Defining a Role for Geology and Forensic Geology in Site Characterization for LRFD Projects

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Geohazards Impacting Transportation in Appalachia
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Defining a Role for Geology and Forensic Geology in Site Characterization for LRFD Projects

- LRFD recognizes the valuable role of geology, as it currently makes extensive use of geologic information

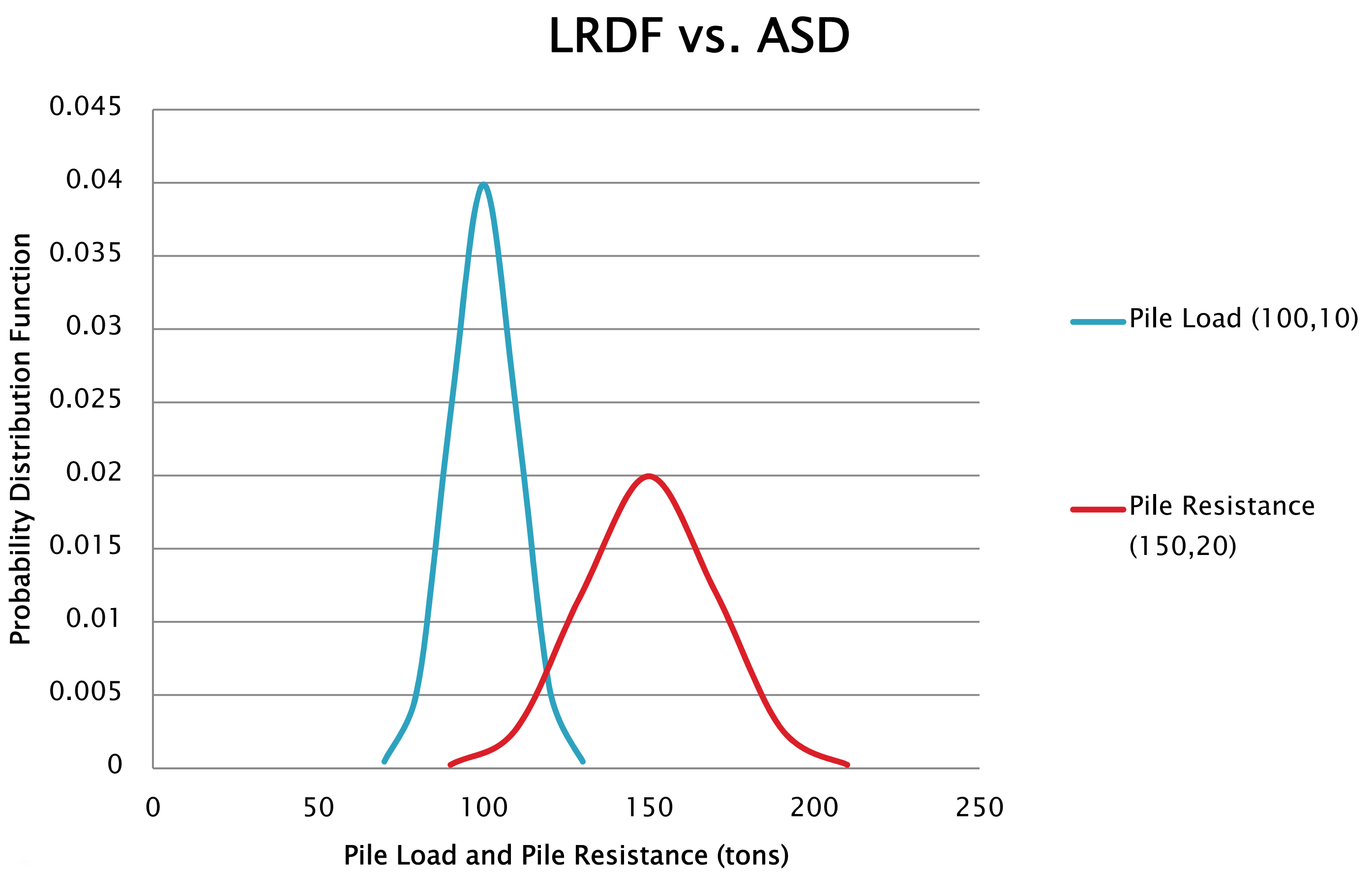
- What is LRFD?
- Does geology have a place in LRFD?
- What is the role of geology in LRFD?

