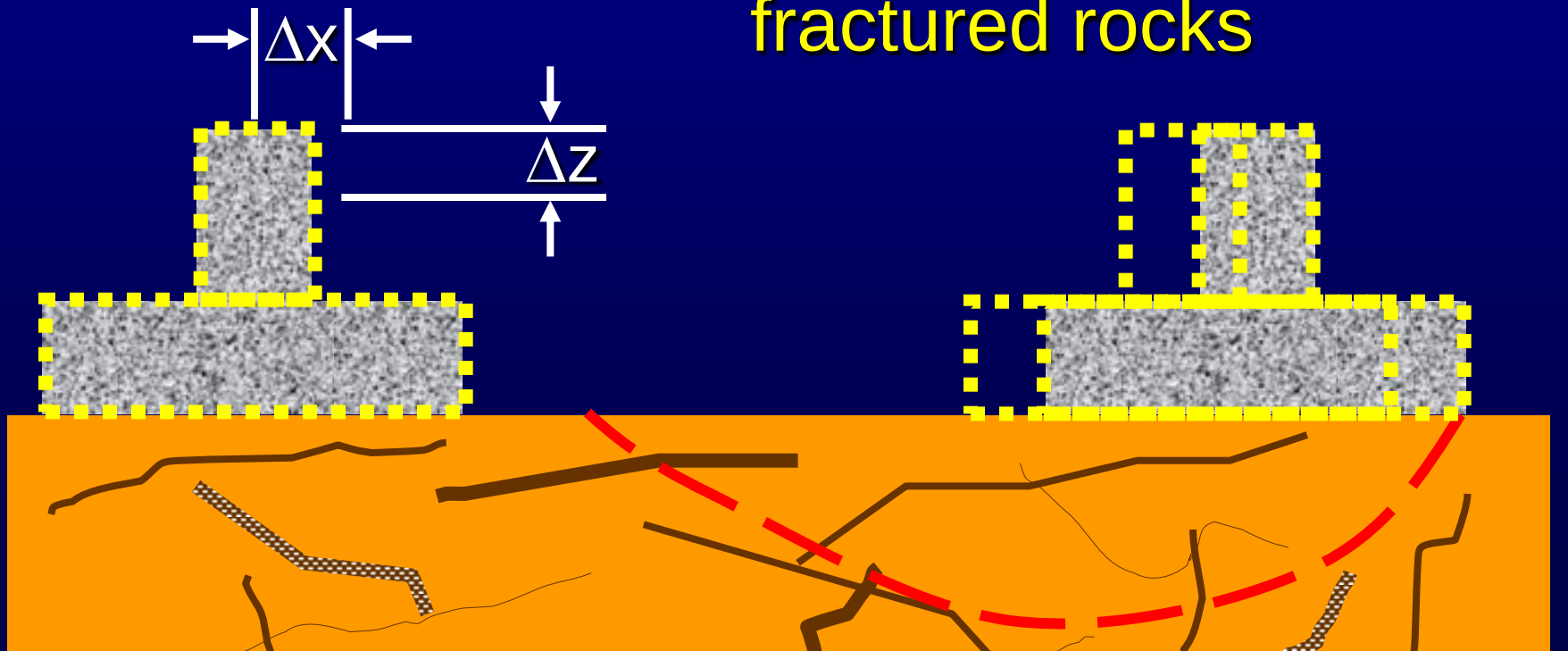
Service Limit State

- Compute displacements and compare to tolerable displacement

Strength Limit State

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

Controlled for soft, fractured rocks

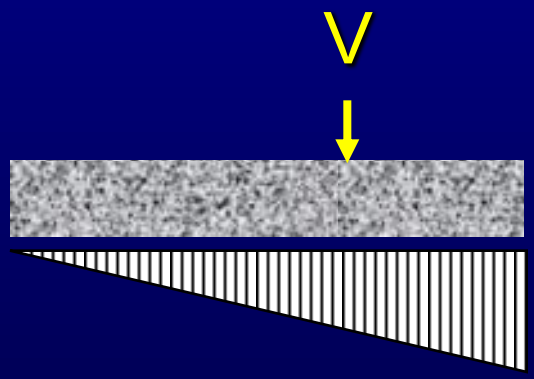


Current LRFD Methodology

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

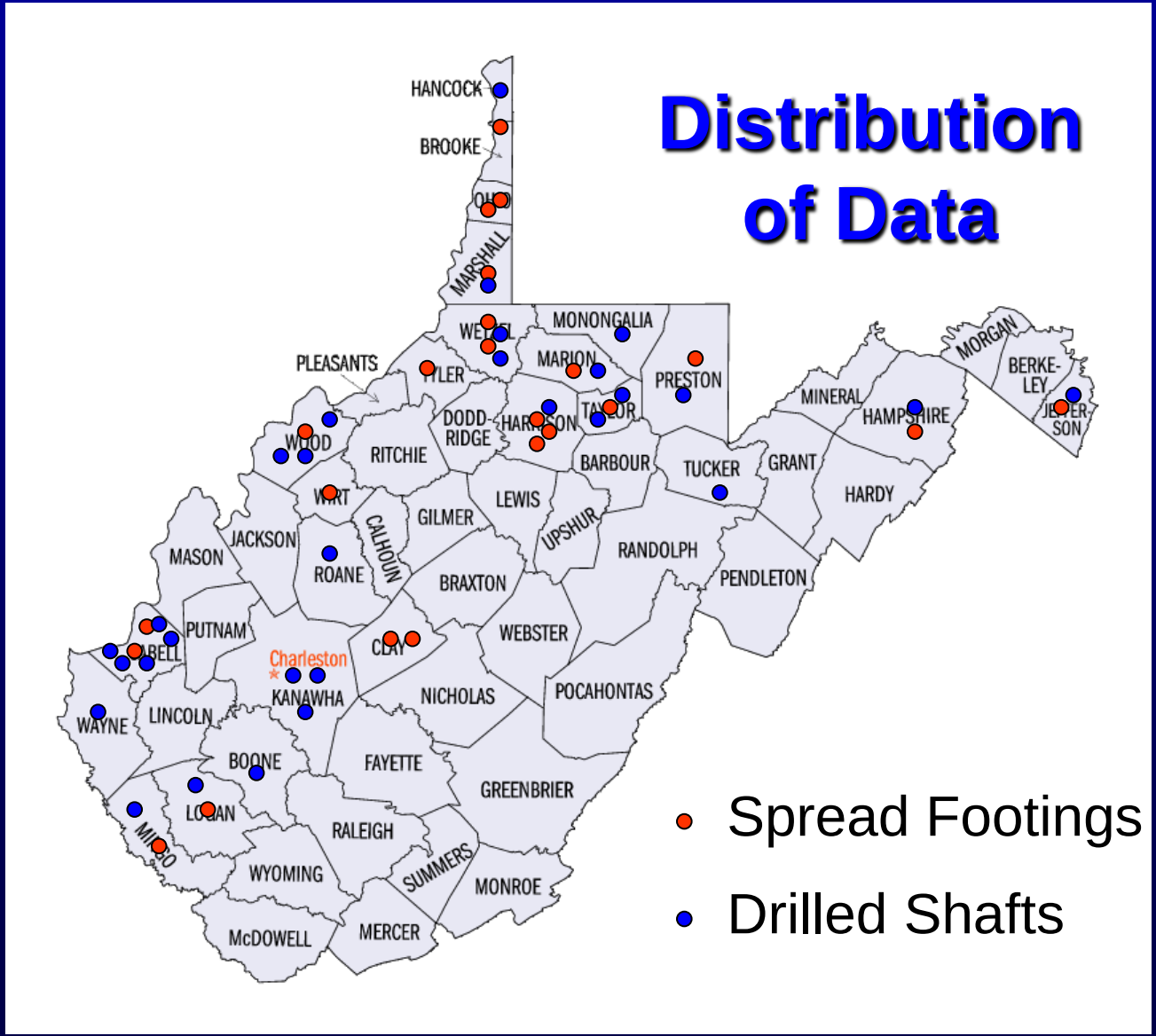
$$q_n = \left[\sqrt{s} + \sqrt{m\sqrt{s} + s}\right] q_u$$

