Fundamental Principles of Foundation Design

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Foundation Design Requires a Blending
of
Soil/Foundation Interaction Modeling
and
Engineering Judgment

Foundation Design Process

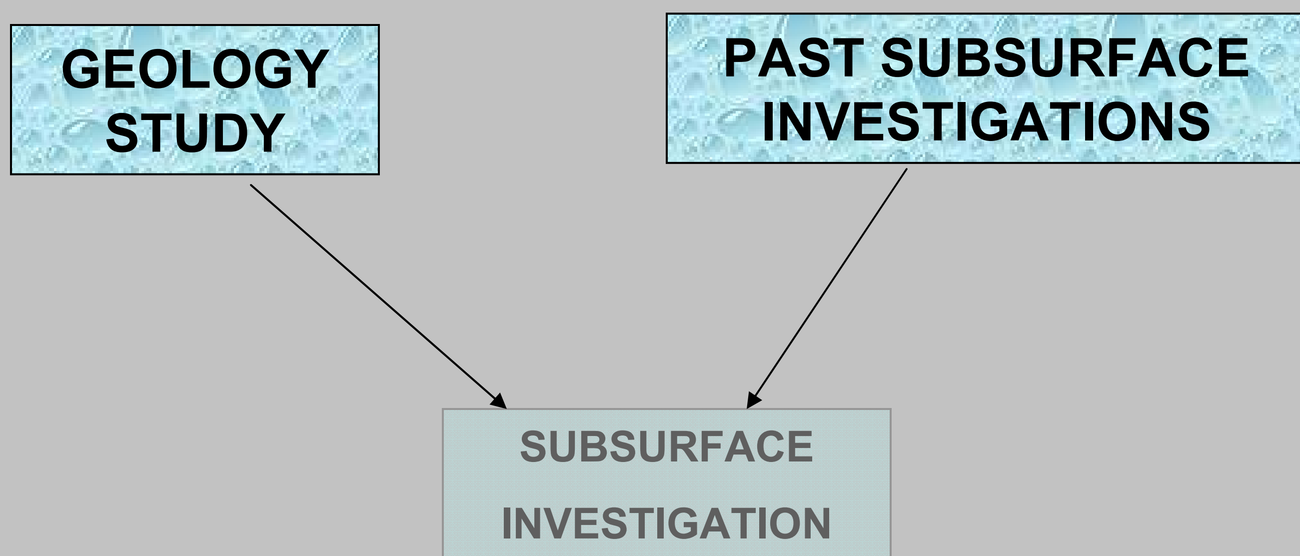
INPUT DATA → FOUNDATION DESIGN → CONTRACT DRAWINGS AND SPECIFICATIONS → CONSTRUCTION MONITORING AND AS-BUILT INFORMATION

Input Data

SUBSURFACE

INVESTIGATION

Input Data


GEOLOGY STUDY
PAST SUBSURFACE INVESTIGATIONS
SUBSURFACE INVESTIGATION

Input Data

GEOLOGY STUDY

PAST SUBSURFACE INVESTIGATIONS

SUBSURFACE INVESTIGATION

STRUCTURE TYPES

(Lattice Towers, Poles, H-Frames, Etc.)

AND ROLE

(Tangent, Runing Angle, Dead End, Etc.)

Input Data

GEOLOGY STUDY

PAST SUBSURFACE INVESTIGATIONS

SUBSURFACE INVESTIGATION

MODE OF FOUNDATION LOADS
(Moment, Horizontal, Uplift, Compression and Combinations)

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(Lattice Towers, Poles, H-Frames, Etc.)

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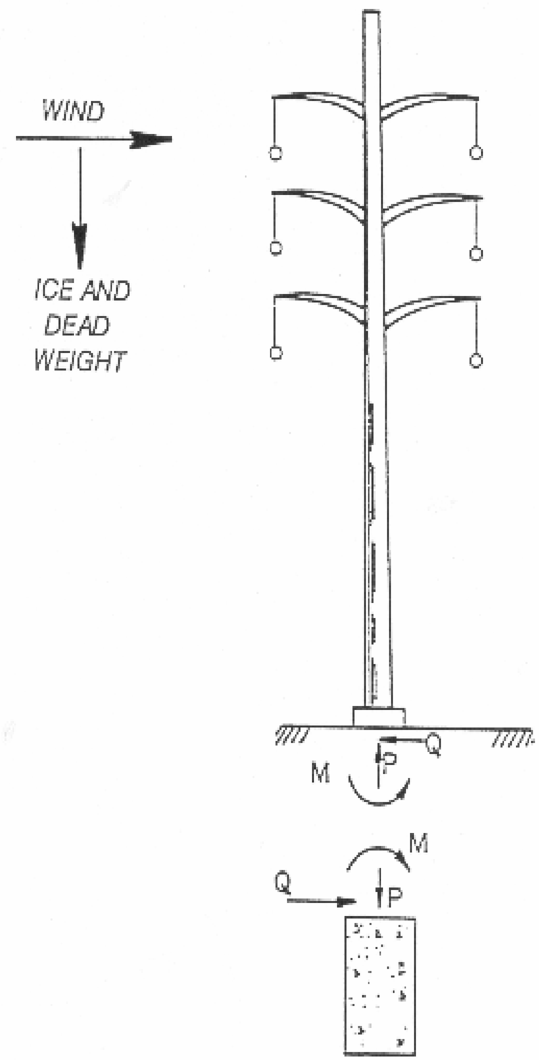
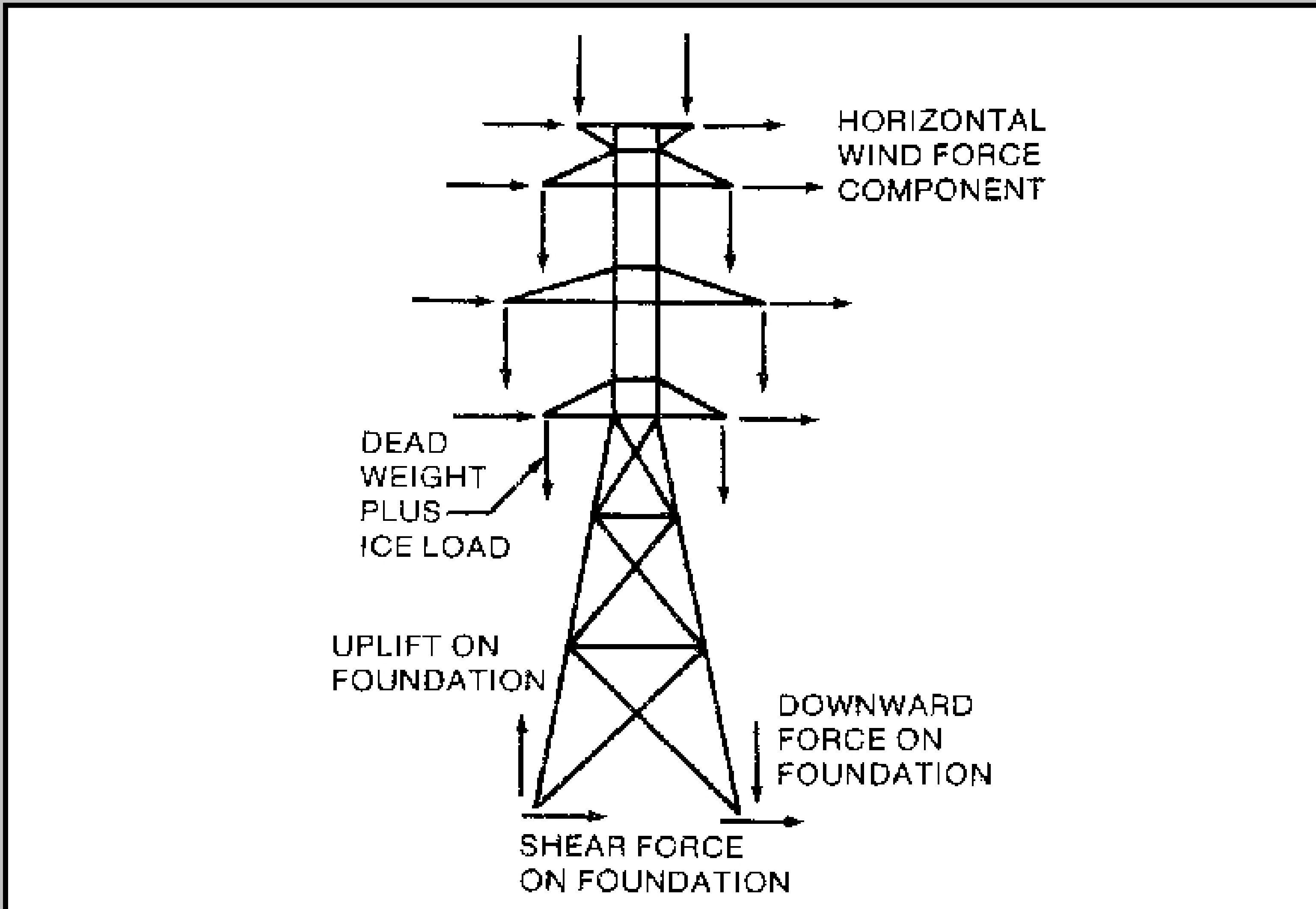


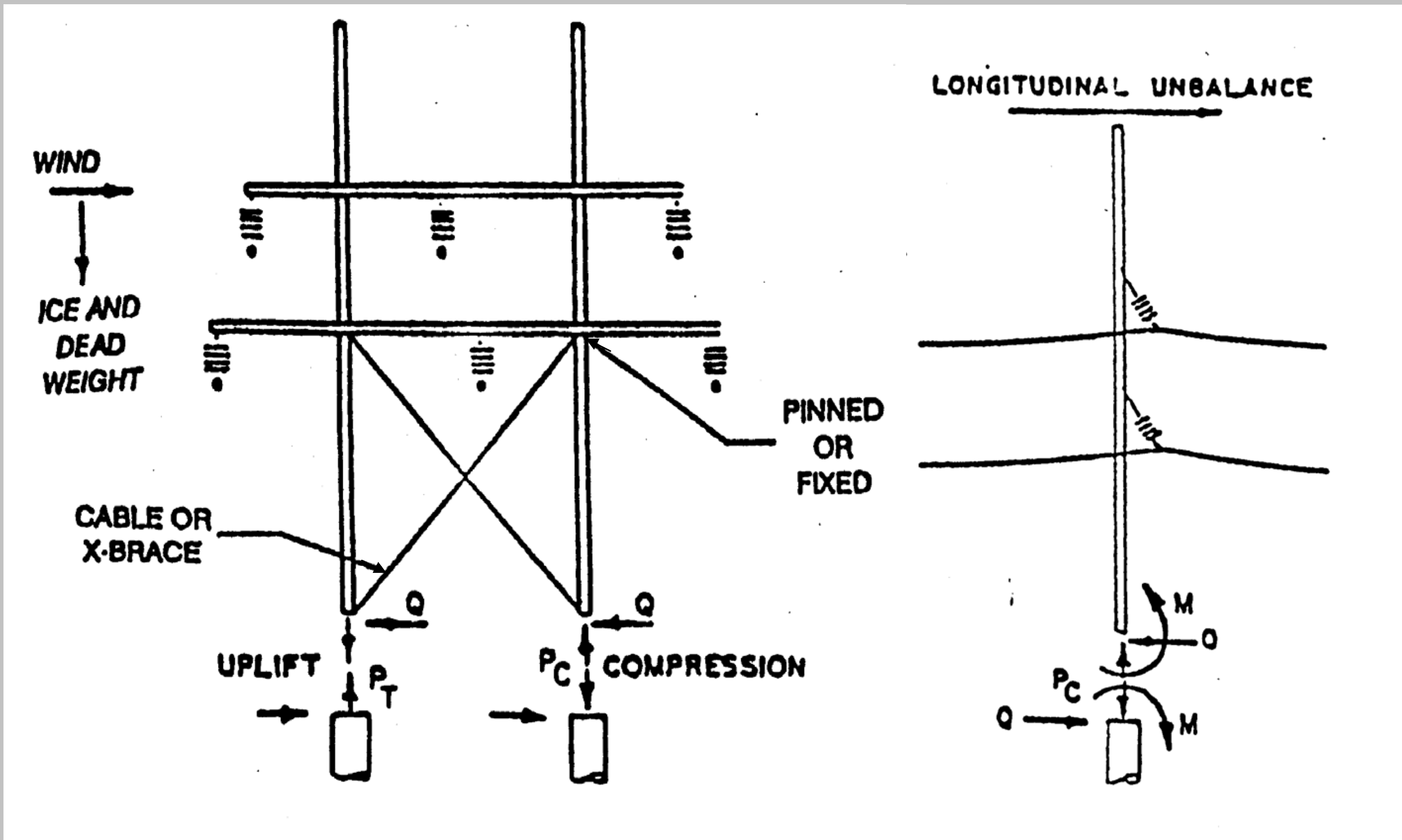
SINGLE POLE STRUCTURES

Input Data



LATTICE TOWER (FOUR-LEGGED) STRUCTURES

Input Data



H-FRAME STRUCTURES

Input Data

GEOLOGY STUDY

PAST SUBSURFACE INVESTIGATIONS

NUMBER, TYPE AND LOCATION OF BORINGS

SUBSURFACE INVESTIGATION

MODE OF FOUNDATION LOADS

(Moment, Horizontal, Uplift, Compression and Combinations)

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(Lattice Towers, Poles, H-Frames, Etc.)