Background and Spirit
AASHTO Code Citations
Example Mini Case Histories
Current Needs

Background and Spirit

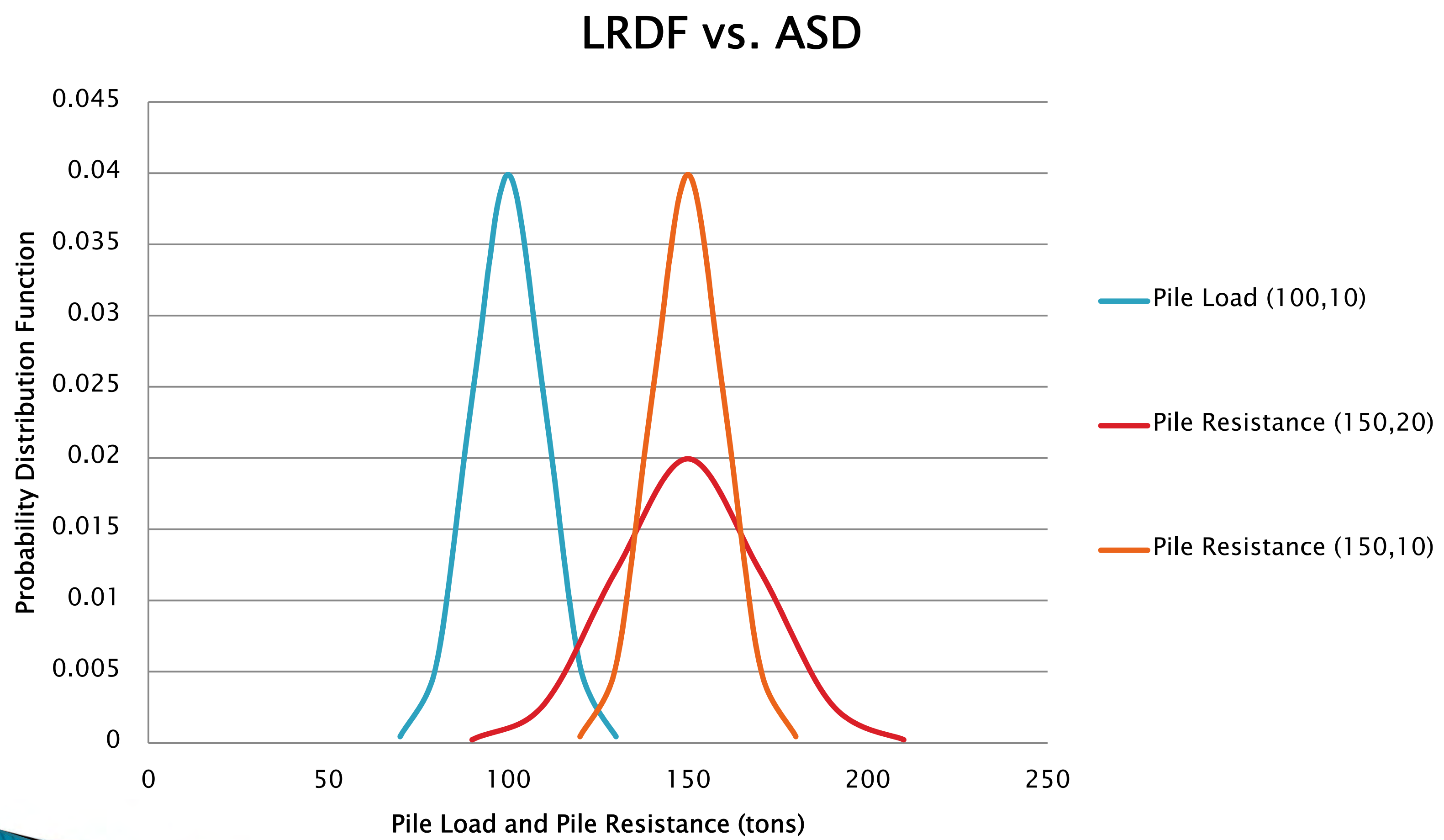
- What is LRFD
  - Load and Resistance Factor Design
  - Relatively new design approach to geotechnical engineers
  - Replaces Allowable Stress Design (ASD) for design of highway projects involving Federal Aid
  - Utilizes the "spirit" of *Probabilistic Design* or *Reliability-based Design*
  - Attempts to formally account for uncertainty in the design process
  - Recognized by structural community….but reluctant to be accepted by our geotechnical brethren
  - Probably unheard of amongst geologists