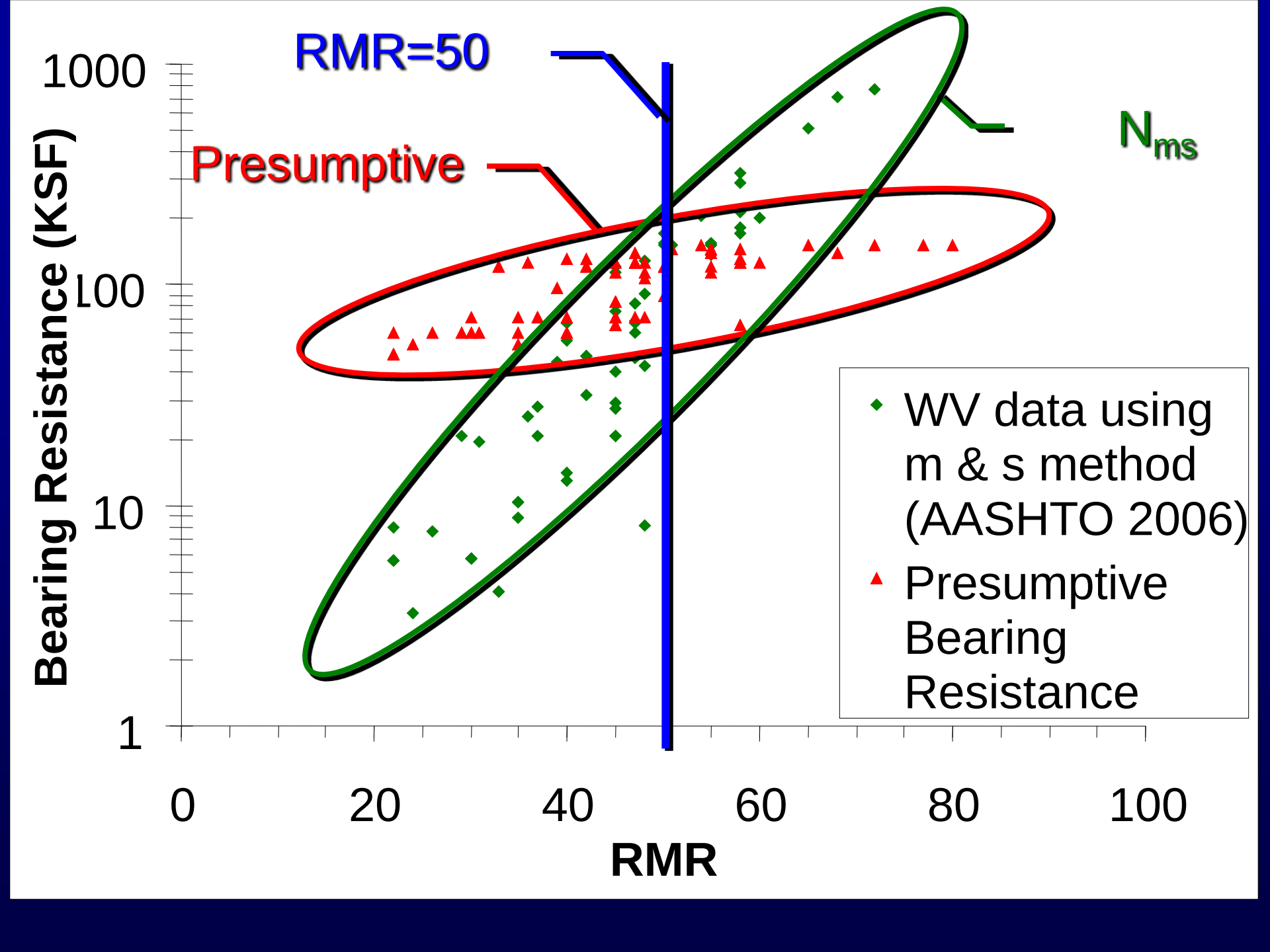
ASD $q_{ult} = N_{ms} C_o$



$$\phi q_n > \frac{V}{B}\left(1 + \frac{6e}{B}\right)$$

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




RMR=50
Presumptive
N_{ms}
1000
100
10
1
Bearing Resistance (KSF)
0
20
40
60
80
100
RMR
WV data using m & s method (AASHTO 2006)
Presumptive Bearing Resistance

