LRFD Implementation Progress In Florida DOT

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Background

- 1992 – First looked at LRFD
- 1993 – Converted English to Metric
- 1994 – AASHTO LRFD Specification
- 1995 (February) – FHWA LRFD Training
- 1995 (October) – Draft Implementation Plan

Draft Implementation Timeline

- Oct 1995 – Implementation Preparation
- July 1997 –Training
- July 1998 – Implementation

Implementation Preparation

- Document Conversion
- Software modification
- Calibration of geotechnical resistance factors for Florida foundations

Implementation Preparation

Document Conversion - All the documents for structural design were converted to LRFD

- Structures Design Guidelines
- Specifications
- Soils and Foundation Handbook
- CADD, and etc.

Implementation Preparation

Software Modification

- In-house
  - FL-Pier (FB-PIER)
  - SPT94/SPT97 (FB-DEEP)
- Commercial

Implementation Preparation

Calibration of Geotechnical Resistance factors for Florida Foundations

- Why did we have to do the calibration?
- How did we do the calibration?

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Reasons

1. AASHTO Resistance Factors were calibrated:
    - For commonly used design methods;
    - For general geologic formations.

Reasons

1. AASHTO Resistance Factors were calibrated:
    - For commonly use design methods;
    - For general geologic formations.
2. Florida has its unique geological formation;
    - Soft Vuggy limestone
    - Ball bearing sands
    - High groundwater table

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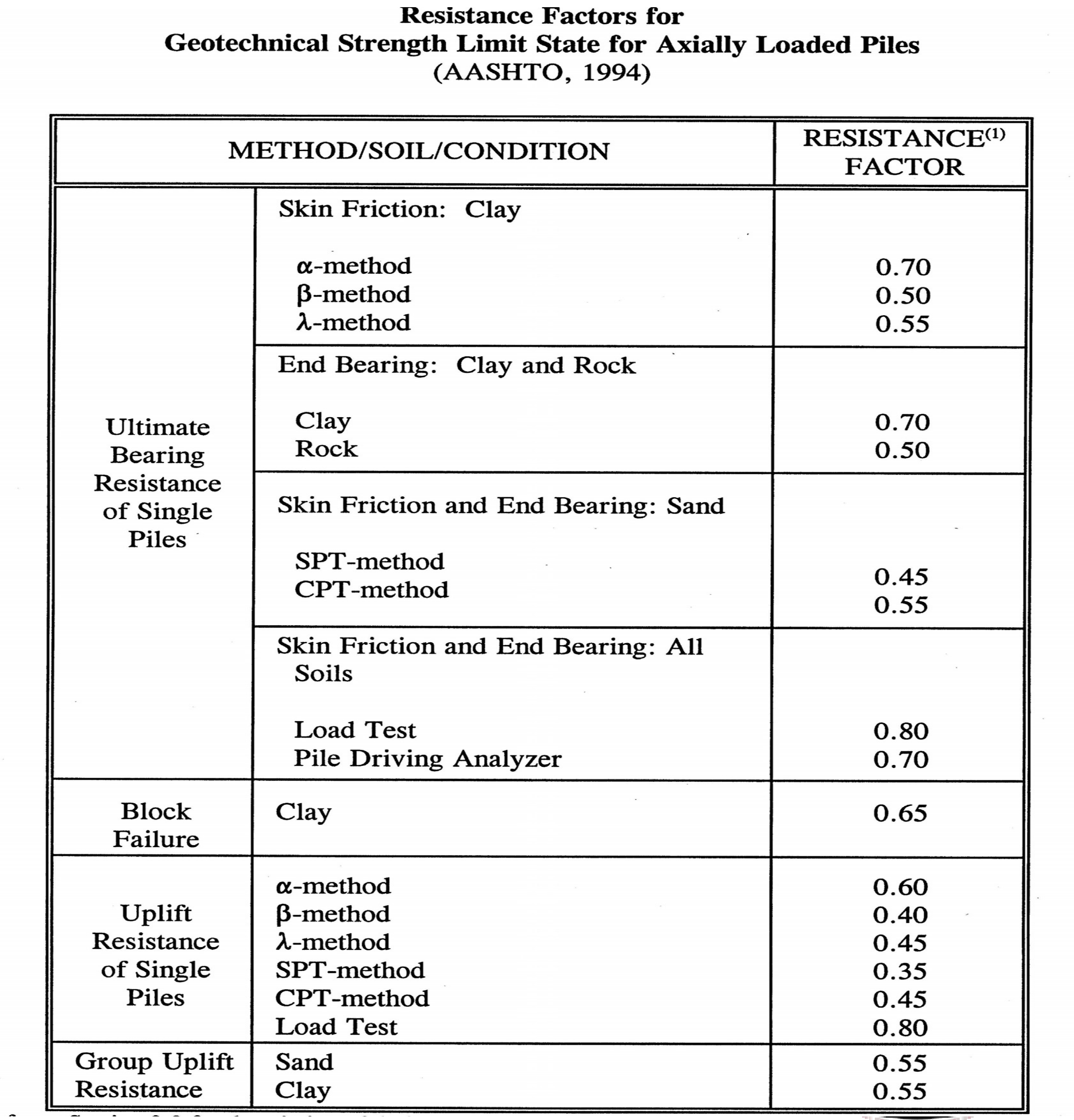
Reasons