Background and Spirit
(Contrast LFRD and ASD)



FS = 150/100 = 1.50

Background and Spirit
(Contrast LFRD and ASD)



FS = 150/100 = 1.50

Background and Spirit
(Probability of Failure)

	Coefficent of Variation of Factor of Safety								
FS(calc)	2%	4%	6%	8%	10%	12%	14%	16%	20%
1.05	0.80%	12%	22%	28%	33%	36%	39%	41%	44%
1.10	0.00%	0.90%	6%	12%	18%	23%	27%	30%	35%
1.15	0.00%	0.03%	1.10%	4%	9%	13%	18%	21%	27%
1.16	0.00%	0.01%	0.70%	3%	8%	12%	16%	20%	26%
1.18	0.00%	0.00%	0.30%	2%	5%	9%	13%	17%	23%
1.20	0.00%	0.00%	0.13%	1.20%	4%	7%	11%	14%	21%
1.25	0.00%	0.00%	0.01%	0.30%	1.40%	4%	6%	9%	15%
1.30	0.00%	0.00%	0.00%	0.06%	0.50%	1.60%	3%	6%	11%
1.35	0.00%	0.00%	0.00%	0.01%	0.20%	0.70%	1.90%	4%	8%
1.40	0.00%	0.00%	0.00%	0.00%	0.04%	0.30%	1.00%	2%	5%
1.50	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.20%	0.70%	3%

COV = Mean/ Sigma

Lesson: As reliability increases (i.e., COV decreases) for constant FS, probability of failure decreases for a constant calculated FS

(after Duncan, 2000)

Background and Spirit
(Why LRFD)

- On surface, we do not disagree that the concept has validity (I hope this is case)

- How to assess Factor of Safety (FS)?
- How to select soil parameters for ASD?
- How to assess mean and standard deviation?

- If we do not have formal way to calculate parameters for LRFD design, then why bother???

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 %

(after Duncan, 2000 and GEC #5, 2002)

AASHTO Code Considerations

- Currently, AASHTO considers primarily design related uncertainty, but does recognizes geology. However…

- Soils
  - Geotechnical investigation
  - Site and property variability

- Rocks
  - Deere (1964) – Rock Quality Designation (RQD)
  - Bieniawski (1977) – Rock Mass Rating (RMR)
  - Barton (1974) – Q System (Q)
  - Hoek and Brown (1995) – Geological Strength Index (GSI)

AASHTO Code

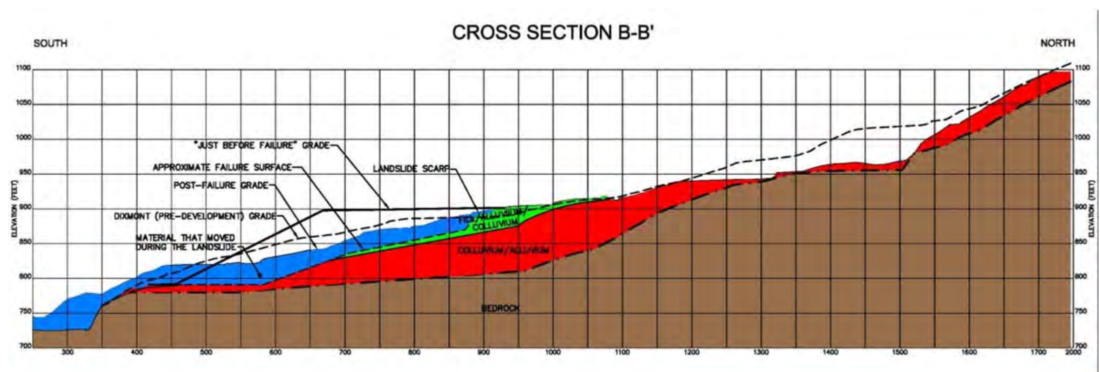
- Soils
  - C.10.4.6.1 – Selection of Design Parameters
    - A geologic stratum is characterized as having the same geologic depositional history and stress history, and generally has similarities throughout the stratum in terms of density, source material, stress history, and hydrogeology
    - The Engineer should assess the variability of relevant data to determine if the observed variability is a result of inherent variability of subsurface materials and testing methods r if the variability is a result of significant variations across the site…see Duncan (2000) and Sabatini, et al (2002)
  - C.10.5.5.2.3 – Site Variability and Resistance Factors
    - Tables 2 and 3 identify resistance factors to be used and numbers of tests needed depending on whether the site variability is classified as low, medium, or high. Site variability may be determined based on judgment, or based on the following suggested criteria…see Paikowski, et al (2004)

