Use and Misuse of Numerical Modeling in Geotechnical Engineering Applications

Youssef Hashash, Ph.D., P.E., F. ASCE
Hall Endowed Professor of Civil & Environmental Engineering
University of Illinois at Urbana-Champaign

GeoVirginia 2016
Oct - 11 - 2016

Acknowledgements

- To the many colleagues in Academia and Practice….
- GeoVirginia Organizers

Outline

- Historical Perspective & Background
- Examples of use
- Examples of misuse
- Looking ahead
- Considerations in engineering practice
- Concluding remarks

It is not new…. Terzaghi

THEORETICAL
SOIL MECHANICS

By
KARL TERZAGHI

JOHN WILEY AND SONS, INC.
NEW YORK *LONDON*

CONTENTS

xiii

It is not new…. Poulos and Davis

ELASTIC SOLUTIONS FOR SOIL AND ROCK MECHANICS

H G Poulos

Reader in Civil Engineering
University of Sydney

E H Davis

Professor of Civil Engineering
(Soil Mechanics)
University of Sydney

Originally Published in 1974 by:

JOHN WILEY & SONS, INC.

NEW YORK · LONDON · SYDNEY · TORONTO

Reprinted in 1991 by:

CENTRE FOR GEOTECHNICAL RESEARCH

UNIVERSITY OF SYDNEY

CONTENTS

Why Numerical Modeling?

Problem:

-Design of new facilities

-Understanding of observed behavior/failure

-Basic studies of engineered system response

Approach:

-Empirical relations (case histories)

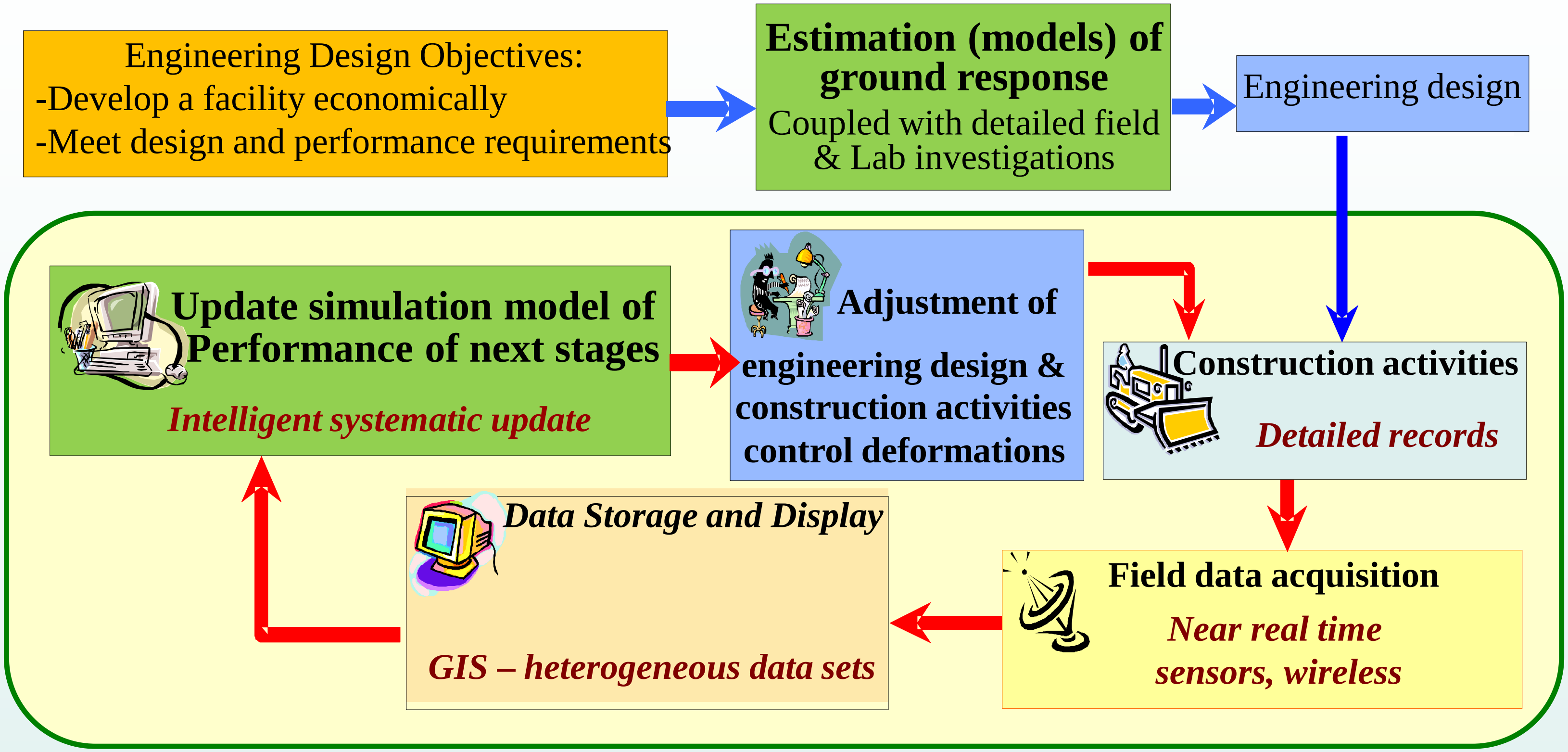
-Simplified/closed form/analytical solutions (e.g. elastic solutions, earth pressure, failure theories)

-Numerical solutions (e.g. slope stability, FE and FD)

Why Numerical Modeling?

- **Limitations of empirical and simplified solutions**
  - Complex geometries, load condition, soil profiles
  - Non-linear, inelastic soil behavior
  - Staged Construction
  - New types of construction
  - Dynamic Behavior
- **Numerical Solutions**
  - Computer revolution
  - Very powerful, versatile tool
  - Provide an additional tool for the design engineer

Role of Model Simulation



- Not a substitute for good engineering and judgment
- Not a substitute for detailed field exploration and laboratory testing programs

Classes of Geotechnical Analysis Problems

- *Elasticity Problems*: Problems involving ***stresses*** and ***deformations***, with ***no failure*** of the soil (linear elasticity, soil is highly non-linear even at small strains)

- *Stability Problems*: Problems dealing with the ultimate failure of a soil mass (e.g. theory of *perfect plasticity)*

- *Elasto-Plastic Problems:* The essential connection between elasticity problems and stability problems. Allow the ***transition*** from initial linear elastic state to the ultimate state of plastic flow

- *Time-dependent Problems*: Long term settlement and consolidation problems

Two Components of Numerical Modeling

I) Domain Equations:

1- Equilibrium equations
2- Equations relating displacements to strains
3- Equations relating stresses to strains

II) Boundary Conditions:

What happens on the surface of the model.

The combination of the domain equations and boundary conditions define a ***Boundary Value Problem (BVP)***

Boundary Value Problems

Global Equilibrium due to externally applied load/construction ⟺ Stress - strain relationships in the medium

Soil Behavior

- *Types of Analyses:*
  - Total stress analysis
  - Effective stress analysis
  - Saturated and partially saturated analysis
  - Static
  - Dynamic

Field Equations of BVP

Soil Behavior/Constitutive Relation

Compatibility, equilibrium and conservation

$$n_s + n_f = 1$$

$$\dot{n}_s + n_s \dot{u}^{s}_{i,i} = 0$$

$$\dot{n}_f + n_f \dot{u}^{f}_{i,i} = 0$$

$$\dot{\varepsilon}^{s}_{ij} = \frac{1}{2}\left(\frac{\partial \dot{u}^{s}_{i}}{\partial x_j} + \frac{\partial \dot{u}^{s}_{j}}{\partial x_i}\right)$$

$$\sigma'_{ij} = \sigma_{ij} + \delta_{ij} p$$

$$p_i + R_i + b_i^{f} = \rho_f n_f \ddot{u}_i^{f}$$

$$\sigma_{ij,j} + b_i = \rho_s n_s \ddot{u}_i^{s} + \rho_f n_f \ddot{u}_i^{f}$$

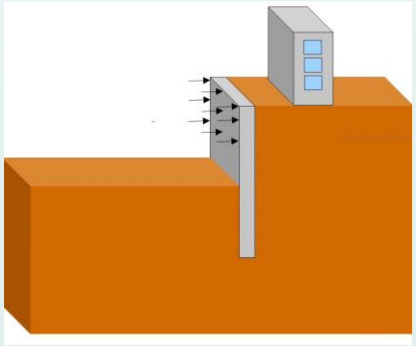
Variables:

n_f, n_s	(2)
u_i^f, u_i^s	(6)
ε_{ij}, σ_{ij}	(12)
σ_{ij}’	(6)
p	(1)
R_i	(3)
??	(30)
Eq.	(21+9)