1. AASHTO Resistance Factors were calibrated:
    - For commonly use design methods;
    - For general geologic formations.
2. Florida has its unique geological formation;
3. Methods of analyses that FDOT used were not included in the AASHTO LRFD specifications;
    - Pile Design - SPT94/SPT97 or FBDeep;
    - Drilled Shaft Design – FHWA or O'Neil Method for sand and clay, McVay's Method for rock socket side shear

Reasons



Resistance Factors for
Geotechnical Strength Limit State for Axially Loaded Piles
(AASHTO, 1994)

METHOD/SOIL/CONDITION		RESISTANCE[1] FACTOR
Ultimate Bearing Resistance of Single Piles	Skin Friction: Clay	
	α-method	0.70
	β-method	0.50
	λ-method	0.55
	End Bearing: Clay and Rock	
	Clay	0.70
	Rock	0.50
	Skin Friction and End Bearing: Sand	
	SPT-method	0.45
	CPT-method	0.55
	Skin Friction and End Bearing: All Soils	
	Load Test	0.80
	Pile Driving Analyzer	0.70
Block Failure	Clay	0.65
Uplift Resistance of Single Piles	α-method	0.60
	β-method	0.40
	λ-method	0.45
	SPT-method	0.35
	CPT-method	0.45
	Load Test	0.80
Group Uplift Resistance	Sand	0.55
	Clay	0.55

