Risk Management for Infrastructure Geotechnical Features

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March 1, 2023

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Bio: Jerry A. DiMaggio

- M.S. Civil Engineering - Clarkson University, New York
- B.S. Civil Engineering – Clarkson University, New York
- P. E. – Several states
- Board Certified Geotechnical Engineer

- Work Experience
  - -2014–Present: Applied Research Associates, Inc., Senior Principal Civil Engineer - Associate
  - -2008–2014: Second Strategic Highway Research Program (SHRP2), National Academies, Implementation Coordinator and Senior Program Officer
  - -1976-2008: U.S. DOT/FHWA, Principal Bridge Engineer/National Geotechnical Program Manager

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Geotechnical Features

A. Shallow Foundations (spread footings and mats)
B. Deep Foundations (drilled shafts, driven piles, CFA piles and micropiles)
C. Earth Retaining Structures (fill, cut and hybrid)
D. Soil and Rock Slopes (engineered fills and cuts)
E. Ground Improvement Methods (over 60 technologies)
F. Geotechnical Aspects of Pavements
G. Dams

Risk Management Within the Geocommunity

- Many members of the Geocommunity (owners, contractors, consultants and material suppliers) believe they understand risks well and routinely apply some form of risk management! **MAYBE TRUE?**
- However, the number of **dispute matters** in this industry and the frequent disappointments in profit, revenue, geofeature performance and excessive staff turnovers suggest otherwise. **TRUE!**
- Members of the Geocommunity are often not participants in organizational training and activities related to risk management **WHY?**

A SUCCESSFUL PROJECT

Failure

Over-design

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Definition and Quantification of Risk

- What is Risk?
  - An event or condition that may (or may not) occur in the future.
  - The event occurrence will have a **negative or positive** impact on project cost, schedule, maintenance of traffic and performance.
- Quantification of Risk
  - Likelihood event will occur times the impact as a result of this event occurrence.
  - **Risks attributed to geotechnical features commonly are the greatest source of risk on many infrastructure projects.**

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DIFFERING SITE CONDITION CLAUSES TYPICALLY RECOGNIZE TWO DISTINCT TYPES OF DSCS, CALLED TYPE 1 AND TYPE 2

Type 1 DSC is an unknown and hidden, concealed, or latent physical condition, which a contractor encounters at the site that differs materially from the conditions indicated in the contract documents. The existence of a Type 1 condition depends upon whether the drawings, specifications, and other contract documents make representations that either expressly or impliedly indicate the expected conditions.

For example: A Type 1 DSC may exist if unsuitable soil is encountered on the site when the drawings and specifications "indicate" that the site contains suitable soil.

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- **Type 2 DSC** is an unknown, unusual, and hidden, concealed or latent physical condition, which the contractor encounters at the site that differs materially from the conditions that an ordinary contractor in the general vicinity of the project would expect to encounter while performing work of the same type and character called for in the contract. The existence of a Type 2 DSC thus depends upon the physical conditions in the general vicinity of the project.
- **For example: A Type 2 DSC may exist if the contractor discovers rock in an area where rock is not normally encountered.**

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WHAT are Common "Geo" Threats (risks)?

- Communication and Coordination with internal and external stakeholders
- Contracts, Plans and Specifications
- Differing Site Conditions
- Interpreting subsurface factual data
- Overly conservative and unconservative designs
- Deep foundation defects during construction
- Difficulty meeting project deformation and acceptance tolerances
- Addressing known and unknown subsurface utilities
- Interpretation and achieving service and design life requirements
- Incomplete geo-feature performance and acceptance criteria
- Natural and manmade obstructions
- Meeting accelerated design and construction schedules

WHAT about "Geo" Opportunities (risks)?

- Innovative Delivery Methods
- Alternative Technical Concepts
- Performance based Specifications
- Constructability and Peer Reviews
- Value Engineering
- Optimized use of Design and Construction Guidance and Tools
- Narrowing the GAP between State of Art and State of Practice
- Reliability based Design Processes (i.e., LRFD, limit state design)
- Improved Procedures for Determining Geomaterial Design and Construction Parameters

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Threat and Opportunity Responses

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CHANGES Deep Foundation Practice 1970 - Current