AASHTO Code

- Rocks
  - C.10.4.6.4 – Rock Mass Strength
    - Because of the importance of the discontinuities in rock, and the fact that most rock is much more discontinuous than soil, emphasis is placed on visual assessment of the rock and the rock.
  - 10.6.2.4.4 – Settlement of Footings on Rock
    - Where rock is broken or jointed (relative rating of 10 or less for RQD and joint spacing), the rock joint condition is poor (relative rating of 10 or less) or criteria for fair to very good rock are not met,….the influence of rock type, condition of discontinuities, and degree of weathering shall be considered in the settlement analysis.
  - C.10.7.3.2.1 – Point Bearing Piles on Rock
    - A definition of hard rock that relates to measureable rock characteristics has not been widely accepted. Local or regional experience with driven piles to rock provides the most reliable definition.

Case History – Soils

- Landslides
  - Geologic setting often controls behavior
  - Instrumentation used to assess movements and time trends
  - Geology explained occurrence of alluvial sediments on colluvial slope
  - Landslide hazard map to assess probability of landslide in glacio-lacustrine setting (Dalqamouni, 2011)



(after Geosyntec Consultants, 2009)

Case History – Soils

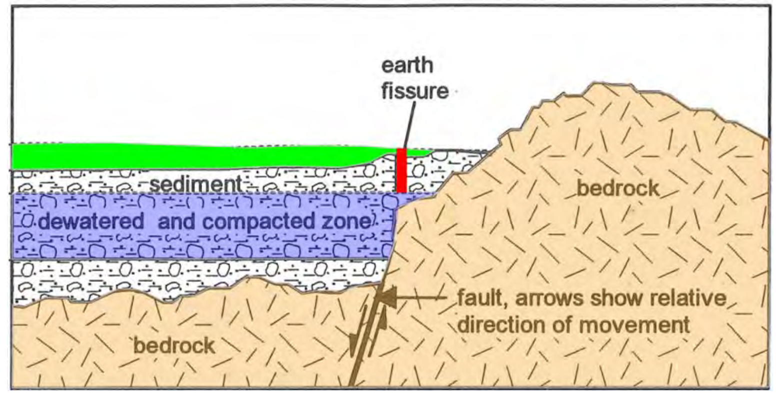
- Levee
  - New Orleans levee systems comprise several miles on intradelta deposits
- Fissures
  - Ground subsidence due to groundwater lowering
  - Significant problem in desert southwest (AZ, CA, NV, NM, others)

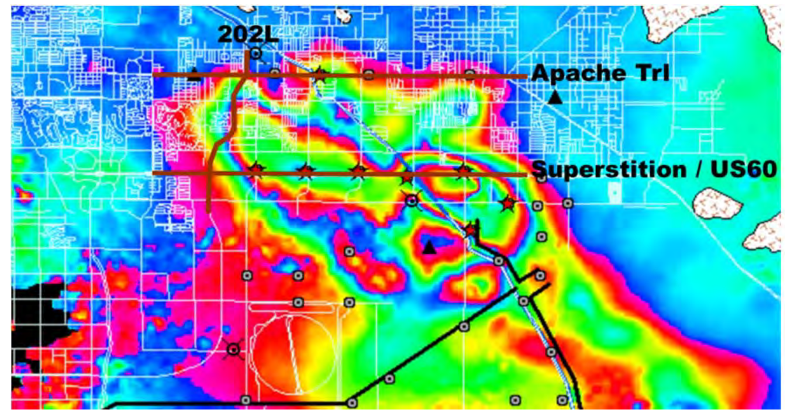
(after Martin, 2010)