Reasons

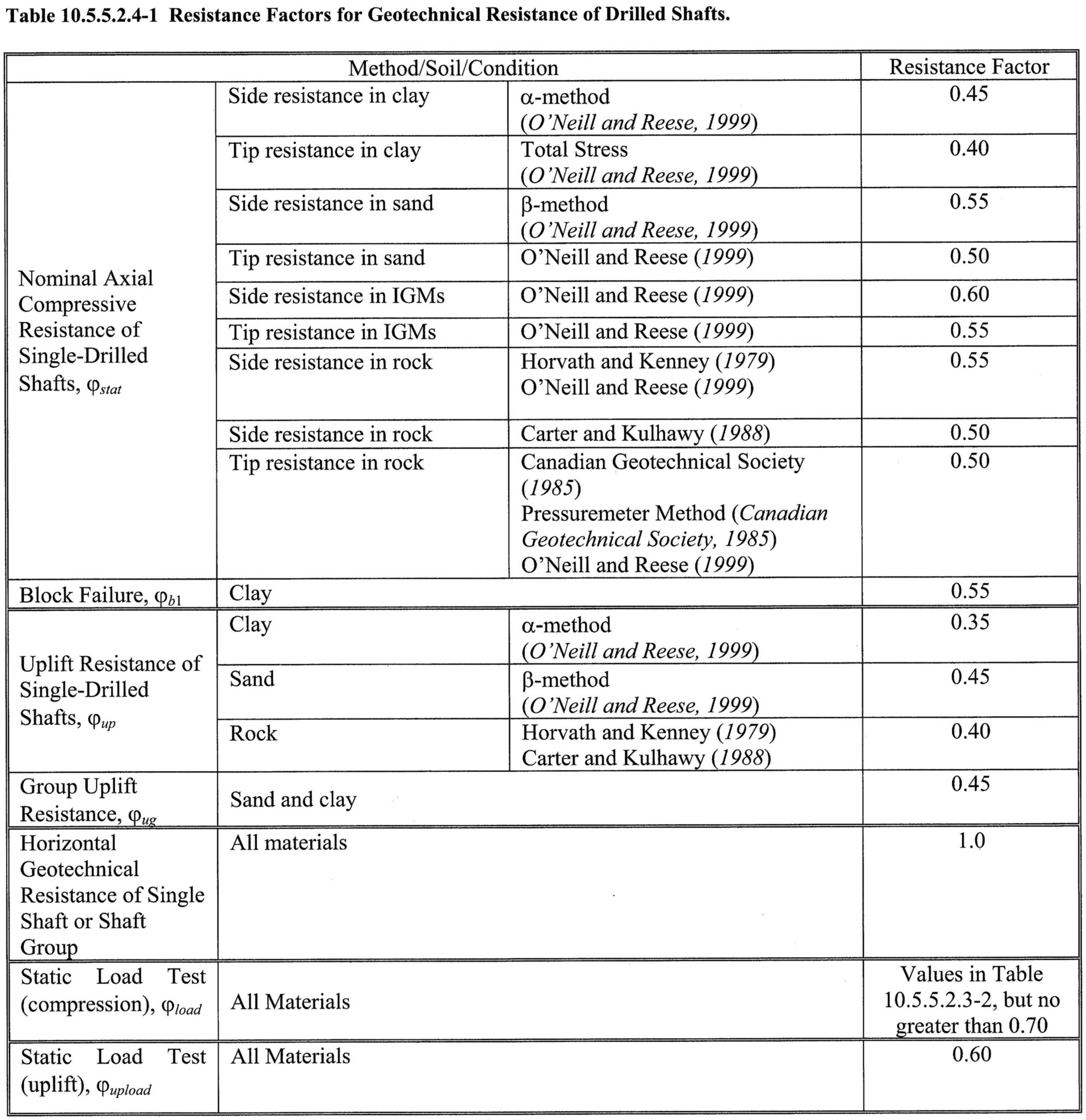


Table 10.5.5.2.4-1 Resistance Factors for Geotechnical Resistance of Drilled Shafts.

Method/Soil/Condition			Resistance Factor
Nominal Axial Compressive Resistance of Single-Drilled Shafts, φ_{stat}	Side resistance in clay	α-method (*O'Neill and Reese, 1999*)	0.45
	Tip resistance in clay	Total Stress (*O'Neill and Reese, 1999*)	0.40
	Side resistance in sand	β-method (*O'Neill and Reese, 1999*)	0.55
	Tip resistance in sand	O'Neill and Reese (*1999*)	0.50
	Side resistance in IGMs	O'Neill and Reese (*1999*)	0.60
	Tip resistance in IGMs	O'Neill and Reese (*1999*)	0.55
	Side resistance in rock	Horvath and Kenney (*1979*) O'Neill and Reese (*1999*)	0.55
	Side resistance in rock	Carter and Kulhawy (*1988*)	0.50
	Tip resistance in rock	Canadian Geotechnical Society (*1985*) Pressuremeter Method (*Canadian Geotechnical Society, 1985*) O'Neill and Reese (*1999*)	0.50
Block Failure, φ_{b1}	Clay		0.55
Uplift Resistance of Single-Drilled Shafts, φ_{up}	Clay	α-method (*O'Neill and Reese, 1999*)	0.35
	Sand	β-method (*O'Neill and Reese, 1999*)	0.45
	Rock	Horvath and Kenney (*1979*) Carter and Kulhawy (*1988*)	0.40
Group Uplift Resistance, φ_{ug}	Sand and clay		0.45
Horizontal Geotechnical Resistance of Single Shaft or Shaft Group	All materials		1.0
Static Load Test (compression), φ_{load}	All Materials		Values in Table 10.5.5.2.3-2, but no greater than 0.70
Static Load Test (uplift), φ_{upload}	All Materials		0.60

