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… Delivering Solutions

Determination of the Bearing Resistance of Rock in West Virginia, 2012 Update

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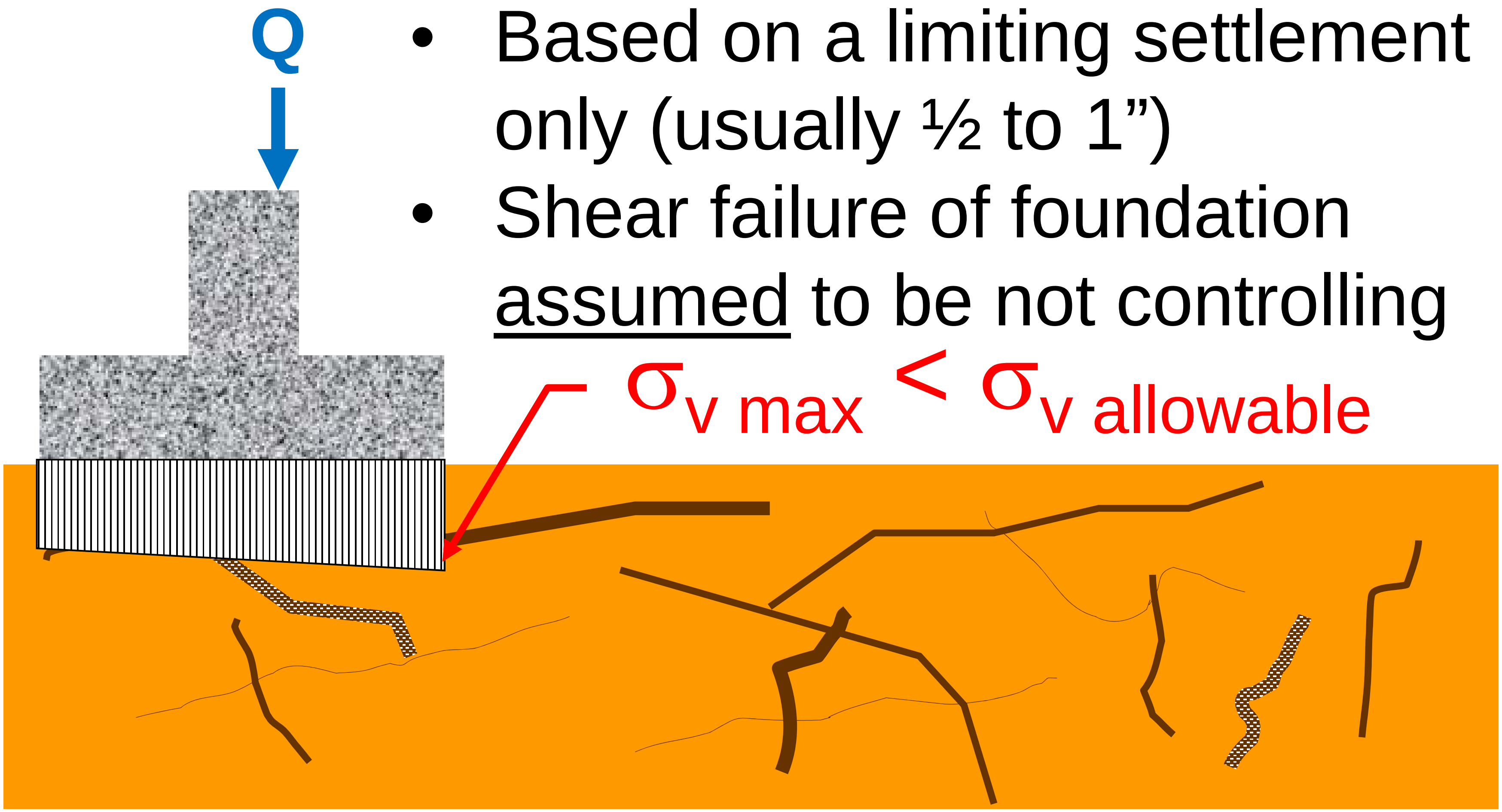
The Problem

