LRFD GEOTECHNICAL IMPLEMENTATION

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LADOTD
Pavement and Geotechnical Services
In Conjunction with
LTRC

WHY LRFD

- FHWA deadline - October 2007
- LRFD is a better method
  - Risk is quantified
  - Accounts for site and model variability
  - Consistent reliability
  - Component level risk control
- Consistent with superstructure design

LRFD vs. ASD

Similarities

- Engineering principles
- Engineering judgment
- Capacity (resistance) evaluation
- Service deformation check

LRFD vs. ASD

Differences

- Empirical vs. risk analyses
- Application of resistances
  - Overall safety factor vs. component level resistance factors
  - Allowable resistances vs. factored resistances
- Site variability and reliability of design methods
- Communication among various design professionals and construction personnel
- Resource requirement
  - More engineering, field investigation, lab testing and field verification tests for LRFD

ASD VS. LRFD

ASD

$$\sum DL + \sum LL \leq R_u / FS$$

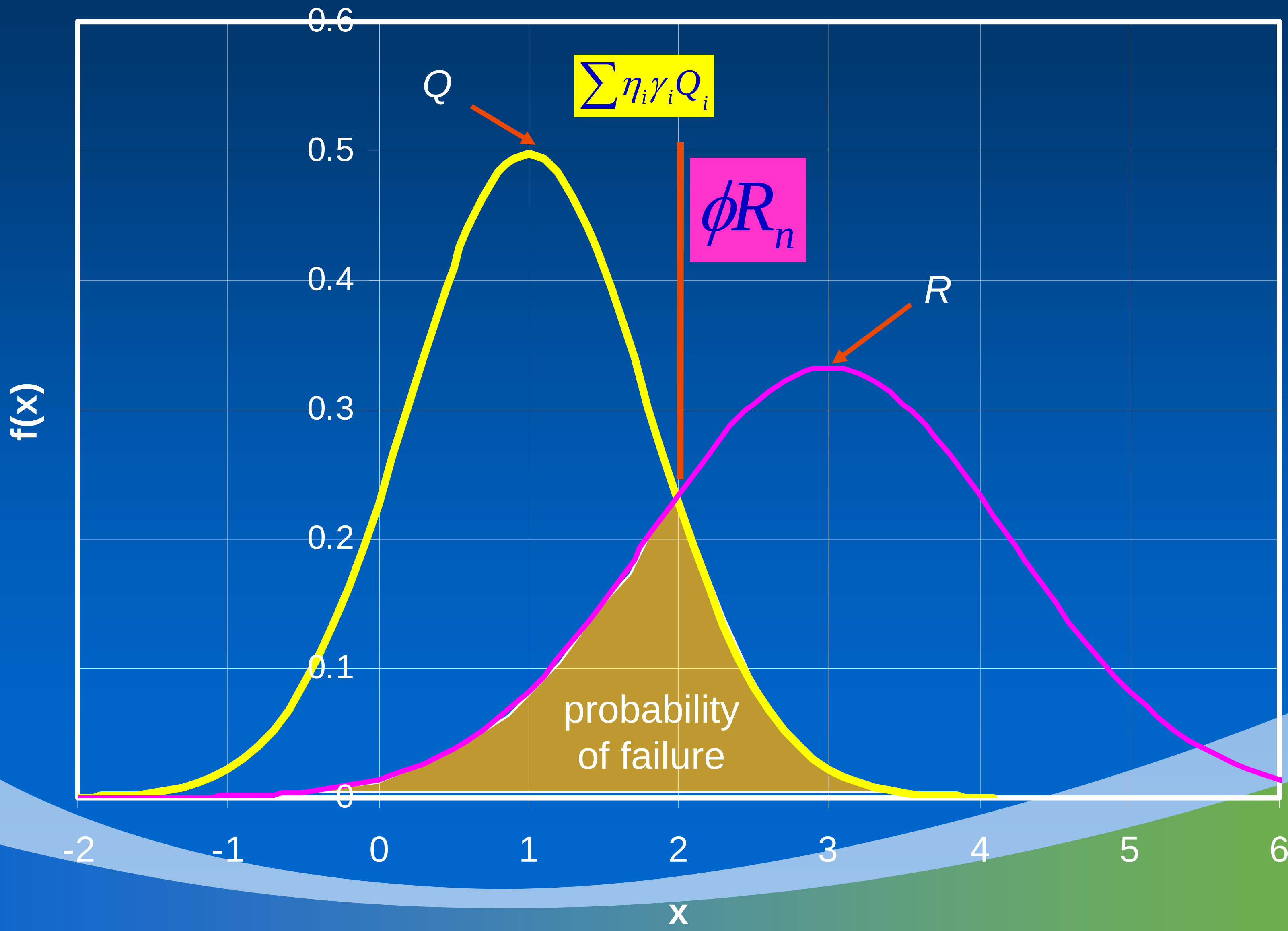
LRFD

$$\eta\left(\sum \gamma_{DL} DL + \sum \gamma_{LL} LL\right) \leq \sum \phi R_u$$

