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Increased Need for Engineering Judgement in the Age of AI and Advanced Analytical Tools

Iowa Transportation Conference
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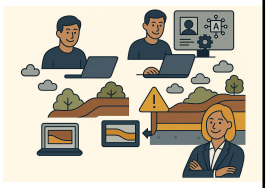
Introduction

- Artificial Intelligence and analytical software continue to advance
- Modern software provides results with low barriers to usage
- Ease of use increases risk of misapplication and decoupling of modeling from complex, natural world
- Need for engineering judgment more vital now than ever

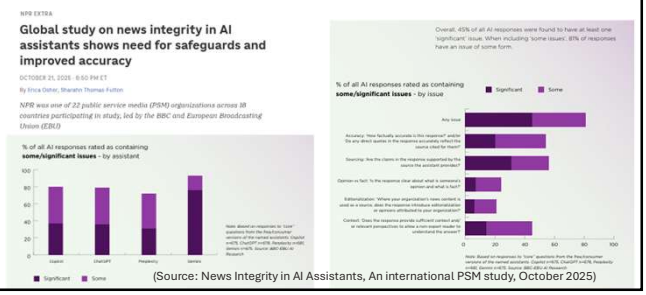


(Image created by M365 Copilot based on these bullet points)

Artificial Intelligence (AI)

- AI models are trained by providing the models with input data
- Hyperparameter optimization - Model fine-tunes the model parameters to best match the training data
- Trained models are tested by using new data
- **Quality, breadth, and bias of the data sets direct the creation of, and therefore, the results produced by, the model**
- These models are *empirical* and are limited by the data sets used to train and verify the models
- Do not possess judgment
- Always give an answer, even if hallucinations

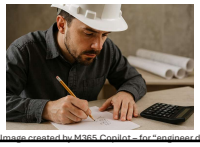
AI Reliability



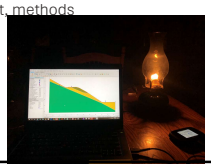
(Source: News Integrity in AI Assistants, An international PSM study, October 2025)

Analytical Tools in Engineering

- Tools used to process, evaluate, analyze, and visualize data
- Pen and paper to AI-assisted computer modeling
- Allow professionals to evaluate the response and/or behavior of a system when subjected to stress changes
- For geotechnical engineering slope stability analysis, generally use Limit Equilibrium and numerical analysis, e.g. Finite Element, methods

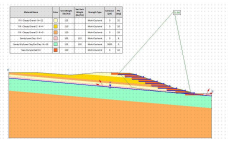


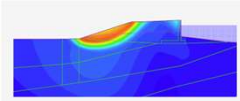
(Image created by M365 Copilot – for "engineer doing calculations with pencil")



Analytical Tools in Geotechnical Engineering – Slope Stability

- Limit Equilibrium (LEM)
  - Considers the equilibrium of a soil mass under the influence of gravity and external loads - compares driving to resistance
  - FS is simply ratio of available resistance to demand
  - Deformation not explicitly considered; simplification
- Finite Element (FEM)
  - Solve complex problems by subdividing larger systems into simpler, smaller parts (finite elements)
  - Assembled into model of overall system
  - Provides magnitude and direction of displacement
  - Eliminates some assumptions of LEM – still approximation, based on constitutive models

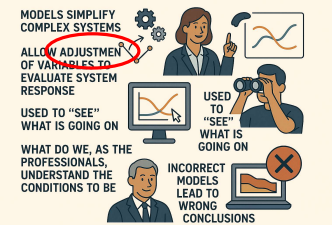




(RS2 image from rocscience.com, 2025)

Understanding Modeling

- Models simplify complex systems
- Allow adjustment of variables to evaluate system response
- Used to "see" what is going on
- What do WE, as the professionals, understand the conditions to be
- Incorrect models lead to wrong conclusions



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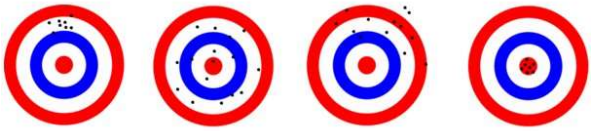
Accuracy, Precision, Reliability, Validity

- Important in evaluating model quality
- All AI and analytical tools will give answers – are they any good?