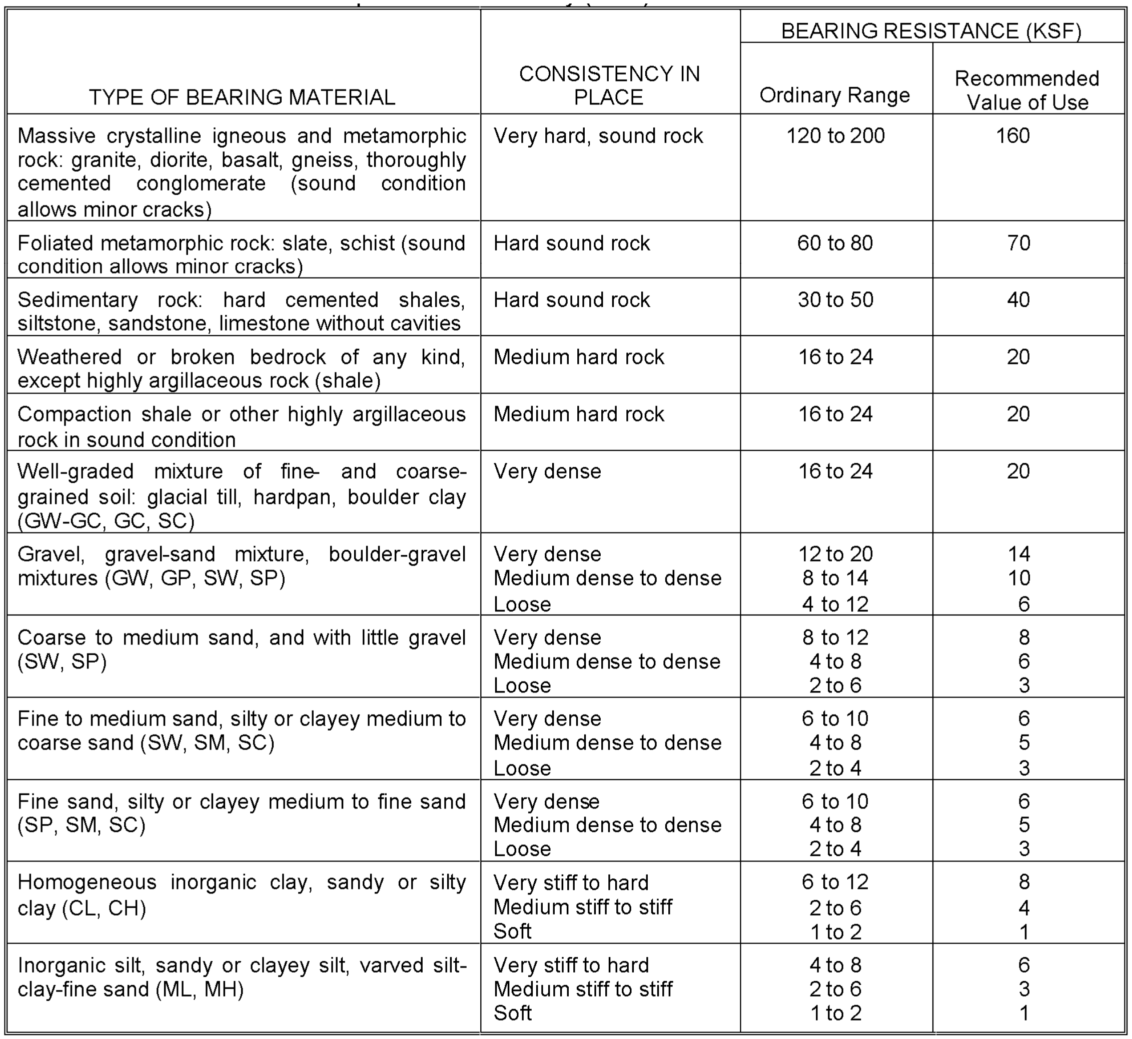
ASD Design

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



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

- 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

LRFD Design

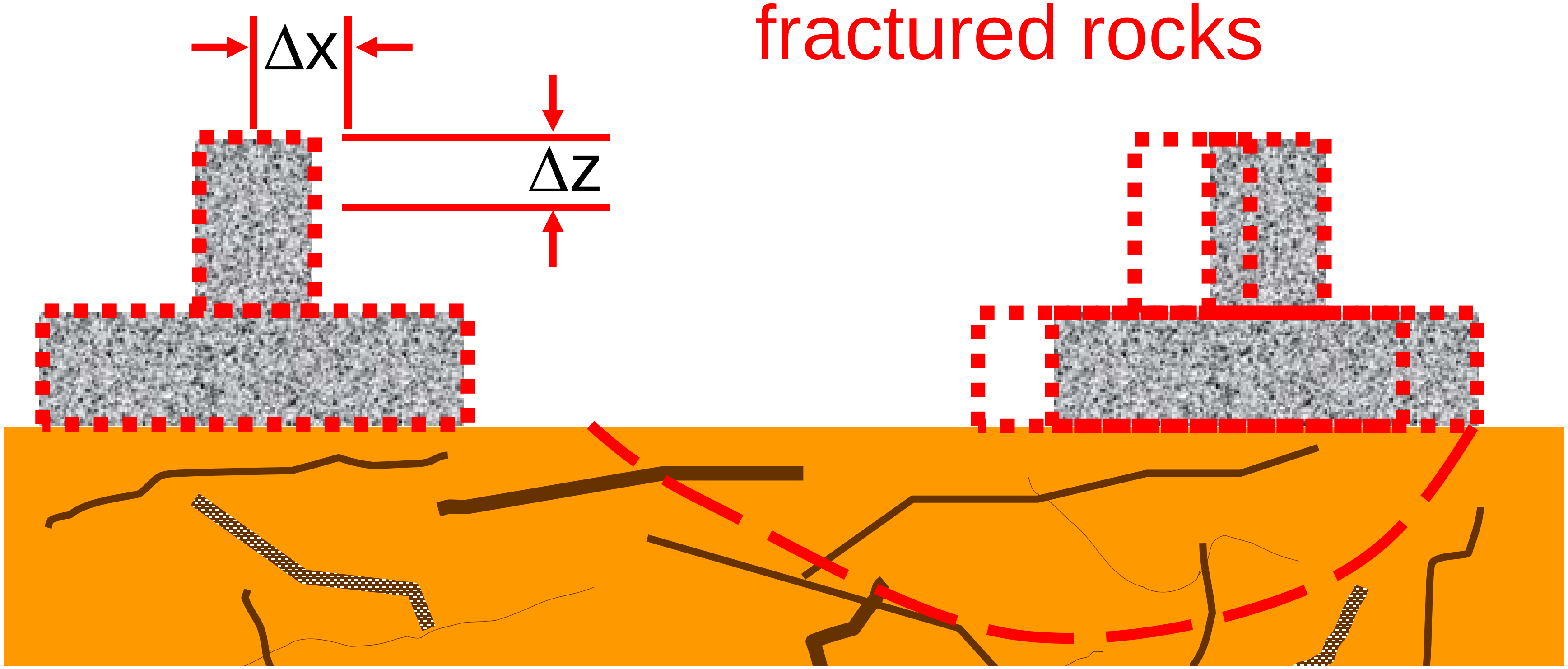
<u>Service Limit State</u>

- Compute displacements and compare to tolerable displacement

<u>Strength Limit State</u>

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

Controlled for soft, fractured rocks

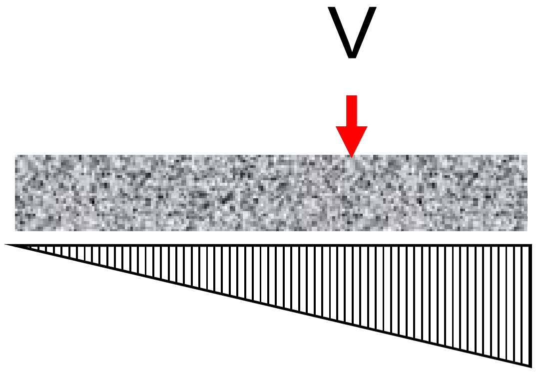


Current LRFD Methodology

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

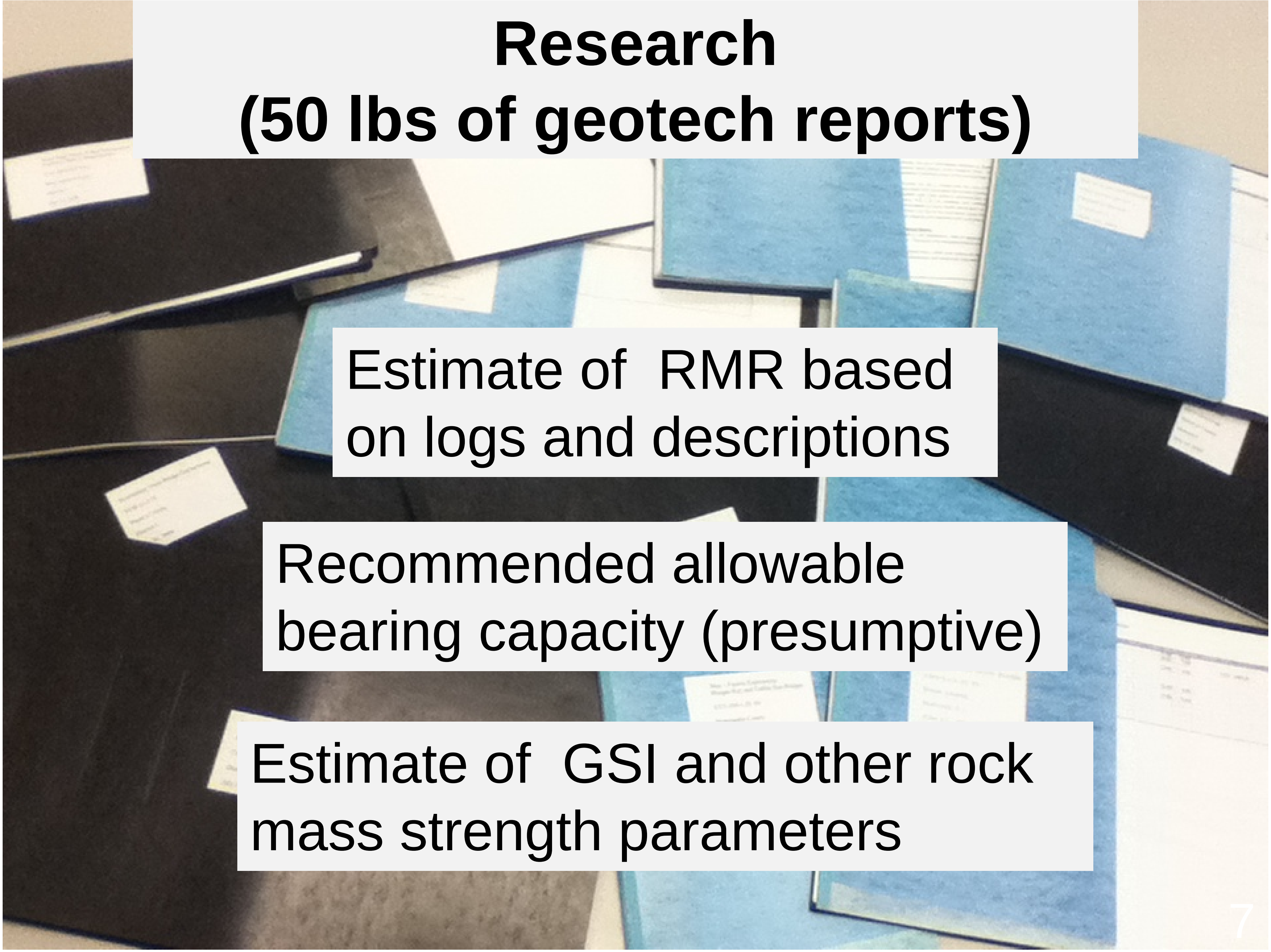
$$q_n = \underbrace{\left[\sqrt{s} + \sqrt{\left(m\sqrt{s} + s\right)}\right]}_{N_{ms}} \underset{\uparrow}{q_u}$$

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



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

Research
(50 lbs of geotech reports)

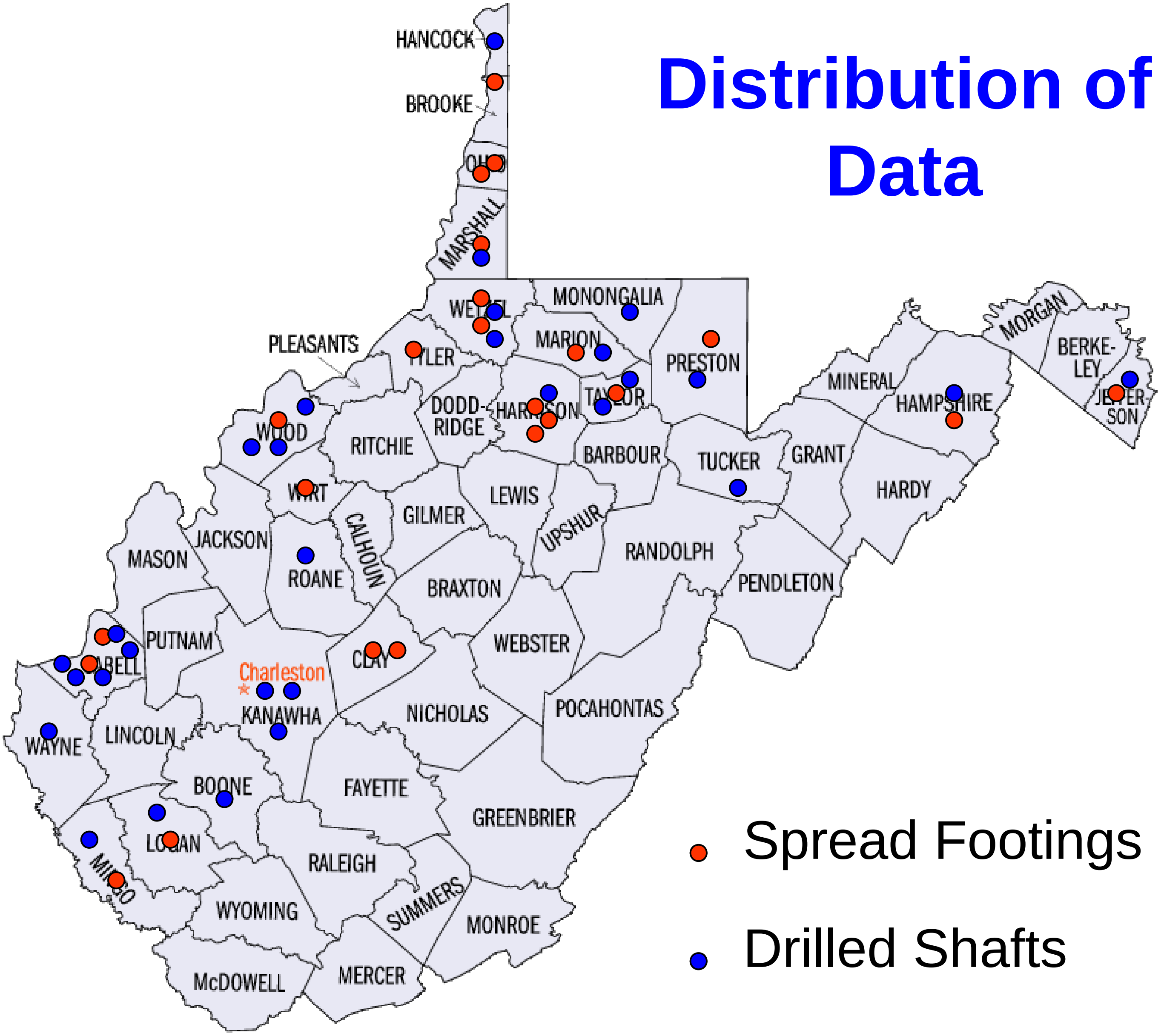


Estimate of RMR based on logs and descriptions

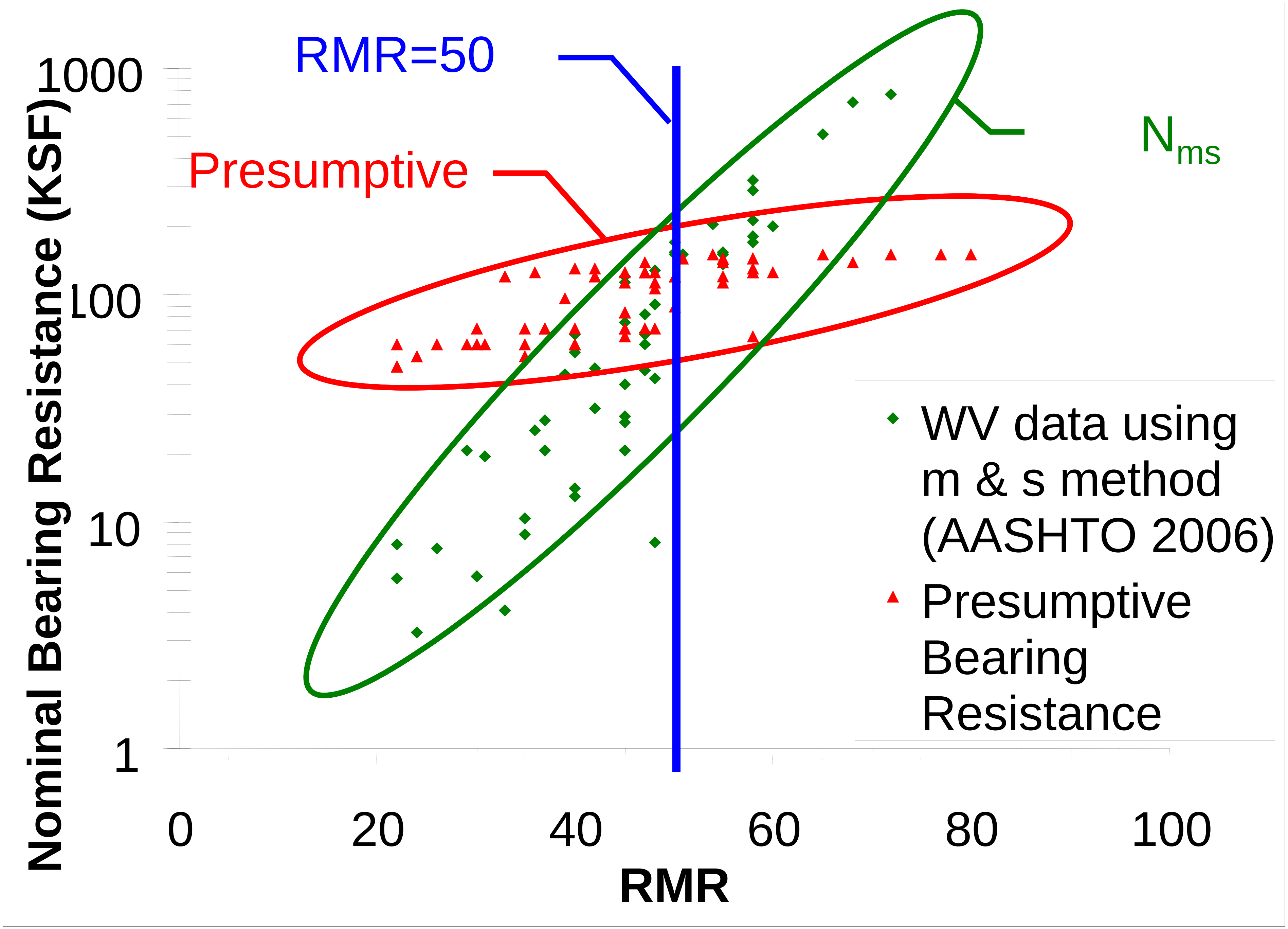
Recommended allowable bearing capacity (presumptive)

Estimate of GSI and other rock mass strength parameters

Distribution of Data



- 🔴 Spread Footings
- 🔵 Drilled Shafts


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

Design Recommendations

- Needed to be as objective as possible
- Needed to be easily implemented in the field
- Needed to provide results consistent with previous successful practice

Design Recommendations

- RMR as published in AASHTO selected as a reasonable basis for bearing resistance determination
- Different methods for RMR < 50 and RMR > 50

Design Recommendation for RMR < 50

- Empirical correlation of RMR to C and ϕ_f (Serafim and Pereira, 1983; Bieniawski, 1989

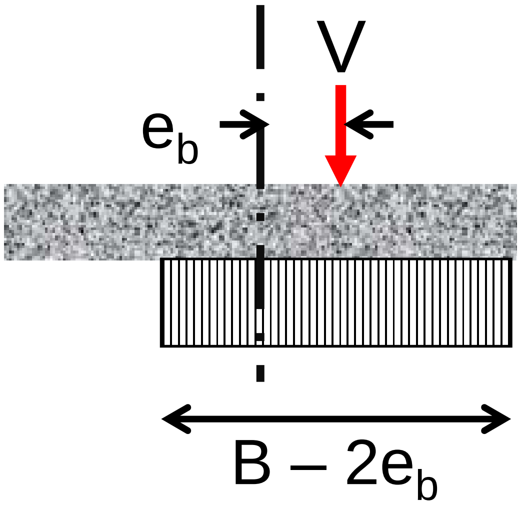
$$Cohesion = C = 104 \times RMR \quad \text{(in PSF)}$$