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GEOLOGY STUDY

PAST SUBSURFACE INVESTIGATIONS

NUMBER, TYPE AND LOCATION OF BORINGS

SUBSURFACE INVESTIGATION

LINE DESIGN CRITERIA

Line Reliability Issues
Component Reliability Issues

MODE OF FOUNDATION LOADS

(Moment, Horizontal, Uplift, Compression and Combinations)

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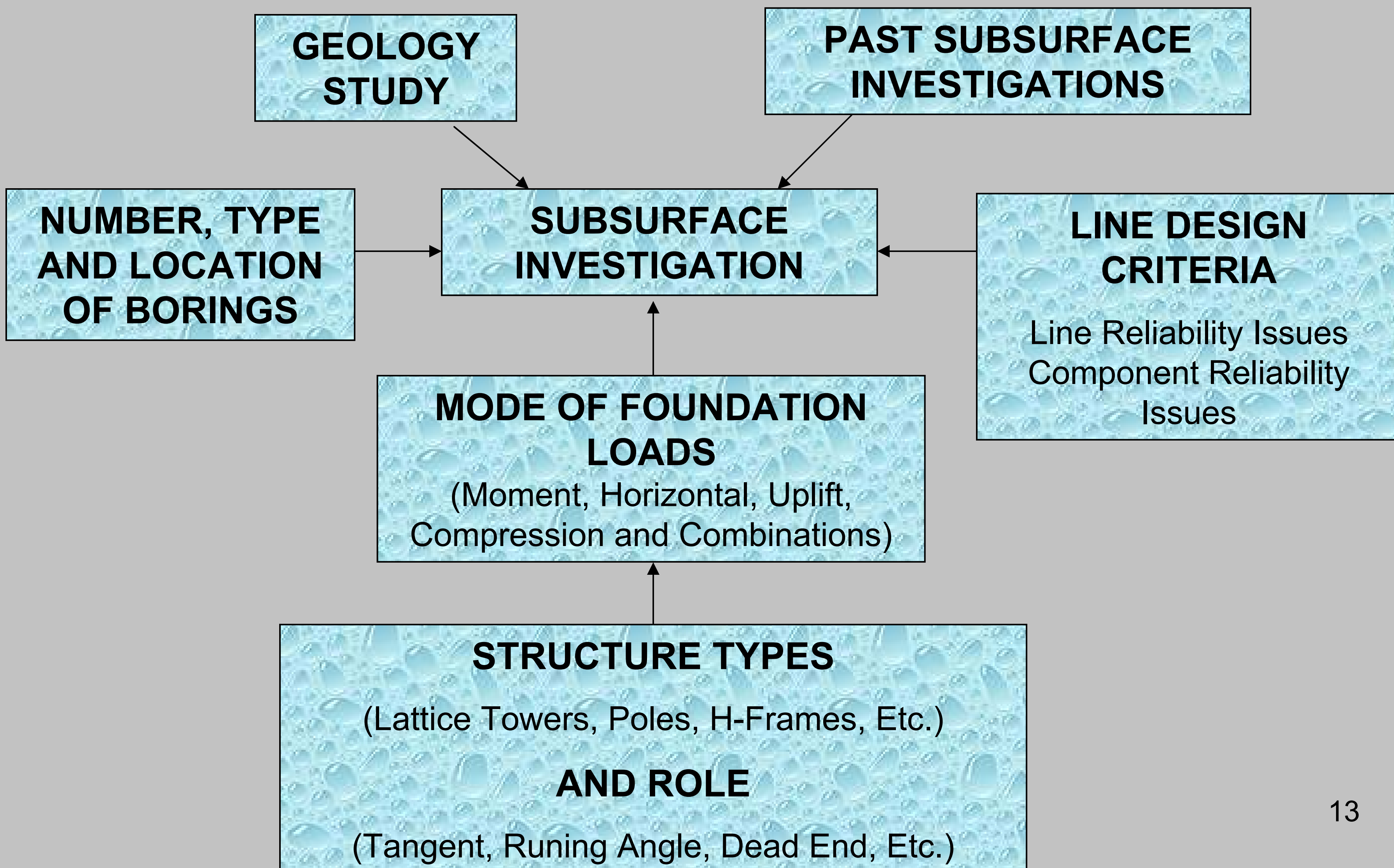
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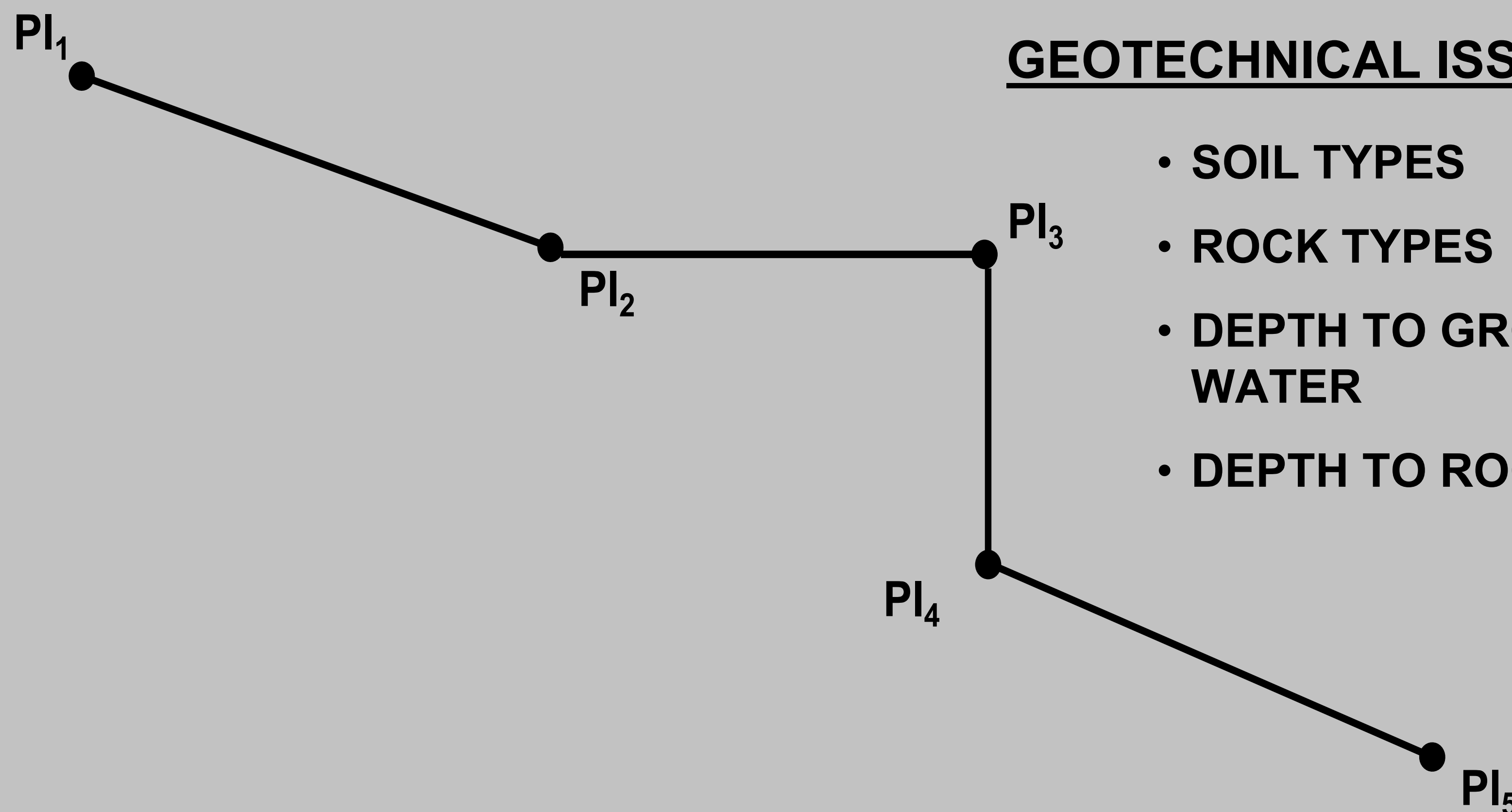
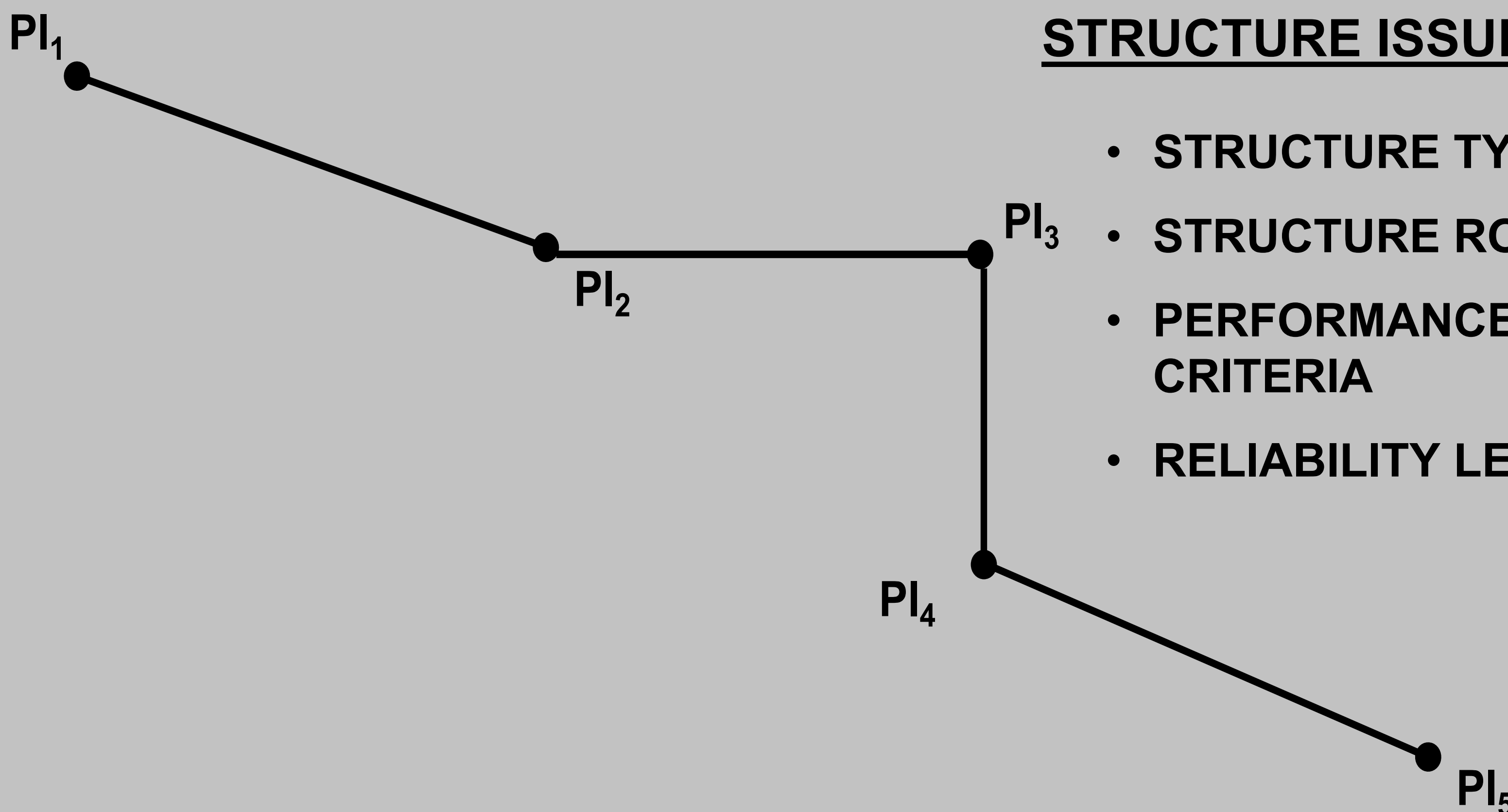
How should you approach obtaining subsurface information and geotechnical design parameters?



GEOTECHNICAL ISSUES

- **SOIL TYPES**
- **ROCK TYPES**
- **DEPTH TO GROUND WATER**
- **DEPTH TO ROCK**

How should you approach obtaining subsurface information and geotechnical design parameters?