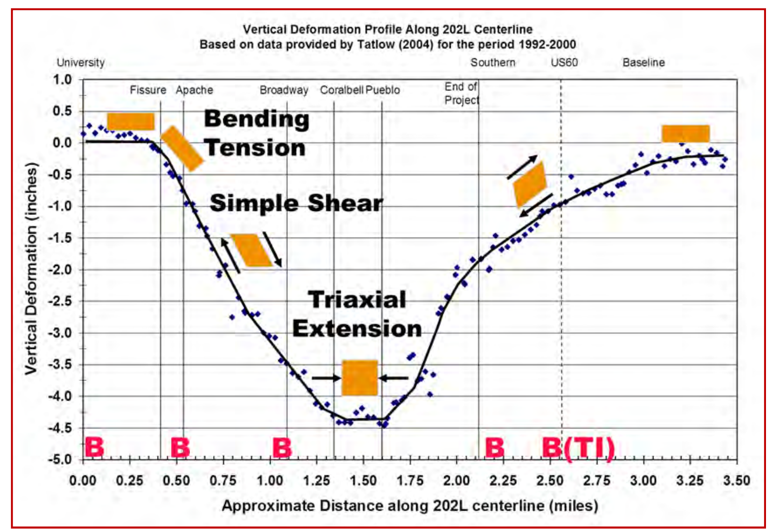
(after NCS Consultants)

Fissures: A Geo-Ether Approach

- Study site geology
- Well records
- Satellite imagery
  - Interferograms
  - InSAR data
- Study deformation and stress paths to convert geo-ether information into downdrag and lateral squeeze with appropriate load factors







(after NCS Consultants, 2011)

Case History – Rocks

- Rockslides (this conference)
  - Major rockslides on I-40 (NC) and SR-64 (TN) in late 2009 impacted major corridors
  - Areas were known to be slide prone and "on the list" for repairs
  - Took opportunity to refine, assess, and address other areas in same corridor
  - Geology influenced characterization, assessment, and repairs

(after Pilipchuk and Wainaina, 2011)

(after Bateman, 2011)

Case History – Rocks

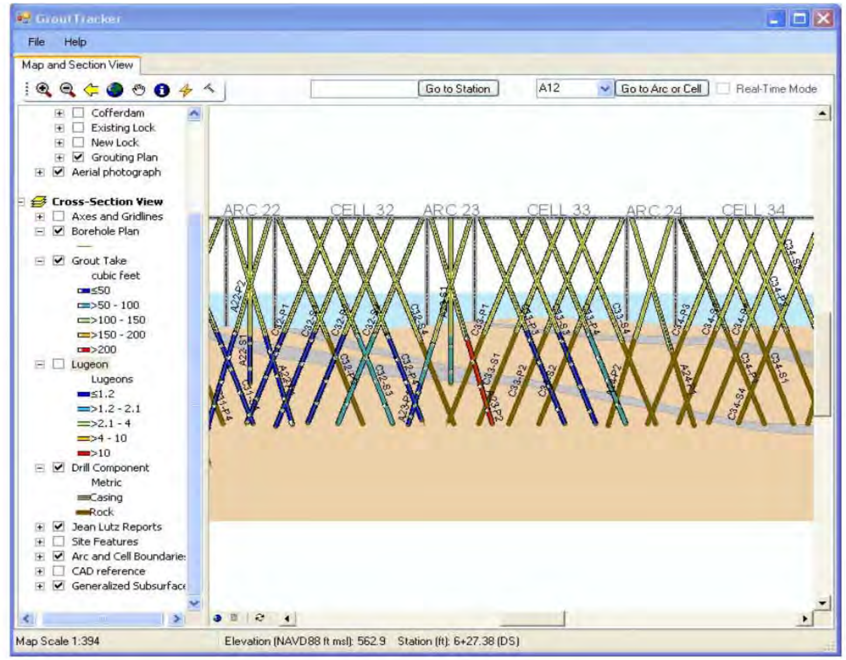
- Foundations
  - Geologic setting influenced foundations exploration and foundation types for O'Callaghan-Tillman Bridge in NM-AZ
- Rock Cuts
  - Rockfall protection and real-time monitoring reduces risk of interference to high speed train in Hooley Cut