Soil Model

$$\dot{\sigma}'_{ij} = C_{ijkl}\dot{\varepsilon}^{s}_{kl}$$

$$R_j = n_f K^{-1}_{ij}\left(\dot{u}_i^{f} - \dot{u}_i^{s}\right)$$

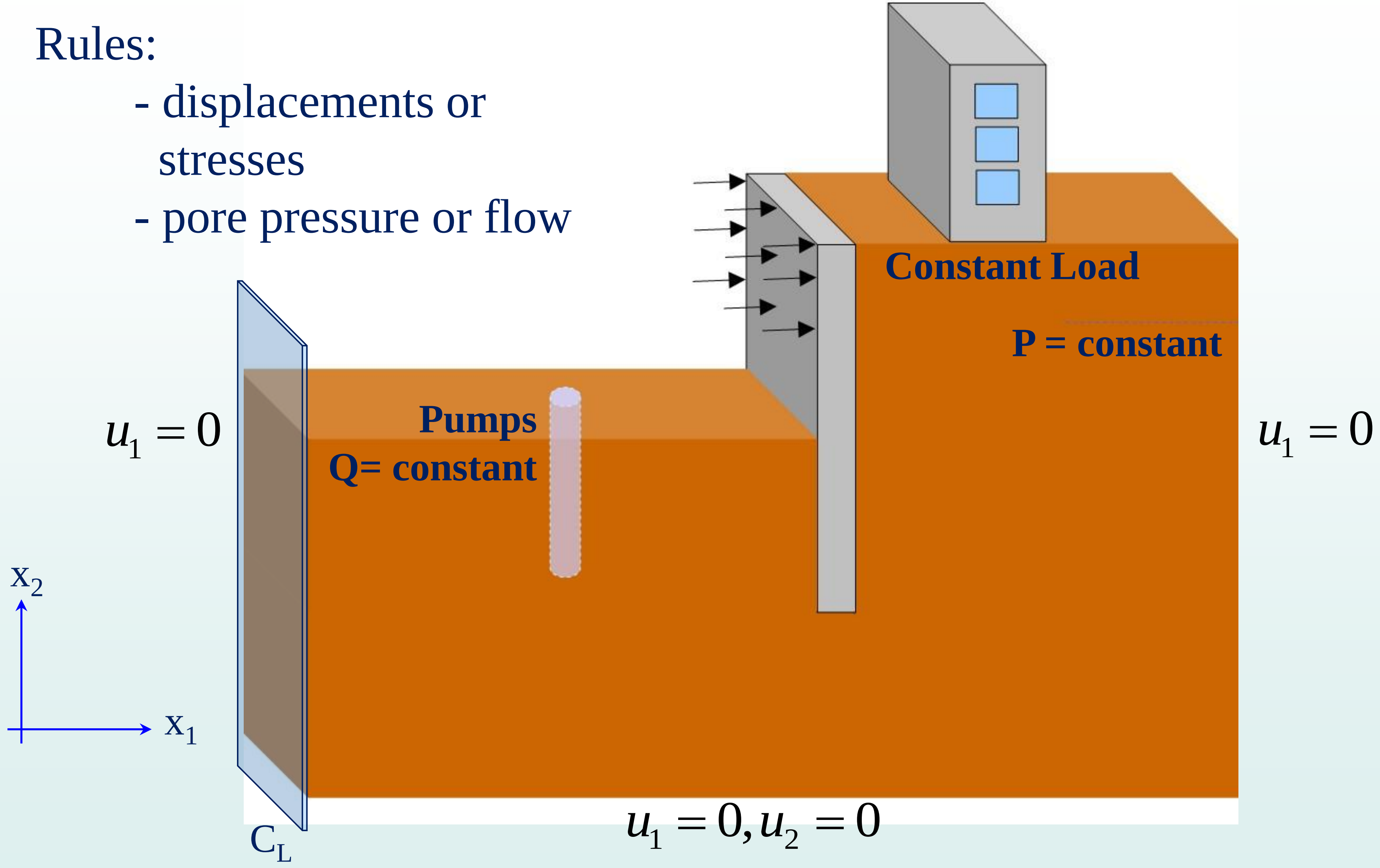


e.g. deep excavation

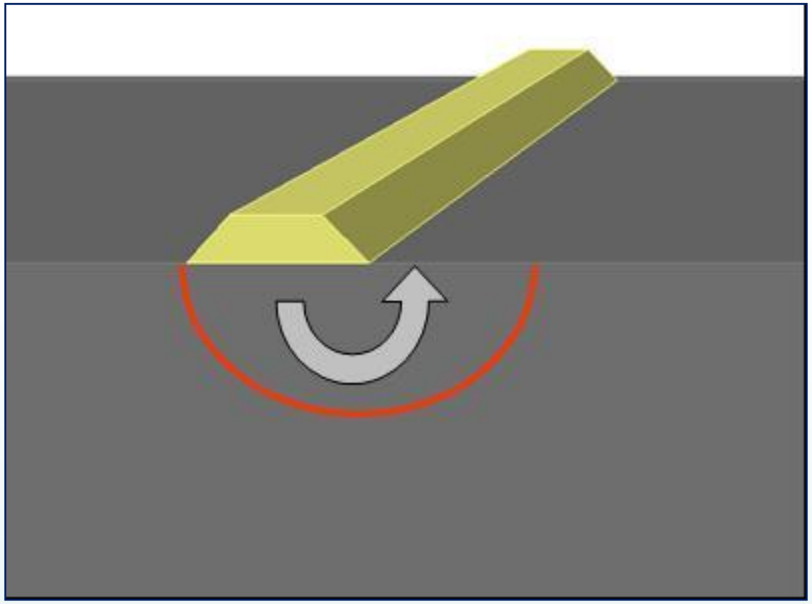
The boundaries in BVP

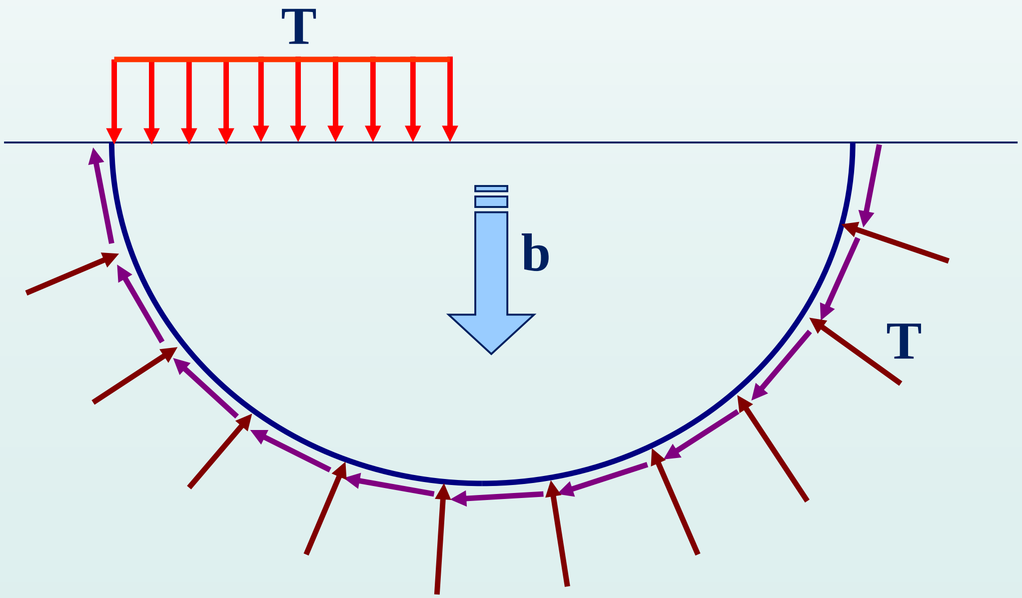
Rules:

- displacements or stresses
- pore pressure or flow



BVP idealization of Surface & Body Forces



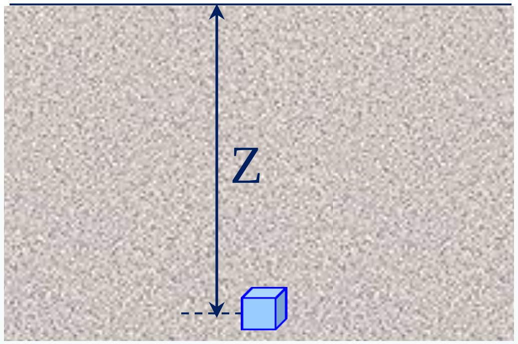


Initial Conditions: State of Stress in Soil

Every element of soil is in ***equilibrium*** under the initial state of stress.

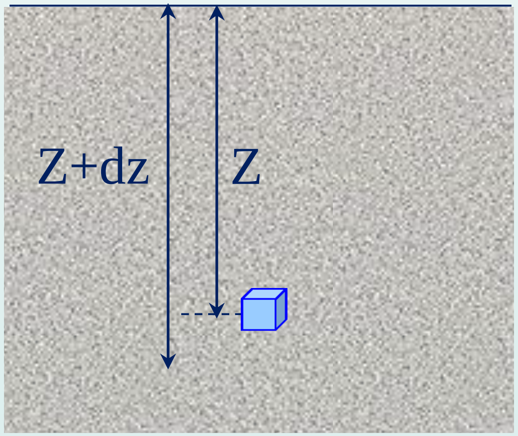
$$\sigma_v = Z\gamma$$

$$\sigma'_h = K_o \sigma'_v$$



Where K_0 is the ***coefficient of earth pressure at rest***.