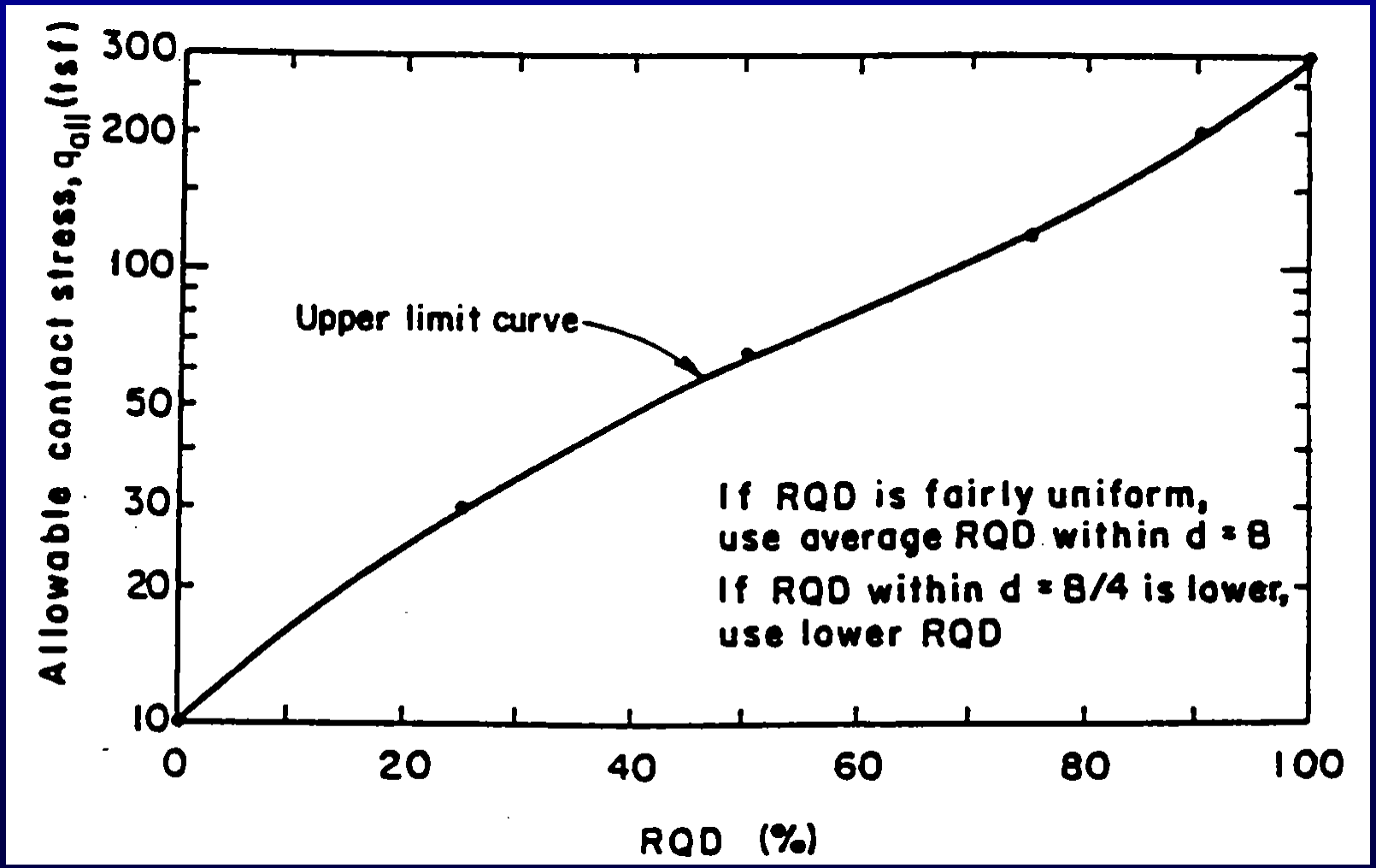
Methods for Determining Bearing Resistance

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

TYPE OF BEARING MATERIAL	CONSISTENCY IN PLACE	BEARING RESISTANCE (KSF)	
		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

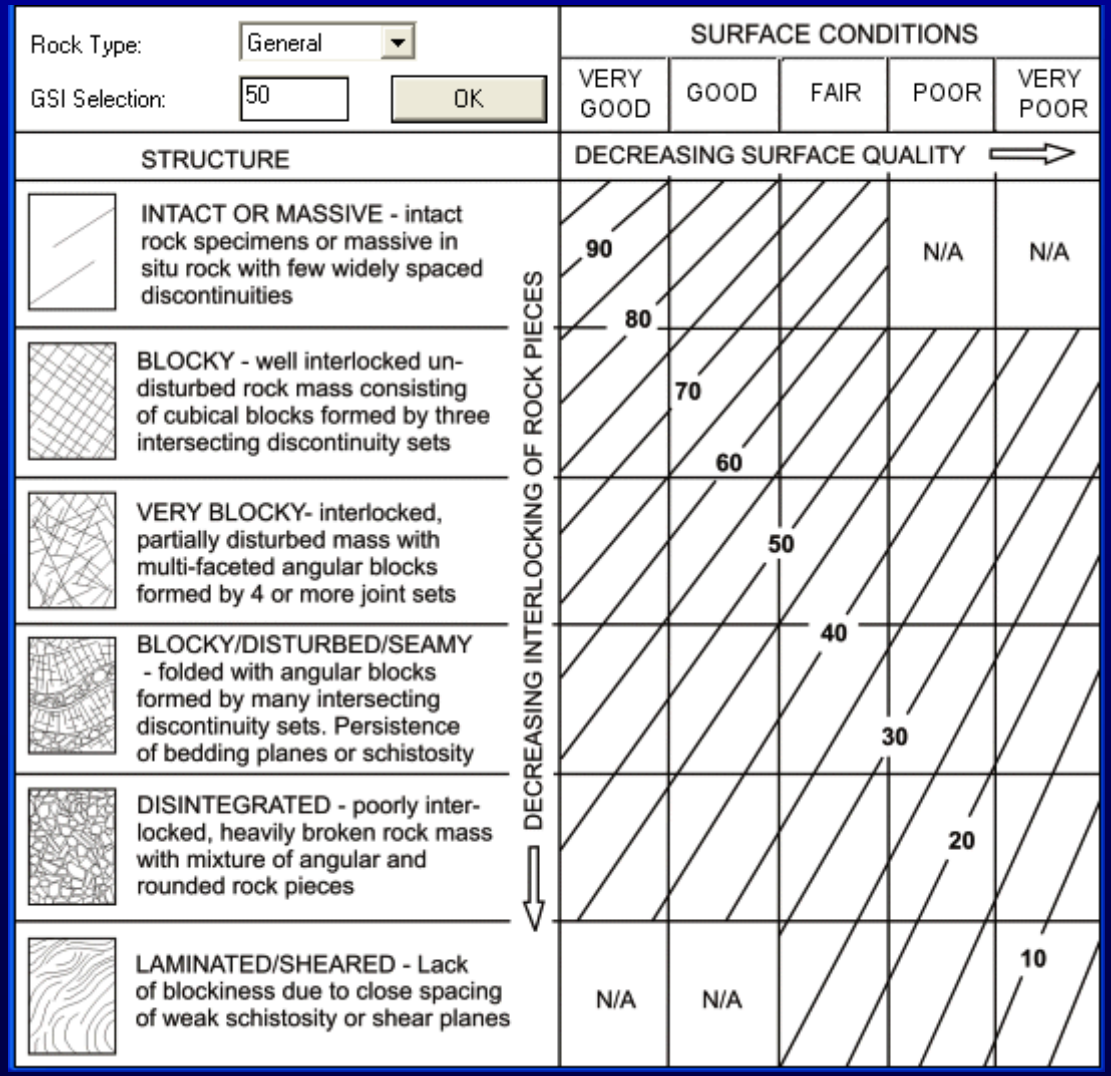
Methods for Determining Bearing Resistance

- Empirical correlation to RQD (AASHTO ASD 4.4.8.1.1)