$$Friction = \phi_f = 5 + \frac{RMR}{2}$$

Design Recommendation for RMR < 50

- General bearing resistance equation

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



$$\phi\, q_n > \frac{\gamma V}{B - 2e_b}$$

Design Recommendation for RMR > 50

- m & s (AASHTO 2006 10.4.6.4-4) Hoek and Brown

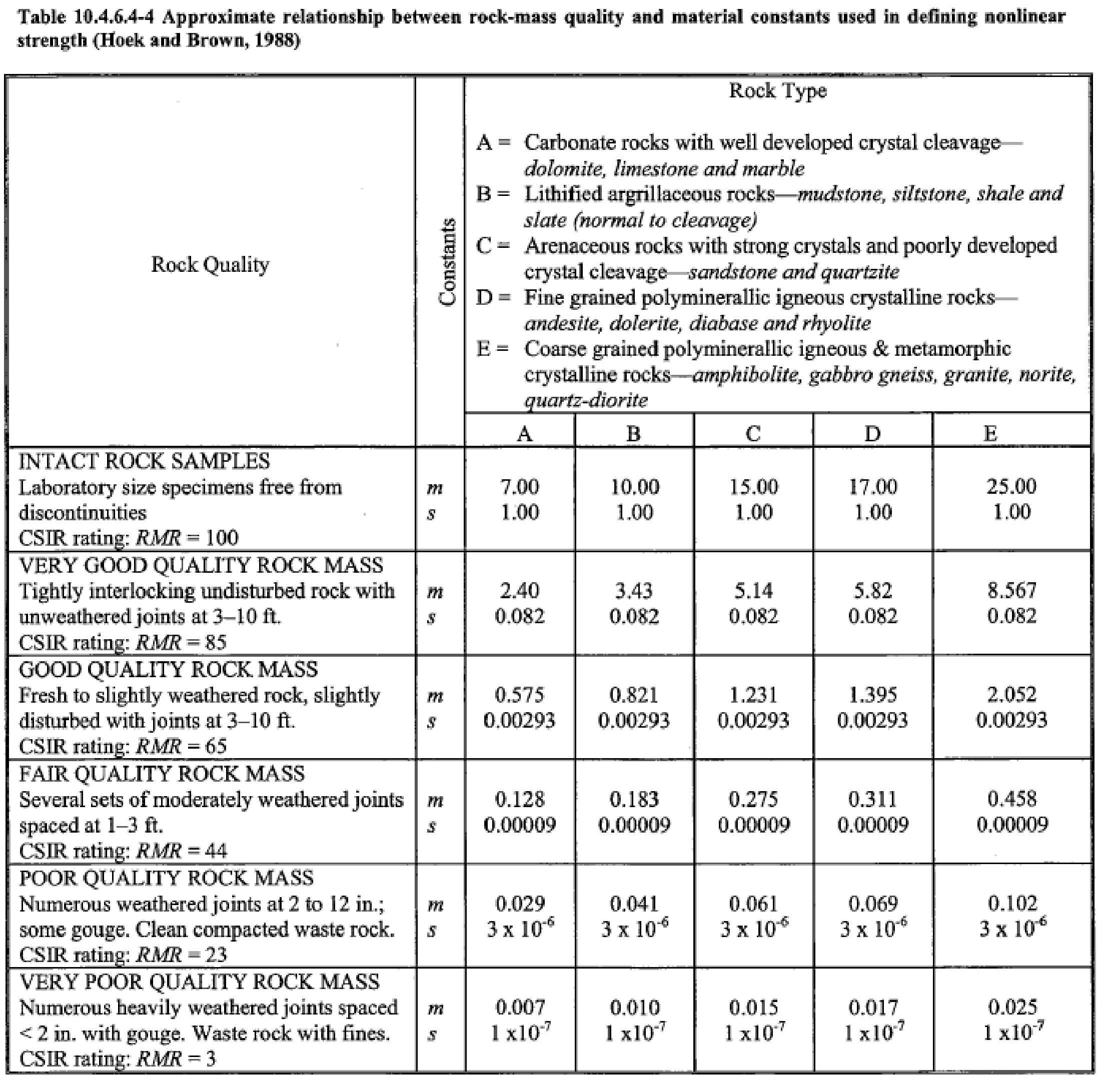


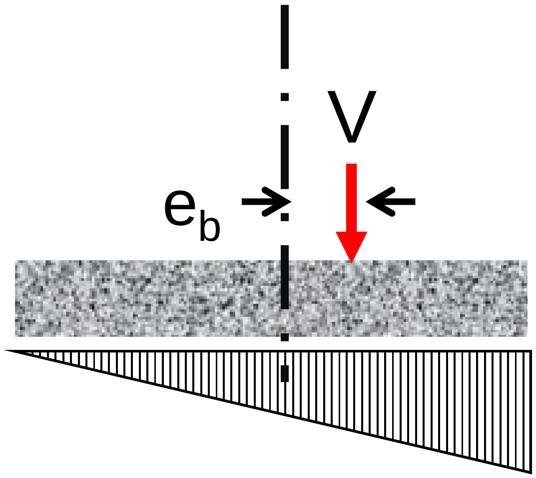
Table 10.4.6.4-4 Approximate relationship between rock-mass quality and material constants used in defining nonlinear strength (Hoek and Brown, 1988)

Rock Quality	Constants	Rock Type A = Carbonate rocks with well developed crystal cleavage—*dolomite, limestone and marble* B = Lithified argrillaceous rocks—*mudstone, siltstone, shale and slate (normal to cleavage)* C = Arenaceous rocks with strong crystals and poorly developed crystal cleavage—*sandstone and quartzite* D = Fine grained polymінerallic igneous crystalline rocks—*andesite, dolerite, diabase and rhyolite* E = Coarse grained polyminerallic igneous & metamorphic crystalline rocks—*amphibolite, gabbro gneiss, granite, norite, quartz-diorite*				
		A	B	C	D	E
INTACT ROCK SAMPLES Laboratory size specimens free from discontinuities CSIR rating: *RMR* = 100	*m* *s*	7.00 1.00	10.00 1.00	15.00 1.00	17.00 1.00	25.00 1.00
VERY GOOD QUALITY ROCK MASS Tightly interlocking undisturbed rock with unweathered joints at 3–10 ft. CSIR rating: *RMR* = 85	*m* *s*	2.40 0.082	3.43 0.082	5.14 0.082	5.82 0.082	8.567 0.082
GOOD QUALITY ROCK MASS Fresh to slightly weathered rock, slightly disturbed with joints at 3–10 ft. CSIR rating: *RMR* = 65	*m* *s*	0.575 0.00293	0.821 0.00293	1.231 0.00293	1.395 0.00293	2.052 0.00293
FAIR QUALITY ROCK MASS Several sets of moderately weathered joints spaced at 1–3 ft. CSIR rating: *RMR* = 44	*m* *s*	0.128 0.00009	0.183 0.00009	0.275 0.00009	0.311 0.00009	0.458 0.00009
POOR QUALITY ROCK MASS Numerous weathered joints at 2 to 12 in.; some gouge. Clean compacted waste rock. CSIR rating: *RMR* = 23	*m* *s*	0.029 3×10^{-6}	0.041 3×10^{-6}	0.061 3×10^{-6}	0.069 3×10^{-6}	0.102 3×10^{-6}
VERY POOR QUALITY ROCK MASS Numerous heavily weathered joints spaced < 2 in. with gouge. Waste rock with fines. CSIR rating: *RMR* = 3	*m* *s*	0.007 1×10^{-7}	0.010 1×10^{-7}	0.015 1×10^{-7}	0.017 1×10^{-7}	0.025 1×10^{-7}

Design Recommendation for RMR > 50

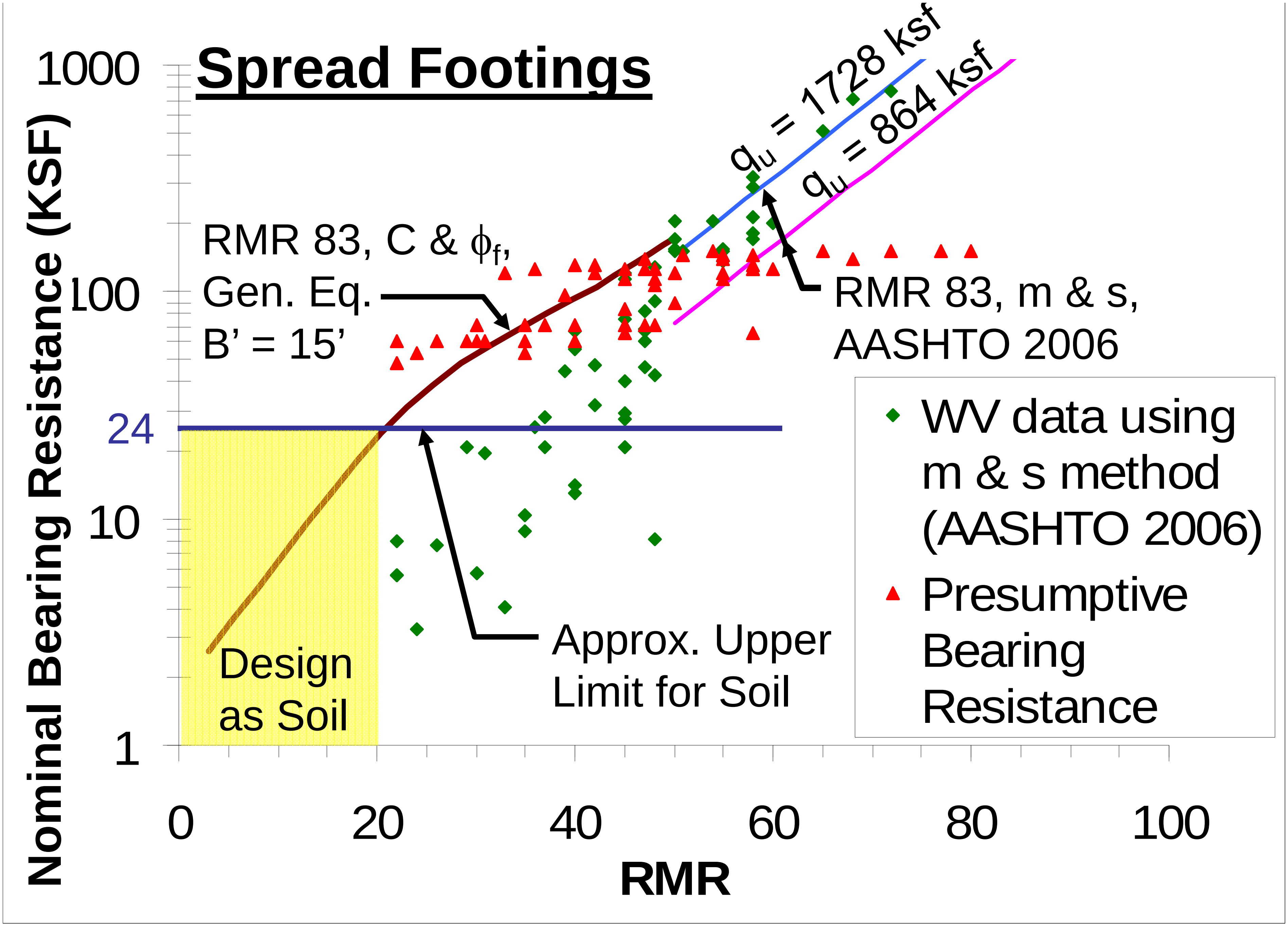
- Lower bound equation (AASHTO 2006 10.8.3.5.4c-2)