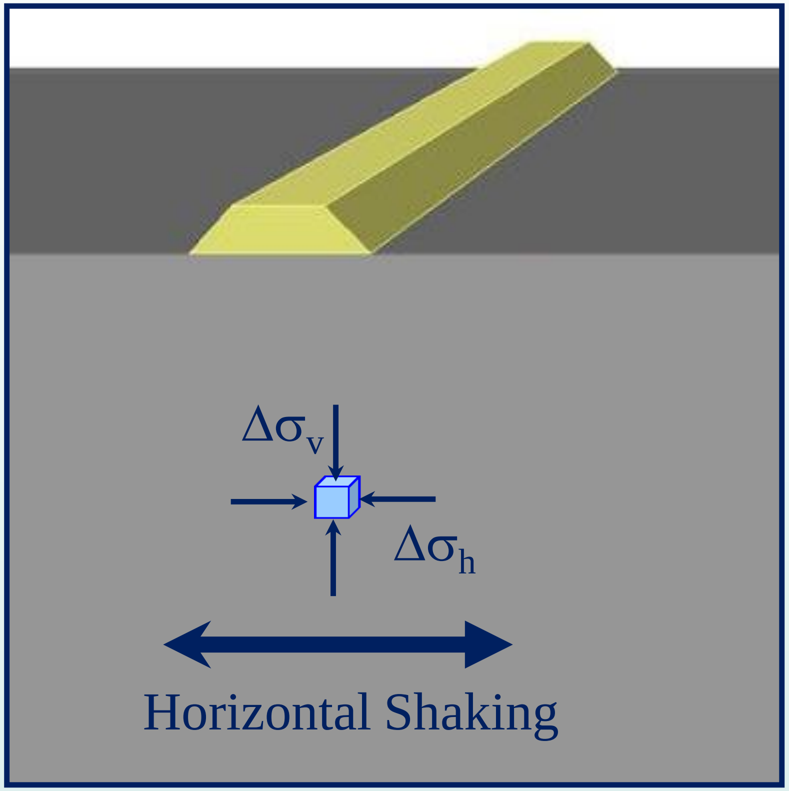
<u>Local Equilibrium & relationship to unit weight</u>

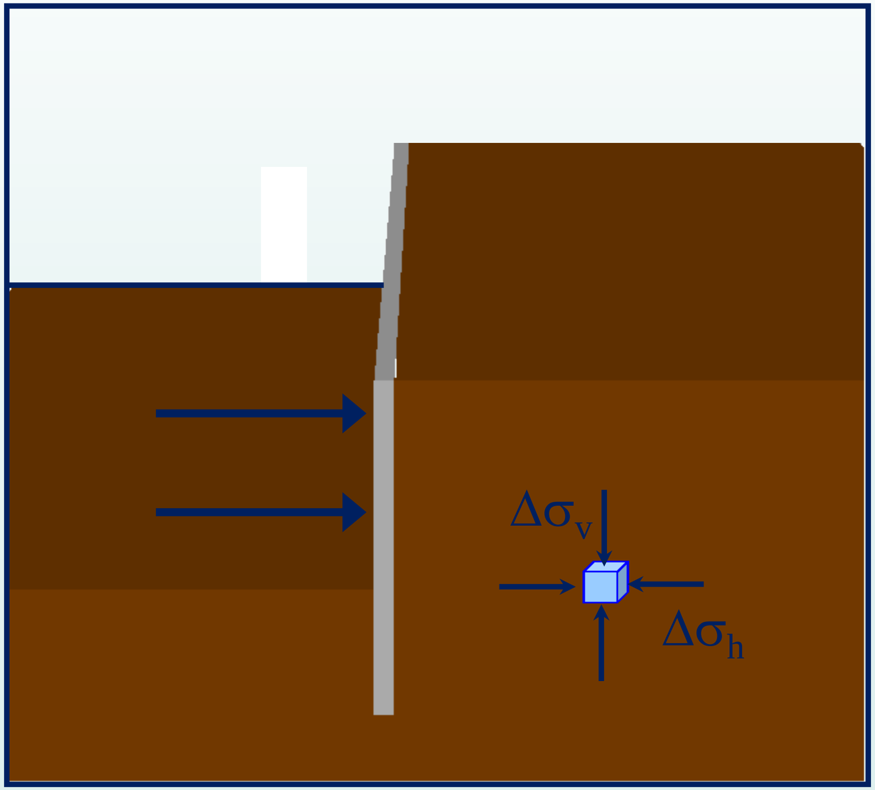


Change in the (initial) state of stress

Construction activities & deformations

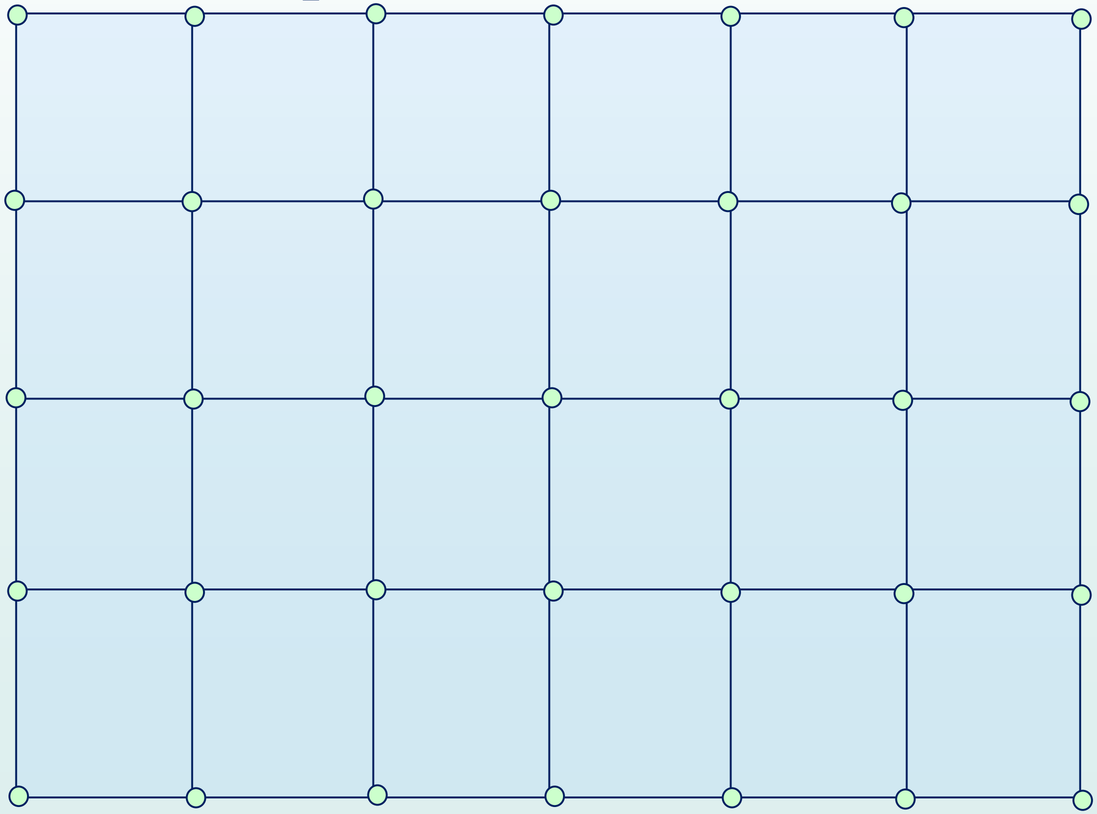
A new state of equilibrium
=> initial state + incremental change = in equilibrium
=> incremental change = satisfies equilibrium





Discretization of BVP

- Numerical Solution of system of differential equations
- Compute solution at discrete points, use interpolation/shape functions for in-between locations

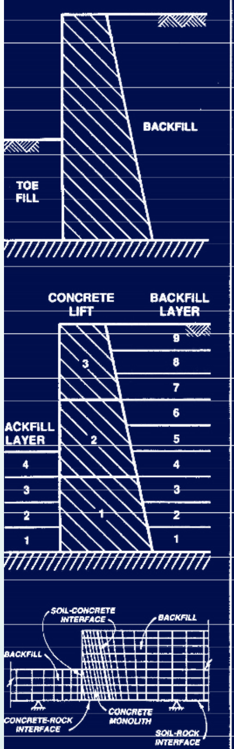


Geotechnical software… The early years

US Army Corps of Engineers

TECHNICAL REPORT ITL-90-6

USER'S GUIDE FOR THE INCREMENTAL CONSTRUCTION SOIL-STRUCTURE INTERACTION PROGRAM SOILSTRUCT



by

R. M. Ebeling

Information Technology Laboratory

J. F. Peters

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

and

G. W. Clough

Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

May 1992
Final Report

Approved For Public Release; Distribution Is Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