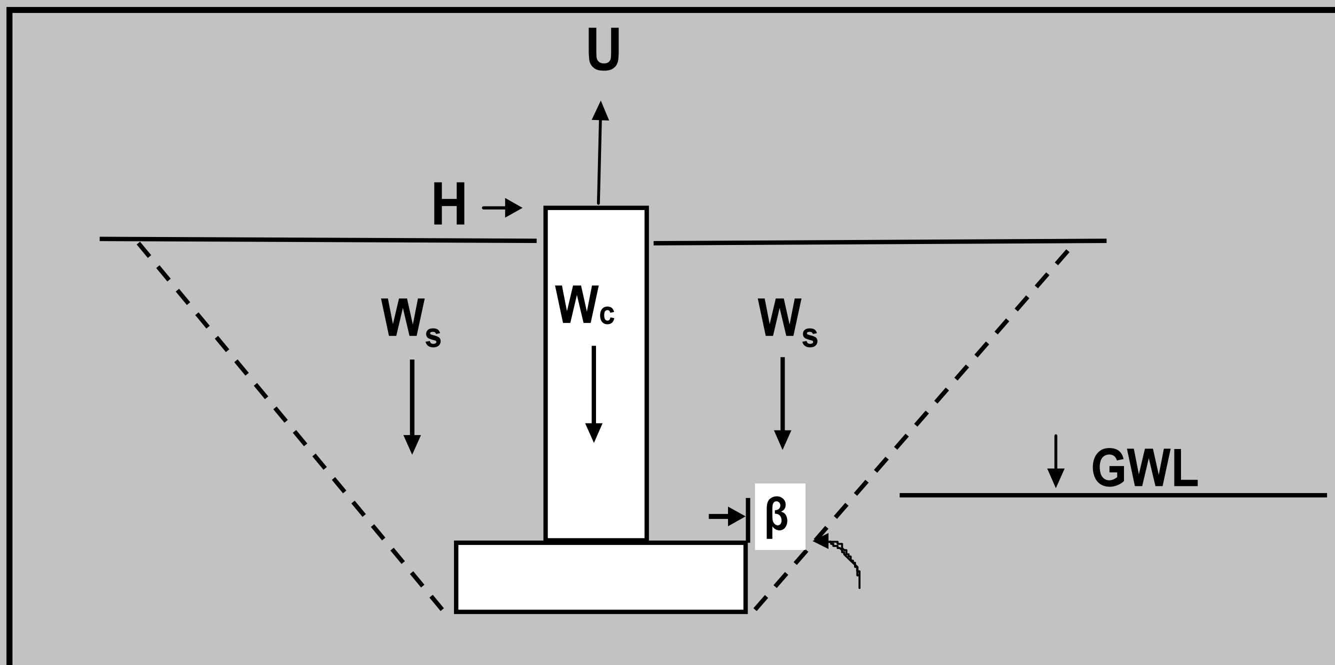


<u>STRUCTURE ISSUES</u>

- **STRUCTURE TYPES**
- **STRUCTURE ROLES**
- **PERFORMANCE CRITERIA**
- **RELIABILITY LEVEL**

- Free-Standing Lattice Tower; Concrete Spread Footings;

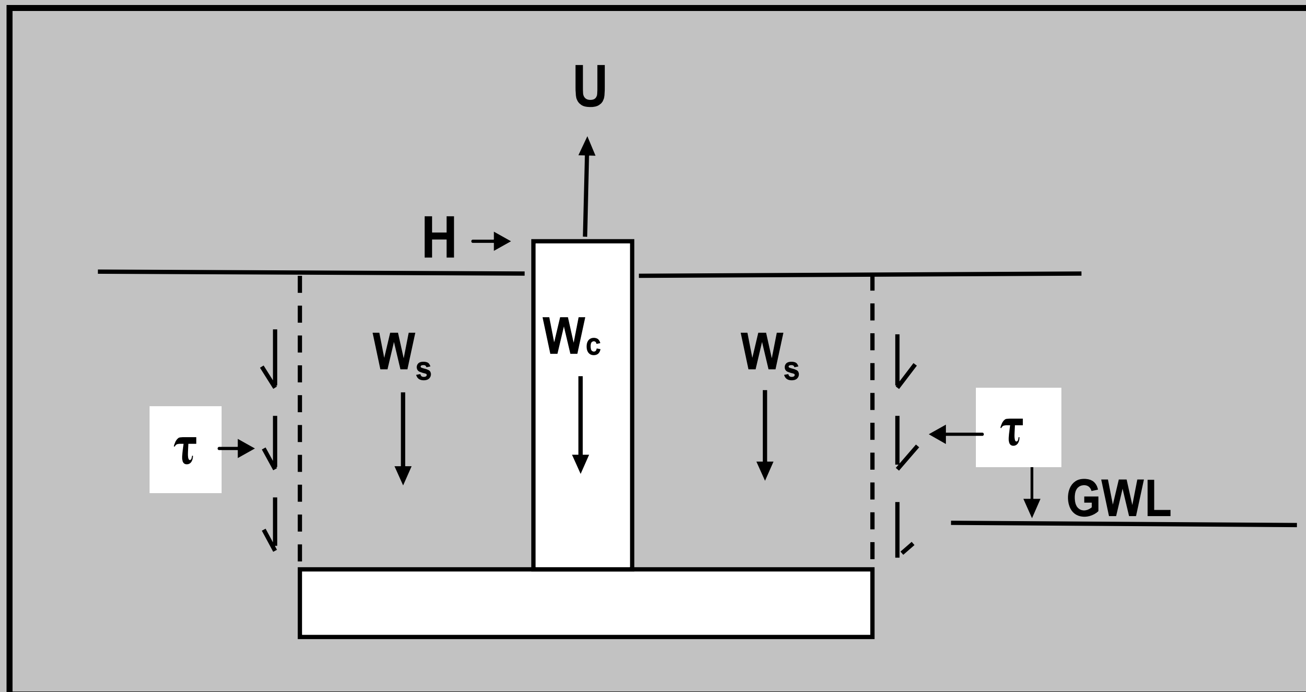
  Frustrum Design Method



- What geotechnical data do we need?
  - *All cohesive soil*
  - *All cohesionless soil*
  - *Layered soil conditions*

- Free-Standing Lattice Tower; Concrete Spread Footings;

Side Friction Design Method

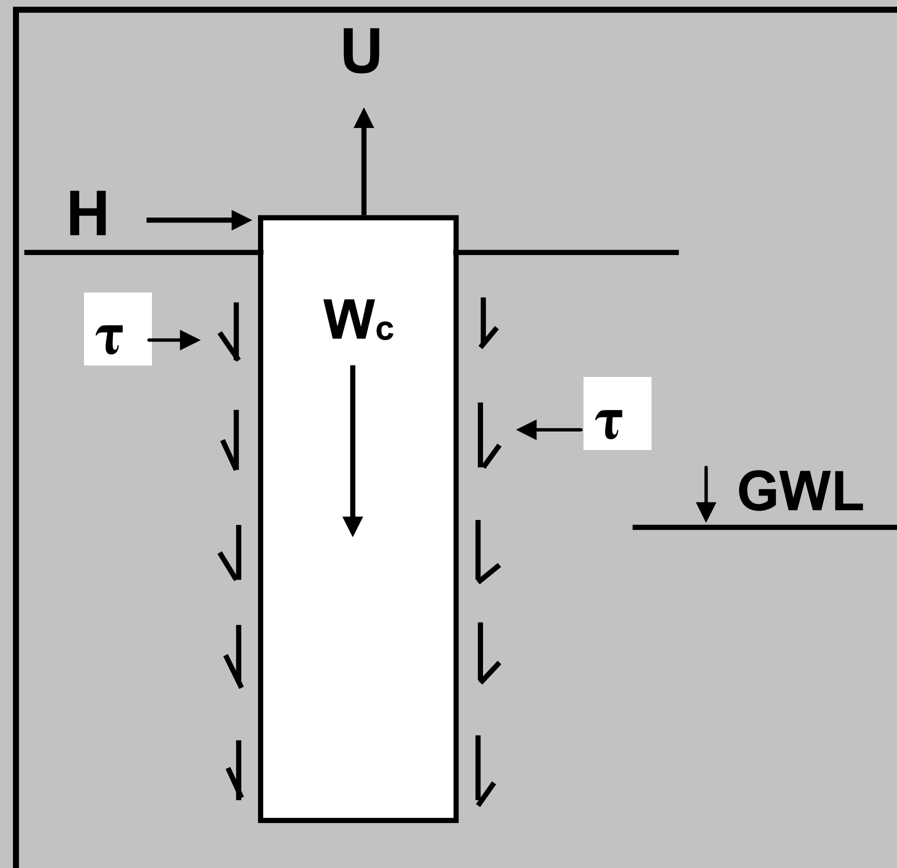


- What geotechnical data do we need?
  - *All cohesive soil*
  - *All cohesionless soil*
  - *Layered soil conditions*

- Free-Standing Lattice Tower; Drilled Shaft;

Cylindrical Shear Design Method

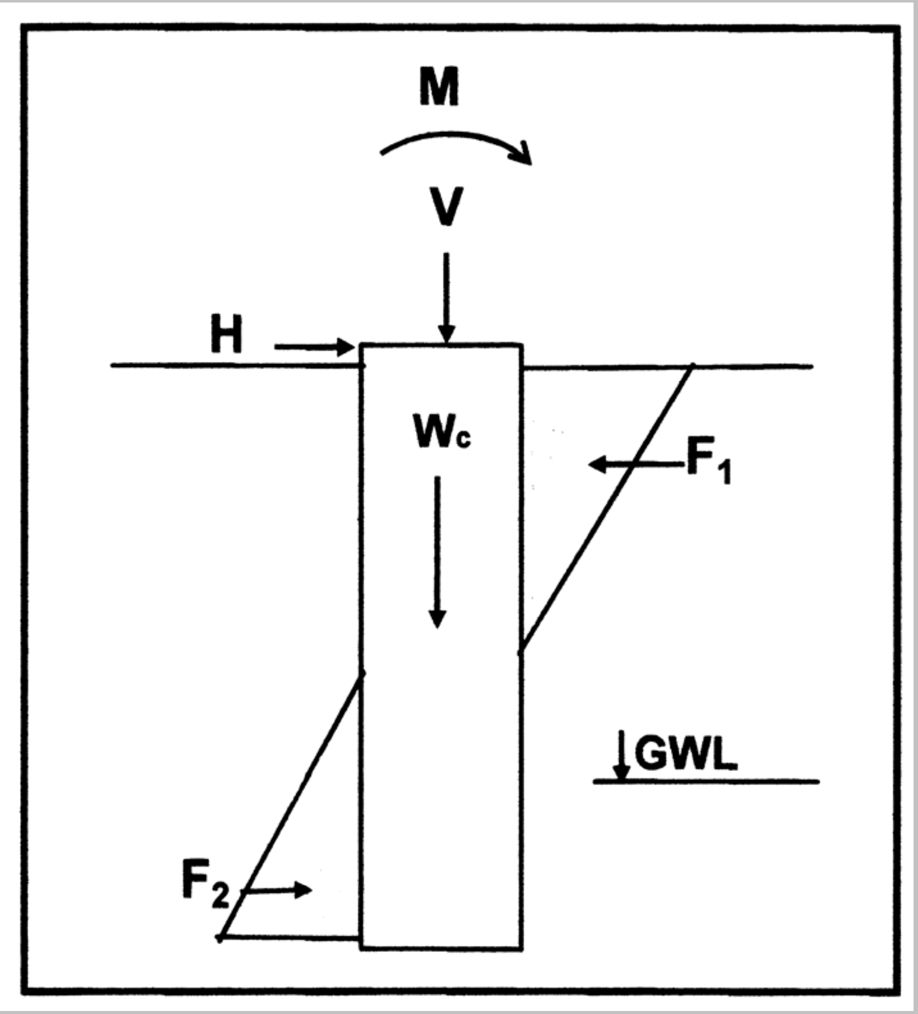
- What geotechnical data do we need?
  - *All cohesive soil*
  - *All cohesionless soil*
  - *Layered soil conditions*



- Tubular Steel Pole; Drilled Shaft;

Hansen Design Method

- What geotechnical data do we need?
  - *All cohesive soil*
  - *All cohesionless soil*
  - *Layered soil conditions*



Foundation Design Process

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ASCE MANUAL 74 RBD METHOD → FOUNDATION DESIGN

ASCE Manual 74 Reliability-Based Design (RBD) Method

The ASCE Method allows the designer to:

- Consider the variability of loadings.
- Consider the variability of component strength.
- Vary reliability levels between lines.
- Vary reliability levels between line components.