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

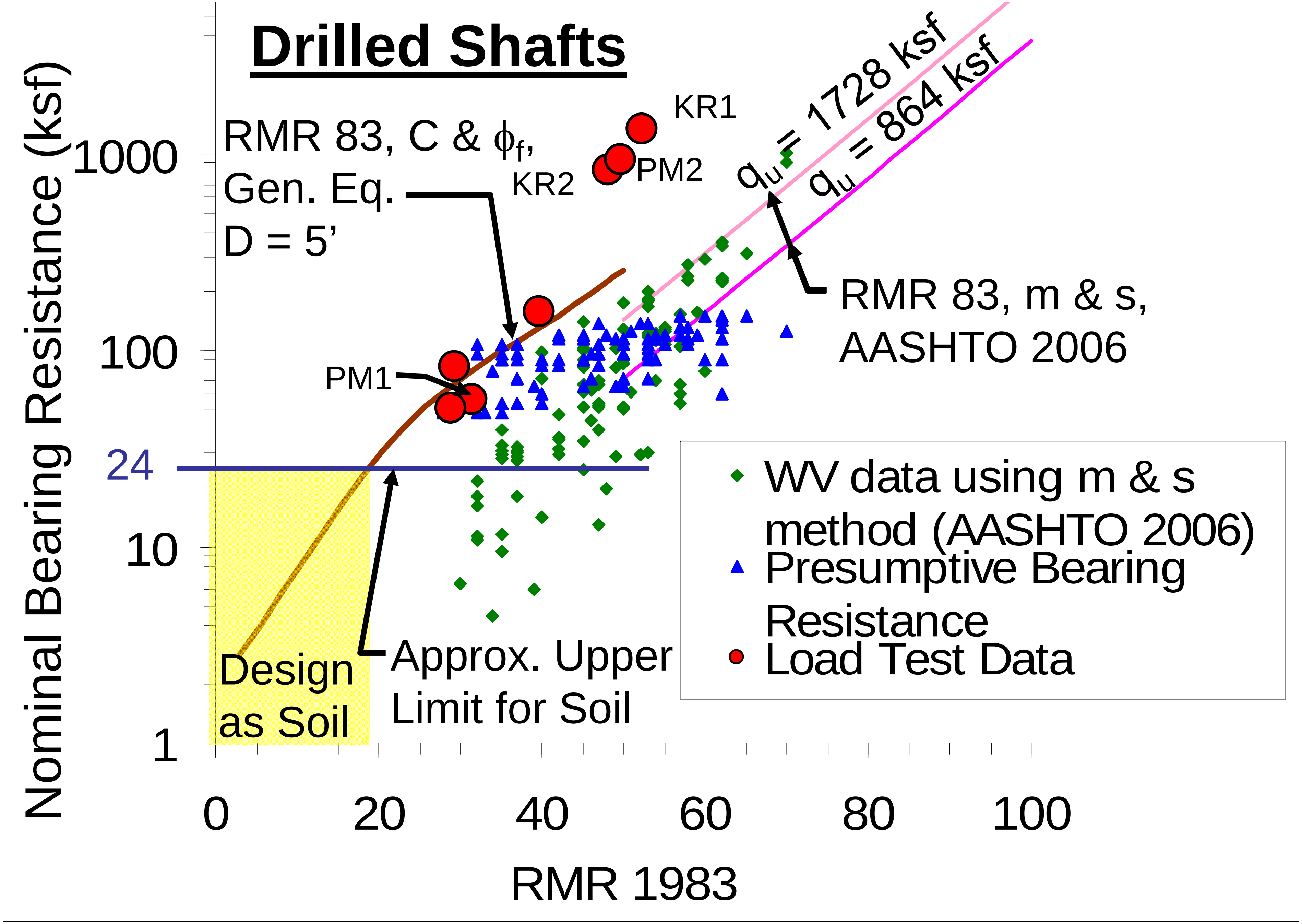


$$\phi\ q_n > \frac{\gamma\ V}{B}\left(1 + \frac{6e_b}{B}\right)$$

Spread Footings

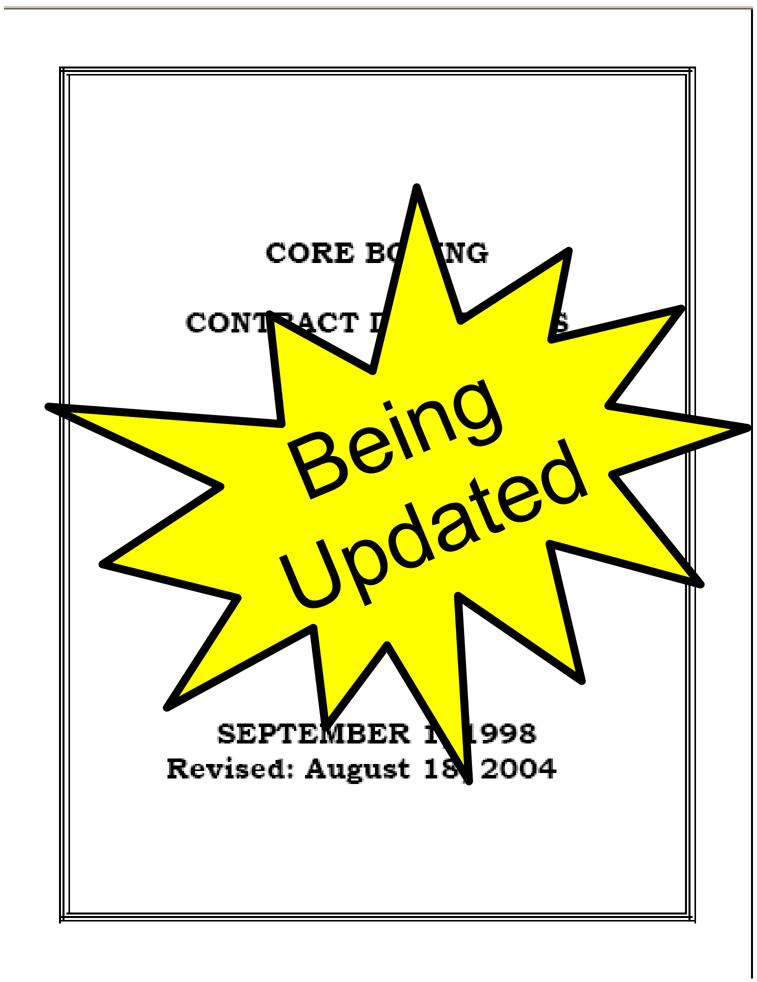


Drilled Shafts

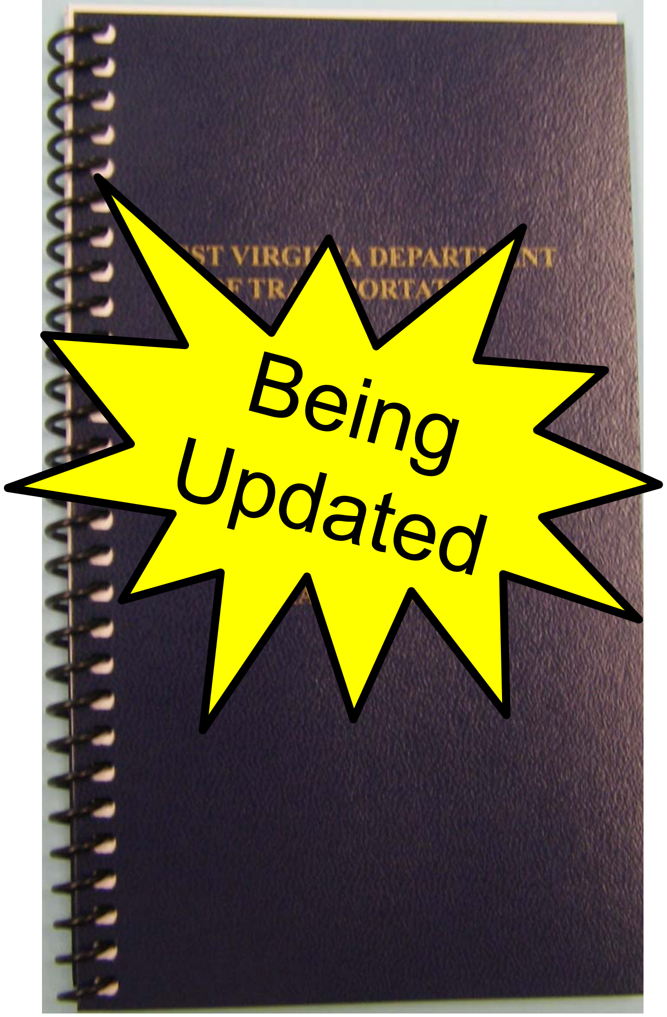


Implementation

Implementation of RMR

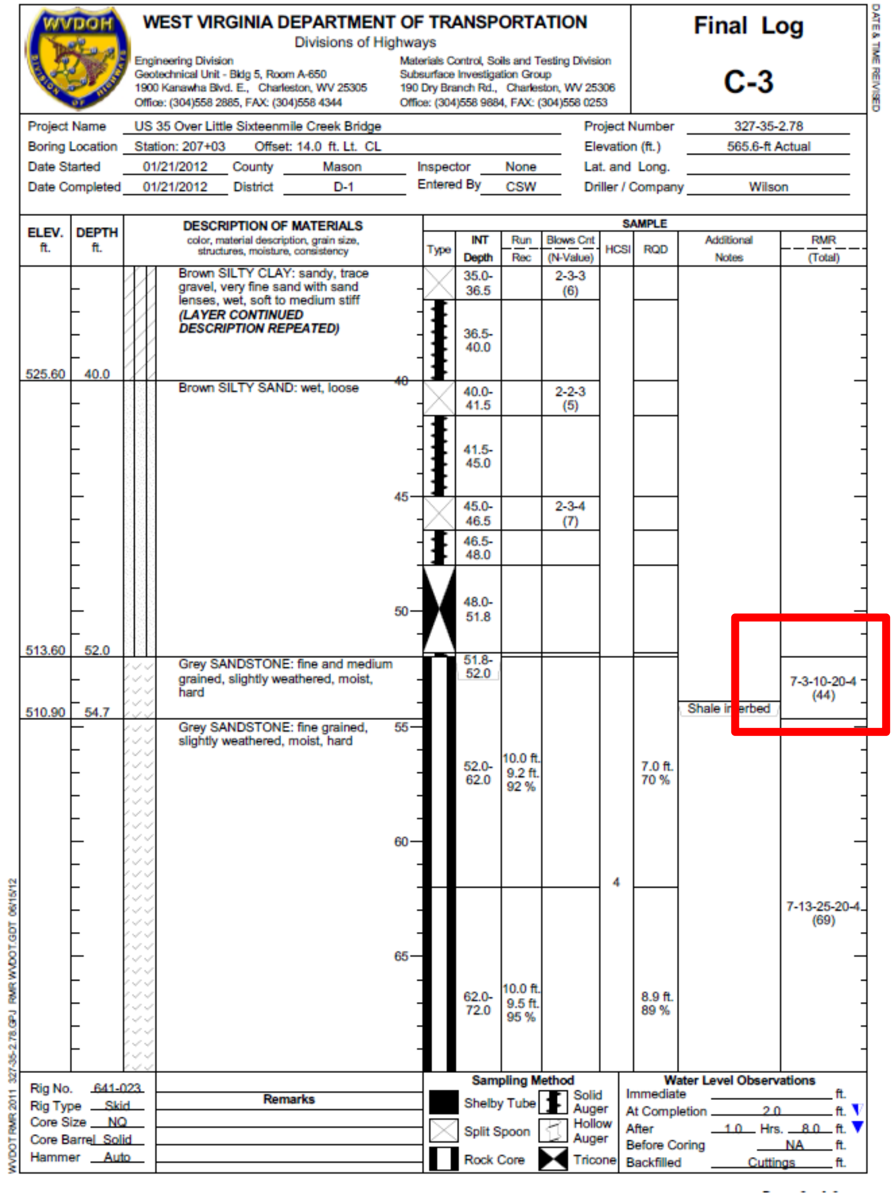


Contract Documents



Inspector Handbook

Implementation of RMR



WEST VIRGINIA DEPARTMENT OF TRANSPORTATION
Divisions of Highways

Engineering Division
Geotechnical Unit - Bldg 5, Room A-650
1900 Kanawha Blvd. E., Charleston, WV 25305
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Materials Control, Soils and Testing Division
Subsurface Investigation Group
190 Dry Branch Rd., Charleston, WV 25306
Office: (304)558 9884, FAX: (304)558 0253

Final Log

C-3

DATE & TIME REVISED

Project Name: US 35 Over Little Sixteenmile Creek Bridge
Project Number: 327-35-2.78
Boring Location: Station: 207+03 Offset: 14.0 ft. Lt. CL
Elevation (ft.): 565.6-ft Actual
Date Started: 01/21/2012 County: Mason Inspector: None
Lat. and Long.:
Date Completed: 01/21/2012 District: D-1 Entered By: CSW
Driller / Company: Wilson

ELEV. ft.	DEPTH ft.	DESCRIPTION OF MATERIALS color, material description, grain size, structures, moisture, consistency	SAMPLE Type	INT Depth	Run Rec	Blows Cnt (N-Value)	HCSI	RQD	Additional Notes	RMR (Total)
		Brown SILTY CLAY: sandy, trace gravel, very fine sand with sand lenses, wet, soft to medium stiff ***(LAYER CONTINUED DESCRIPTION REPEATED)***	☒	35.0-36.5		2-3-3 (6)				
525.60	40.0		┇	36.5-40.0						
		Brown SILTY SAND: wet, loose	☒	40.0-41.5		2-2-3 (5)				
			┇	41.5-45.0						
			☒	45.0-46.5		2-3-4 (7)				
			┇	46.5-48.0						
513.60	52.0		⧗	48.0-51.8						
510.90	54.7	Grey SANDSTONE: fine and medium grained, slightly weathered, moist, hard	▯	51.8-52.0					Shale interbed	7-3-10-20-4 (44)
		Grey SANDSTONE: fine grained, slightly weathered, moist, hard	▯	52.0-62.0	10.0 ft. 9.2 ft. 92 %		4	7.0 ft. 70 %		
			▯	62.0-72.0	10.0 ft. 9.5 ft. 95 %			8.9 ft. 89 %		7-13-25-20-4 (69)