HOW ASD DEALS WITH RISK – DRIVEN PILES

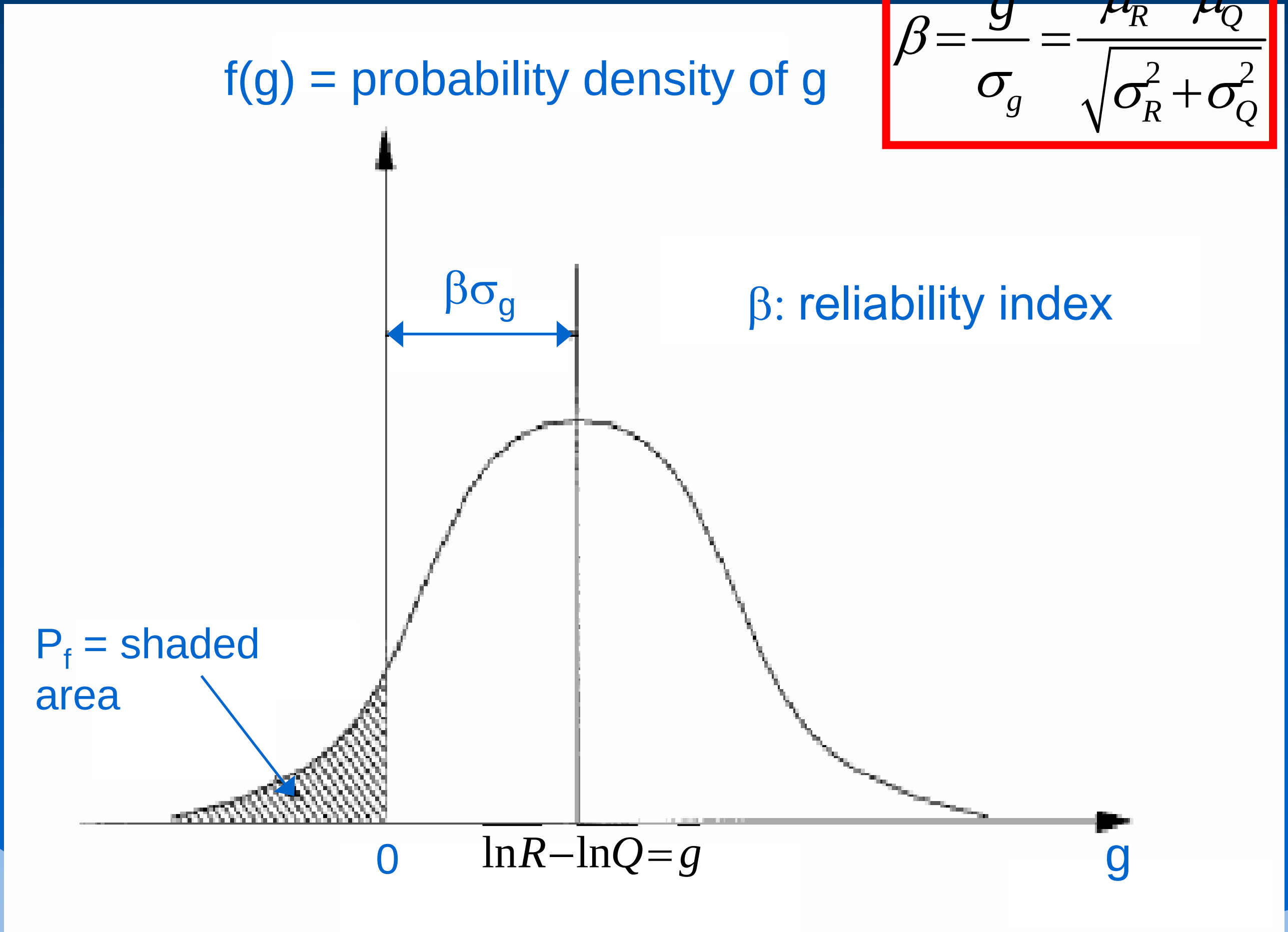
Basis for Design and Type of Construction Control	Increasing Design/Construction Control				
Subsurface Exploration	X	X	X	X	X
Static Calculation	X	X	X	X	X
Dynamic Formula	X				
Wave Equation		X	X	X	X
CAPWAP Analysis			X		X
Static Load Test				X	X
Factor of Safety (FS)	3.50	2.75	2.25	2.00	1.90

HOW LRFD TREATS RISK?