The Load Resistance Factor Design (LRFD) equation presented in Section 1 of Manual 74 for weather-related (reliability based) loads is as follows:

$$\Phi_C R_e > \text{effect of } [DL + \gamma\, Q_{50}] \qquad (1)$$

in which:

- **Φ_C = strength (resistance) factor which can be selected to adjust the reliability of the component;**
- **R_e = the e-th % design strength for the component;**
- **DL = dead load effect in the component;**
- **γ = load factor applied to the live load effect Q_{50};**
- **Q_{50} = load effect produced by combinations of wind velocity, ice thickness, and/or temperature, which has a 50-year return period**

Load Factors to Adjust Line Reliability by Factor LRF

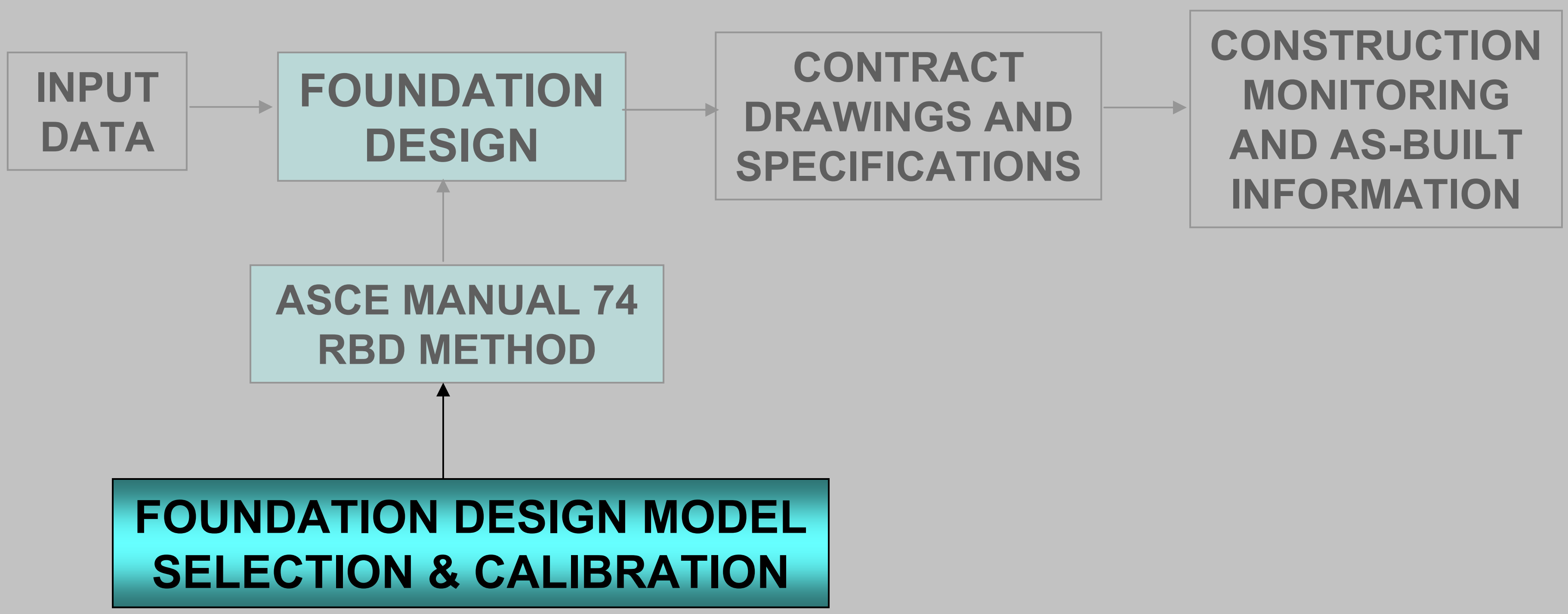
Line Reliability Factor (LRF)	1	2	4	8
Load Factor, γ	1.0	1.15	1.3	1.4
Load Return Period - RP (years)	50	100	200	400

Strength Factors to Adjust Component Reliability by Factor CRF for Strength Exclusion Limit, e of 5 to 10%

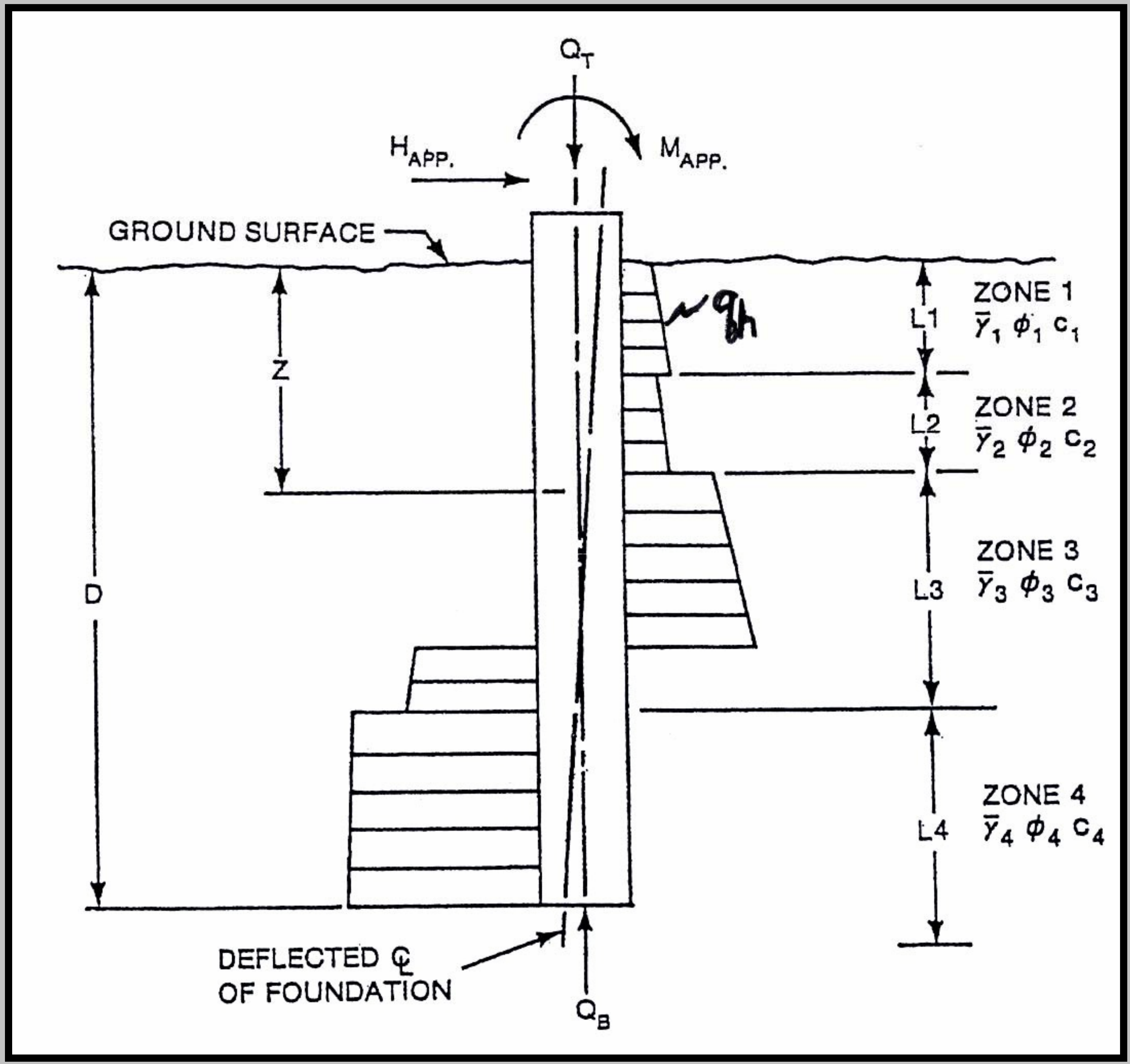
Component Reliability Factor (CRF)	1	2	4
CRF, Φ_C, for COV_R = 10-20%	1.00	0.85	0.73
CRF, Φ_C, for COV_R = 30%	1.05	0.87	0.76
CRF, Φ_C, for COV_R = 40%	1.09	0.88	0.77
CRF, Φ_C, for COV_R = 50%	1.11	0.90	0.75

NOTE: COV_R = Coefficient of Variation of Resistance

Foundation Design Process

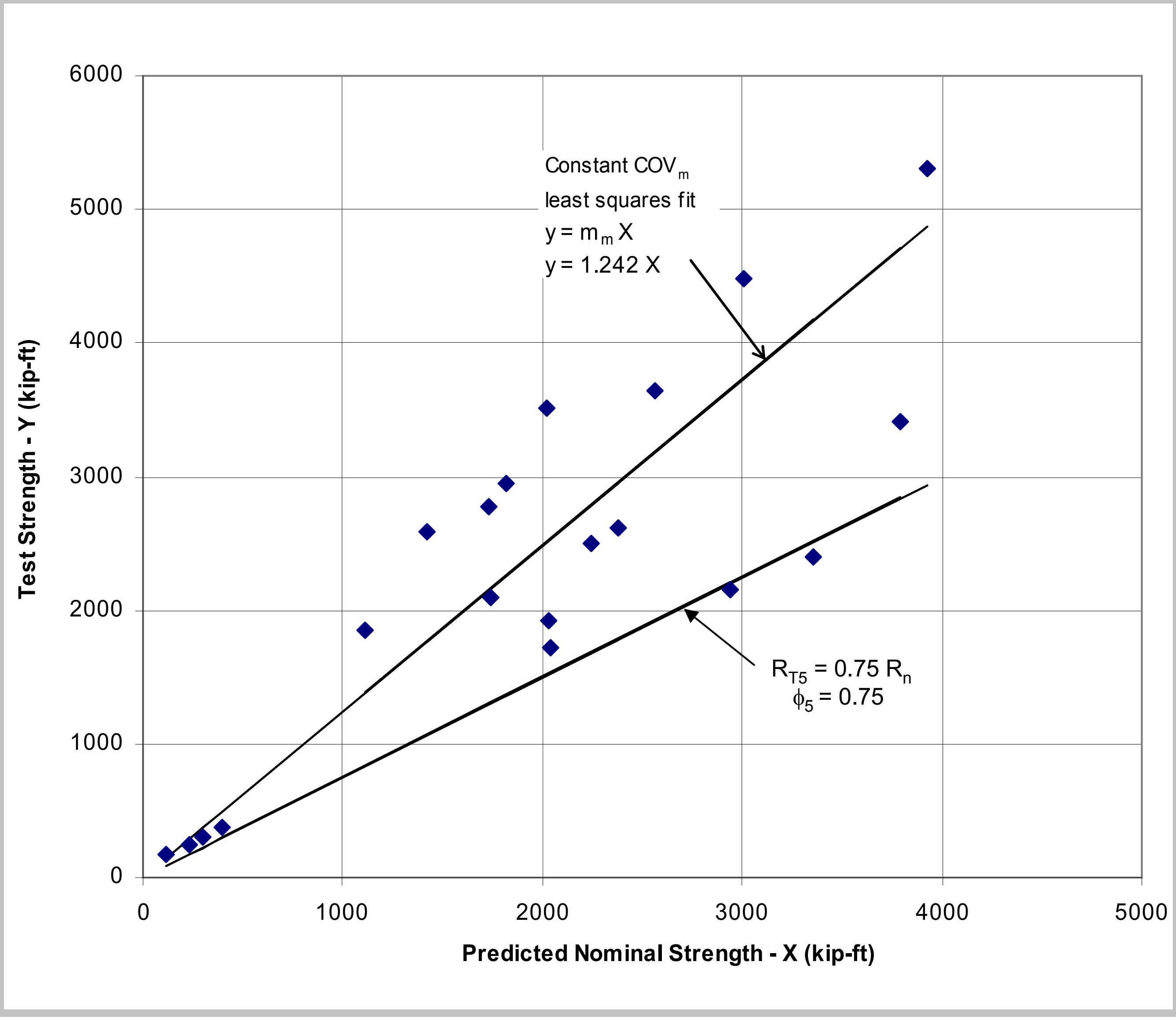


Hansen Design Model



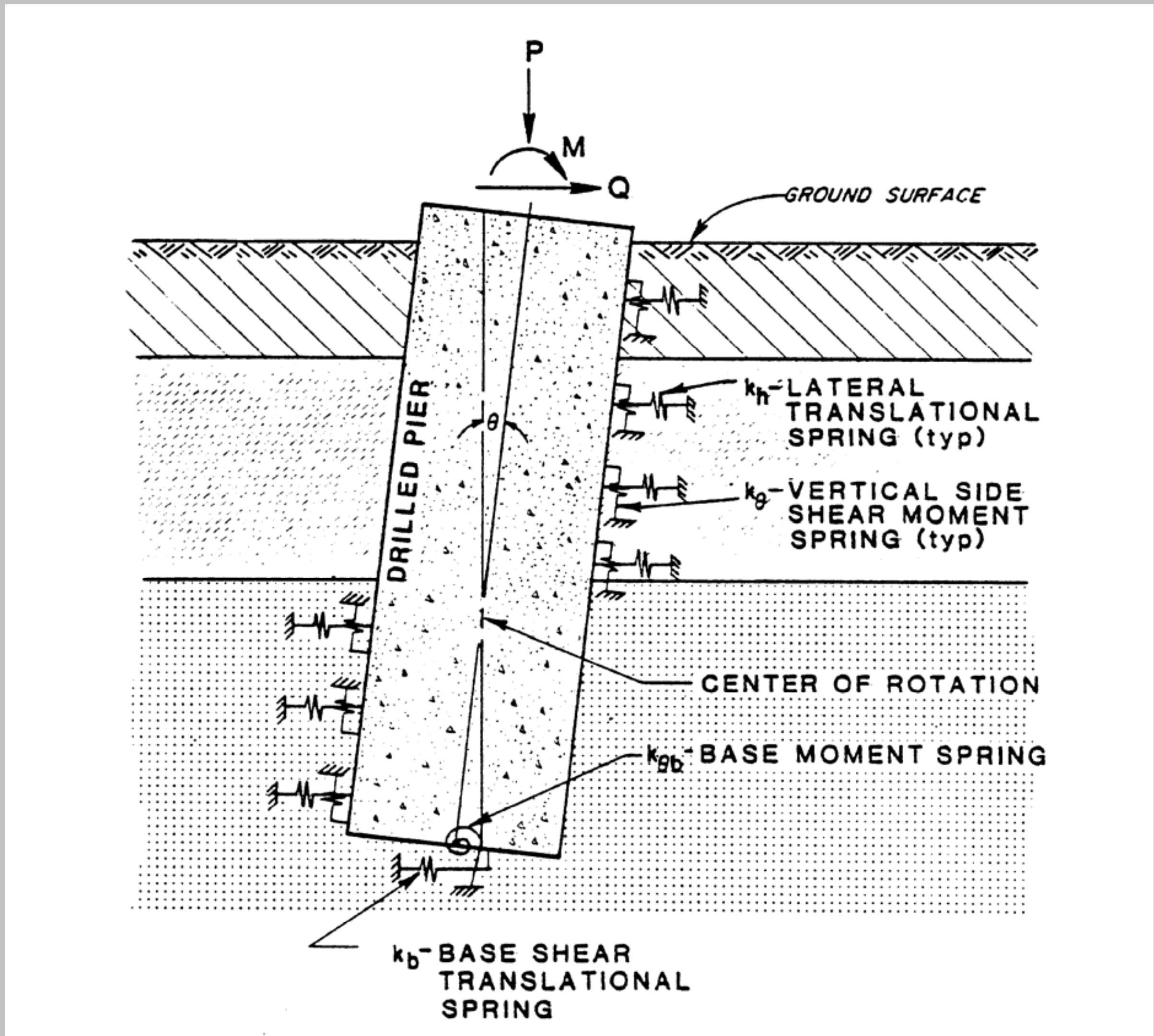
Calibration of Hansen Design Model

TP3 Revised, 4-in criteria – Drilled Shafts Under Drained Moment – 20 Tests – Lognormal PDF