Methods for Determining Bearing Resistance

- Methods based on GSI



Methods for Determining Bearing Resistance

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

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

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

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

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

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

Methods for Determining Bearing Resistance

- 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

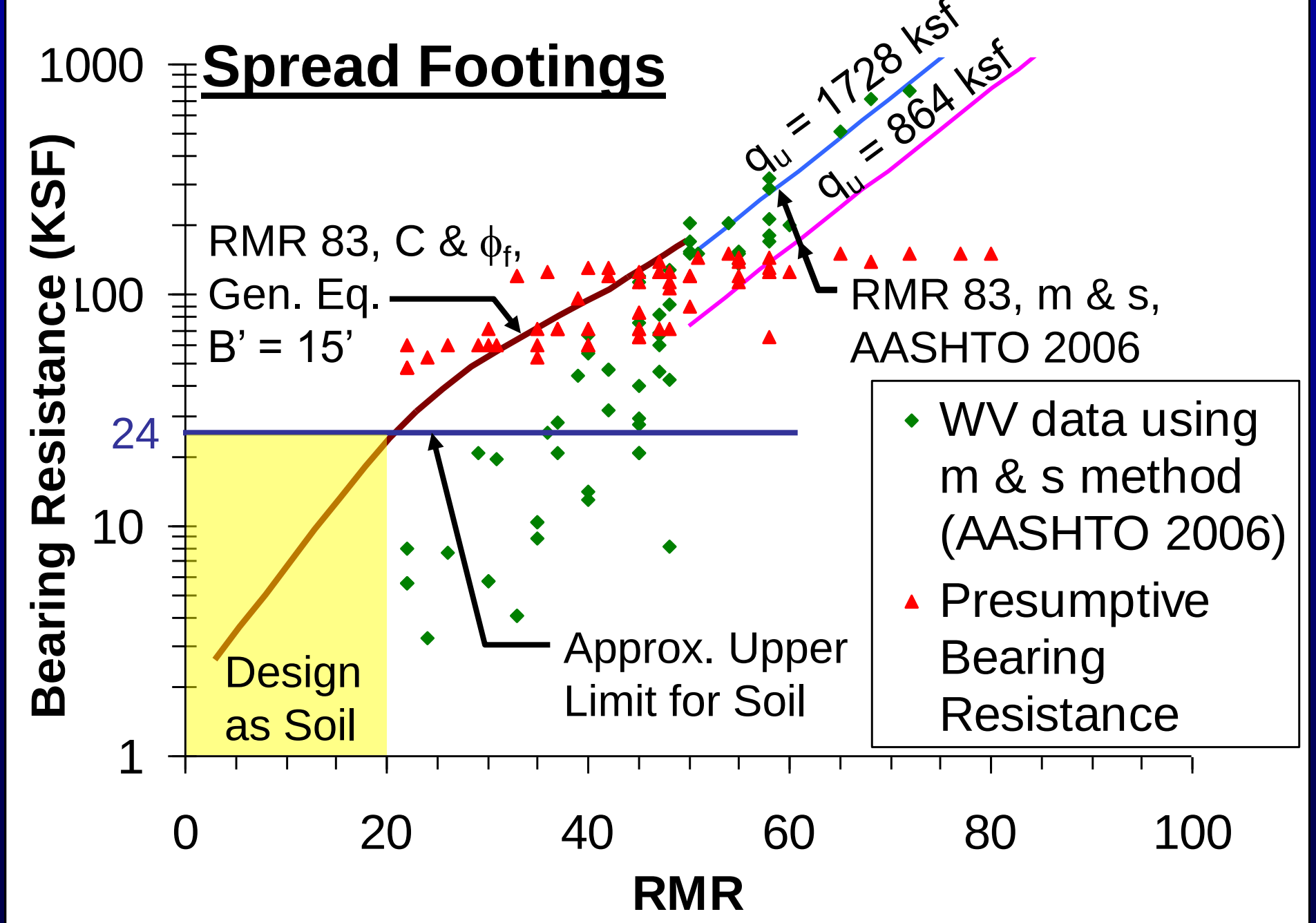
Methods for Determining Bearing Resistance

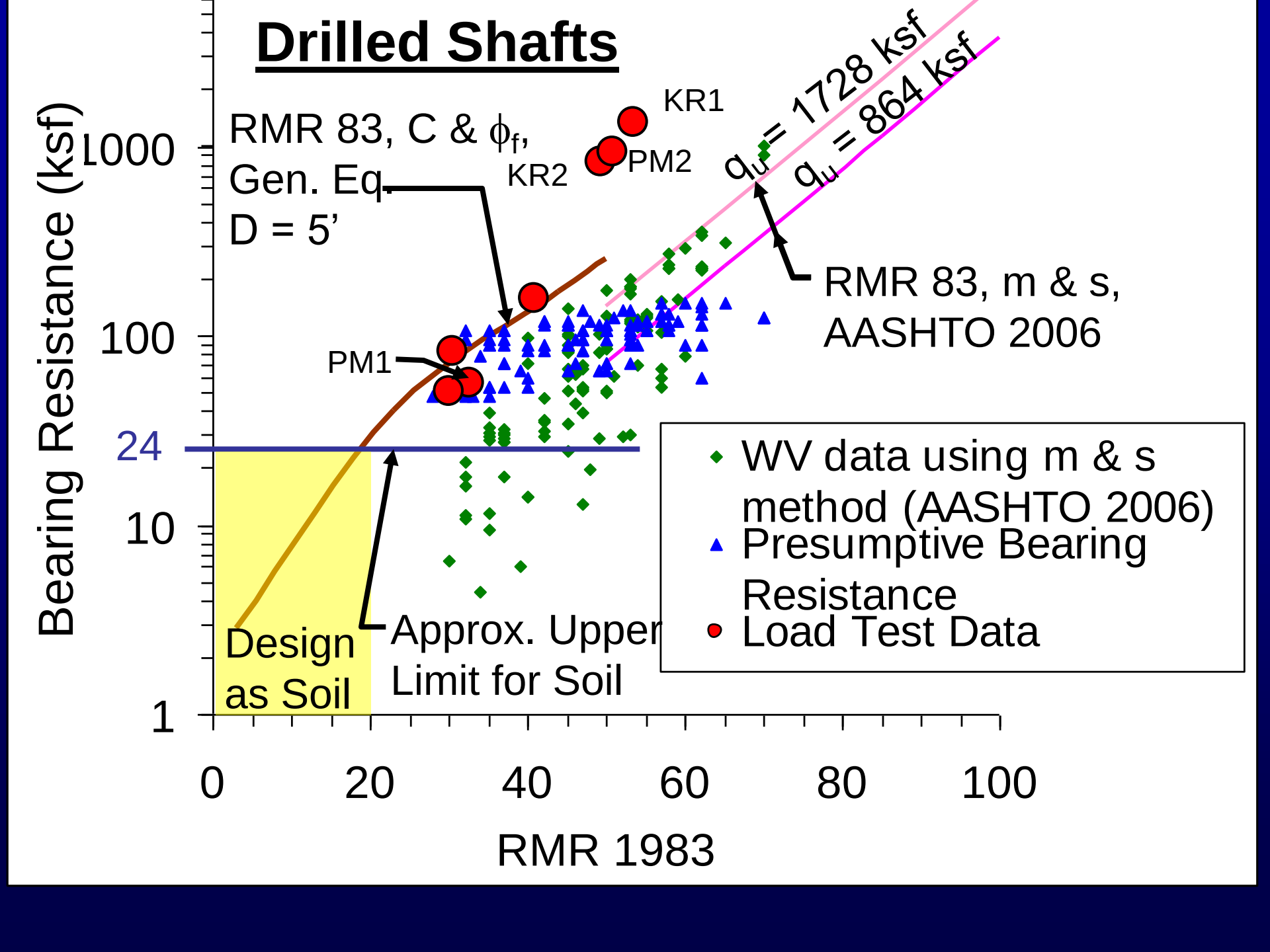
- N_{ms} method (AASHTO ASD 4.4.8.1.2) or m & s method (AASHTO 2006 10.8.3.5.4c-2)