Reliability Index, β

$$\beta = \frac{g}{\sigma_g} = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$



P_f	β
10^{-1}	1.28
10^{-2}	2.33
10^{-3}	3.09
10^{-4}	3.71
10^{-5}	4.26
10^{-6}	4.75
10^{-7}	5.19
10^{-8}	5.62
10^{-9}	5.99

RELIABILITY DESIGN CONCEPT

- Reliability Index (β) (risk index?)
  - mean resistance, dispersion of resistance
  - High RI : Low risk
- Same risk for both super and sub structures

TARGET RISK (AASHTO)

- Superstructure β=3.5 P_f = 0.0002
- Substructure β=2.3 P_f = 0.01
  - Redundancy (5-pile group)
  - Reduce resistance factors by 20 percent for no or small redundancy
  - If two piles failed, P_f= 0.01^2 =0.0001 implies failure of 2 piles will be the critical condition

FACTORS CONSIDERED FOR RESISTANCE FACTOR SELECTION

$$\phi = \frac{\lambda_R \left(\frac{\gamma_D Q_D}{Q_L} + \gamma_L \right) \sqrt{\left[\frac{\left(1 + COV_{Q_D}^2 + COV_{Q_L}^2\right)}{\left(1 + COV_R^2\right)} \right]}}{\left(\frac{\lambda_{Q_D} Q_D}{Q_L} + \lambda_{Q_L} \right) \exp\left\{ \beta_T \sqrt{\ln\left[\left(1 + COV_R^2\right)\left(1 + COV_{Q_D}^2 + COV_{Q_L}^2\right)\right]} \right\}}$$

High bias – High resistance factor

High variation – Low resistance factor

High reliability – Low resistance factor

AASHTO BRIDGE DESIGN SPECIFICATIONS

- Chapter 10: Foundations
  - 10.4 Soil and Rock Properties
  - 10.5 Limit States and Resistance Factors
    - 10.5.5 Resistance Factors
  - 10.6 Spread Footings
  - 10.7 Driven Piles
  - 10.8 Drilled Shafts
- Chapter 11: Abutment, Piers and Wall

RESISTANCE FACTOR VS. SAFETY FACTOR

Resistance Factors (β=2.3)	0.8	0.75	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.35	0.3
20% Reduction	0.64	0.6	0.56	0.52	0.48	0.44	0.4	0.36	0.32	0.28	0.24
Equivalent FS (β=2.3)	1.72	1.83	1.97	2.11	2.29	2.58	2.8	3.05	3.44	3.93	4.58
Equivalent FS (20% Reduction)	2.15	2.23	2.46	2.64	2.86	3.12	3.4	3.82	4.30	4.91	5.73

FUNDAMENTALS OF LRFD

Principles of Limit State Designs

- Four limit states
- Identify the applicability of each of the primary limit states.
- Resistance