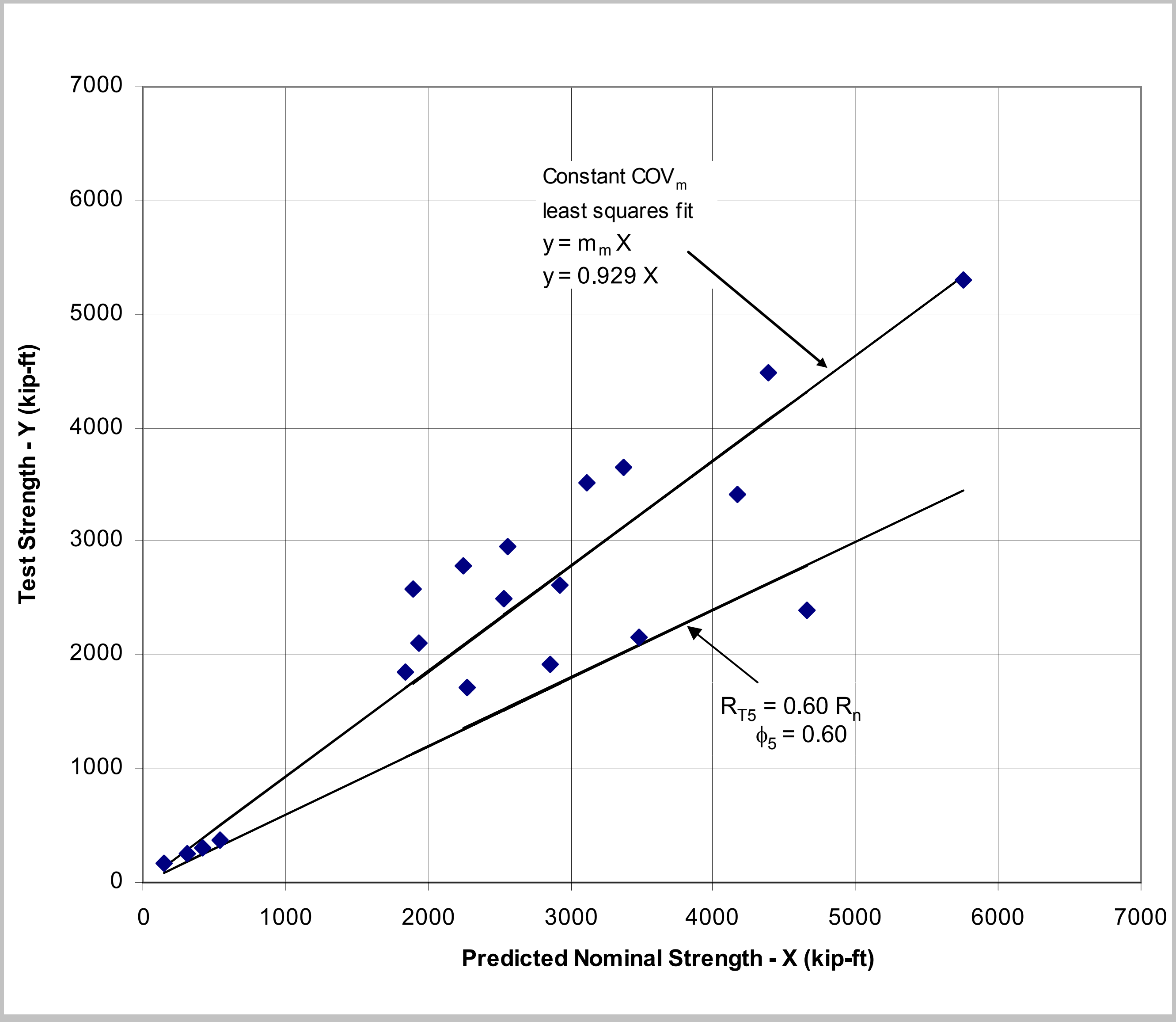
MFAD Design Model

The Schematic Four-Spring Model in MFAD

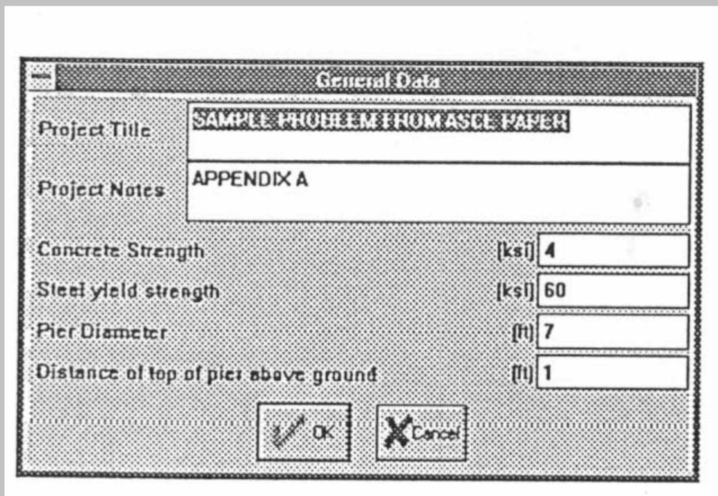


Calibration of MFAD Design Model

TP3 Revised, 4-in criteria – Drilled Shafts Under Drained Moment – 20 Tests – Lognormal PDF



CAISSON Design Model



General Data

Project Title: SAMPLE PROBLEM FROM ASCE PAPER

Project Notes: APPENDIX A

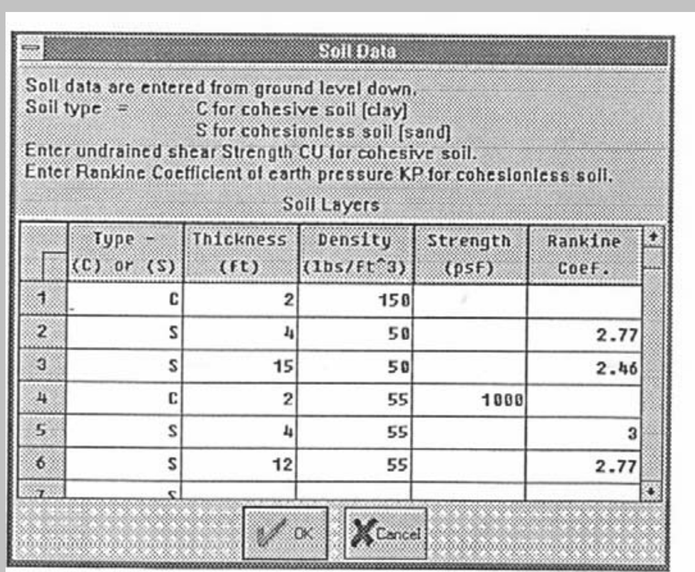
Concrete Strength [ksi] 4

Steel yield strength [ksi] 60

Pier Diameter [ft] 7

Distance of top of pier above ground [ft] 1

OK Cancel



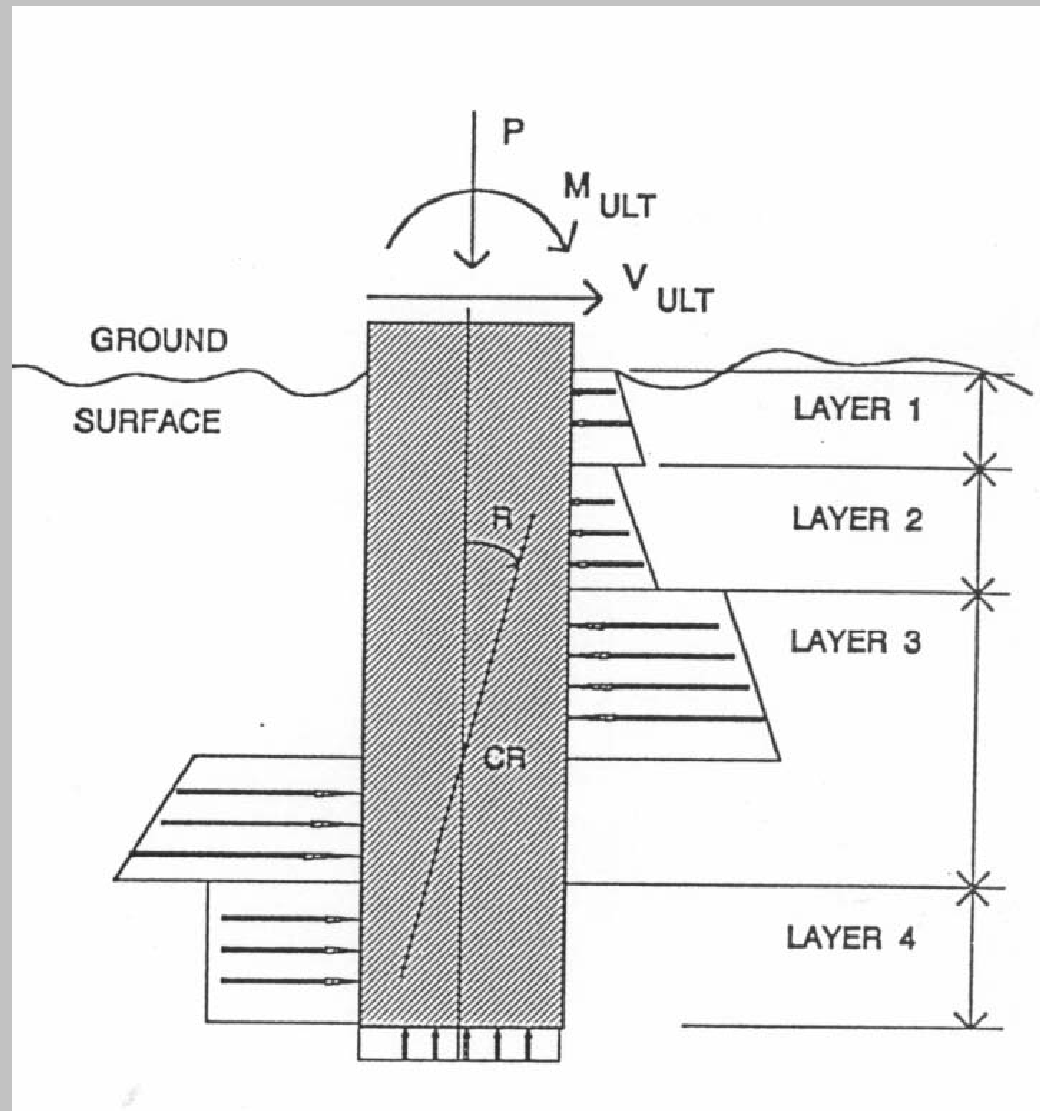
Soil Data

Soil data are entered from ground level down.
Soil type = C for cohesive soil (clay)
S for cohesionless soil (sand)
Enter undrained shear Strength CU for cohesive soil.
Enter Rankine Coefficient of earth pressure KP for cohesionless soil.