Reasons

1. AASHTO Resistance Factors were calibrated:
    - For commonly use design methods;
    - For general geologic formations.
2. Florida has its unique geological formation;
3. Methods of analyses that FDOT used are not included in the AASHTO LRFD specifications;
4. Adopting the AASHTO LRFD specifications without considering Items 2 & 3 would be either overly or under conservative.

Reasons

Realistic Resistance Factors should be calibrated for the combination of

- Foundation Type
- Soil Type / local geological condition
- Method of field exploration and laboratory testing
- Design Methodology

How did we do the calibration?

1. Estimate the resistance factors in ASD design methods by fitting with the factors of safety to avoid drastic deviation from the past safe and satisfactory practices as follows;

ASD $$\frac{R_n}{FS} \geq Q_D + Q_L \rightarrow R_n \geq FS(Q_D + Q_L)$$

LRFD $$\phi R_n \geq \gamma_D Q_D + \gamma_L Q_L \rightarrow \phi \geq \frac{\gamma_D Q_D + \gamma_L Q_L}{R_n}$$

How did we do the calibration?

Thus

$$\phi \geq \frac{\gamma_D Q_D + \gamma_L Q_L}{FS(Q_D + Q_L)}$$

$$\phi \geq \frac{\gamma_D Q_D / Q_L + \gamma_L}{FS(Q_D / Q_L + 1)}$$

How did we do the calibration?

2. Observe the resistance factor versus safety factors with different bridge span lengths, dead/live load ratios, type of foundations and design methods.

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How did we do the calibration?

QD/QL	Resistance Factor, ϕ			
	FS=1.5	FS=2.0	FS=2.5	FS=3.0
1	1.00	0.75	0.60	0.50
2	0.94	0.71	0.57	0.47
3	0.92	0.69	0.55	0.46
4	0.90	0.68	0.54	0.45
5	0.89	0.67	0.53	0.44
6	0.88	0.66	0.53	0.44
7	0.88	0.66	0.53	0.44
8	0.87	0.65	0.52	0.44
9	0.87	0.65	0.52	0.43
Median	0.94	0.70	0.56	0.47
Recommended	0.95	0.70	0.55	0.50

How did we do the calibration?

Calibration using Reliability Theory

- FOSM Method
- FDOT Deep Foundation Database
  - For Piles and Drilled Shafts

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How did we do the calibration?

Consider both loads, Q, and resistance, R, are random variables and Q < R. The probability of failure is;

$$P_f = P(R < Q) = P[(R - Q) < 0]$$

Calibration using Reliability Theory

Assume R and Q are log-normal distribution then;

$$P_f = P[\ln(R/Q) < 0)] = 1 - f\left[\frac{\ln(\bar{R}/\bar{Q})\sqrt{(1+V_Q^2)/(1+V_R^2)}}{\sqrt{\ln[(1+V_R^2)(1+V_Q^2)]}}\right]$$

$\bar{R}$ = mean resistance values
$\bar{Q}$ = mean load values
V_R, V_Q = coefficients of variation of R and Q

Calibration using Reliability Theory

Reliability Index

$$\beta = \frac{\ln(\bar{R}/\bar{Q})\sqrt{(1+V_Q^2)/(1+V_R^2)}}{\sqrt{\ln[(1+V_R^2)(1+V_Q^2)]}}$$