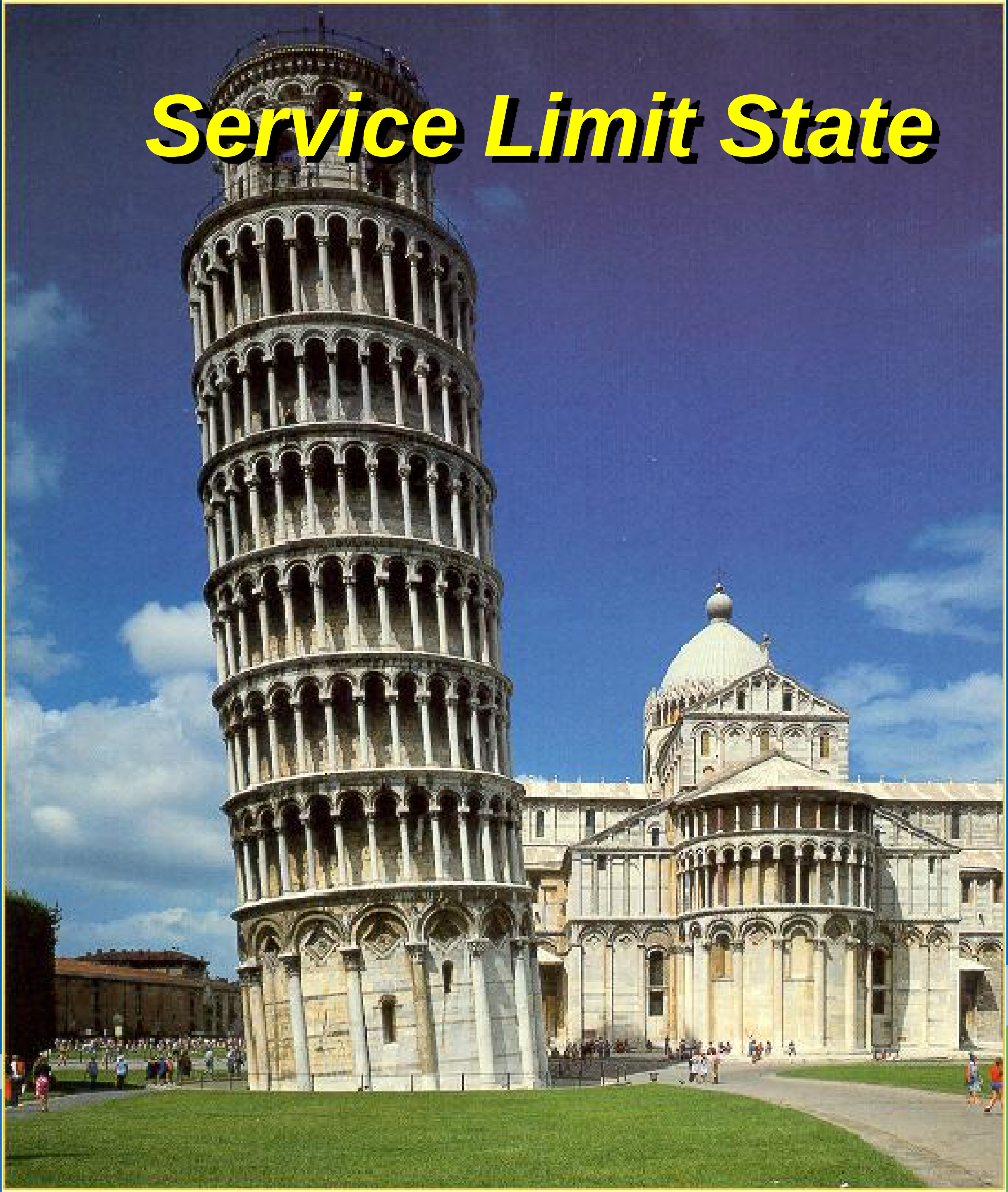
DEFINITION OF LIMIT STATE

A Limit State is a <u>defined condition</u> beyond which a structural component, ceases to satisfy the provisions for which it is designed.

LIMIT STATES (1)

- Service Limit States
  - Settlements
    - Transient loads may be omitted for time-dependent settlement
  - Horizontal Movements
  - Overall Stability
  - Scour at design flood

Service Limit State




Service Limit State

LIMIT STATES (2)

- Strength Limit States
  - Consideration of structural resistance and loss of lateral and vertical support due to scour
- Extreme Event Limit States
  - Vessel collision, seismic, storm surge…
  - Normal resistance factors
- Fatigue Limit State