Soil Layers

	Type - (C) or (S)	Thickness (Ft)	Density (lbs/Ft^3)	Strength (psF)	Rankine Coef.
1	C	2	150		
2	S	4	50		2.77
3	S	15	50		2.46
4	C	2	55	1000	
5	S	4	55		3
6	S	12	55		2.77
7	S				

OK Cancel



Calibration of CAISSON Design Model

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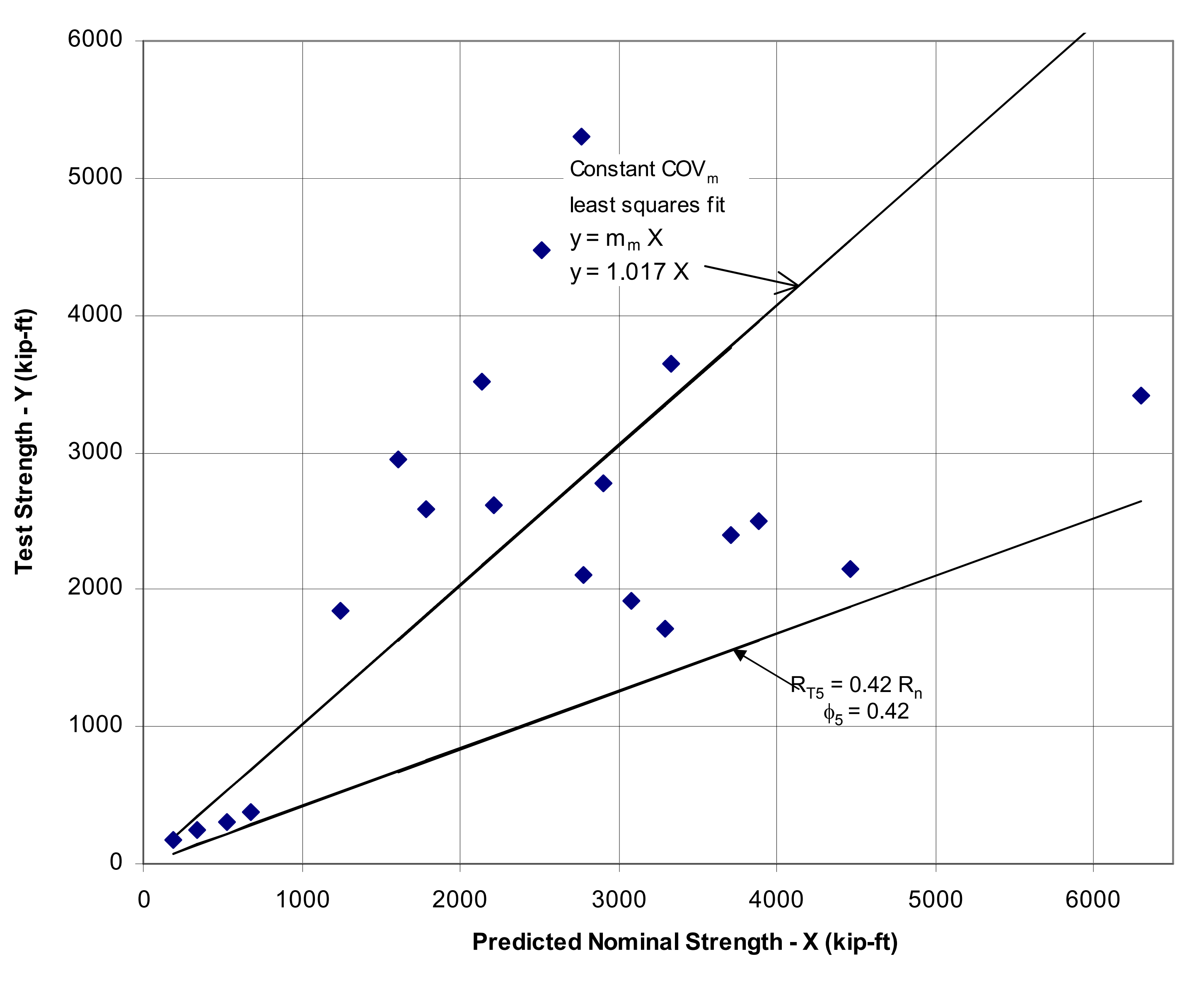
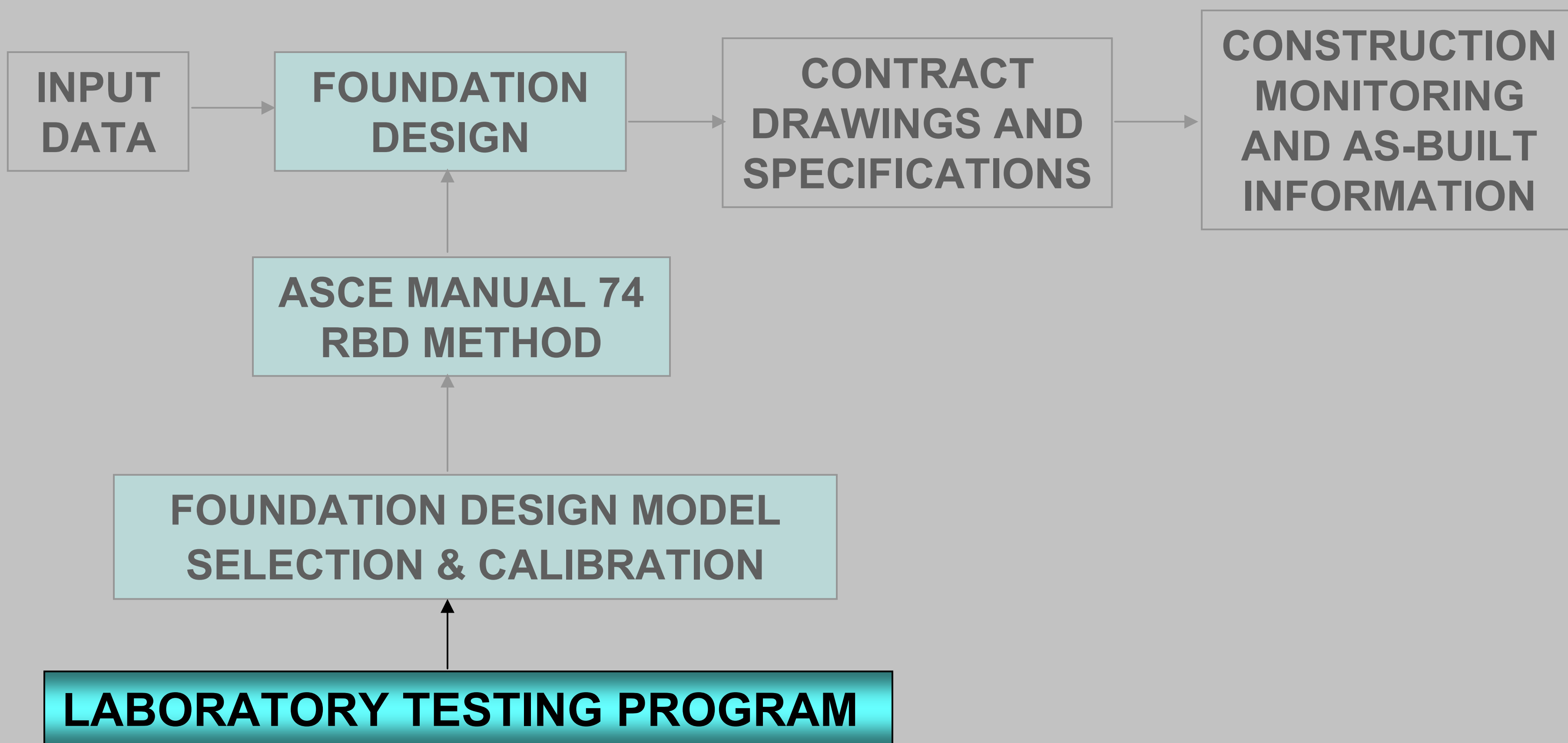


Summary of Calibration Statistics and Strength Factor Data

Design Model	n	m_m	COV_m(%)	ϕ_5 (Lognormal PDF)
Hansen	20	1.24	28.9	0.75
MFAD	20	0.93	24.9	0.60
CAISSON	20	1.02	49.9	0.42

Foundation Design Process



Laboratory Testing Program

COHESIVE SOILS

- Total Density
- Moisture Content
- Undrained Shear Strength
- Modulus of Deformation

COHESIONLESS SOILS

- Total Density
- Moisture Content
- Angle of Internal Friction
- Compaction Characteristics
- Modulus of Deformation

Engineering Property Correlations – Cohesionless Soils

Table 1A
Empirical Values for ϕ, D_r, and Unit Weight of Cohesionless Soils Based on Standard Penetration Resistance

Description		Very Loose		Loose		Medium		Dense		Very Dense	
Relative density, D_r	0		0.15		0.35		0.65		0.85		1.00
Standard penetration number, N			4		10		30		50		
Approximate angle of internal friction, ϕ°*	25°–30°		27°–32°		30°–35°		35°–40°		38°–43°		
Approximate range of moist unit weight (γ) pcf		70–100+		90–115		110–130		110–140		130–150	

*Use larger value of ϕ for cohesionless soils with 5% or less fine sand or silt, or both.

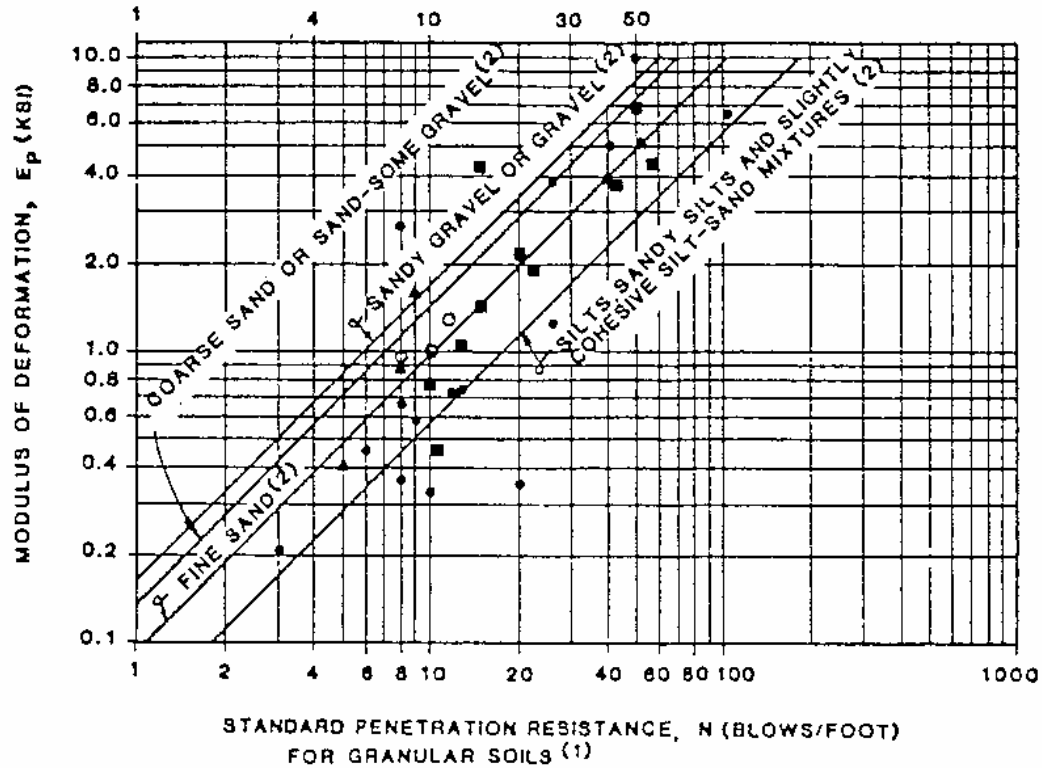
Engineering Property Correlations – Cohesive Soils

Cohesive Soils

Consistency		Very Soft		Soft		Medium Stiff		Stiff		Very Stiff		Hard
Standard Penetration Resistance, N (blows per foot)	0		2		4		8		16		32	
Total Unit Weight of Saturated Soil (pcf)			100-120			110-130			120-140			>130

UNDRAINED SHEAR STRENGTH OF COHESIVE SOILS (3)

Consistency		Very Soft		Soft		Medium Stiff		Stiff		Very Stiff		Hard
Unconfined Compressive strength, q_u, (tsf)	0		0.25		0.50		1.00		2.00		4.00	
Standard Penetration Resistance, N (blows per foot)	0		2		4		8		16		32	



SOILS TESTED IN THIS PROJECT

- • SILTY SAND
- ▲ SILTY SAND AND GRAVEL
- ■ SAND
- o SILT-SANDY SILT

NOTES:

1. N-VALUES UTILIZED TO ENTER THE CHART ARE DEFINED AS STANDARD PENETRATION RESISTANCE FOR 2" O.D. SAMPLER, NOT CORRECTED FOR OVERBURDEN PRESSURE.
2. REFER TO J.H. SCHMERTMANN, (4).
3. 1 KSI = 6.895 MPa
   1 FT. = 0.3048 m

Figure 3-2. Modulus of Deformation for Granular Soils As A Function of Standard Penetration Resistance