Rock Mass Quality	General Description	RMR[1] Rating	NGI[2] Rating	RQD[3] (%)	N_{ms}[4] A	B	C	D	E
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, undisturbed 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 moderately 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_{ult} for an equivalent soil mass				

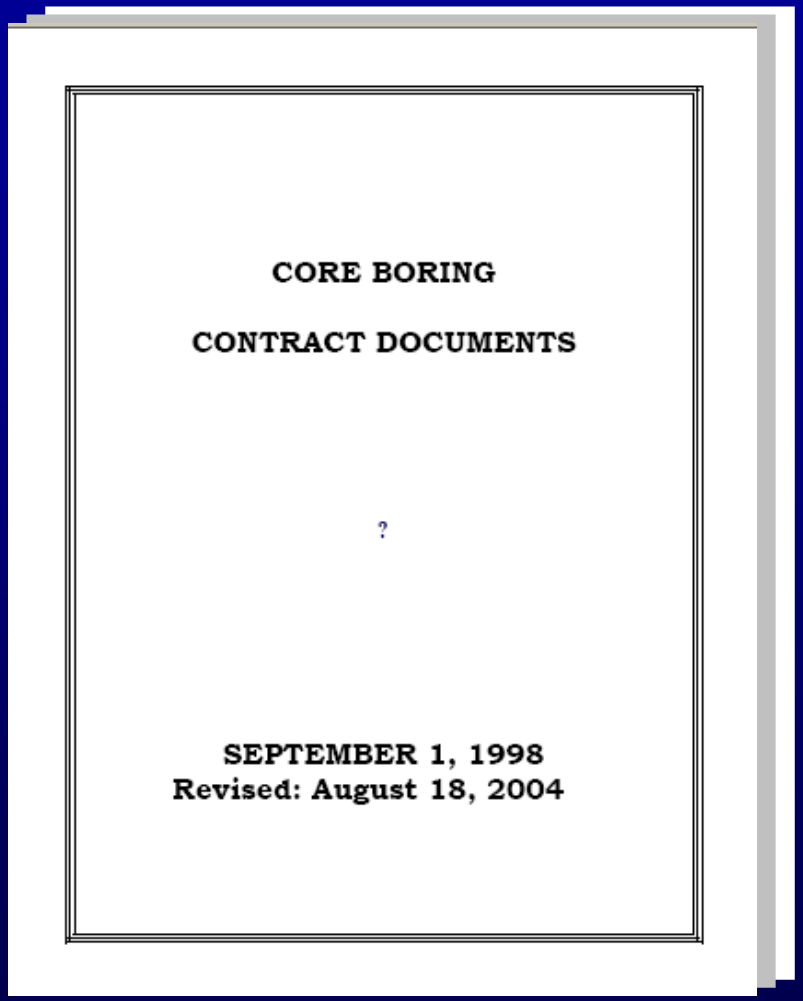
$$q_n = \left[\sqrt{s} + \sqrt{m\sqrt{s} + s}\right] q_u$$

WINNER for RMR greater than 50

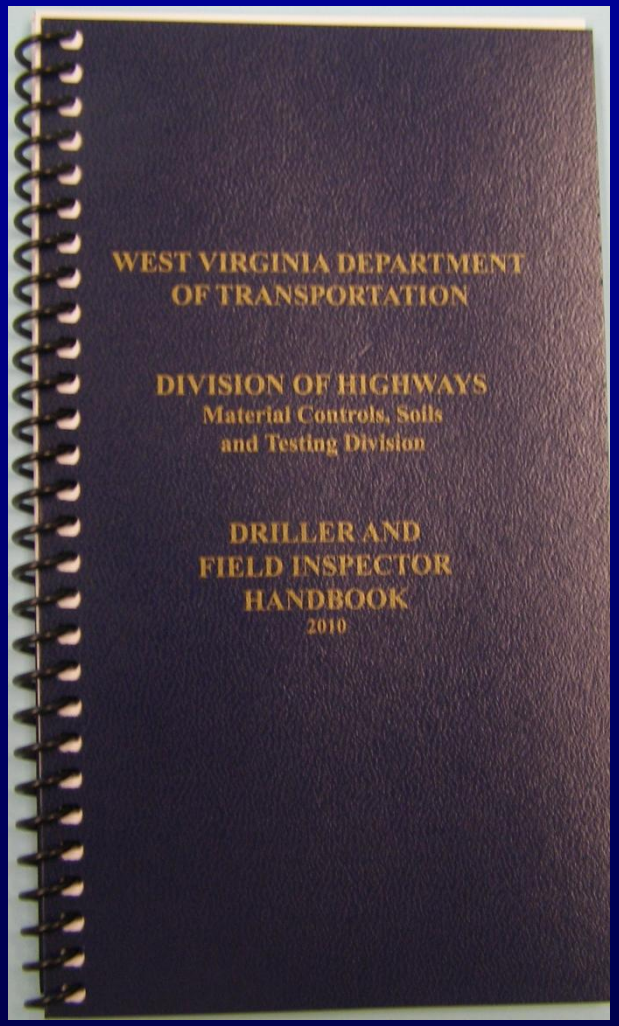

Spread Footings
1000
100
24
10
1
Bearing Resistance (KSF)
0
20
40
60
80
100
RMR
q_u = 1728 ksf
q_u = 864 ksf
RMR 83, C & ϕ_f,
Gen. Eq.
B' = 15'
RMR 83, m & s,
AASHTO 2006
Design
as Soil
Approx. Upper
Limit for Soil
WV data using
m & s method
(AASHTO 2006)
Presumptive
Bearing
Resistance