Strength
Limit State

Extreme Event Limit State

DEFINITION OF RESISTANCE

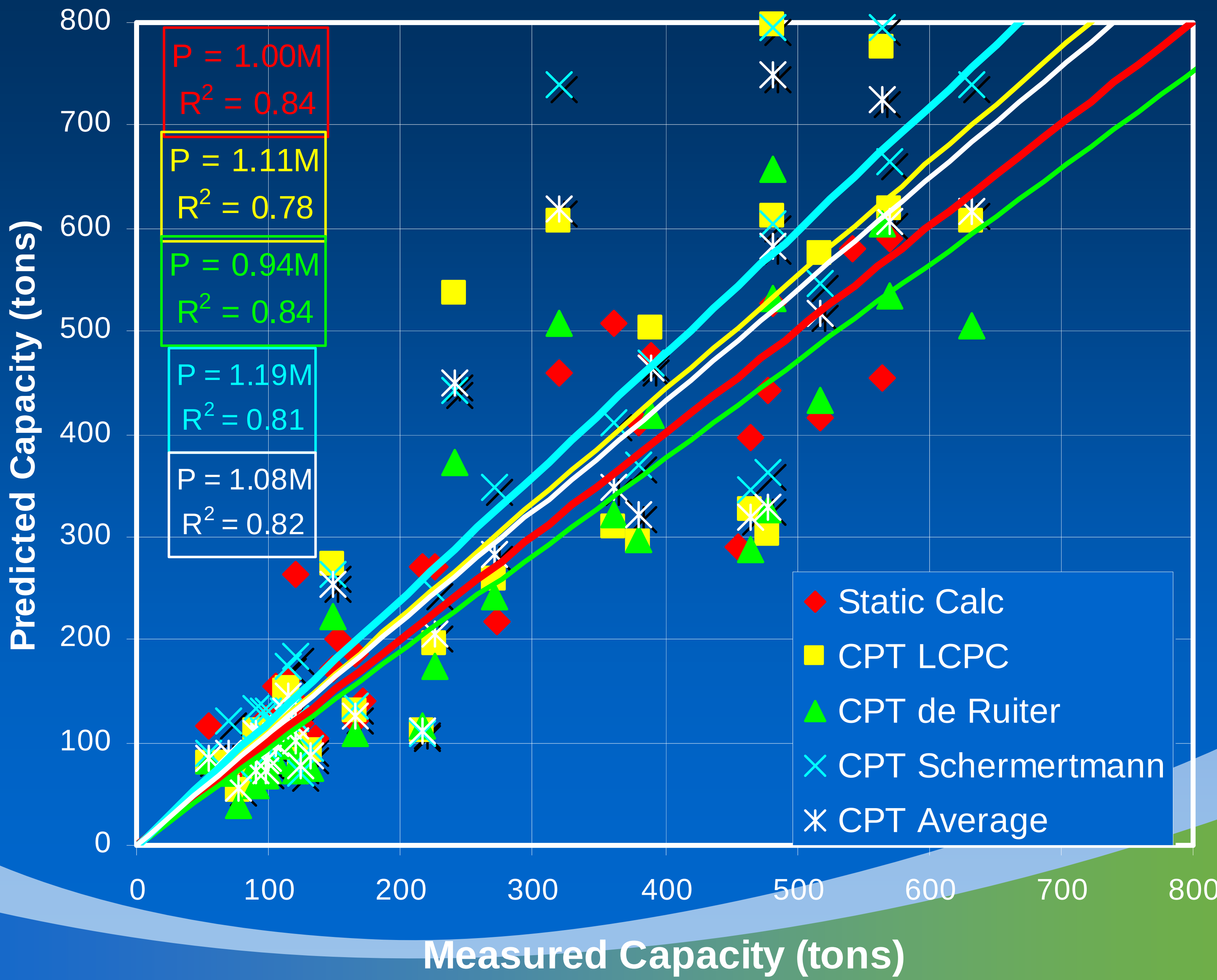
Resistance is a <u>quantifiable value that defines</u> the point beyond which the particular limit state under investigation for a particular component will be exceeded.

RESISTANCES

- Force (static/ dynamic, dead/ live)
- Stress (normal, shear, torsional)
- Number of cycles
- Temperature
- Strain

LADOTD AND LTRC CALIBRATION

- Team
  - Dr. Abu-Farsakh w/LTRC
  - Dr. “Sean” Sunming Yoon w/LTRC
- 52 Load Tests
- First Order Second Moment Method (FOSM)
- First Order Reliability Method
- Monte Carlo Simulation
- $\beta = 2.5$



P = 1.00M
R^2 = 0.84
P = 1.11M
R^2 = 0.78
P = 0.94M
R^2 = 0.84
P = 1.19M
R^2 = 0.81
P = 1.08M
R^2 = 0.82
Static Calc
CPT LCPC
CPT de Ruiter
CPT Schermertmann
CPT Average
Predicted Capacity (tons)
Measured Capacity (tons)
0
100
200
300
400
500
600
700
800

PILE CAPACITY VARIABILITY AND RESISTANCE FACTORS

	Soil Borings	CPT Methods			
	Static Calc	Average	LCPC	Schmertmann	De Ruiter Beringen
Rm/Rcalc	0.97	1.04	1.06	0.92	1.21
Standard Dev.	0.243	0.310	0.337	0.320	0.335
COV	0.249	0.297	0.317	0.348	0.278
Resistance Factors	0.53	0.52	0.50	0.41	0.62