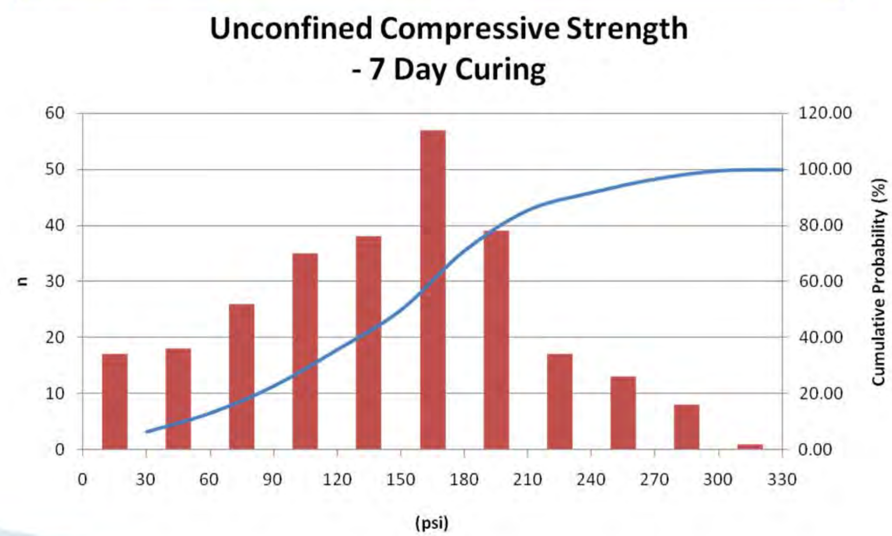
(after Anderson, 2011)

(after Yu, 2010)

Case History – Ground Improvement

- Grouting
  - GIS technologies allow 3D visualization of subsurface geology and ground improvement performance
  - Statistical analysis of data (e.g., grout take, strength) facilitates interpretation of results and optimization of construction methods





(after Rosen, et al, 2011)

Case History – Cost/Benefit

Real Benefits: $36K/project*

- Electronic Data ✔
  - +$1,000
- Geophysics ✔
  - +$6,000
- InSitu Tests ✔
  - +$12,000
- Lab Tests ✔
  - +$2,000
- Performance Monitoring ✔
  - +$5,000
- Construction Control ✔
  - +$10,000

*A reasonable "estimated mean project value range" of any 1 item above may be 5% - 20% of standard geotechnical investigation/processing costs on typical projects- potentially much more if features are found that dramatically impact structural designs.

(after Dasenbrock, 2011)

Future Needs

- Rock Slopes and Foundations
  - Recognize that you only want to fix once, but hopefully learn from past repairs
  - Sliding modes of failure for foundations
- Intermediate Geomaterials (IGMs)
  - Good soil versus bad rock
  - Use of pressuremeter for characterization
  - Evolve to GSI system for fair to poor rock
- Geology, forensic geology, and back analyses offers us a chance to understand the actual properties of materials that we find difficult to quantify

Recommendations

- Define the problem correctly and collect appropriate information to assess properties and variability
- Do not discount geology ….but do not try to "fit" geology to pure statistical analysis
- Get help from above (e.g., satellite imagery) and below (e.g., instrumentation), but be sure to use this information…they are not just new toys
- Geologic features do not know State boundaries, so collaboration in regional forums (like this one) could prove highly effective
- Calibration is needed to assess appropriate resistance factors that account for properties and variability
- Begin the transition from ASD to LRFD

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