- Load demand, performance requirements/ constraints have increased significantly. **Foundation designs have become more complex and become more "optimized".**
- Pile material **strengths and sizes** (L and D) have increased significantly.
- Frequency, types and importance of **load and integrity** tests have increased significantly.
- Load Resistance Factor Design platform **requires" a close relationship between the design and construction disciplines** (reliability-based design).
- Construction equipment, specifications and plan details have become very complex. **Project financing and delivery methods have changed**.
- **CONSTRUCTION HAS BECOME MORE IMPORTANT AND INCREASINGLY CRITICAL**

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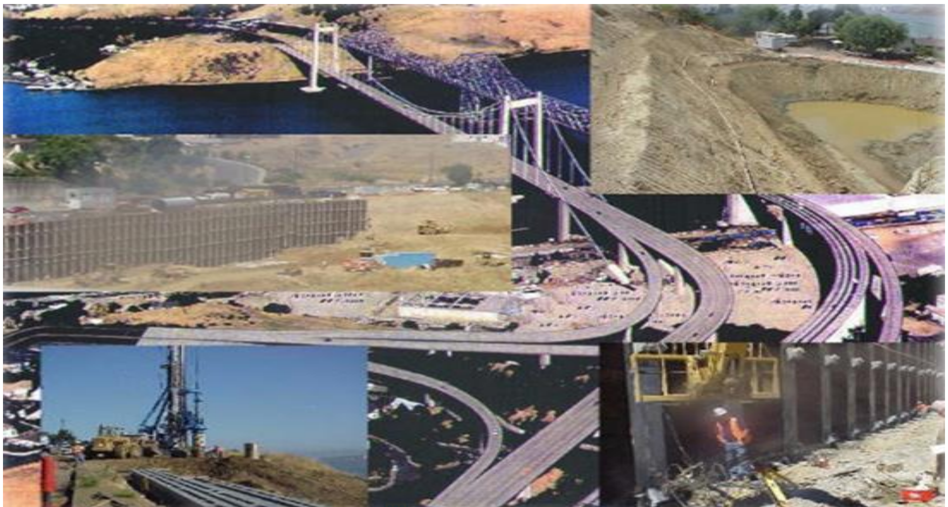
Geotechnical Asset Management



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Soil Characteristics

- Composed of individual grains of rock
- Relatively low strength
- Coarse grained (+ #200)
  - High permeability
- Fine grained (- #200)
  - Low permeability
  - Time dependent effects

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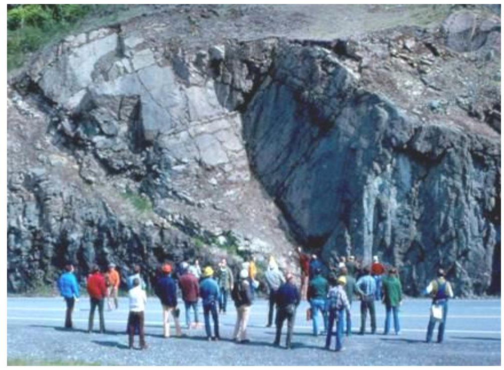
Rock Characteristics

- **Strength**
  - **Regional geomaterials,** q_u = 50-1500 psi
    $N1_{60}$ (or N_{60})> 50
  - Hard rock, q_u > 1500 psi
- **Rock mass properties**



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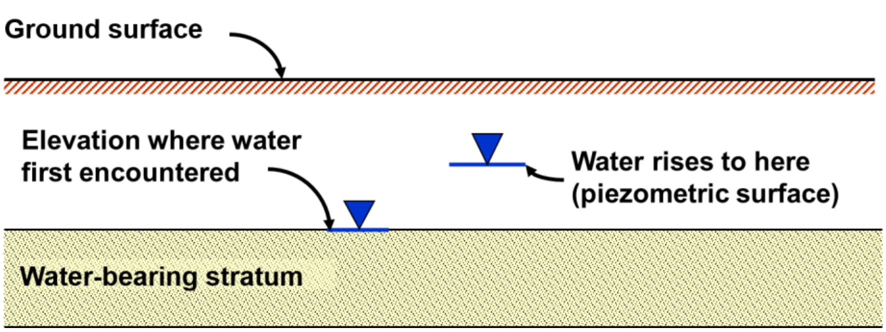
Ground Water Conditions



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EVALUATION OF SOIL SHEAR STRENGTH

- Unconfined compression (UC)
- Unconsolidated undrained triaxial compression (UU)
- Consolidated drained triaxial compression (CD)
- Consolidated undrained triaxial compression (CU)
- Direct shear (DS)
- Direct simple shear (DSS)