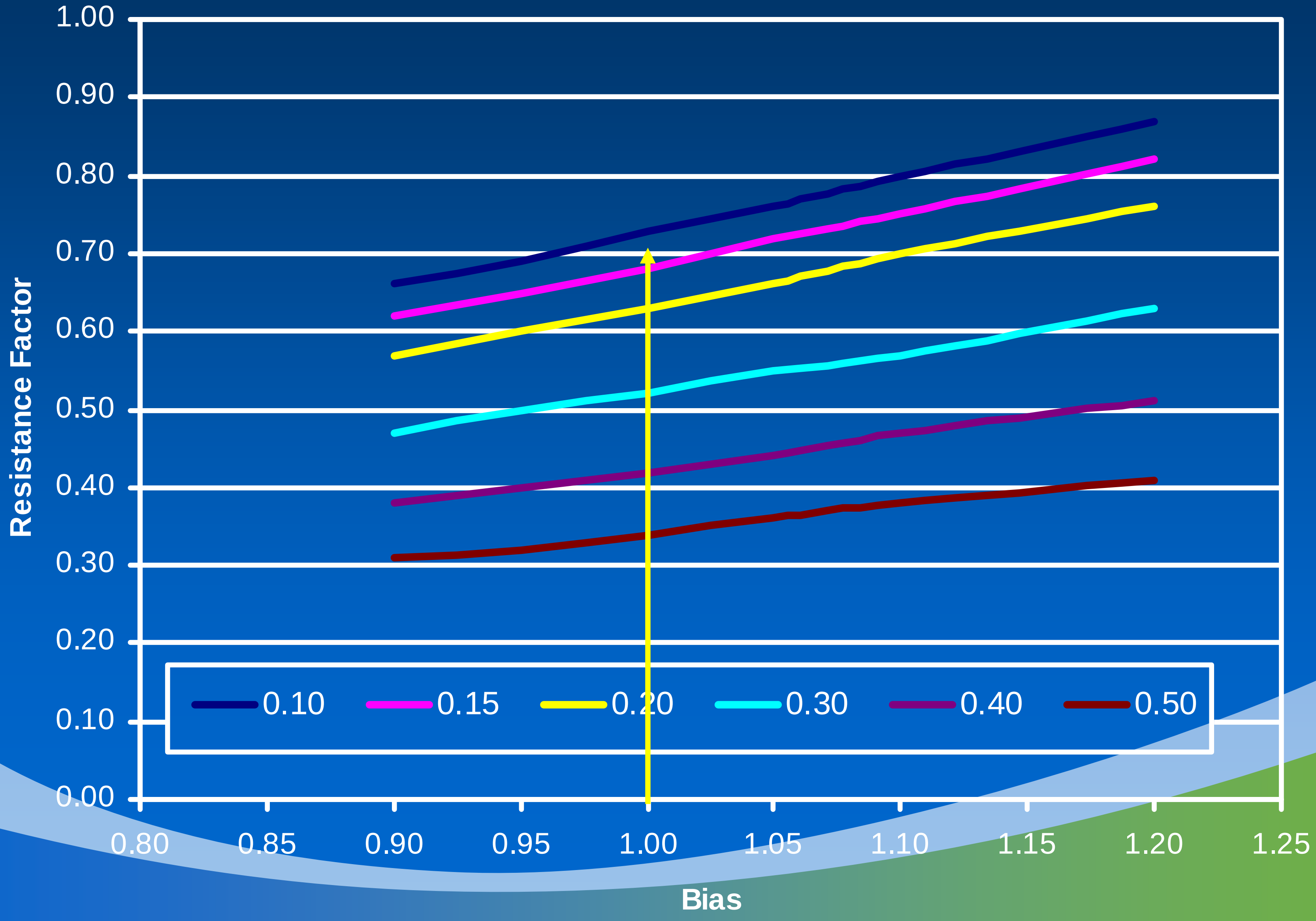
RESISTANCE FACTORS DRIVEN PILES

Design Method		Resistance Factor (ϕ)	
		LADOTD	AASHTO 2006
Static Method	α-Tomlinson method and Nordlund method	0.53	0.35-0.40
	Nordlund method	0.50	0.45
CPT method	Schmertmann,	0.41	0.50
	LCPC/LCP	0.50	-
	de Ruiter and Beringen	0.62	-
	Average	0.52	-
Dynamic Measurement	CAPWAP (EOD)	1.20	-
	CAPWAP (BOR)	0.53	0.65

RESISTANCE FACTOR W/LOAD TESTS

Number of Static Load Test per Site	Resistance Factor		
	Site Variability		
	Low **COV <0.25**	Medium 0.25<COV<0.40	High COV>0.40
1	0.80	0.70	0.55
2	0.90	0.75	0.65
3	0.90	0.85	0.75
more than 4	0.90	0.90	0.80

LOAD TEST VARIABILITY



DYNAMIC TESTING REQUIREMENT

Site Variability	Low	Medium	High
Number of Piles within Site	Number of PDA & CAPWAP		
<=15	3	4	6
16-25	3	5	8
26-50	4	6	9
51-100	4	7	10
101-500	4	7	12
>500	4	7	12