Rig No. 641-023
Rig Type Skid
Core Size NQ
Core Barrel Solid
Hammer Auto

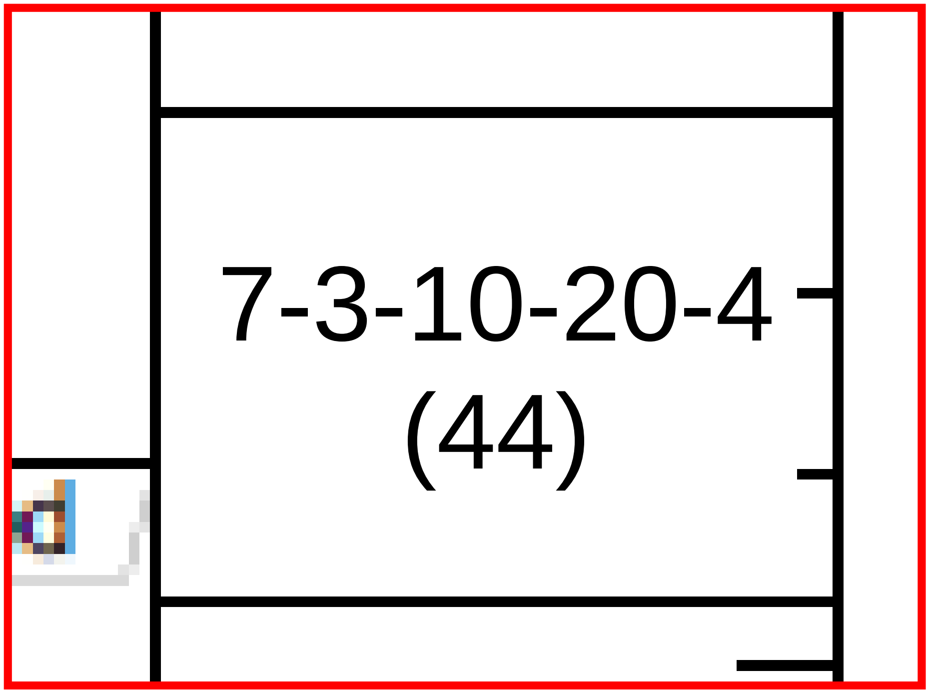
Remarks

Sampling Method

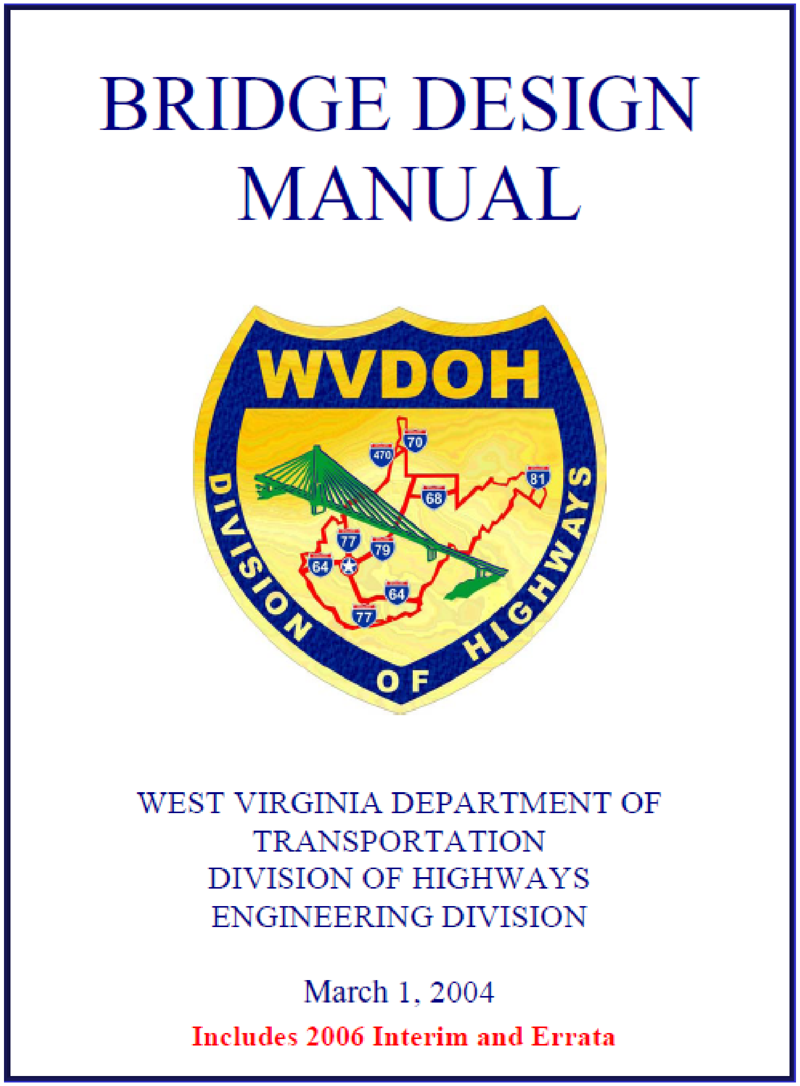
■	Shelby Tube	┇	Solid Auger
☒	Split Spoon	▯	Hollow Auger
▯	Rock Core	⧗	Tricone

Water Level Observations
Immediate ft.
At Completion 2.0 ft. ▽
After 1.0 Hrs. 8.0 ft. ▼
Before Coring NA ft.
Backfilled Cuttings ft.

WVDOT RMR 2011 327-35-2.78.GPJ RMR WVDOT.GDT 06/15/12



Implementation of Design Procedures

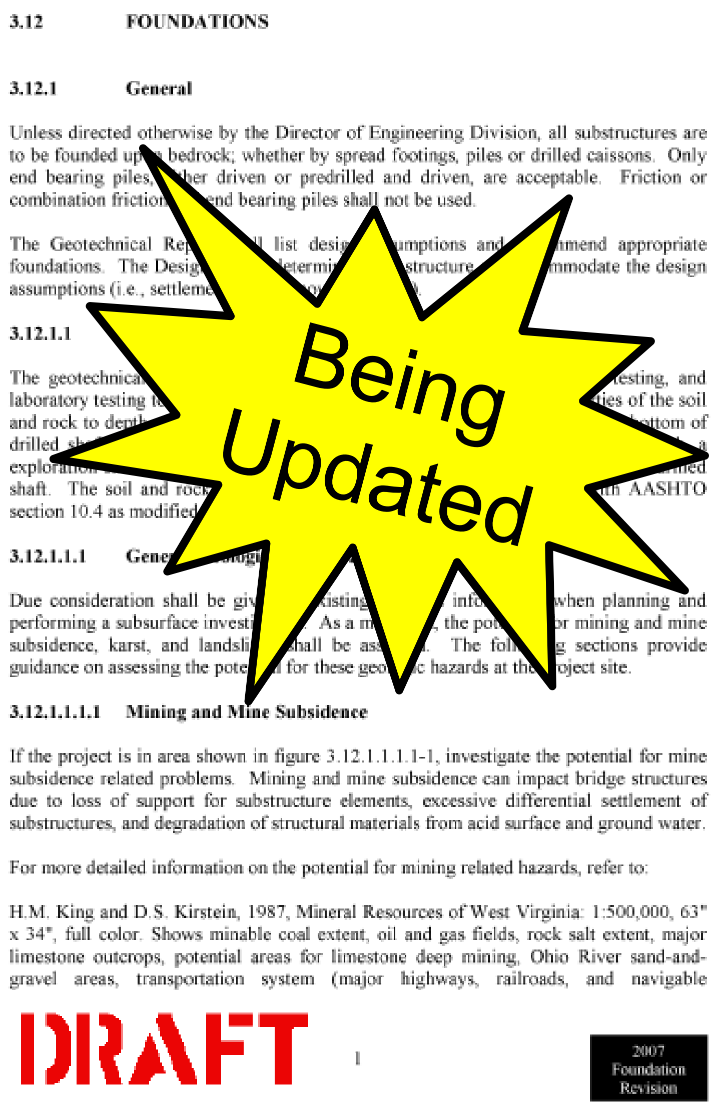


BRIDGE DESIGN
MANUAL

WEST VIRGINIA DEPARTMENT OF
TRANSPORTATION
DIVISION OF HIGHWAYS
ENGINEERING DIVISION

March 1, 2004

Includes 2006 Interim and Errata



3.12 FOUNDATIONS

3.12.1 General

Unless directed otherwise by the Director of Engineering Division, all substructures are to be founded up[illegible] bedrock; whether by spread footings, piles or drilled caissons. Only end bearing piles, [illegible]her driven or predrilled and driven, are acceptable. Friction or combination friction [illegible] end bearing piles shall not be used.

The Geotechnical Rep[illegible]ll list desig[illegible]umptions and [illegible]mmend appropriate foundations. The Desig[illegible]determi[illegible]structure [illegible]mmodate the design assumptions (i.e., settleme[illegible]).

3.12.1.1 [illegible]

The geotechnica[illegible]testing, and laboratory testing t[illegible]ties of the soil and rock to dept[illegible]bottom of drilled sh[illegible] a exploration [illegible]ned shaft. The soil and rock [illegible]h AASHTO section 10.4 as modified [illegible]

3.12.1.1.1.1 Gene[illegible]

Due consideration shall be giv[illegible]xisting [illegible] info[illegible] when planning and performing a subsurface investi[illegible]. As a m[illegible], the pot[illegible]or mining and mine subsidence, karst, and landsli[illegible] shall be ass[illegible]. The foll[illegible]g sections provide guidance on assessing the pote[illegible] for these geo[illegible]c hazards at the [illegible]roject site.

3.12.1.1.1.1 Mining and Mine Subsidence

If the project is in area shown in figure 3.12.1.1.1.1-1, investigate the potential for mine subsidence related problems. Mining and mine subsidence can impact bridge structures due to loss of support for substructure elements, excessive differential settlement of substructures, and degradation of structural materials from acid surface and ground water.

For more detailed information on the potential for mining related hazards, refer to:

H.M. King and D.S. Kirstein, 1987, Mineral Resources of West Virginia: 1:500,000, 63" x 34", full color. Shows minable coal extent, oil and gas fields, rock salt extent, major limestone outcrops, potential areas for limestone deep mining, Ohio River sand-and-gravel areas, transportation system (major highways, railroads, and navigable