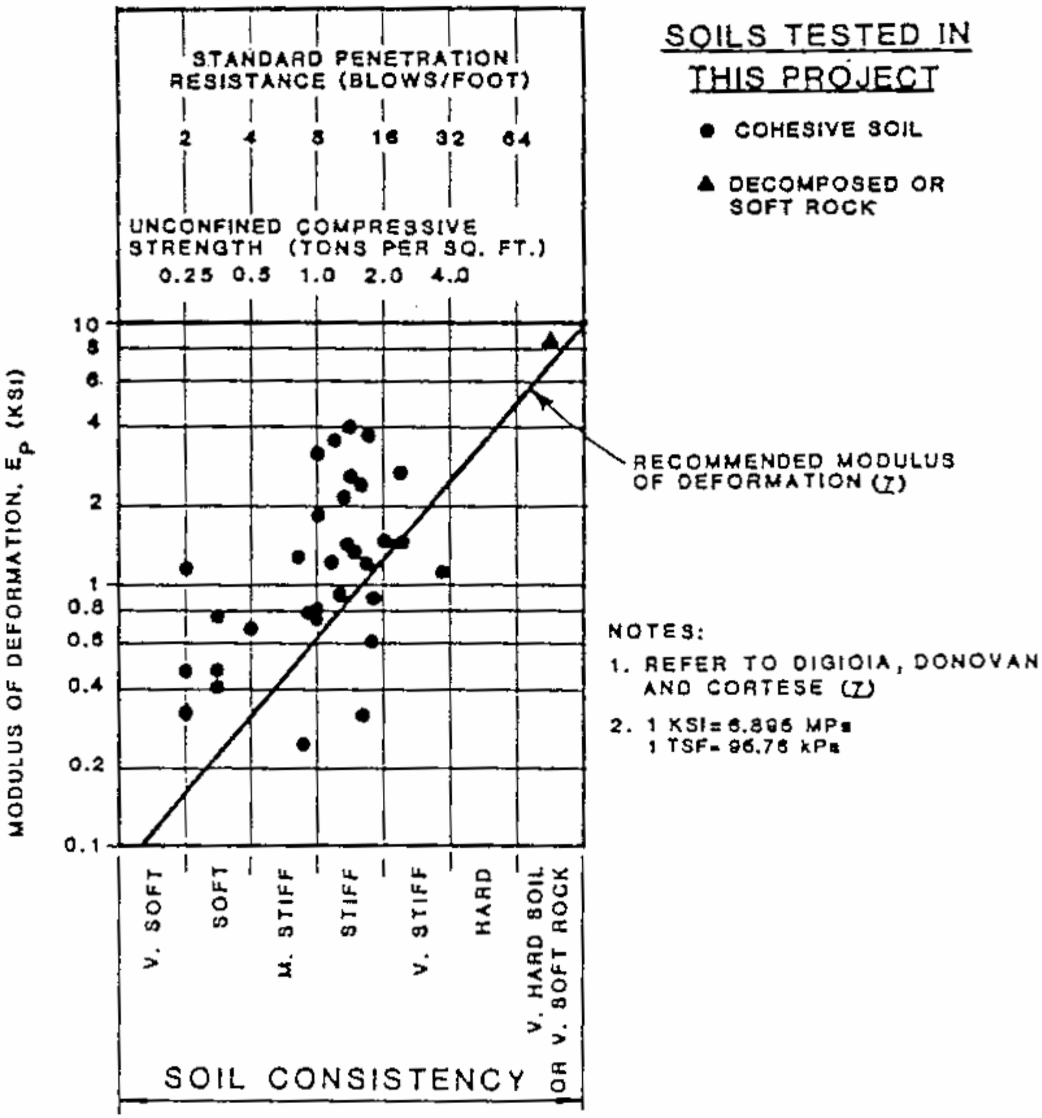
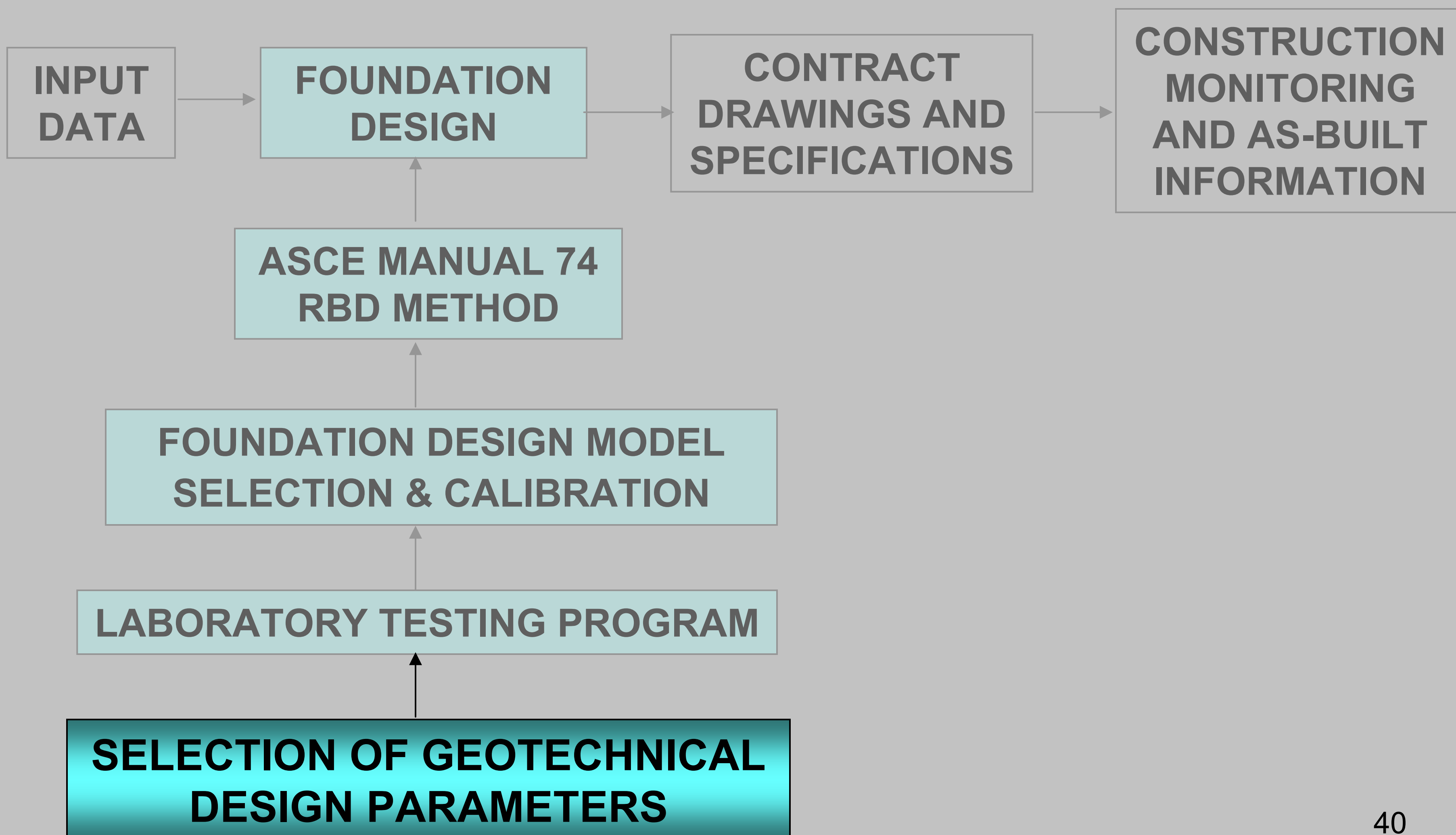


Figure 3-3. Modulus of Deformation As A Function of Soil Consistnecy

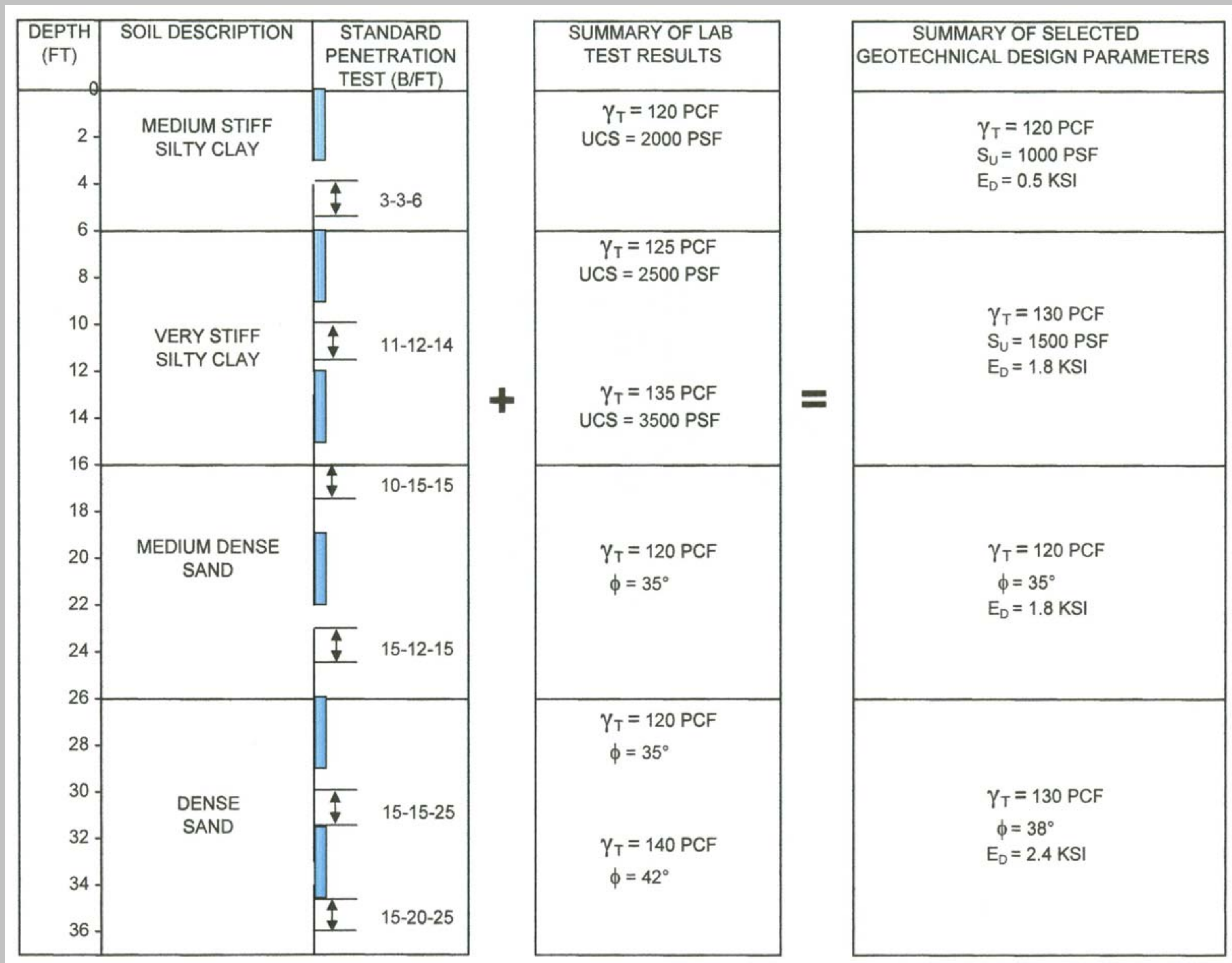
Foundation Design Process



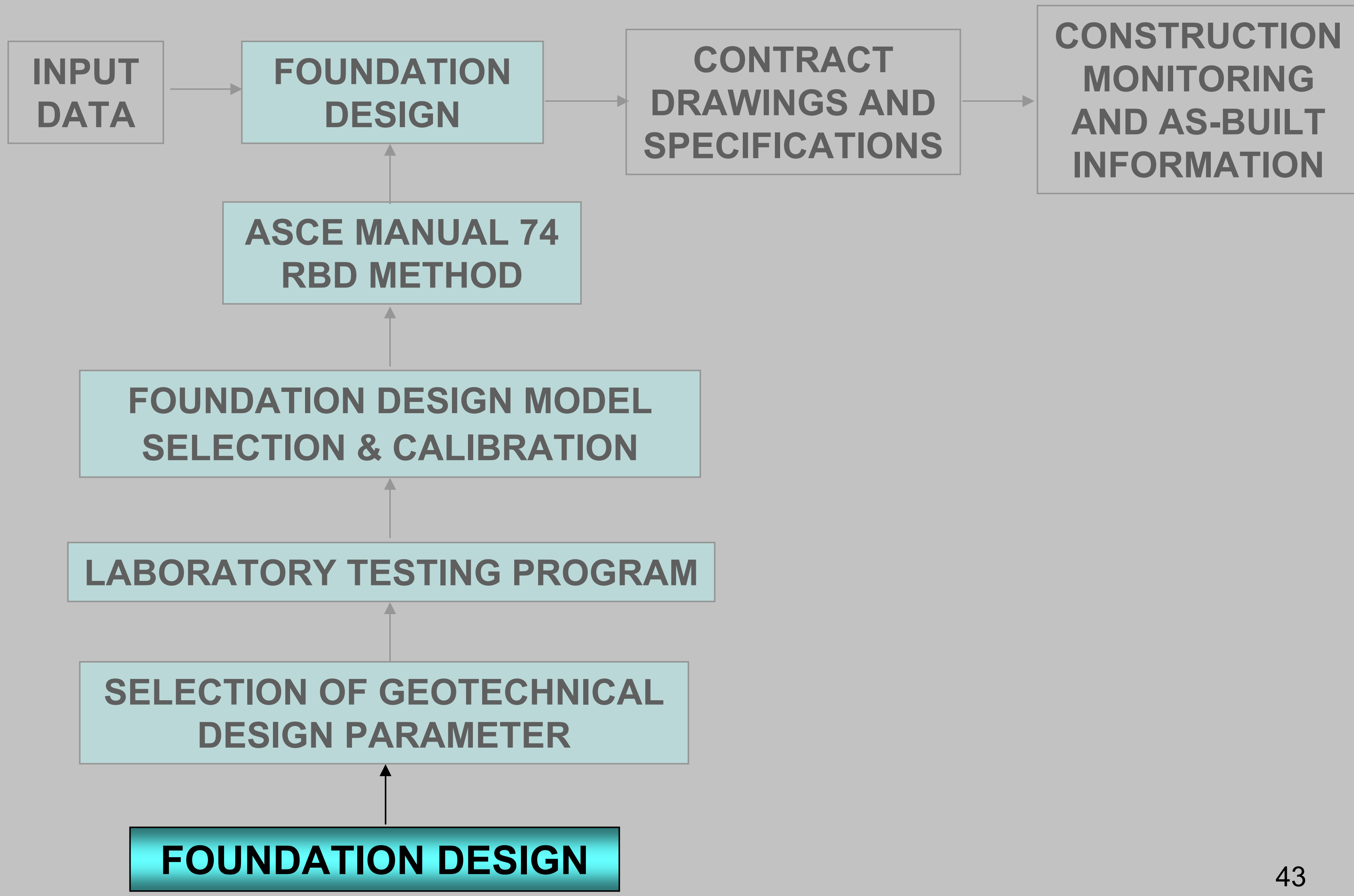
Selection of Geotechnical Design Parameters