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Calibration using Reliability Theory

Reliability Index β	Probability of Failure P_f
2.0	1.00E-01
2.5	0.99E-02
3.0	1.15E-03
3.5	1.34E-04
4.0	1.56E-05
4.5	1.82E-06

Probability of Failure Pf	Reliability Index β
1.0E-01	1.96
1.0E-02	2.50
1.0E-03	3.03
1.0E-04	3.57
1.0E-05	4.10
1.0E-06	4.64

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Calibration using Reliability Theory

Select Target Reliability Index, β_T
for calibration of the resistance factor.

$$\phi = \frac{\lambda_R(\gamma_D Q_D / Q_L + \gamma_L)\sqrt{(1+V_{QD}^2+V_{QL}^2)/(1+V_R^2)}}{(\lambda_{QD} Q_D / Q_L + \lambda_{QL})\exp[\beta_T\sqrt{\ln[(1+V_R^2)(1+V_{QD}^2+V_{QL}^2)}]}$$

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Deep Foundations Calibrations

- Driven Piles
  - SPT-94 – FDOT Pile Design Software
  - Dynamic Load Testing using PDA
  - Static Load Testing
  - Osterberg Cell Load Test
  - Statnamic Load Test

Resistance Factors for Driven Piles

Design	Method	ASD		Target Reliability Index, β_T	Resistance Factor, ϕ
		FS	β		
Compression	SPT94	2.0	2.45-2.57	2.5	0.65
	PDA(EOD)	2.5	3.04-3.14	2.5	0.65
	WEAP	3.0	2.28-3.11	2.5	0.35
	Static Load Test	2.0	-	2.5	0.75
Uplift	SPT94	2.0	-	-	0.55
	Static Load Test	2.0	-	-	0.65
Lateral Load	Structure Stab.	-	-	-	-

Resistance Factors for Driven Piles

Design	Method	Resistance Factor, ϕ		
		AASHTO		FDOT
		1994	2007	
Compression	SPT94	0.45	0.3	0.65
	PDA(EOD)	0.7	0.65	0.65
	WEAP	-	0.40	0.35
	Static Load Test	0.80	0.55-0.80[a]	0.75
Uplift	SPT94	0.35	0.25	0.55
	Static Load Test	0.80	0.60	0.65

a. for different site variability

Deep Foundations Calibrations

- Drilled Shafts
  - Design shafts embedded in both soils and rocks
  - Design shafts socketed in rock only
  - Static Load Test
  - Osterberg Cell Load Test
  - Statnamic Load Test

Resistance Factors for Drilled Shafts

(Bridge foundation)

Design	Method	ASD		Target Reliability Index, β_T	Resistance Factor, ϕ
		FS	β		
Compression * (in rock)	Side friction including soil	2.5	4.45-4.60	4.0	0.60
	Side friction only	2.5	3.73-3.83	3.5	0.65
	Including 1/3 end bearing	2.5	3.49-3.59	2.5	0.55
	Load Test (including static, Statnamic, & Osterberg)	2.0	-	2.5	0.75
Uplift	Same as side friction only	2.5	-	-	0.50
Lateral Load	Structure Stab.	-	-	-	1.0

* Note : Use McVay's side friction method for design

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Resistance Factors for Drilled Shafts

(Bridge foundation)

Design	Method	Resistance Factor, ϕ		
		AASHTO		FDOT
		1994	2007	
Compression* (in rock)	Side friction only	0.55-0.65	0.60	0.65
	Including 1/3 end bearing	-	0.55	0.55
	Load Test (including static, Statnamic, & Osterberg)	0.80	$0.55\text{-}0.70^b$	0.75
Uplift	Same as side friction only	-	0.40	0.50
Lateral Load	Structure Stab.	-	-	-

- * : Use McVay's side friction method for design
- b: for various site variability but no greater than 0.70.