- SPT
- CPT
- Pressuremeter
- Dilatometer
- Field Vane Shear

Selection of Geomaterial Shear Strength

- **Rate of construction loading** to soil conductivity
- Effect of Applied **Load Direction** on measured shear strength
- Effects of expected **levels of deformation** on structure
- **Influence of Construction Sequence and Means and Methods**

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Measured or interpreted parameter value	Coefficient of Variation, V (%)
Unit weight, γ	3 to 7 %
Buoyant unit weight, γ_b	0 to 10 %
Effective stress friction angle, ϕ'	2 to 13 %
Undrained shear strength, s_u	13 to 40 %
Undrained strength ratio (s_u/p_o)	5 to 15 %
Compression index, C_c	10 to 37 %
Preconsolidation pressure, p_c	10 to 35 %
Hydraulic conductivity of saturated clay, k	68 to 90 %
Hydraulic conductivity of partially-saturated clay, k	130 to 240 %
Coefficient of consolidation, c_v	33 to 68 %
Standard penetration blow count, N	15 to 45 %
Electric cone penetration test, q_c	5 to 15 %
Mechanical cone penetration test, q_c	15 to 37 %
Vane shear test undrained strength, s_{uVST}	10 to 20 %

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Duncan (2000), FHWA (2006)

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AASHTO Soil and Rock Design Property Selection

- In-situ and Geophysical Tests
- Laboratory Tests
- Back Analysis based on Site Performance
  - Assess **Variability** of subsurface materials and test methods
  - **Sensitivity analysis**: mean and mean minus 1 sigma
  - Service Limit: **Evaluate upper and lower bound**
  - Strength Limit: **Average property values** were used for calibration (not minimums)

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Link between Site Characterization and Risk

Improved site characterization will generally reduce risks (threats) associated with design, construction, and operation of infrastructure features by:

- Reducing the likelihood of encountering a differing site condition arising during construction
- Increasing the reliability of estimated soil and rock properties
- Decreasing uncertainty of subsurface conditions during construction
- Increasing the confidence in understanding the role and variability of groundwater on the project

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CONTRACT DOCUMENTS

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Driven Pile Project Plans Should Include

- Location of piles.
- Pile numbering system to clearly identify each pile in group or bent.
- Pile type, section, and estimated length.
- Pile toe details, driving shoe, closure plate, etc.
- Pile splicing details.
- Pile cut off elevation.
- Pile cap connection details.

- Estimated pile toe elevation.
- Minimum pile toe elevation, if needed.
- Required pile batter and direction.
- Orientation of H-piles.
- Factored resistance, R_r.
- Nominal resistance, R_n.
- Nominal driving resistance, R_{ndr}.
- Location/elevation of subsurface explorations.
- Results of subsurface exploration.

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Driven Pile Typical Specification Sections

- Description
- Submittal and approvals
- Materials
- Driving equipment and appurtenances
- Determination of nominal resistance and basis of acceptance
- Preparation and driving
- Method of measurements
- Basis of payment

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Submittals Should Address and Acceptance Should be Clear

- Pile installation plan requirements
- Pile equipment acceptance details
  - Acceptance by wave equation
  - Acceptance by alternate method
- Review period by owner

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Foundation Acceptance - Each Pile

- Satisfies pile location and alignment tolerances
- Meets minimum pile penetration depth requirements
- Satisfies structural integrity review
- Meets nominal resistance requirements

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Inspection: Observation and Documentation

- Monitoring, Documentation and Inspection are needed to assure the design performance requirements as outlined in the contract documents are obtained during construction.
- Provide the primary means for identification and initial assessment of potential problems.
- Inspection is also needed to identify unanticipated ground conditions encountered during construction that might require field adjustments and changes to design requirements.
- Inspector's records provide a basis for evaluating contractor claims of a "differing site condition" (DSC).

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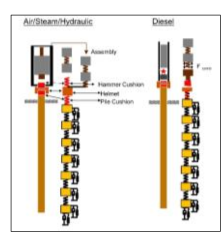
Nominal Resistance Verification Methods

Static Load Test

Dynamic Measurements



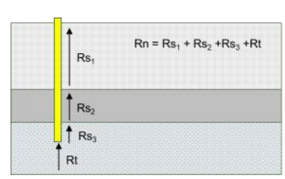
Wave Equation Analysis

$$R_{ndr} = 1.75\sqrt{E_d}\log_{10}(10\,N_b) - 100$$

Where:

R_{ndr} = nominal driving resistance (kips).
E_d = developed hammer energy (ft-lbs) in the form of ram weight, W, (lbs) times stroke height, h (ft).
N_b = pile penetration resistance (blows/inch).