Reliable not Valid
Precise not Accurate

Not Reliable but Valid
Not Precise but Accurate

Not Reliable and not Valid
Not Precise and not Accurate

Reliable and Valid
Precise and Accurate

Challenges in Geotechnical Modeling

- High variability in earth materials
- Limited and non-continuous data collection
- Empirical methods have variable reliability
- High variability even in lab tests
- Implications for modeling accuracy

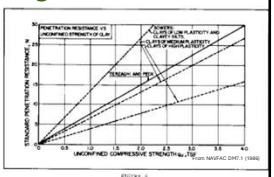
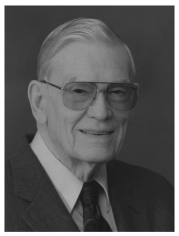


Table 1: Variability of Geotechnical Properties

	γ COV (%)		ϕ (deg) COV (%)		PI COV (%)		Unconfined Compression Test, Su COV (%)	
Material	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Clay	2 -13	7	10 – 56	21	9 -57	29	6 – 56	33
Sand	0 - 10	NR	5 – 11	9	NA	NA	NA	NA

NR = Not Reported
NA = Not Applicable

Challenges in Geotechnical Modeling



- Ralph Peck (1969, emphasis added): "In the engineering for such works as large foundations, tunnels, cuts, or earth dams, a vast amount of effort and labor goes into securing **only roughly approximate values for the physical constants that appear in the equations**. Many variables… remain unknown. Therefore, the results of the computations are **not more than working hypotheses**, subject to confirmation or modification during construction…"

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The Need for Engineering Judgment

Human expertise critical for interpretation

Humans possess judgment

Test the results of the AI outputs and analytical tools against the observed, measured world

Distinguishing between "correct" and realistic results

Exercise judgment

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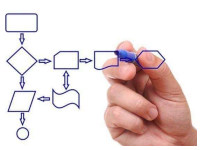
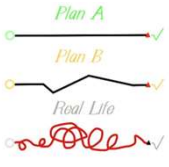
How Can We Exercise Judgement

- Leverage and capture experience
- Create defined processes
- Compare the answers to observed and measured reality





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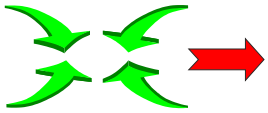
Conceptual Site Model (CSM)



- Working model
- Synthesis of known site information
- Updated as additional data obtained
- Integrates diverse data sources
- Snapshot of the site in present time
- Reconstruction of how the site became what it is
- Predict what might occur in future
- Not a specific tool, but rather a process to create a documented, educated understanding
- What is the SITE telling us?

(Image created by M365 Copilot; had to ask to make geologist female)

Importance of CSM

- Allows us to:
  - Identify constraints
  - Manage risk
  - Have a rational basis for analysis and design
  - Properly mitigate hazards
  - Provide efficient and effective solutions
  - Plan and execute construction effectively
  - Innovate
  - Work safely
- Mitigate Uncertainty

Developing the CSM

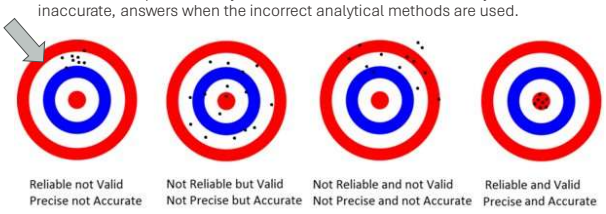
- Integrate desktop and field data to create a conceptual site model
  - Take collected data, integrate, and analyze
  - Use science – physical laws, mechanics, statics, dynamics, etc.
  - Use art – creativity, interpretation, intuition, experience, etc.
- Ask self
  - What is significance of data collected?
  - What are interdependencies?
  - Do I have a sense of the morphology of the site?
  - Do I understand the constraints?
  - Can I explain to another person?
- Identify areas of continued uncertainty and associated risks