SOILSTRUCT

CONTENTS

Implementation of Numerical Methods

- Finite Element Method (FEM)

- Finite Difference Method (FDM)

- Boundary Element Method (BEM)

- Discrete Element Methods (DEM)

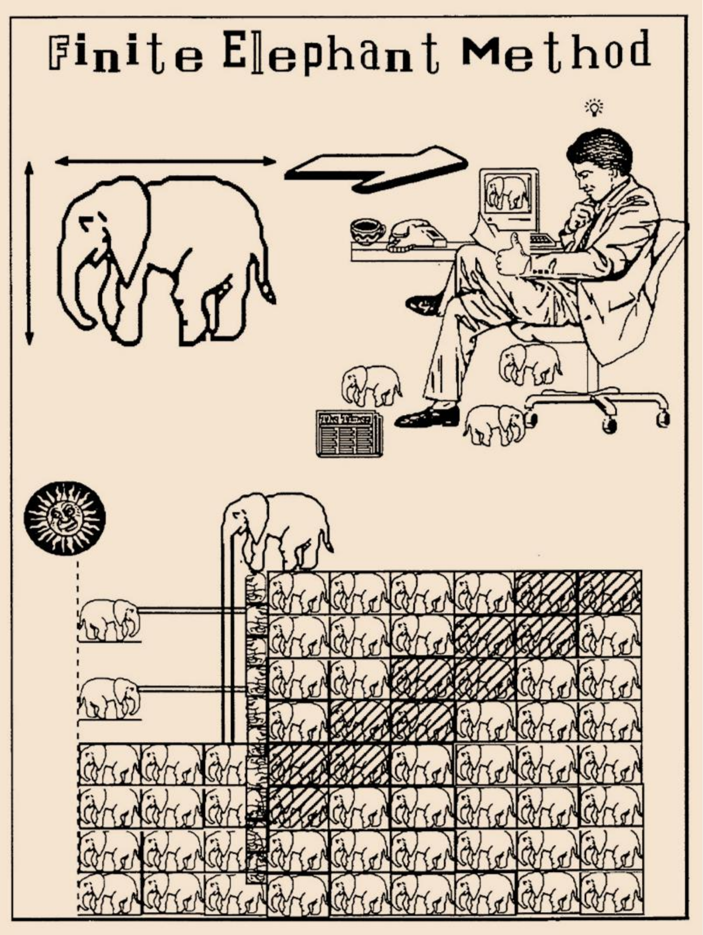
- Commercial software:
    - FLAC, PLAXIS, ABAQUS..

...

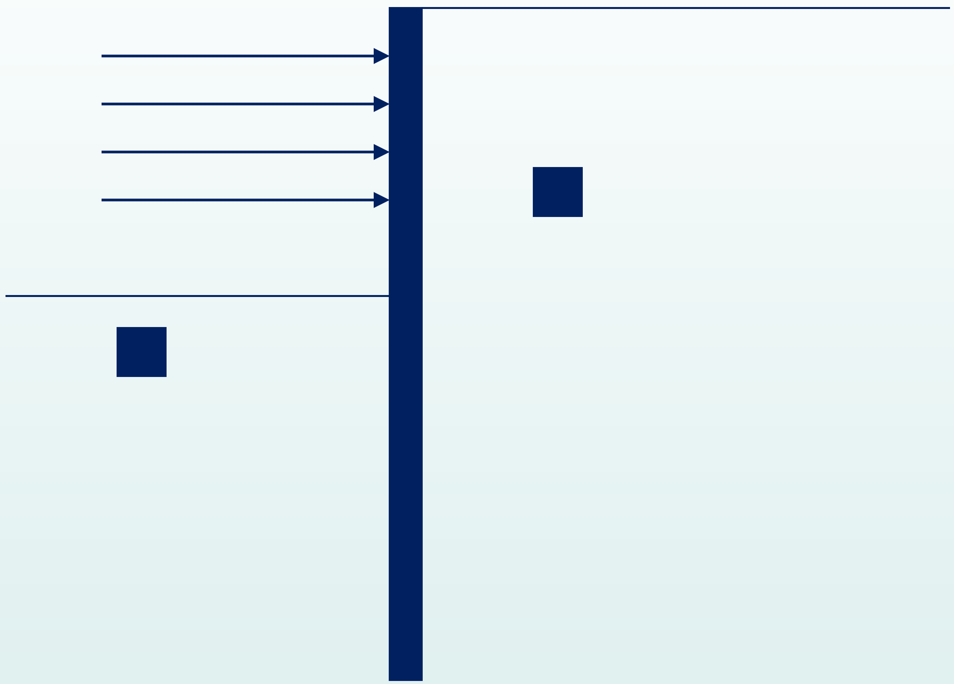
Also:

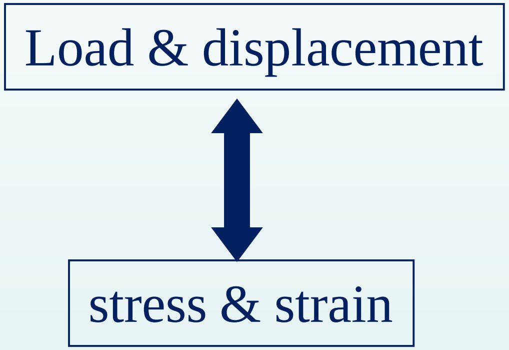
Hybrid Methods (such as Discrete Finite Element Method, DFEM)

Coupled Methods (such as Hydro-Mechanical, Thermo-Hydro-Mechanical, etc)



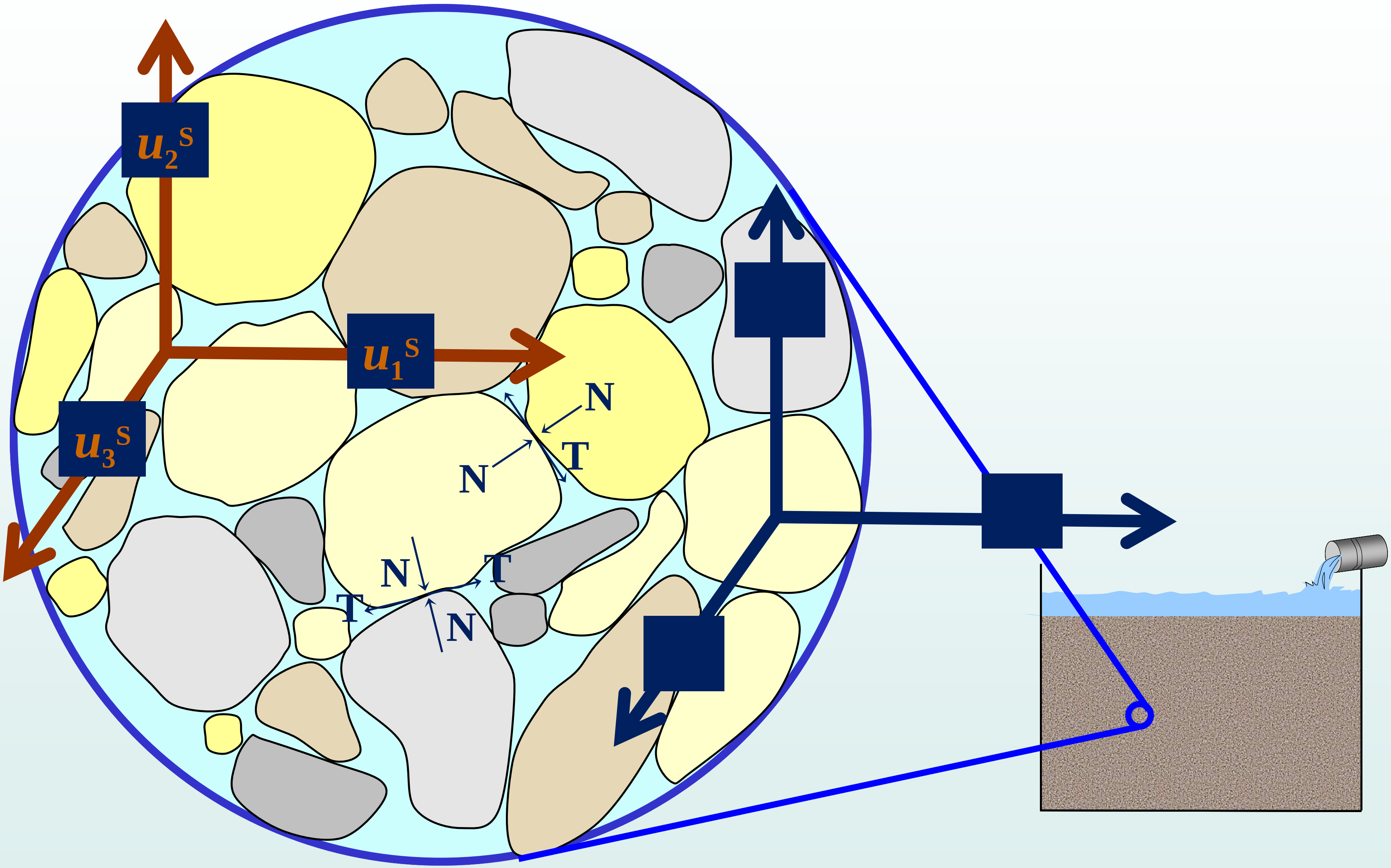
Soil Behavior: Stress and Strain in Soil