IMPLICATION OF RESISTANCE FACTORS – DRIVEN PILES

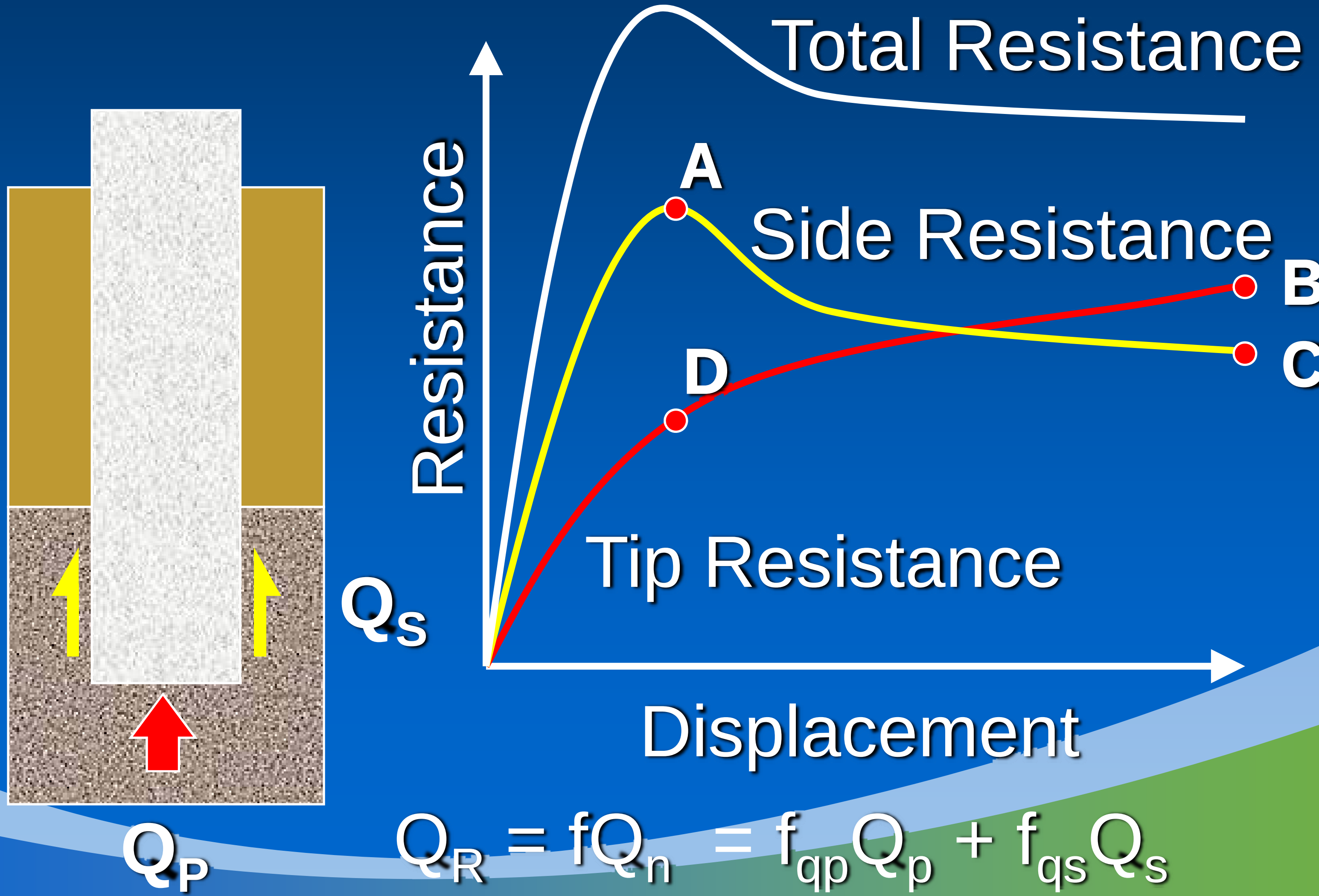
ASD

- Static load tests
  - FS = 3.0 to 3.5 vs. 2
  - Ratios of 1.5 to 1.75
- Dynamic tests
  - FS = 2.5 vs. 3.0 TO 3.5
  - Ratio of 1.2 TO 1.4
- Static and dynamic test frequency
  - Fixed, less tests
- Dynamic test objective
  - Mostly for drivability
    - Initial driving only
    - CAPWAP only necessary

LRFD

- Static load test
  - ϕ=0.7 to 0.9 vs. 0.28 to 0.35
  - Ratios of 2 to 3.21
- Dynamic tests
  - ϕ=0.65 vs. 0.28 to 0.35
  - Ratios of 1.86 to 2.32
- Static and dynamic test frequency
  - Depend on site variability, more tests
- Dynamic test objective
  - Mostly for capacity verifications
    - Initial driving and restrikes
    - CAPWAP for all