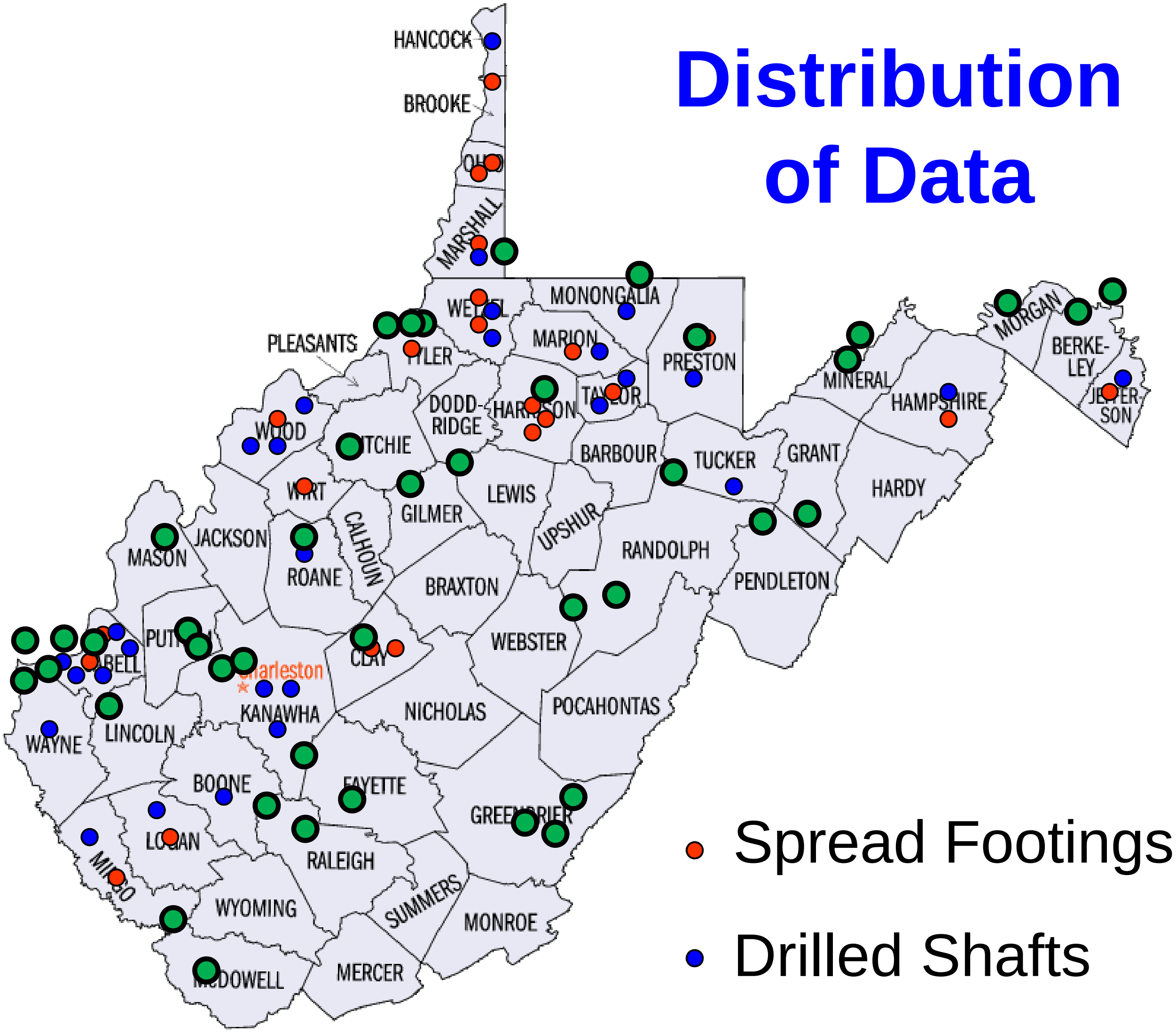
DRAFT

2007
Foundation
Revision

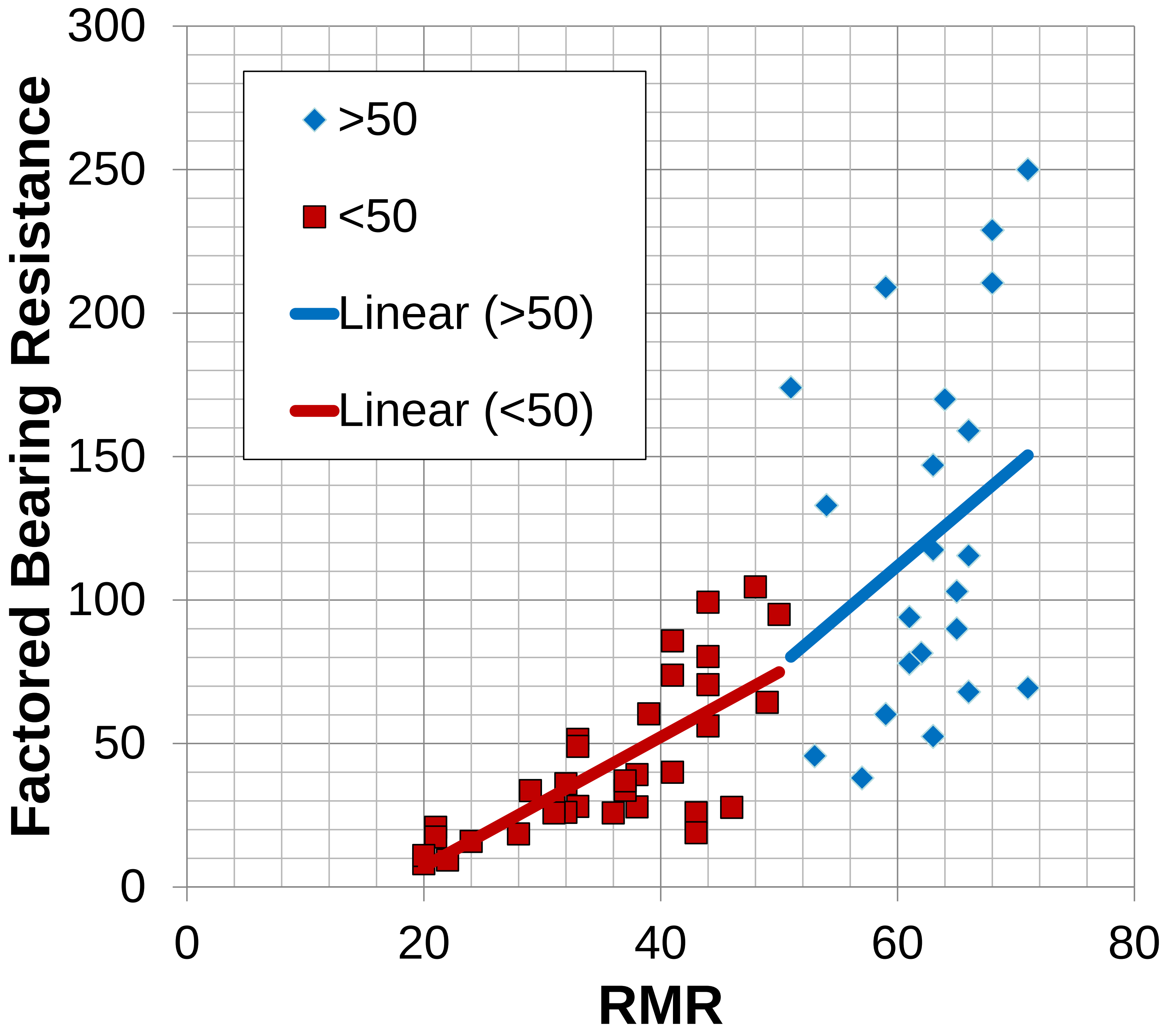
Being
Updated

Performance of implemented solution

Distribution of Data

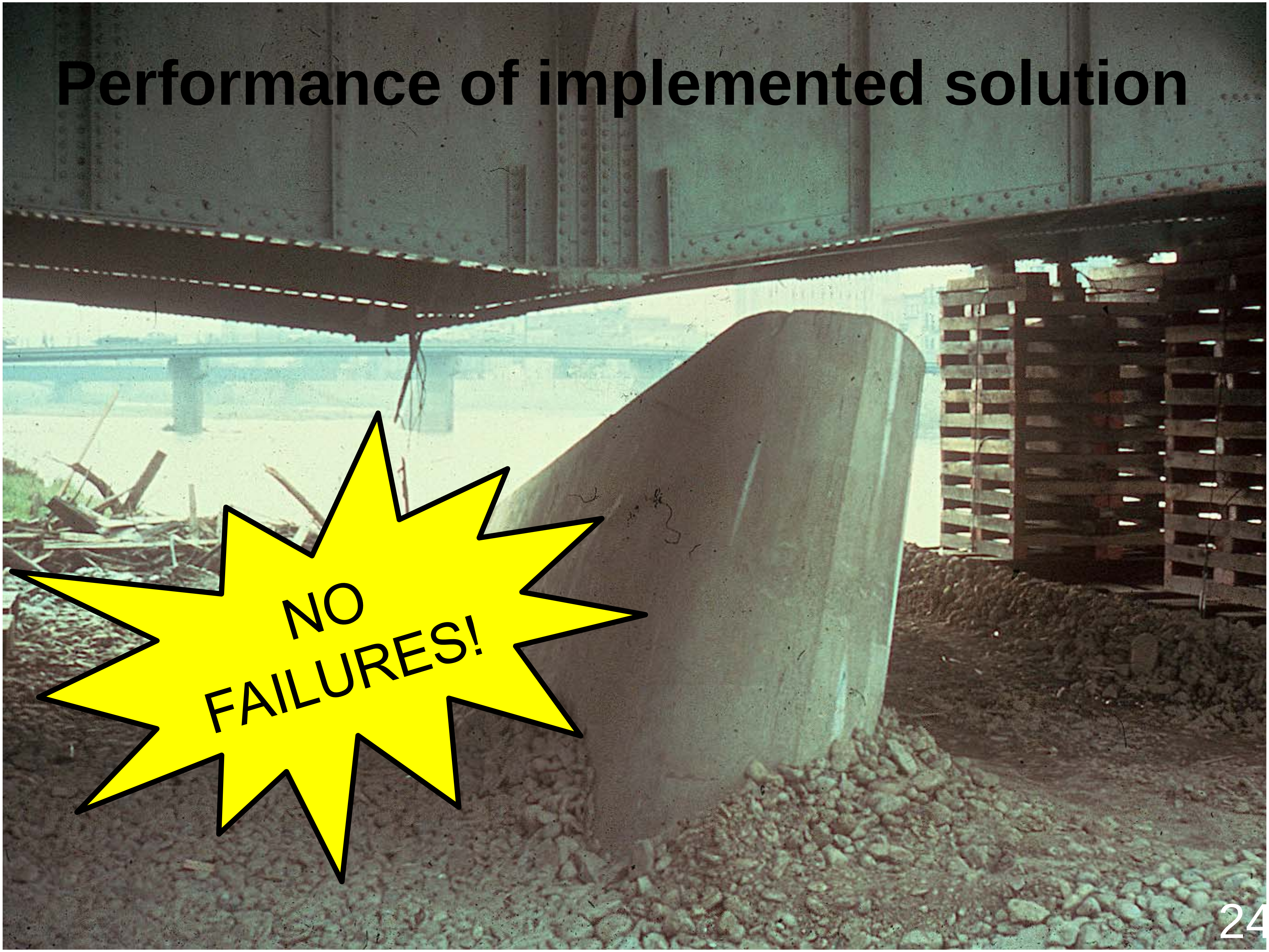


- 🟠 Spread Footings
- 🔵 Drilled Shafts
- 🟢 Recent

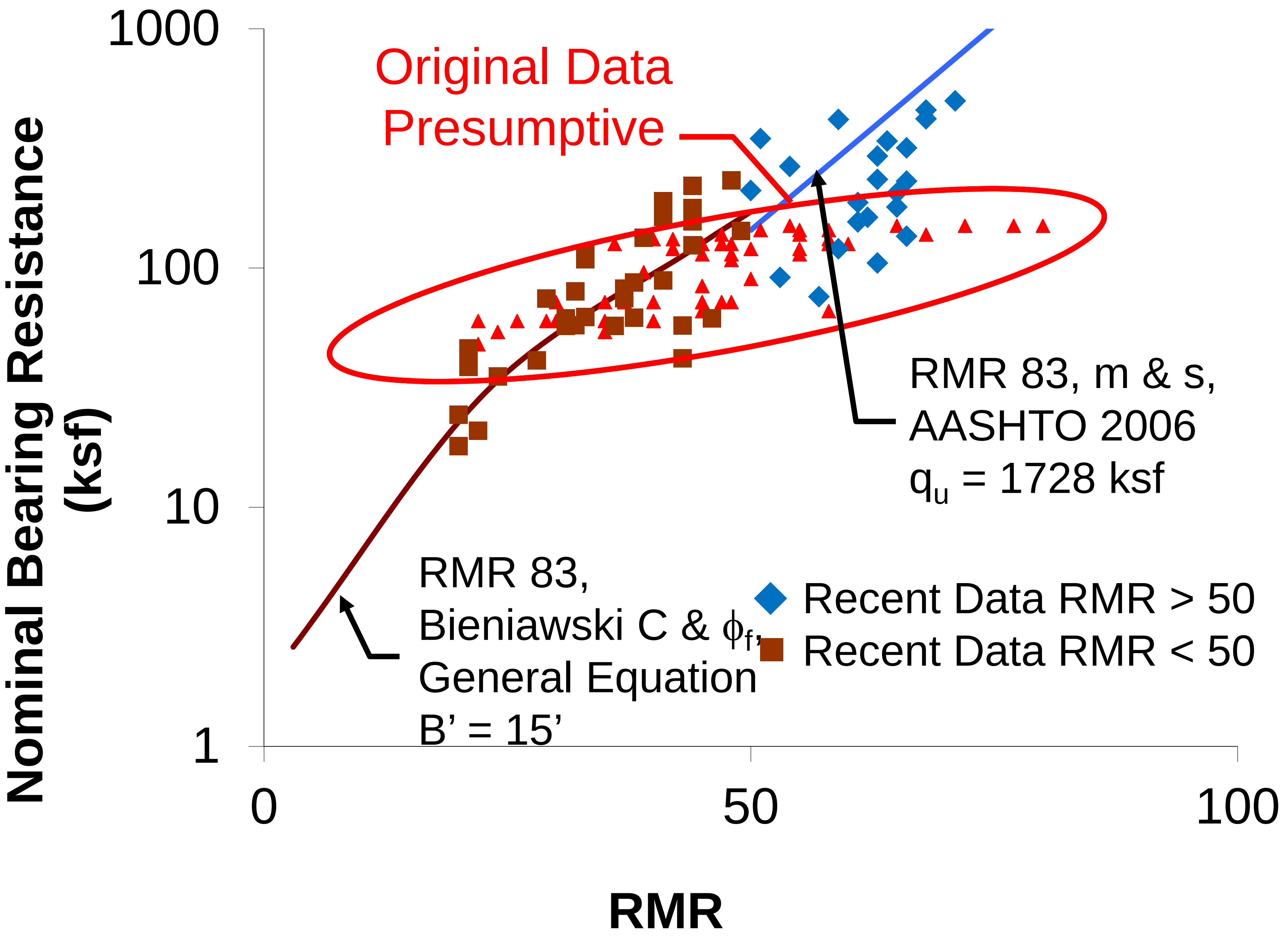


Factored Bearing Resistance
300
250
200
150
100
50
0
0
20
40
60
80
RMR
>50
<50
Linear (>50)
Linear (<50)