Drilled Shafts
RMR 83, C & ϕ_f,
Gen. Eq.
D = 5'
KR1
KR2
PM2
PM1
q_u = 1728 ksf
q_u = 864 ksf
RMR 83, m & s,
AASHTO 2006
Bearing Resistance (ksf)
1000
100
24
10
1
0
20
40
60
80
100
RMR 1983
WV data using m & s method (AASHTO 2006)
Presumptive Bearing Resistance
Load Test Data
Design as Soil
Approx. Upper Limit for Soil

Implementation of RMR



Contract Documents



Inspector Handbook

RMR

rock mass strength

- q_u
- RQD
- Spacing
- Condition
- Water

Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

PARAMETER			RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	>175 ksf	85 to 175 ksf	45 to 85 ksf	20 to 45 ksf	For this low range – uniaxial compressive test is preferred		
		Uniaxial compressive strength	>4320 ksf	2160 to 4320 ksf	1080 to 2160 ksf	520 to 1080 ksf	215 to 520 ksf	70 to 215 ksf	20 to 70 ksf
	Relative Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% to 100%	75% to 90%	50% to 75%	25% to 50%	<25%		
	Relative Rating		20	17	13	8	3		
3	Spacing of joints		>10 ft	3 to 10 ft	1 to 3 ft	2 in. to 1 foot	<2 in.		
	Relative Rating		30	25	20	10	5		
4	Condition of joints		• Very rough surfaces • Not continuous • No separation • Hard joint wall rock	• Slightly rough surfaces • Separation <0.05 in • Hard joint wall rock	• Slightly rough surfaces • Separation <0.05 in • Soft joint wall rock	• Slicken-sided surfaces - or - • Gouge <0.2 in. thick - or - • Joints open 0.05 to 0.2 in. • Continuous joints	• Soft gouge >0.2 in. thick - or - • Joints open >0.2 in. • Continuous joints		
	Relative Rating		25	20	12	6	0		
5	Ground water conditions (use one of the three evaluation criteria as appropriate to the method of exploration)	Inflow per 30 ft tunnel length	None	<400 gallons/hr	400 to 2000 gallons/hr	>2000 gallons/hr			
		Ratio= joint water pressure/ major principal stress	0	0.0 to 0.2	0.2 to 0.5	>0.5			
		General Conditions	Completely Dry	Moist only (interstitial water)	Water under moderate pressure	Severe water problems			
	Relative Rating		10	7	4	0			

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

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Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

	PARAMETER		RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	>175 ksf	85 to 175 ksf	45 to 85 ksf	20 to 45 ksf	For this low range – uniaxial compressive test is preferred		
		Uniaxial compressive strength	>4320 ksf	2160 to 4320 ksf	1080 to 2160 ksf	520 to 1080 ksf	215 to 520 ksf	70 to 215 ksf	20 to 70 ksf
	Relative Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% to 100%	75% to 90%		50% to 75%	25% to 50%		<25%
	Relative Rating		20	17		13	8		3
3	Spacing of joints		>10 ft	3 to 10 ft		1 to 3 ft	2 in. to 1 foot		<2 in.
	Relative Rating		30	25		20	10		5
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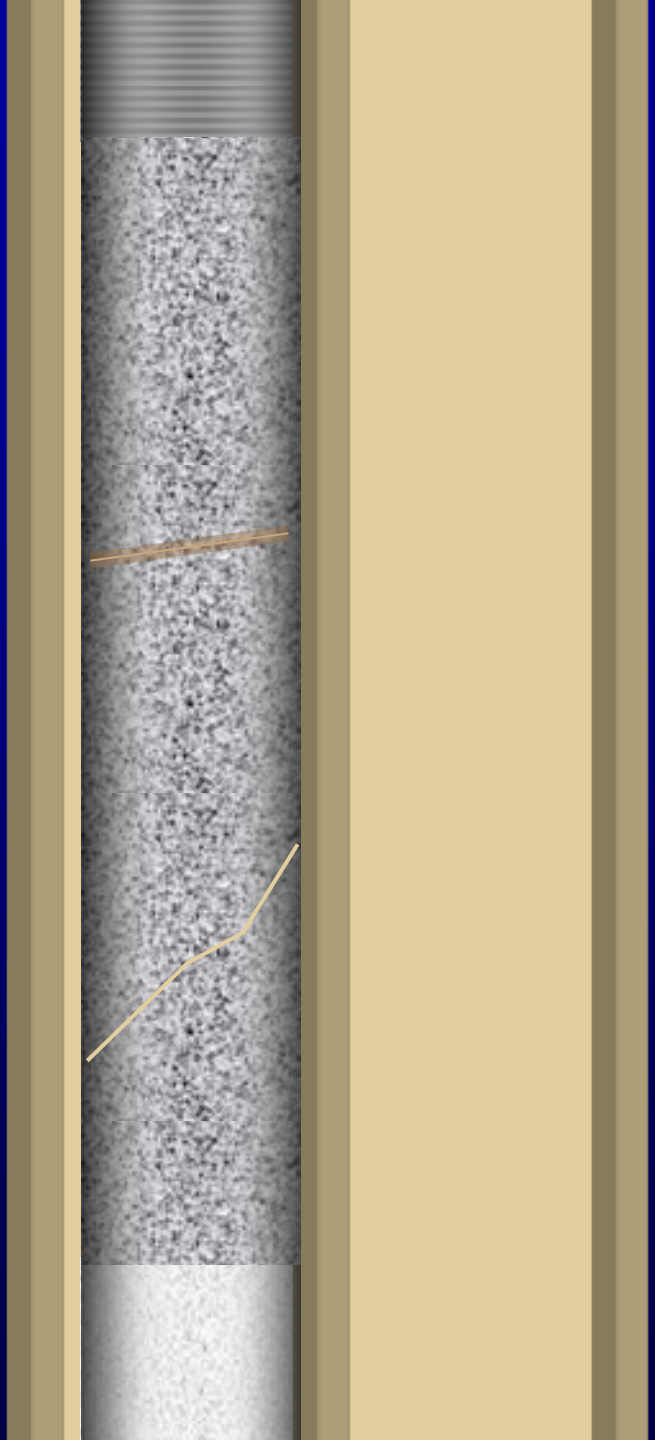
	Relative Rating		25	20		12	6		0
5	Ground water conditions (use one of the three evaluation criteria as appropriate to the method of exploration)	Inflow per 30 ft tunnel length	None	<400 gallons/hr		400 to 2000 gallons/hr			>2000 gallons/hr
		Ratio= joint water pressure/ major principal stress	0	0.0 to 0.2		0.2 to 0.5			>0.5
		General Conditions	Completely Dry	Moist only (interstitial water)		Water under moderate pressure			Severe water problems
	Relative Rating		10	7		4			0



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

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Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