Resistance Factors for Drilled Shafts

(Miscellaneous Structures)

Design	Method	ASD		Target Reliability Index, β_T	Resistance Factor, ϕ
		FS	β		
Compression*	Same as bridge foundations	2.5	-	-	0.55
Uplift	Same as bridge foundations	2.5	-	-	0.50
Lateral Load	Brom's	1.5	-	-	0.9
Tosion	FDOT Structures Office	1.0	-	-	1.0

* Note : Use McVay's side friction method for design

Implementation Plan - 1995

- Documents
- Software
- Resistance factors calibration for Florida foundations
- Training

Training

- Training started in July 1997
  - Six (6) two-day training sessions in Metric Units
  - Topics covered
    - Loads
    - Concrete Design
    - Steel Design
    - Geotechnical Design

LRFD Implementation - 1998

- Intended to implement LRFD starting July 1998 in Metric units
- Obstacles
  - In March 1998: Change Metric to English
  - LRFD Curved Girder & Movable Bridge Specifications were not available
  - Retaining Walls (MSE & Cast-in-Place)
    - Design Software not available

LRFD Implementation - 2002

- Complete implementation in 2002
- Except
  - Steel curved girder - LFD Specification
  - MSE Walls - ASD
    - Design software not available

LRFD Implementation – Fine Tuning

- Calibrate the resistance factor for Statnamic load test - 2003
- Added Non-redundant resistance factor for drilled shaft design - 2005

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Resistance Factors for Drilled Shafts 2007

Bridge foundation

Design	Method	Resistance Factor, ϕ
Compression * (in rock)	Side friction only	0.60
	Including 1/3 end bearing	0.55
	Non-Redundant (2005)	0.45
	Load Test (including static, , & Osterberg)	0.75
	Statnamic (March 2003)	0.70
Uplift	Same as side friction only	0.50
Lateral Load	Structure Stab.	-

* Note : Use McVay's side friction method for design

Resistance Factors for Driven Piles 2007

Design	Method	Resistance Factor, ϕ
Compression	SPT94	0.65
	PDA(EOD)	0.65
	WEAP	0.35
	Static Load Test	0.75
	Statnamic (March 2003)	0.70
Uplift	SPT94	0.55
	Static Load Test	0.65

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Implementation - 2007

- MSE Walls – 100% LRFD since July 1, 2007
- FDOT provides
  - EXCEL Spreadsheet for MSE wall external stability analyses
  - EXCEL Spreadsheet for Cantilever Wall Design

Implementation - 2007

These retaining walls programs were written with the modification of bearing resistance factor:

- AASHTO:
  - All retaining Walls $\phi_b = 0.45$ (SPT)
- FDOT:
  - MSE Walls $\phi_b = 0.55$
  - Cantilever Walls $\phi_b = 0.50$

Recent Works on Resistance Factors

- **Cylinder piles** –Calibrated resistance factors, ϕ, and added to FB-DEEP,
- **Site Variability** - Using geostatistic and bootstrap analyses to calibrate resistance factors, ϕ, with the consideration of 3-D site variability, expect to have results in later part of 2008 or early 2009;
- **New Instrumentation System** - Evaluating a new system of embedded instrumentation for wireless monitoring of deep foundations, during and after construction;
- **New Design Concept** - Using FDOT's new web-base geotechnical database in the design to increase the confidence level. Resistance factors will be re-calibrated when enough data is collected by using this approach.

Summary

- FDOT implemented LRFD starting in January 2002,
- Implemented the LRFD MSE wall design in July 2007 ;
- Fine tune and re-calibrate resistance factors for any items that are deemed necessary and is an on-going work.

Conclusion

- AASHTO resistance factors should be used with caution because they may not be proper for every state;
- A geotechnical database should be developed by each state;
- Resistance factors should be calibrated based on locally developed database and local geologic conditions as well as experience;
- A standard procedure should be developed for resistance factor calibration.

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END

Any Questions?