CSM Usage

- CSM is basis for analysis and design
- Requires the professional to take time to research the site, digest the data, and develop the conceptual understanding (the CSM) that present a hypothesis of the materials and the mechanisms of failure **PRIOR to creating an analytical model or consulting AI**
- Analytical models are used to test the hypotheses – do the results match what was observed in the field? Are they reasonable?
- Calibrate analytical to observed and measured

Case History

- Illustrates how precise analytical results result in mathematically correct, but inaccurate, answers when the incorrect analytical methods are used.



Case History: Oklahoma Roadway Failure

- Project had failed previously and was repaired using RSS
- Soon after initial fix, embankment failed again in same manner, but now behind RSS
- Less experienced design engineer leading new repair project

Original Failure

RSS Failure

Site Modeling

- Design engineer pulled together a solid Conceptual Site Model
  - Aerial photos
  - Geologic maps
  - Geotechnical investigation data
  - As-built plans and specifications
  - Construction records
  - Site reconnaissance photos and videos
- From reviewed CSM, design engineer created analytical model
  - Subsurface conditions and soil properties from Conceptual Site Model
  - Hypothesized a global failure of the embankment soil
  - Note: original RSS repair used circular surfaces to analyze failure and design fix

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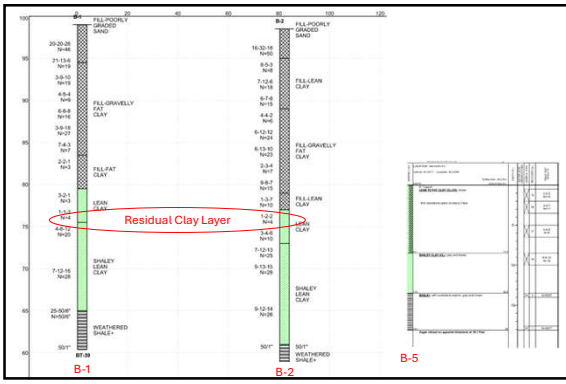

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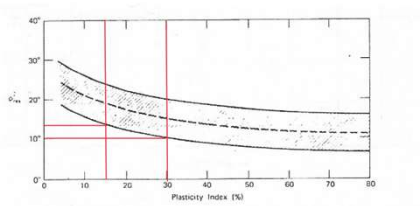
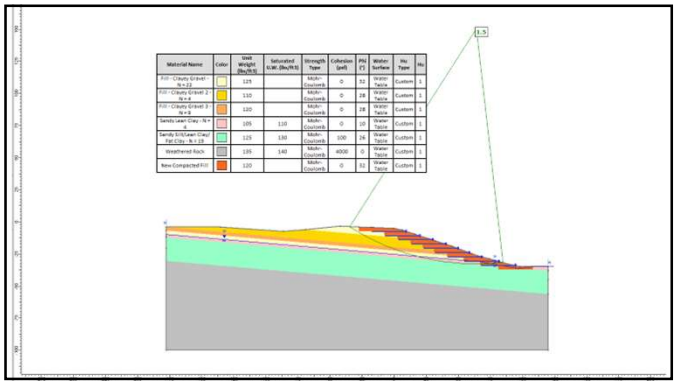
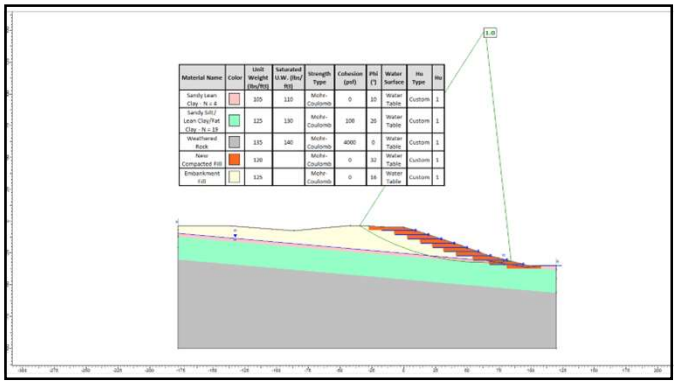
Residual Friction Angles