Dynamic Formula



Static Analysis

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Pile Testing Methods

Analysis Method	Resistance Factor (ϕ) (AASHTO 2014)	Est.			Measure		
		Capacity	Stress	Energy	Capacity	Stress	Energy
Dynamic formula	0.10 (EOD) or 0.40 (EOD)	X					
Wave equation	0.50 (w field confirmation of hammer)	X	X	X			
Dynamic testing*	0.65 (2%) or 0.75 (100%) (0.5 uplift)	X				X	X
Static load test**	0.75 to 0.80 (wo/w dynamic) (0.6 UPLIFT)				X		

* Dynamic Test requires signal matching **Static Test requires one test pile per site

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What is a Driving Criteria?

- Driven pile foundations are generally installed using a driving criterion that **equates the blow count and hammer stroke to the nominal geotechnical resistance.**
- A **minimum pile penetration depth may often also be included** in the driving criterion in cases when scour, foundation settlement, uplift or lateral loading demands impact design performance**.**

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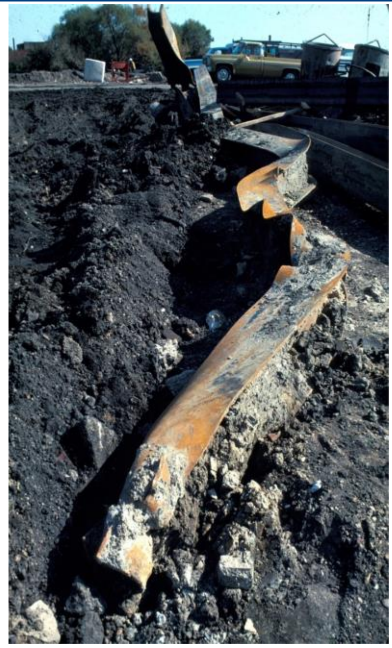
We have the learned the meaning of the word "drivability"



Practical and Absolute Refusal

- **Practical refusal** is defined as a pile penetration resistance (blow count) of **10 blows per in for a maximum of 3 consecutive inches.** Practical refusal is often used as a criterion for piles driven to a consistent and hard bearing layer. Blow counts greater than 10 blows per in should be used with care for concrete and timber piles.
- **Absolute refusal is defined as 20 blows for one inch or less** of pile penetration.
- **Driving should terminate immediately once either criteria are achieved with a properly sized and properly working hammer.**

Drilled Shaft Inspection

- Inadequate Flow of Concrete through Tightly Spaced Spiral Reinforcement

Concrete

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Integrity Testing

The following definitions are from ASTM D6760.

- **Anomaly** - an irregularity or series of irregularities observed in the NDT results, indicating a possible flaw.
- **Flaw** - any deviation from the planned shape or material characteristics (or both) of the drilled shaft
- **Defect** - a flaw that, because of either size or location, may significantly detract from the drilled shaft's performance

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Non-Destructive Integrity Tests

Part of TABLE 16-1: COMMON NDT METHODS FOR DRILLED SHAFTS IN TRANSPORTATION APPLICATIONS

Test Feature:	Crosshole Sonic Logging (CSL)	Thermal Integrity Profiling (TIP)	Gamma-Gamma
ASTM or Other Standard	ASTM D 6760	ASTM D 7949	Caltrans Test 233
Basic Concept	Acoustic signals generated in embedded access tubes are measured in adjacent tubes; Signal velocity and strength provide evaluation of concrete quality between the tubes	By monitoring the temperature profile generated by the heat of hydration as concrete cures, shaft geometry can be inferred; low temperature zones indicate potential defects; Requires temperature-measuring cables or access tubes embedded in the concrete	Gamma rays emitted from a source are backscattered by concrete and measured by a detector; measured gamma ray counts correlate to concrete density; source and detector are located in a single probe lowered into access tubes
Primary Application	Assessment of concrete quality inside the reinforcing cage	Assessment of concrete quality for the entire cross section	Assessment of concrete quality around the perimeter of the shaft

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WHAT about "Geo" Opportunities (risks)?

- Innovative Delivery Methods
- Alternative Technical Concepts
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Q & A

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