Soil Model: Multi-Phase Nature of Soil

Two Phase Soil: solids and water (100% saturated) with fluid flow



DEM simulation with Polyhedral Particles

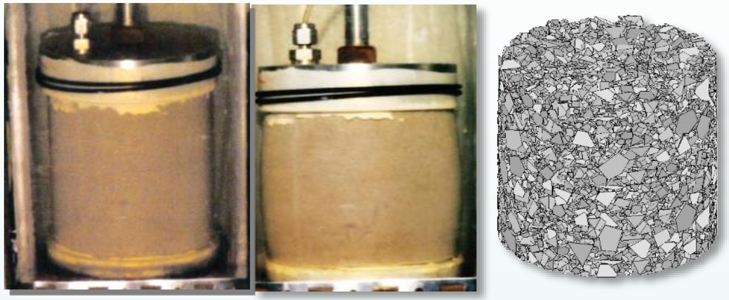
Soil-bucket interaction simulation

(Nezami et al., 2007)

~3 hours per 1 sec. simulation w/ 25000 particles*

Triaxial compression tests

(Lee et al., 2012)



2~3 days to shear each sample
up to 10% of ε_{axial} w/ 9000 particles‡

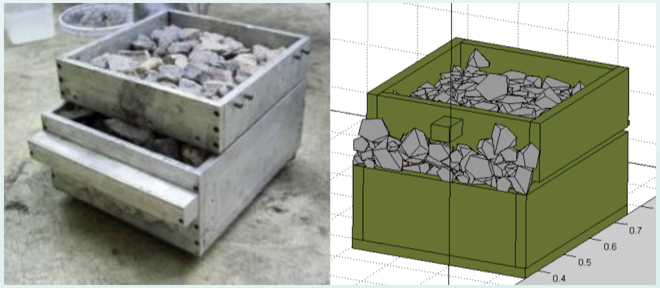
Bearing tests on JSC-1A bed

(Lee et al., 2011)

~2 hours per 1 sec. simulation w/ 17000 particles‡

Direct Shear Box tests

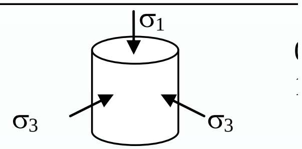
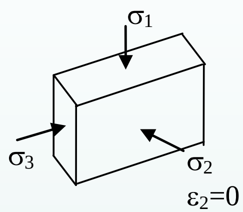
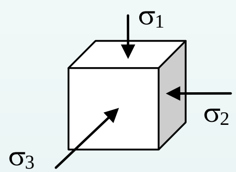
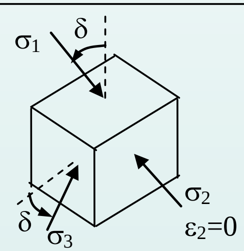
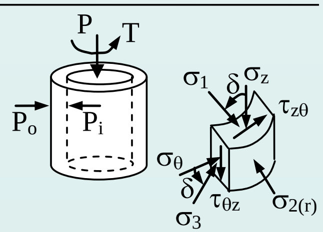
(Huang et al, 2011)

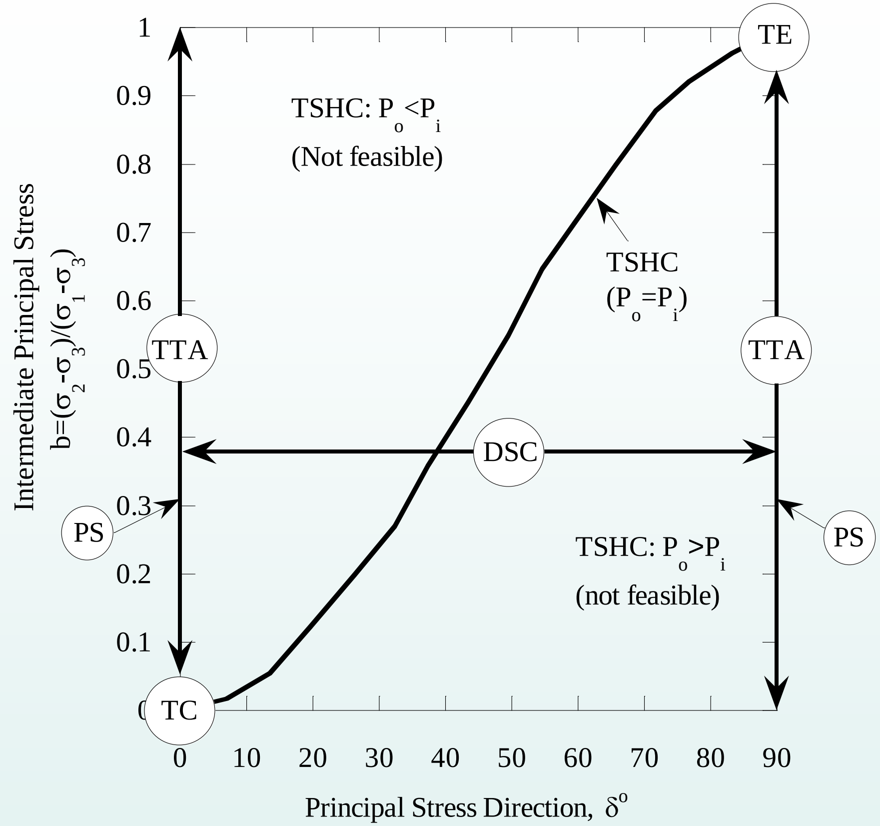


Complexity of Soil Behavior: Stress-Strain-Strength Relations

- Static (monotonic) vs. Dynamic (cyclic)
- Soil vs. Rock
- Lab Shear Tests vs. Field Shearing Modes
- Strain Rate Effects
- Consolidation effects
- continuum vs. discontinuum effects

Multitude of shearing modes

No.	Test Name	Loading conditions
(a)	Triaxial	
(b)	Plane strain	
(c)	True triaxal	
(d)	Direct simple cell (DSC)	
(e)	Hollow cylinder	



DSC: Directional Shear Cell
TC: Triaxial Compression
TE: Triaxial Extension
PS: Plane Strain
TSHC: Torional Shear Hollow Cylinder
TTA: True Triaxial Apparatus

Simplified: Isotropic Linear Elasticity

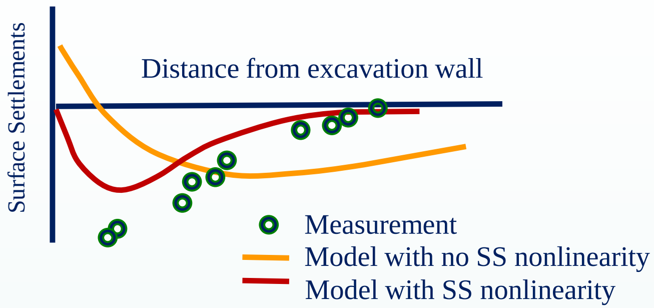
$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{31} \end{Bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \times \begin{bmatrix} 1-\nu & \nu & \nu & 0 & 0 & 0 \\ & 1-\nu & \nu & 0 & 0 & 0 \\ & & 1-\nu & 0 & 0 & 0 \\ & & & \frac{(1-2\nu)}{2} & 0 & 0 \\ & \text{Symmetric} & & & \frac{(1-2\nu)}{2} & 0 \\ & & & & & \frac{(1-2\nu)}{2} \end{bmatrix} \begin{Bmatrix} \epsilon_{11} \\ \epsilon_{22} \\ \epsilon_{33} \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{31} \end{Bmatrix}$$

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{31} \end{Bmatrix} = \begin{bmatrix} \left(K+\frac{4}{3}G\right) & \left(K-\frac{2}{3}G\right) & \left(K-\frac{2}{3}G\right) & 0 & 0 & 0 \\ & \left(K+\frac{4}{3}G\right) & \left(K-\frac{2}{3}G\right) & 0 & 0 & 0 \\ & & \left(K+\frac{4}{3}G\right) & 0 & 0 & 0 \\ & & & G & 0 & 0 \\ \text{Symmetric} & & & & G & 0 \\ & & & & & G \end{bmatrix} \begin{Bmatrix} \epsilon_{11} \\ \epsilon_{22} \\ \epsilon_{33} \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{31} \end{Bmatrix}$$