	PARAMETER		RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	>175 ksf	85 to 175 ksf	45 to 85 ksf	20 to 45 ksf	For this low range – uniaxial compressive test is preferred		
		Uniaxial compressive strength	>4320 ksf	2160 to 4320 ksf	1080 to 2160 ksf	520 to 1080 ksf	215 to 520 ksf	70 to 215 ksf	20 to 70 ksf
	Relative Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% to 100%	75% to 90%		50% to 75%	25% to 50%		<25%
	Relative Rating		20	17		13	8		3
3	Spacing of joints		>10 ft	3 to 10 ft		1 to 3 ft	2 in. to 1 foot		<2 in.
	Relative Rating		30	25		20	10		5
4	Condition of joints		• Very rough surfaces • Not continuous • No separation • Hard joint wall rock	• Slightly rough surfaces • Separation <0.05 in • Hard joint wall rock		• Slightly rough surfaces • Separation <0.05 in • Soft joint wall rock	• Slicken-sided surfaces - or - • Gouge <0.2 in. thick - or - • Joints open 0.05 to 0.2 in. • Continuous joints		• Soft gouge >0.2 in. thick - or - • Joints open >0.2 in. • Continuous joints
	Relative Rating		25	20		12	6		0
5	Ground water conditions (use one of the three evaluation criteria as appropriate to the method of exploration)	Inflow per 30 ft tunnel length	None	<400 gallons/hr		400 to 2000 gallons/hr			>2000 gallons/hr
		Ratio= joint water pressure/ major principal stress	0	0.0 to 0.2		0.2 to 0.5			>0.5
		General Conditions	Completely Dry	Moist only (interstitial water)		Water under moderate pressure			Severe water problems
	Relative Rating		10	7		4			0

Fracture Spacing

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

$$\text{Average spacing} = \frac{\text{length of identified interval}}{\text{number of discontinuities in interval}}$$

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

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Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

PARAMETER			RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	>175 ksf	85 to 175 ksf	45 to 85 ksf	20 to 45 ksf	For this low range – uniaxial compressive test is preferred		
		Uniaxial compressive strength	>4320 ksf	2160 to 4320 ksf	1080 to 2160 ksf	520 to 1080 ksf	215 to 520 ksf	70 to 215 ksf	20 to 70 ksf
	Relative Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% to 100%	75% to 90%		50% to 75%	25% to 50%		<25%
	Relative Rating		20	17		13	8		3
3	Spacing of joints		>10 ft	3 to 10 ft		1 to 3 ft	2 in. to 1 foot		<2 in.
	Relative Rating		30	25		20	10		5
4	Condition of joints		• Very rough surfaces • Not continuous • No separation • Hard joint wall rock	• Slightly rough surfaces • Separation <0.05 in • Hard joint wall rock		• Slightly rough surfaces • Separation <0.05 in • Soft joint wall rock	• Slicken-sided surfaces - or - • Gouge <0.2 in. thick - or - • Joints open 0.05 to 0.2 in. • Continuous joints		• Soft gouge >0.2 in. thick - or - • Joints open >0.2 in. • Continuous joints
	Relative Rating		25	20		12	6		0
5	Ground water conditions (use one of the three evaluation criteria as appropriate to the method of exploration)	Inflow per 30 ft tunnel length	None	<400 gallons/hr		400 to 2000 gallons/hr			>2000 gallons/hr
		Ratio= joint water pressure/ major principal stress	0	0.0 to 0.2		0.2 to 0.5			>0.5
		General Conditions	Completely Dry	Moist only (interstitial water)		Water under moderate pressure			Severe water problems
	Relative Rating		10	7		4			0

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	Rough 4	Slightly rough 2	Smooth 1	Slickensided 0
Infilling (inches)		Hard filling		Soft filling	
	None 5	<0.2 4	>0.2 3	<0.2 2	>0.2 0
Weathering	None 5	Slightly 4	Moderate 2	Highly 1	Decomposed 0

Sub: Discontinuity Length

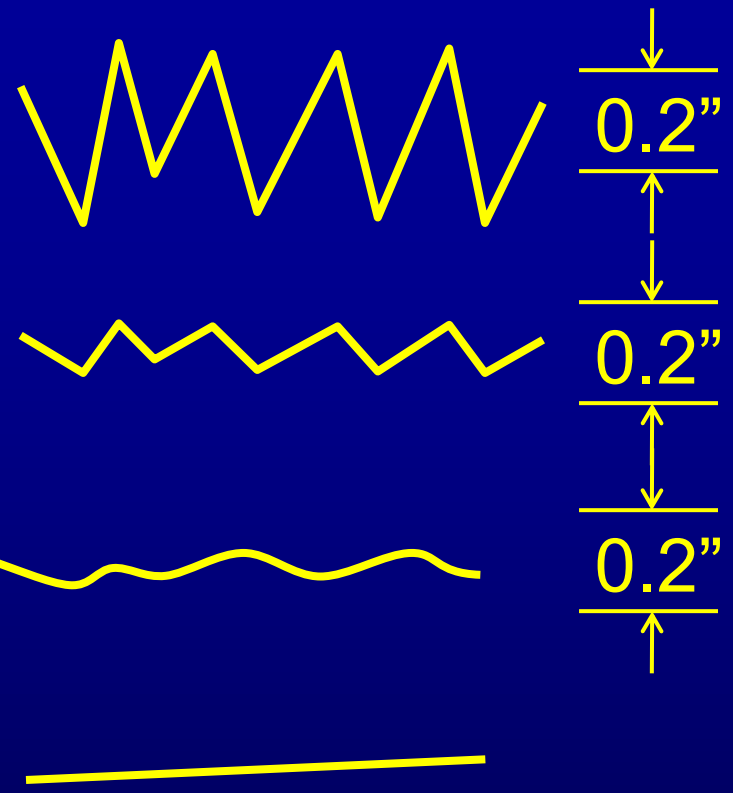
- Estimate based on exposed outcrops and site geology
- Compare with adjacent boreholes
- Use default value of 2 where this parameter is hard to estimate

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

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Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