Performance of implemented solution

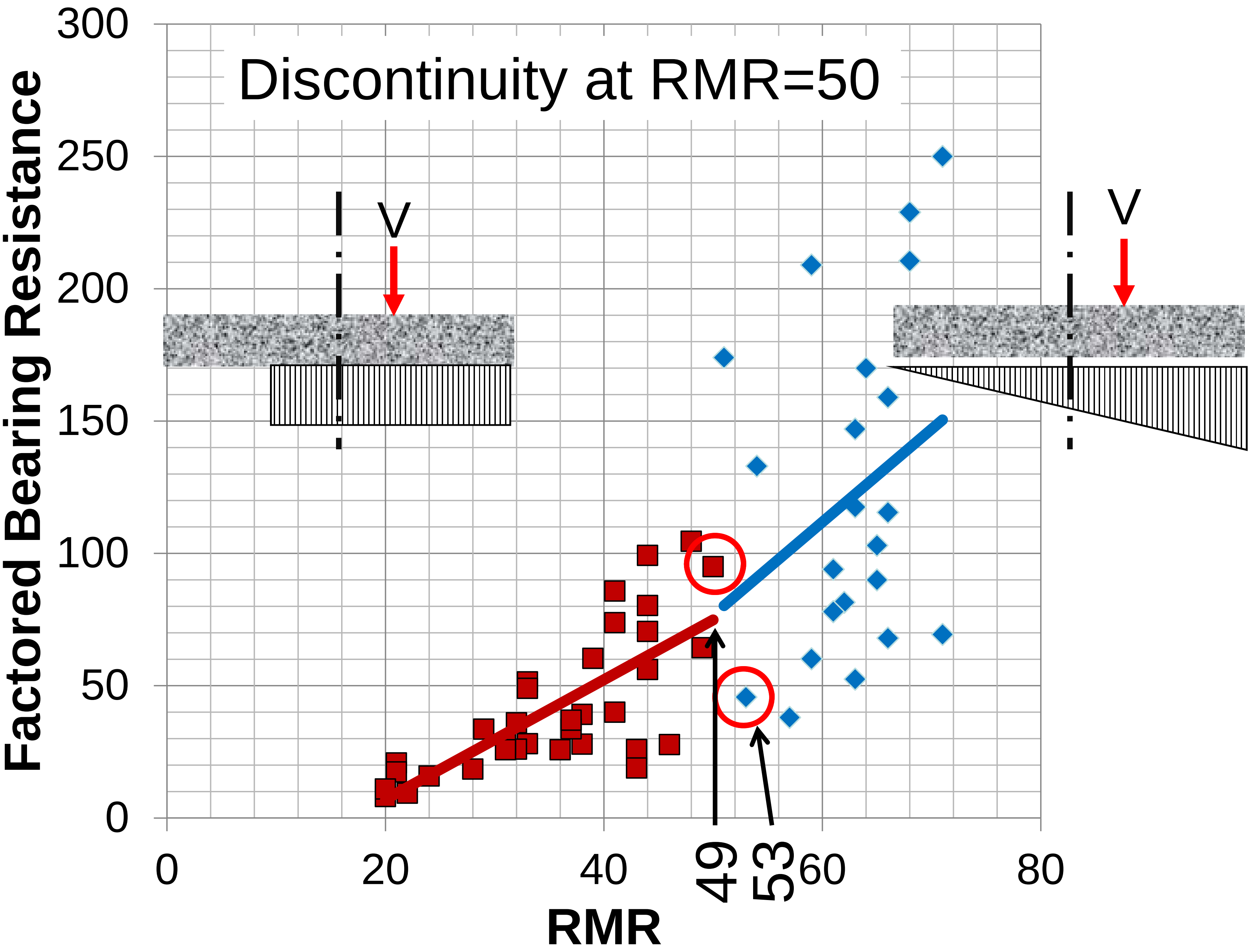


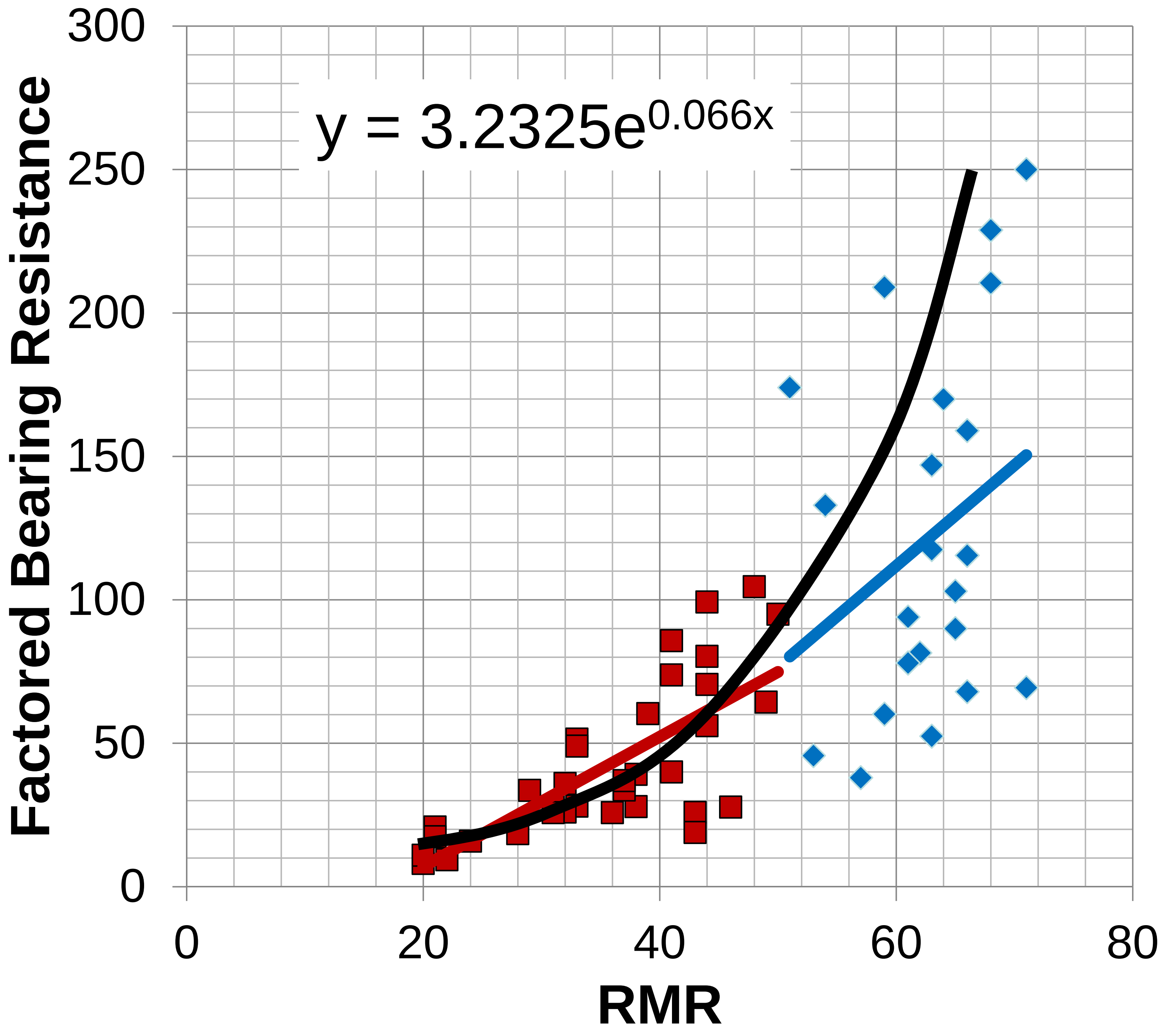
NO FAILURES!

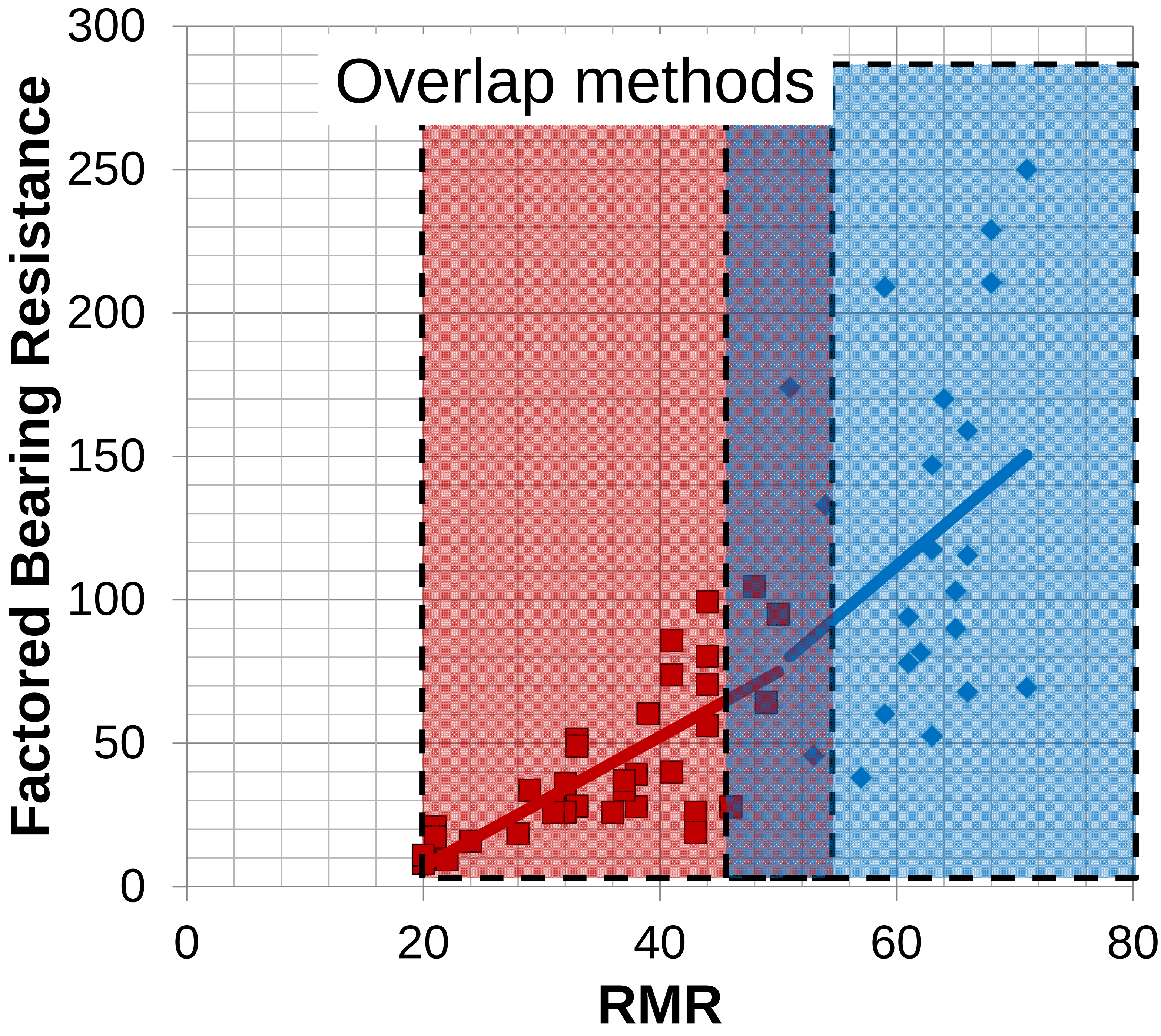

Nominal Bearing Resistance (ksf)
1000
100
10
1
0
50
100
RMR
Original Data Presumptive
RMR 83, m & s, AASHTO 2006 q_u = 1728 ksf
RMR 83, Bieniawski C & ϕ_f, General Equation B' = 15'
◆ Recent Data RMR > 50
■ Recent Data RMR < 50

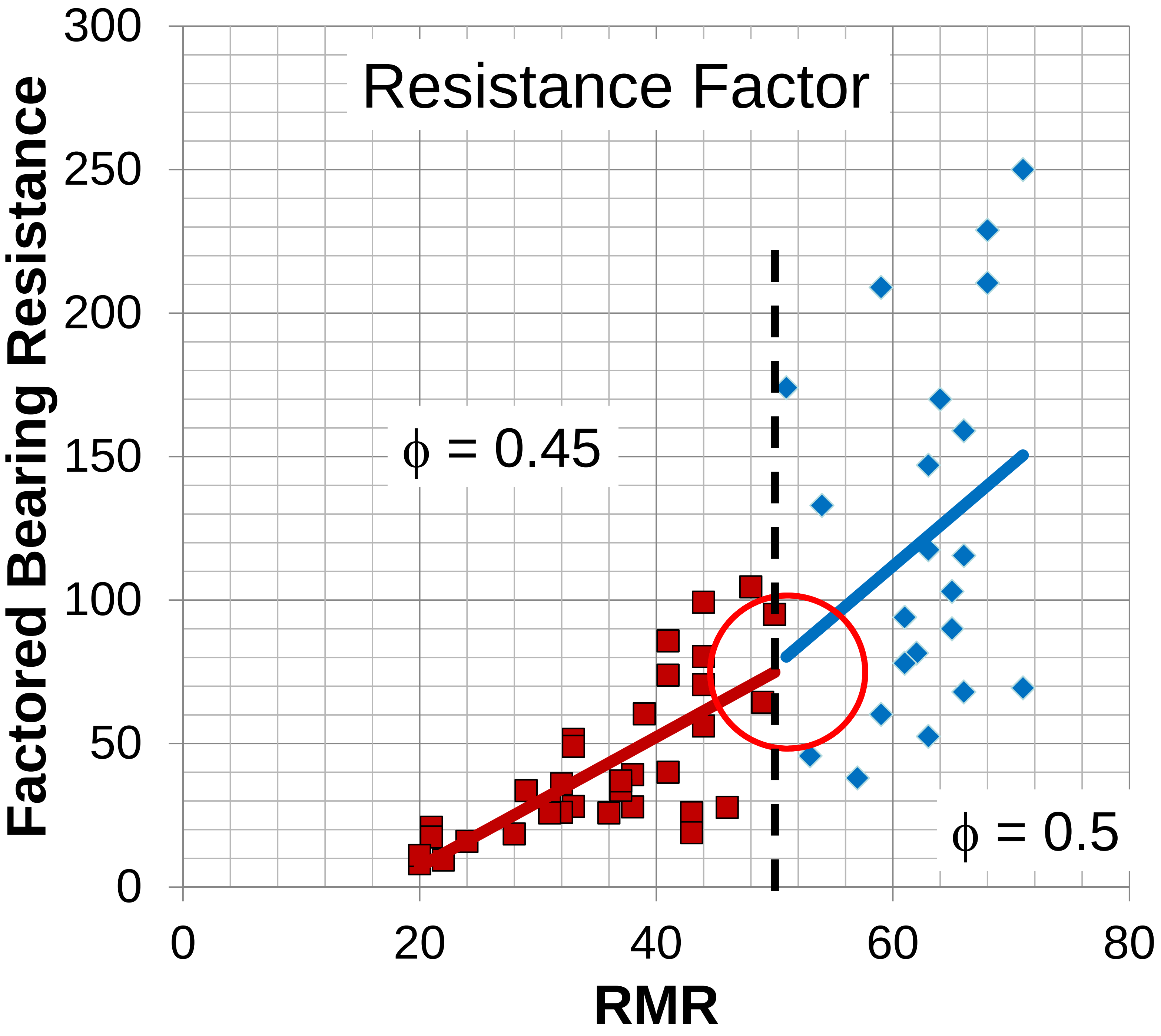
Issues

- Discontinuity at RMR=50
- Resistance factor
- Confusion about design methodology
- Presentation of recommended bearing resistance for RMR < 50


Discontinuity at RMR=50
Factored Bearing Resistance
300
250
200
150
100
50
0
0
20
40
49
53
60
80
RMR
V
V


y = 3.2325e^0.066x
Factored Bearing Resistance
RMR
300
250
200
150
100
50
0
0
20
40
60
80


Overlap methods
Factored Bearing Resistance
RMR
0
50
100
150
200
250
300
0
20
40
60
80


Resistance Factor
ϕ = 0.45
ϕ = 0.5
Factored Bearing Resistance
RMR
0
50
100
150
200
250
300
0
20
40
60
80

Resistance Factor

Calibration to ASD:

$FS = \gamma / \phi$

Average load factor $\gamma = 1.4$

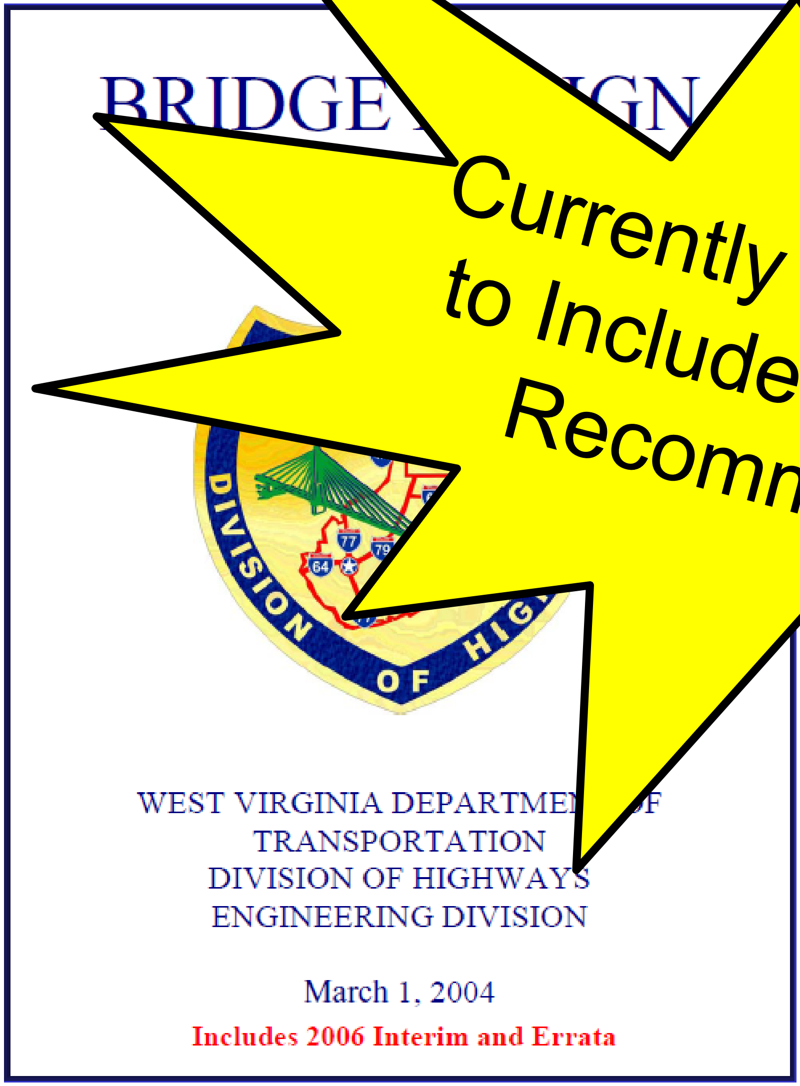
For $\phi = 0.5$; FS = 2.8

For $\phi = 0.45$; FS = 3.1

$\phi = 0.45$ will be recommended in BDM

Confusion about Design Procedures

Currently Being Updated to Include these Design Recommendations


BRIDGE IGN

WEST VIRGINIA DEPARTMEN OF
TRANSPORTATION
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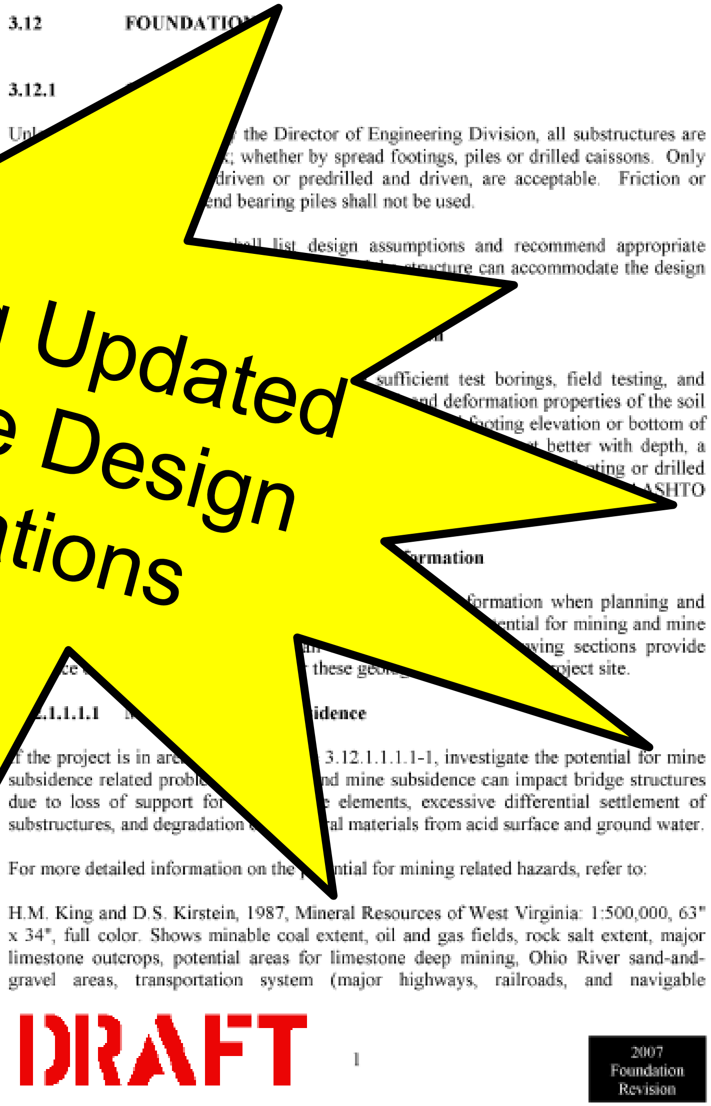

3.12 FOUNDATIO

3.12.1

Unl the Director of Engineering Division, all substructures are x; whether by spread footings, piles or drilled caissons. Only driven or predrilled and driven, are acceptable. Friction or end bearing piles shall not be used.

hall list design assumptions and recommend appropriate structure can accommodate the design

sufficient test borings, field testing, and and deformation properties of the soil footing elevation or bottom of better with depth, a ting or drilled ASHTO

formation

formation when planning and ential for mining and mine wing sections provide these geolo oject site.

.1.1.1.1 idence

f the project is in are 3.12.1.1.1.1-1, investigate the potential for mine subsidence related proble nd mine subsidence can impact bridge structures due to loss of support for e elements, excessive differential settlement of substructures, and degradation al materials from acid surface and ground water.

For more detailed information on the ntial for mining related hazards, refer to:

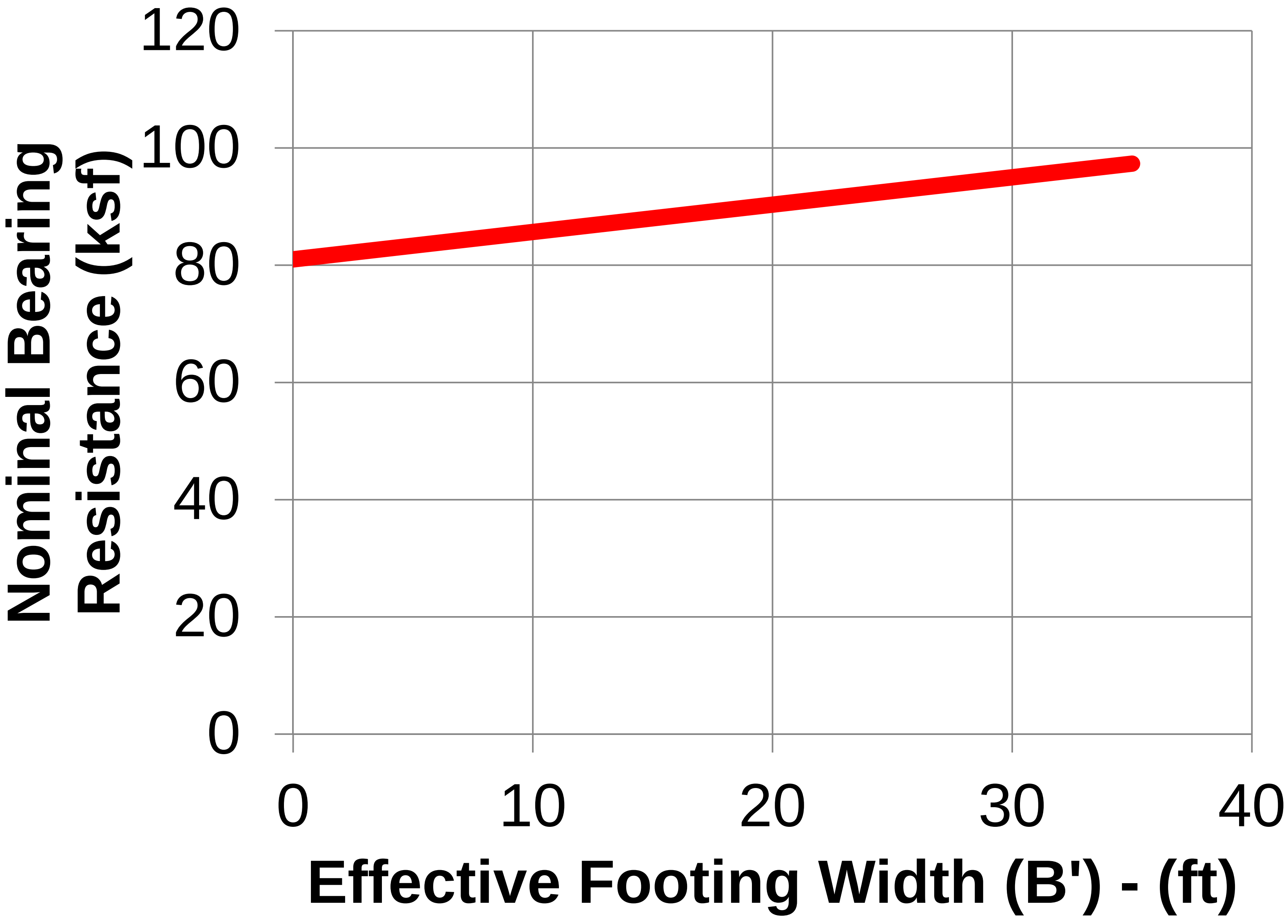
H.M. King and D.S. Kirstein, 1987, Mineral Resources of West Virginia: 1:500,000, 63" x 34", full color. Shows minable coal extent, oil and gas fields, rock salt extent, major limestone outcrops, potential areas for limestone deep mining, Ohio River sand-and-gravel areas, transportation system (major highways, railroads, and navigable

DRAFT

1

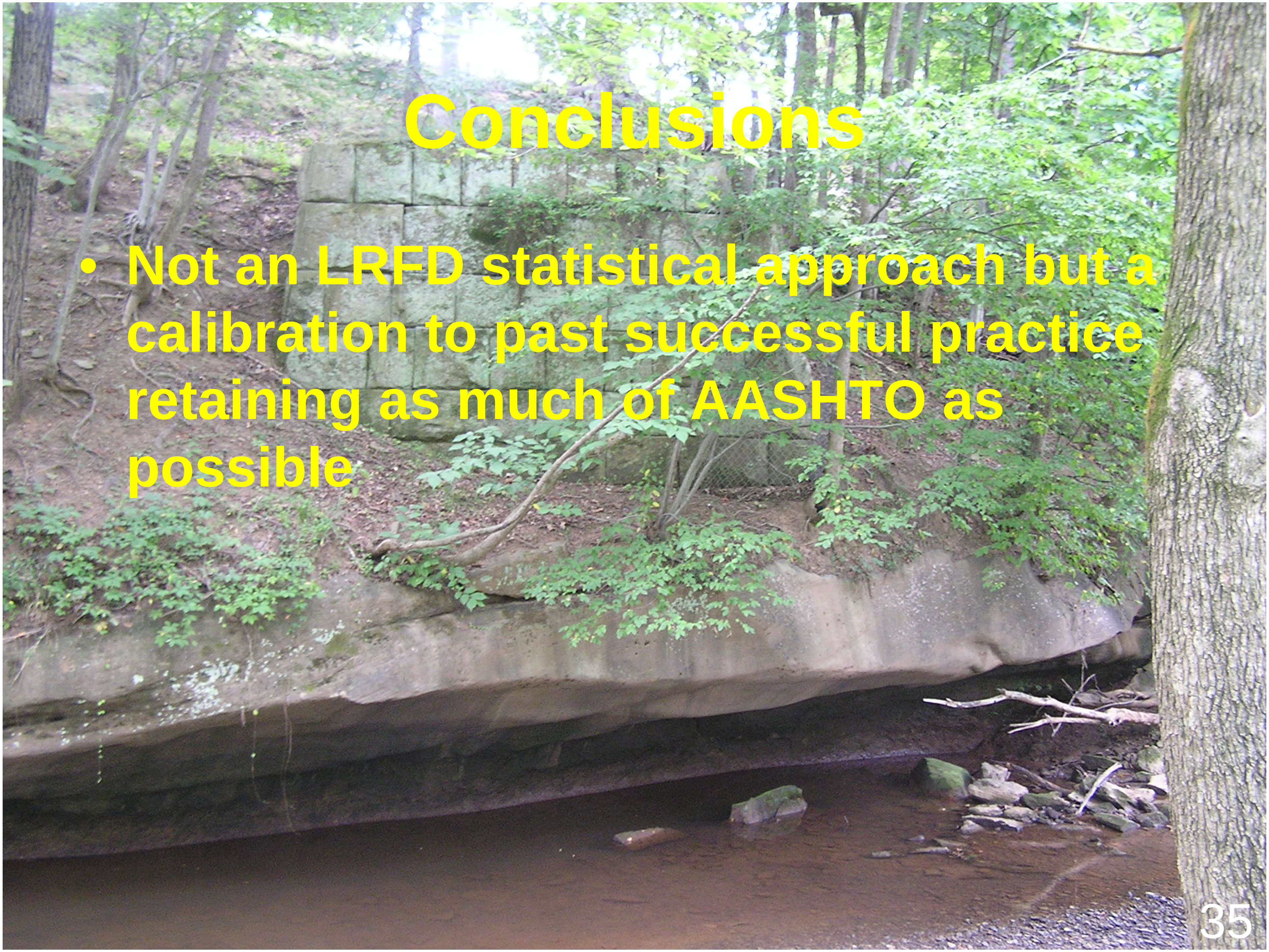
2007
Foundation
Revision

Presentation of Bearing Resistance



Conclusions

- RMR = 50 is appropriate split between methods



Conclusions

- Not an LRFD statistical approach but a calibration to past successful practice retaining as much of AASHTO as possible

Conclusions

- Many fewer complaints about "unreasonable" bearing resistance

Creating Value …

… Delivering Solutions

Questions?

Joe Carte, P.E.
W.V Department of Transportation

Scott Zang, P.E.
Michael Baker Jr., Inc.

Baker