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{31} \end{Bmatrix} = \begin{bmatrix} \lambda+2\mu & \lambda & \lambda & 0 & 0 & 0 \\ & \lambda+2\mu & \lambda & 0 & 0 & 0 \\ & & \lambda+2\mu & 0 & 0 & 0 \\ & & & \mu & 0 & 0 \\ & \text{Symmetric} & & & \mu & 0 \\ & & & & & \mu \end{bmatrix} \begin{Bmatrix} \epsilon_{11} \\ \epsilon_{22} \\ \epsilon_{33} \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{31} \end{Bmatrix}$$

Stiffness Nonlinearity at Small Strains

- Burland 1989 – Small is Beautiful
- Whittle, A. J. and Y. M. A. Hashash (1994). On importance of small strain non-linearity and stiffness.
- V_s as a fundamental geotech parameter
- Representation of nonlinearity now more readily available in commercial software (e.g. PLAXIS)



After Simpson et. al 1979

SASW testing, TTC, SF

Material Constitutive Models: Plasticity

→ **Plasticity based models**, concept of a loading criterion, different behavior of loading and unloading

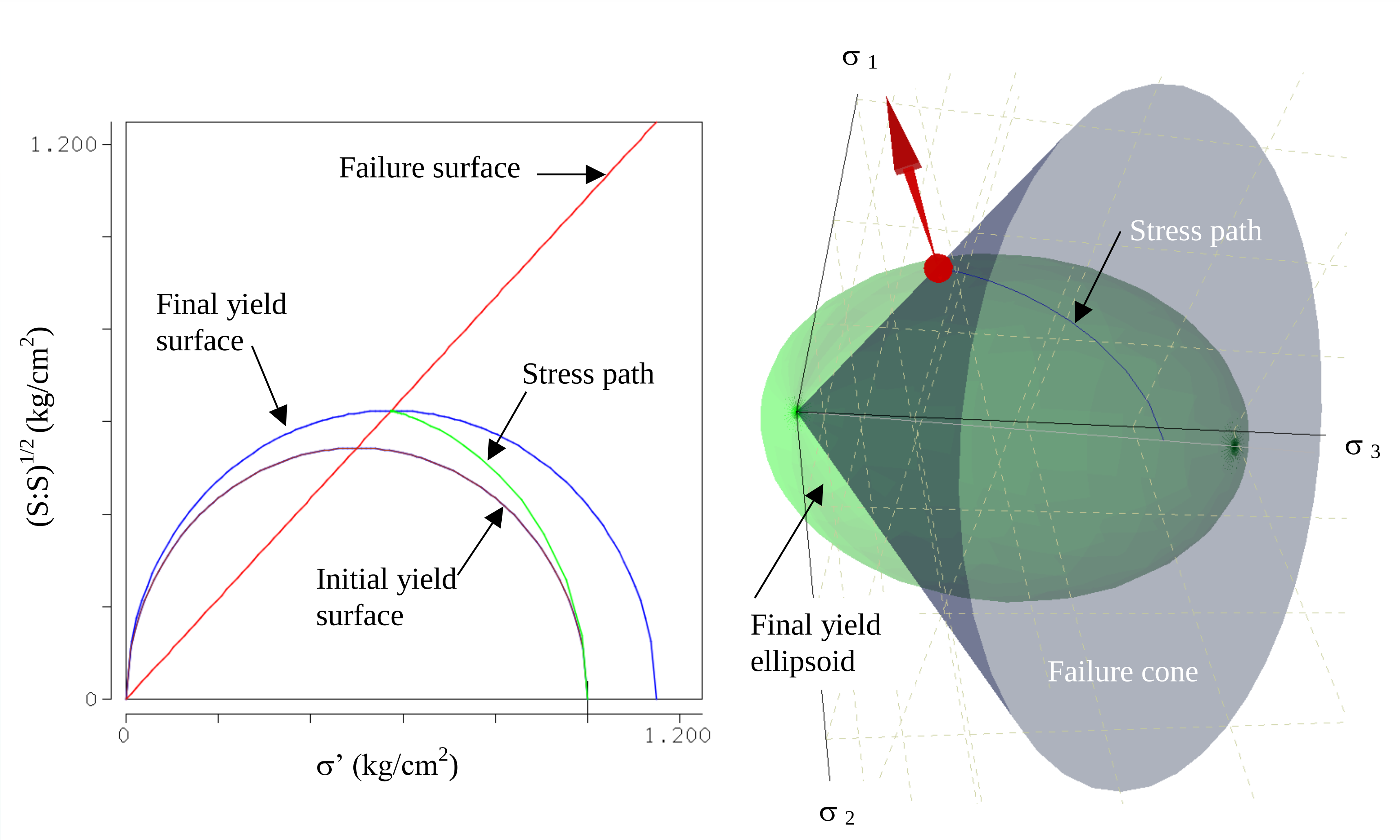
Flow theory of plasticity:

- Initial yield surface
- Evolution of the yield surface (hardening rule), perfect plasticity → no evolution
- Flow rule

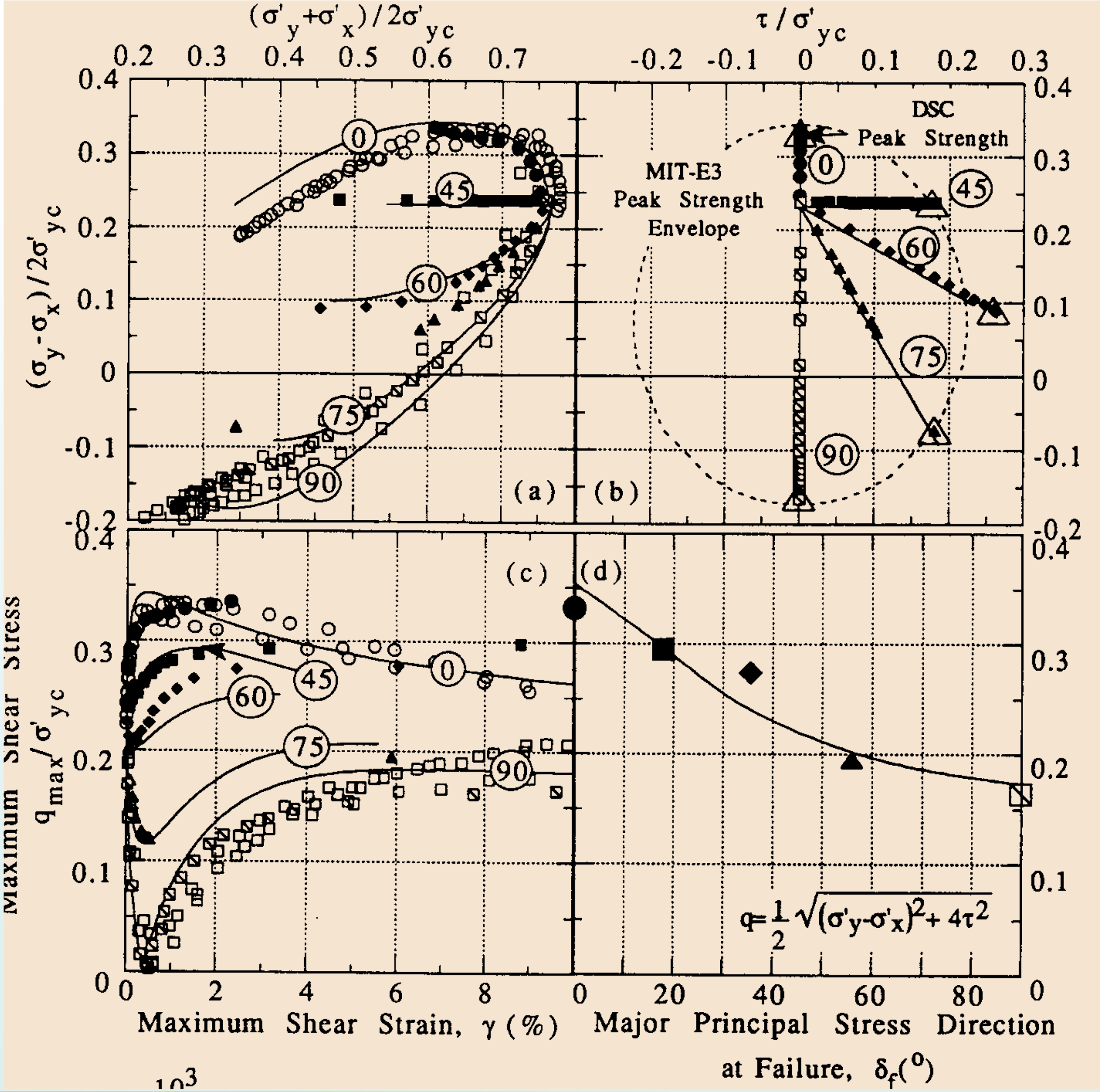
Can represent:

- Dilatancy
- Nonlinear hysteretic behavior

Yield and Failure Surfaces



Ex.: MIT-E3 Plane Strain Tests Simulations



Executing a numerical analysis

I) Pre-Processing Stage:

1- Simplify the geometry to fit the modeling capabilities
2- Discretize the simplified geometry (FE, FD, DE, etc)
3- Define geometric and hydraulic boundary conditions
4- Define initial state of stress and pore pressure
5- Define material profile and properties