PARAMETER			RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	>175 ksf	85 to 175 ksf	45 to 85 ksf	20 to 45 ksf	For this low range – uniaxial compressive test is preferred		
		Uniaxial compressive strength	>4320 ksf	2160 to 4320 ksf	1080 to 2160 ksf	520 to 1080 ksf	215 to 520 ksf	70 to 215 ksf	20 to 70 ksf
	Relative Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% to 100%	75% to 90%		50% to 75%	25% to 50%		<25%
	Relative Rating		20	17		13	8		3
3	Spacing of joints		>10 ft	3 to 10 ft		1 to 3 ft	2 in. to 1 foot		<2 in.
	Relative Rating		30	25		20	10		5
4	Condition of joints		• Very rough surfaces • Not continuous • No separation • Hard joint wall rock	• Slightly rough surfaces • Separation <0.05 in • Hard joint wall rock		• Slightly rough surfaces • Separation <0.05 in • Soft joint wall rock	• Slicken-sided surfaces - or - • Gouge <0.2 in. thick - or - • Joints open 0.05 to 0.2 in. • Continuous joints		• Soft gouge >0.2 in. thick - or - • Joints open >0.2 in. • Continuous joints
	Relative Rating		25	20		12	6		0
5	Ground water conditions (use one of the three evaluation criteria as appropriate to the method of exploration)	Inflow per 30 ft tunnel length	None	<400 gallons/hr		400 to 2000 gallons/hr			>2000 gallons/hr
		Ratio= joint water pressure/ major principal stress	0	0.0 to 0.2		0.2 to 0.5			>0.5
		General Conditions	Completely Dry	Moist only (interstitial water)		Water under moderate pressure			Severe water problems
	Relative Rating		10	7		4			0

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

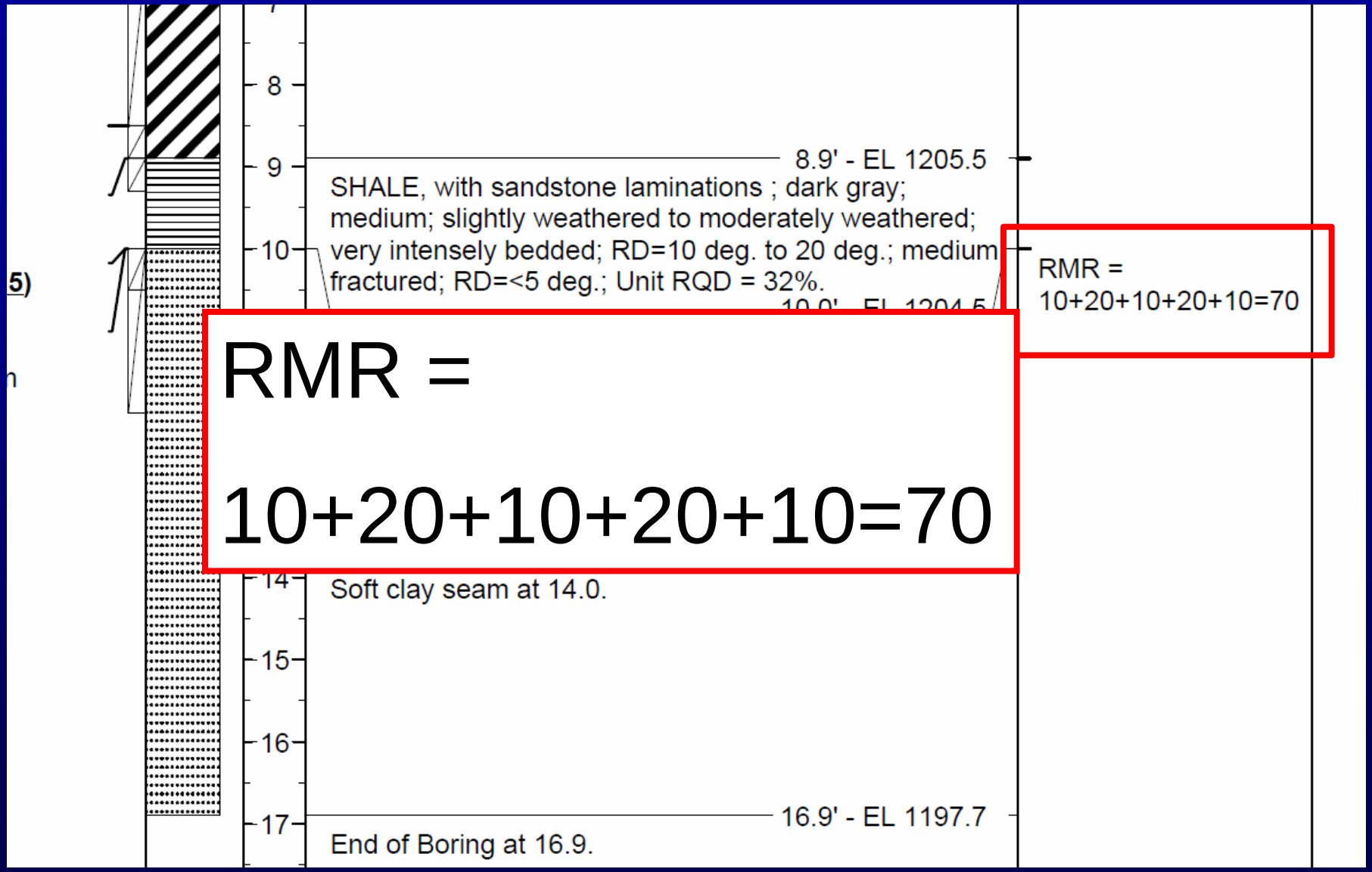
rock mass strength

- q_u
- RQD
- Spacing
- Condition
- Water

Table 10.4.6.4-1 Geomechanics Classification of Rock Masses

	PARAMETER		RANGES OF VALUES						
1	Strength of intact rock material	Point load strength index	>175 ksf	85 to 175 ksf	45 to 85 ksf	20 to 45 ksf	For this low range – uniaxial compressive test is preferred		
		Uniaxial compressive strength	>4320 ksf	2160 to 4320 ksf	1080 to 2160 ksf	520 to 1080 ksf	215 to 520 ksf	70 to 215 ksf	20 to 70 ksf
	Relative Rating		15	12	7	4	2	1	0
2	Drill core quality RQD		90% to 100%	75% to 90%		50% to 75%	25% to 50%		<25%
	Relative Rating		20	17		13	8		3
3	Spacing of joints		>10 ft	3 to 10 ft		1 to 3 ft	2 in. to 1 foot		<2 in.
	Relative Rating		30	25		20	10		5
4	Condition of joints		• Very rough surfaces • Not continuous • No separation • Hard joint wall rock	• Slightly rough surfaces • Separation <0.05 in • Hard joint wall rock		• Slightly rough surfaces • Separation <0.05 in • Soft joint wall rock	• Slicken-sided surfaces - or - • Gouge <0.2 in. thick - or - • Joints open 0.05 to 0.2 in. • Continuous joints		• Soft gouge >0.2 in. thick - or - • Joints open >0.2 in. • Continuous joints
	Relative Rating		25	20		12	6		0
5	Ground water conditions (use one of the three evaluation criteria as appropriate to the method of exploration)	Inflow per 30 ft tunnel length	None	<400 gallons/hr		400 to 2000 gallons/hr			>2000 gallons/hr
		Ratio= joint water pressure/ major principal stress	0	0.0 to 0.2		0.2 to 0.5			>0.5
		General Conditions	Completely Dry	Moist only (interstitial water)		Water under moderate pressure			Severe water problems
	Relative Rating		10	7		4			0

Method for Recording RMR



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

Questions