RESIDUAL (POST FAILURE)

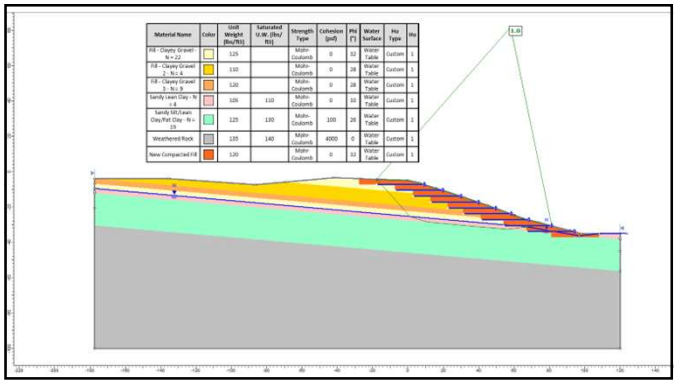


- Model did not show failure! RSS repair works??
- Analytical model did not match observed conditions in the field.
- Maybe estimate of soil properties incorrect.
- Engineer revised and reran.
- Showed failure similar to observed field conditions.



Precise but Inaccurate

- To show failure, engineer had to reduce shear strength of embankment fill
  - Original: long term drained friction angle, phi = 26 - 32 deg
  - Revised: long term drained friction angle, phi = 16 deg
- Not reasonable – material is compacted, low plasticity, in-spec embankment
- Revisit the CSM with reviewing engineer
- What was missed?
  - Subsurface model OK
  - **Sloping residual shale surface (phi = 10 deg) IS present in model as indicated by borings**
- **Reviewer found inappropriate (circular) surfaces used for subsurface conditions**
- **Rerun using non-circular surfaces**



Revised Back Analysis – Best Estimate Properties

- Model using original, best estimate soil properties and non-circular surfaces - FS~1.0
- Failure in model along the residual clay layer as anticipated by judgment
- Analytical model behavior consistent with observed field behavior
- Can now use analytical model to determine remedial solution

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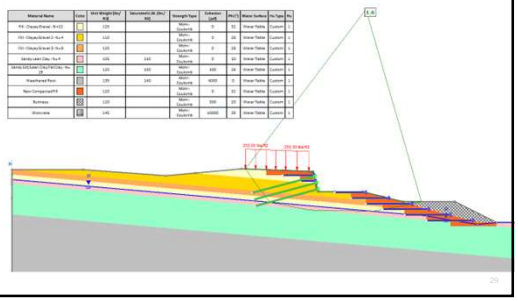
Repair Solution

- Stabilized using
  - Unloading slope
  - Soil nail and shotcrete
  - Toe buttress



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Case History: Summary

- Always do a senior review!!
- Case History illustrates that analytical modeling will provide results that are precise, but not accurate
- The results were precisely wrong even with correct subsurface information, because inappropriate surfaces used
- Original RSS repair also used circular surfaces to analyze failure and design fix
- Good CSM was key to identifying problems with analytical model
- Revised model using non-circular surfaces matched field conditions

Conclusion

- Human judgment is irreplaceable
- Analytical tools require human judgment
- Ease of use requires even more judgement
- Precision does not guarantee accuracy
- CSM is critical for model validation
- CSM aligns models with reality

Closing Thoughts:

THE ANALOG AGE IS OVER

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Thank you!

Questions? Thoughts? Comments?

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