Drilled Shaft Resistance



$$Q_R = fQ_n = f_{qp}Q_p + f_{qs}Q_s$$

LADOTD'S CURRENT EFFORT

Calibrating resistance factors for

- Failure condition
- 0.5 inch displacement
- 1 inch displacement

AASHTO Geotechnical Resistance Factors Drilled Shafts

Method	ϕ_{Comp}	ϕ_{Ten}
α - Method (side)	0.55	0.45
β - Method (side)	0.55	0.45
Clay or Sand (tip)	0.5	
Rock (side)	0.55	0.45
Rock (tip)	0.55	
Group (sand or clay)	0.55	0.45
Load Test	0.7	

AASHTO Table 10.5.5.2.3-1

DIFFICULTIES WITH DRILLED SHAFT CALIBRATION

- A lack of good load tests
- Calibration is more difficult

Currently, AASHTO resistance factors are being used until calibration is complete.

HOW TO APPLY RESISTANCE FACTORS

- Evaluate site variability
  - cov < 0.25; 0.25 < cov < 0.4; cov > 0.4
- Determine the need for static load tests and the number of load tests
- Determine redundancy
- Select resistance factors based on Tables 10.5.5.2.3.1-3 (Driven Piles)
- Calculate pile capacities using resistance factors
- Check serviceability
- Determine pile tip elevations

SPECIAL PROBLEMS

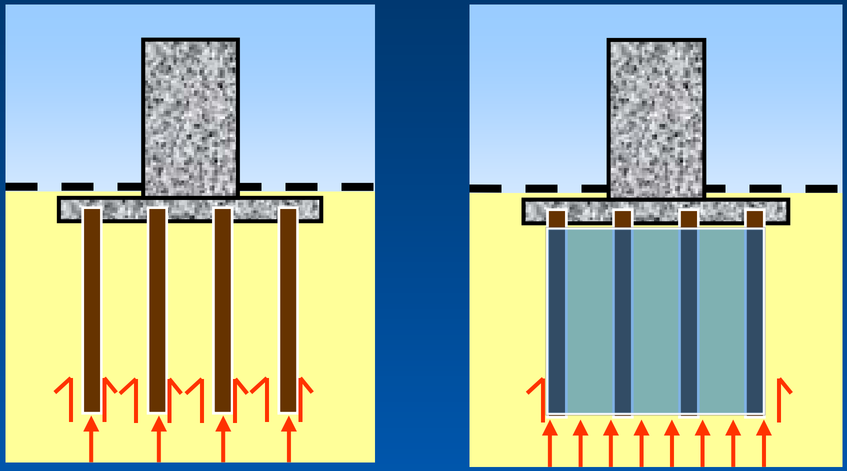
- Downdrag
- Scour
- Group efficiency

DOWNDRAG

- **New provisions in article** 3.11.8 **regarding determination of downdrag as a load**
- Revisions to load factors pending additional analysis/research

Prediction Method	Maximum	Minimum
Piles, α-Tomlinson	1.4	0.25
Piles, λ-Method	1.05	0.30
Drilled shafts, O'Neill and Reese (1999)	1.25	0.35

Group Resistance



For cohesive soils use equivalent pier approach

$R_{n\ group} = \eta \times R_{n\ single}$

where:

η = 0. 65 at c-c spacing of 2.5 diameters

η = 1.0 at c-c spacing of 6 diameters

For cohesionless soils, use group efficiency factor approach

EXPLROATION FREQUENCY

- Exploration spacing for bridges
  - 100 feet to 200 feet max.
  - If structures have width > 100 feet, additional borings will be needed
  - Retaining wall will require two rows of borings with no more than 100-ft spacings
- Boring depths are similar to current DOTD practice

TESTING REQUIREMENT

- No SPT in sand – no change
- All strength tests are to be UU or CU
  - UC can be used: supplemental only
- More laboratory or field testing many be needed to determine site variability
- Implications
  - Better quality tests (lower variability) can save cost

ENGINEERING INTERPRETATION

- Plots of depth vs. Su
- Depth vs. OCR or σ_p'
- Selection of sites (reaches) within a project
- Site variability
- Selection of resistance factors
  - Load tests?
    - Static or dynamic
    - quantity
  - Site variability

DIFFICULTIES

- Insufficient data for calibration
- Slope stability
- Shaft deflection calibration
- Scour design compatibility
  - 100 yr design; 500 yr check

FUTURE EFFORT

- Continue calibration effort
  - Walls and other foundation systems
  - Incorporate construction QC/QA into design
- Develop design manual
- Modify standard specifications
  - Sections 804 and 814
- Training
  - 2009 DOTD Conference

OTHER IMPLICATIONS

- Much greater demand on resources
- Feedback from construction
- Methods without resistance factor calibration cannot be used
- Show justification on the resistance factor selection
- More reliable system

Questions