II) Processing Stage:

1- Impose variations to the model (e.g., staged construction)
2- Compute the response of the model

III) Post-Processing Stage:

1- Reduce and process the resulting data
2- Display the results (visualization)
2- Analyze the results

Essential Component: Engineering Experience, Judgment and Good Intuition

Example Uses of Numerical Modeling

- Urban Excavation
- Reactivated landslide
- Deep ground freezing
- Blasting in confined space

Deep Excavation in an Urban Area

Garage at Post office Square, Boston, MA

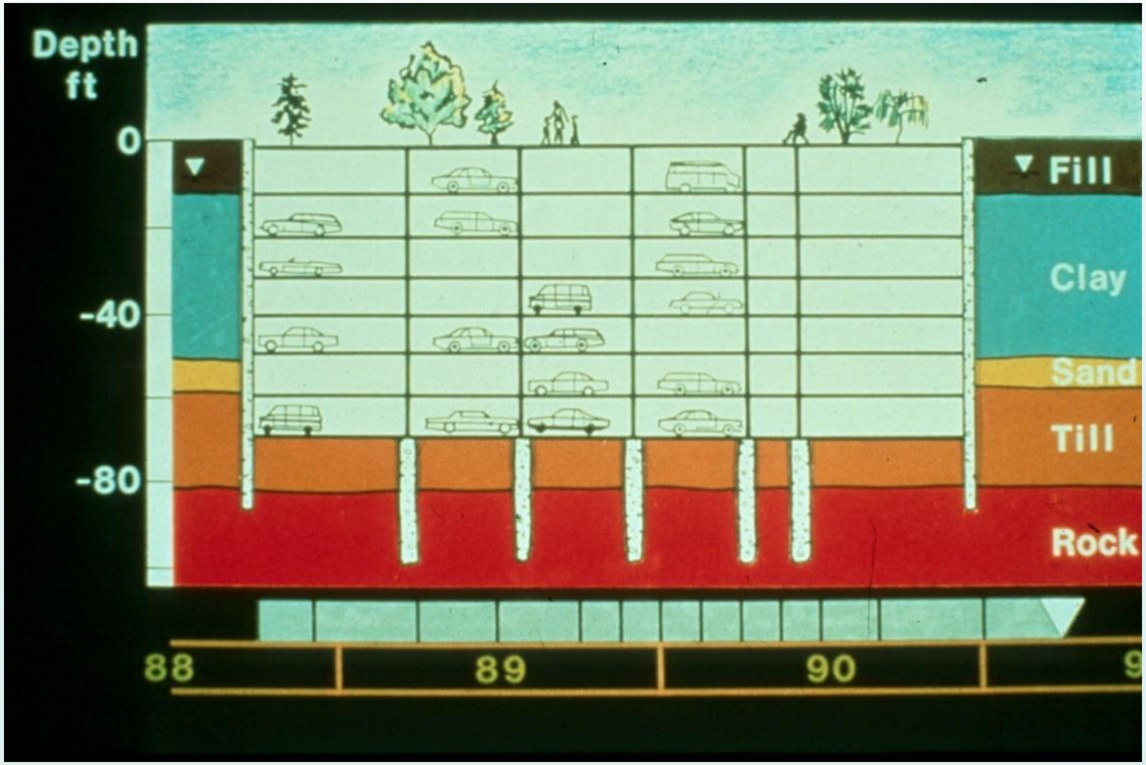
Design Problem:

-Top-down construction, 1st of its kind in Boston

-Load in support system

-Water inflow into excavation

-Adjacent structures



Deep Excavation in an Urban Area

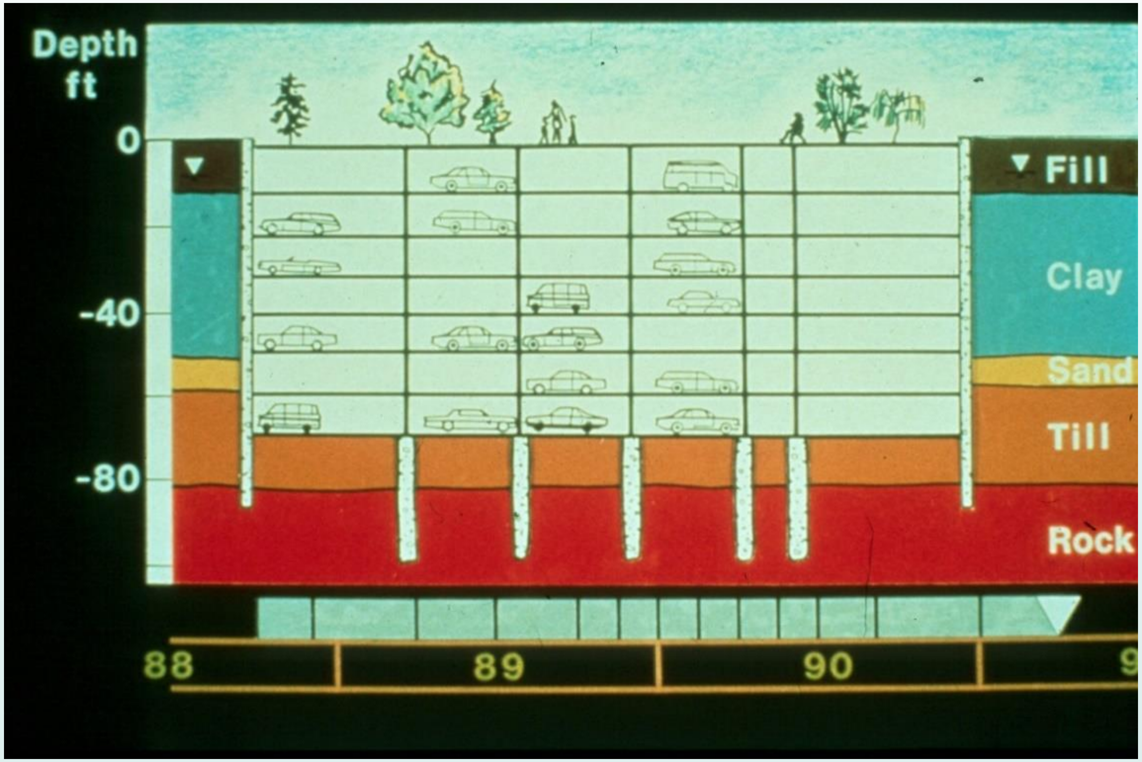
Garage at Post office Square

Approach:

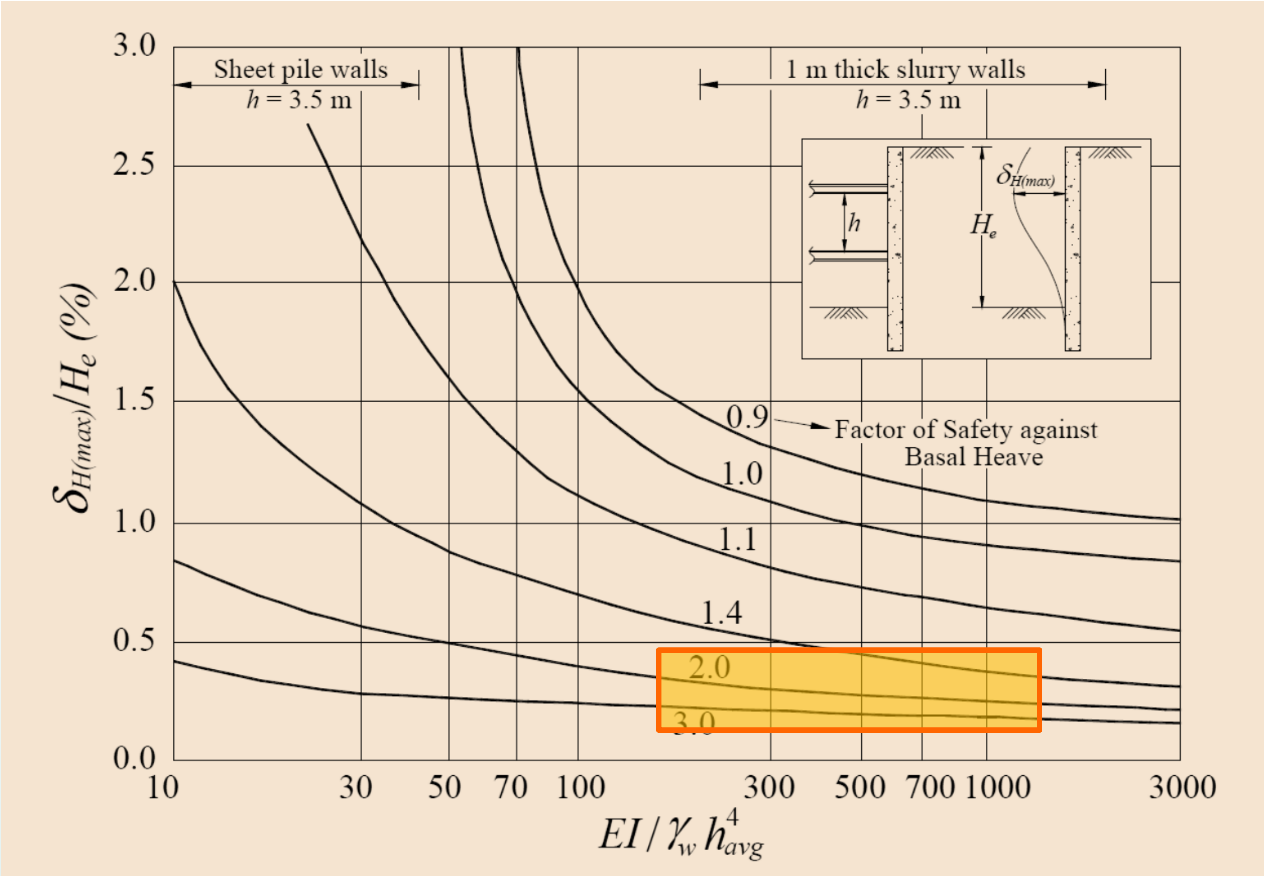
-Empirical relations: charts, not for keyed in walls, limited precedence