BORING LOG + **SUMMARY of LAB TEST RESULTS** = **SUMMARY of SELECTED GEOTECHNICAL DESIGN PARAMETERS**

Selection of Geotechnical Design Parameters

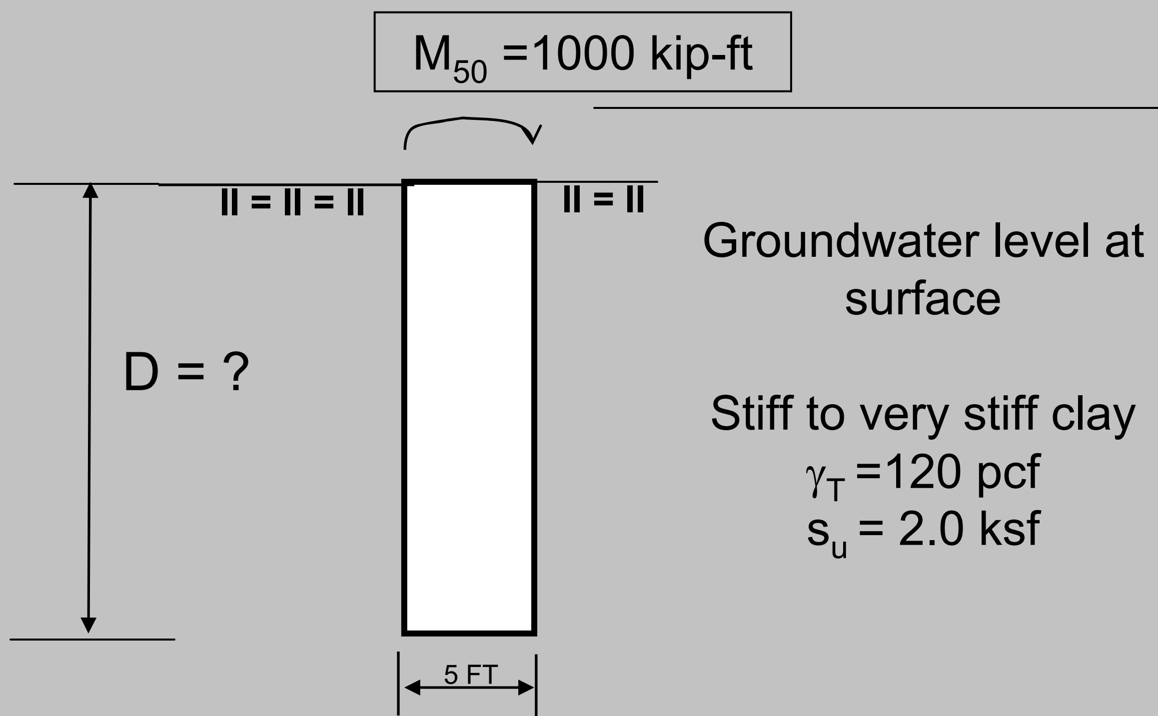


Foundation Design Process



Foundation Design Process

Laterally Loaded Drilled Shaft



Groundwater level at surface

Stiff to very stiff clay
γ_T =120 pcf
s_u = 2.0 ksf

Using the reliability-based design approach, determine D for the Hansen, MFAD and CAISSON design methods.

Foundation Design Process

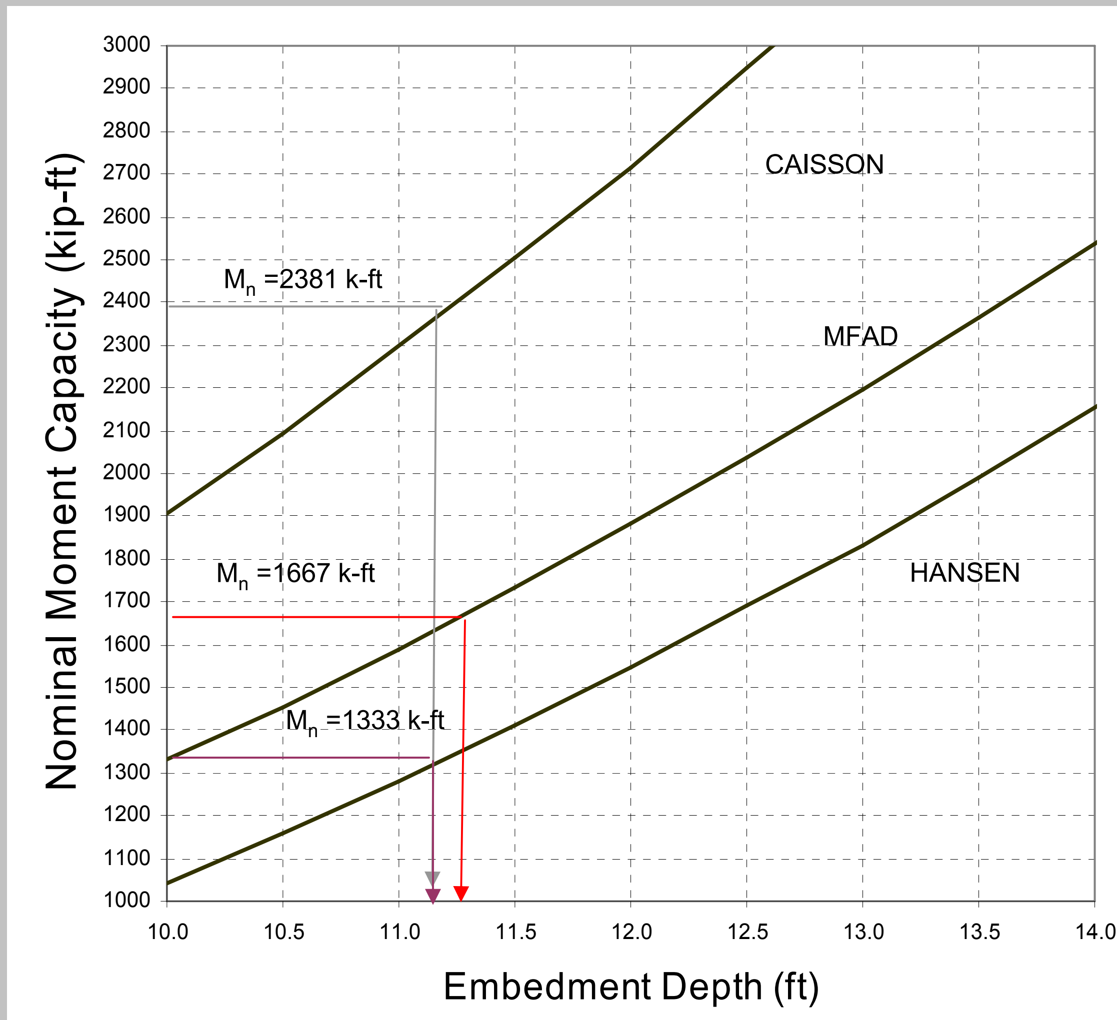
Laterally Loaded Drilled Shaft
Lognormal PDF

Design Model	Φ_5	The Required Nominal Design Moment Capacity (1)
Hansen	0.75	1333
MFAD	0.60	1667
CAISSON	0.42	2381

(1) The nominal design capacity moment required = M_{50}/ϕ_5

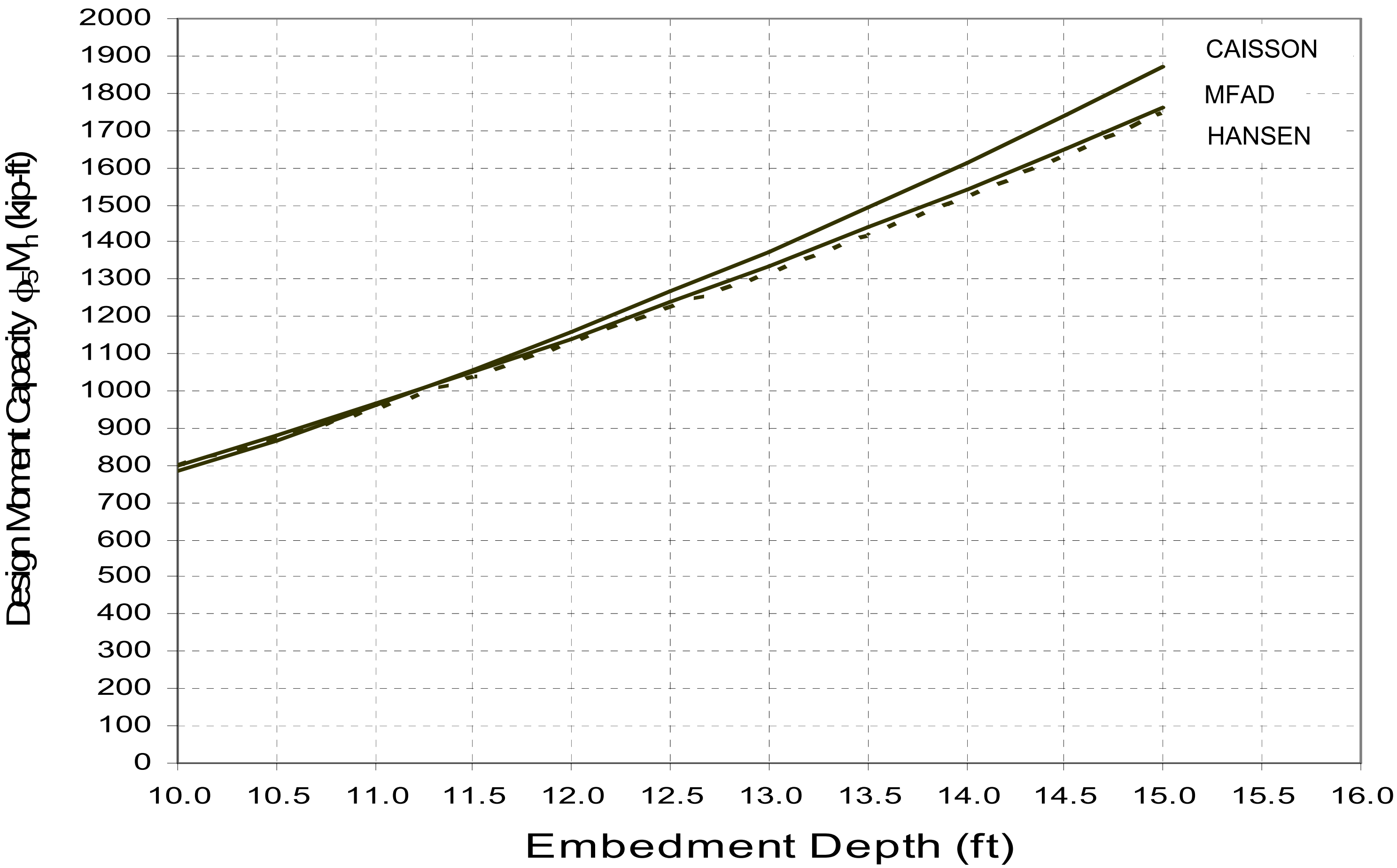
Foundation Design Process

Nominal Moment Capacity (M_n) Versus Embedment Depth



Foundation Design Process

Design Moment Capacity ($\Phi_5 M_n$) Versus Embedment Depth



Summary

•FOUNDATION DESIGN REQUIRES A BLENDING
- SOIL/FOUNDATION INTERACTION MODELING
- ENGINEERING JUDGEMENT

•A WELL-PLANNED SUBSURFACE INVESTIGATION IS CRITICAL

•IMPLEMENTATION OF THE RBD METHOD IN ASCE MANUAL 74 IS RECOMMENDED

•CALIBRATING FOUNDATION DESIGN METHODS PROVIDES A RATIONAL DESIGN FRAMEWORK FOR DEVELOPING STRENGTH FACTORS

•FIELD INSPECTION OF CONSTRUCTION AND GEOTECHNICAL PARAMETER CONFIRMATION ARE CRITICAL