-Simplified/closed form/Analytical solutions: None

-Numerical solutions: construction staging, coupled stress-flow analysis



Empirical Relations



After Clough and O'Rourke 1990

…dependent on details of construction process

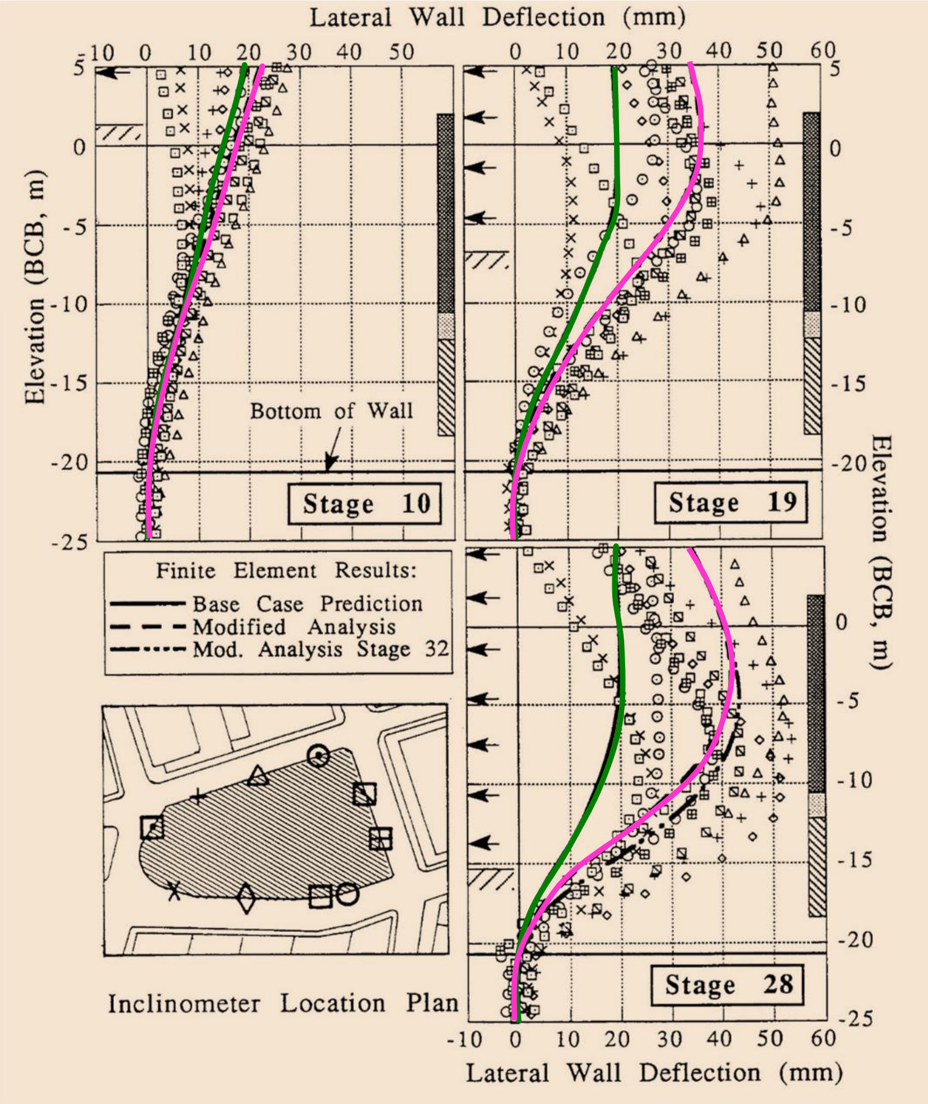
…require more comprehensive monitoring

…need for higher fidelity numerical model

Deep Excavation in an Urban Area

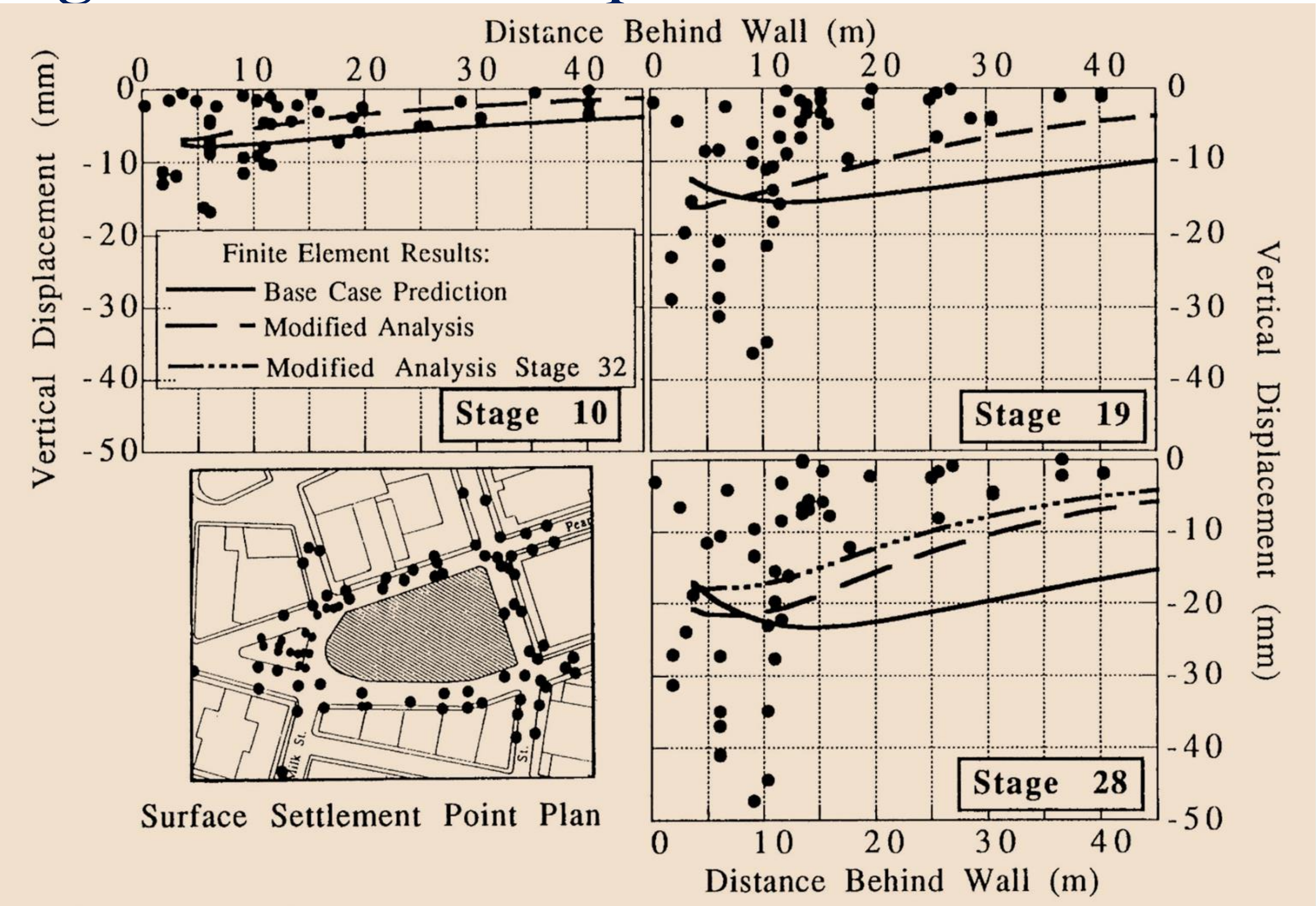
Garage at Post office Square

- Mismatch in estimated lateral movement
- Mismatch in settlements
- Should we change stiffness?
- Concrete shrinkage
- Drainage



Deep Excavation in an Urban Area

Garage at Post office Square



Stabilization of an Ancient Landslide

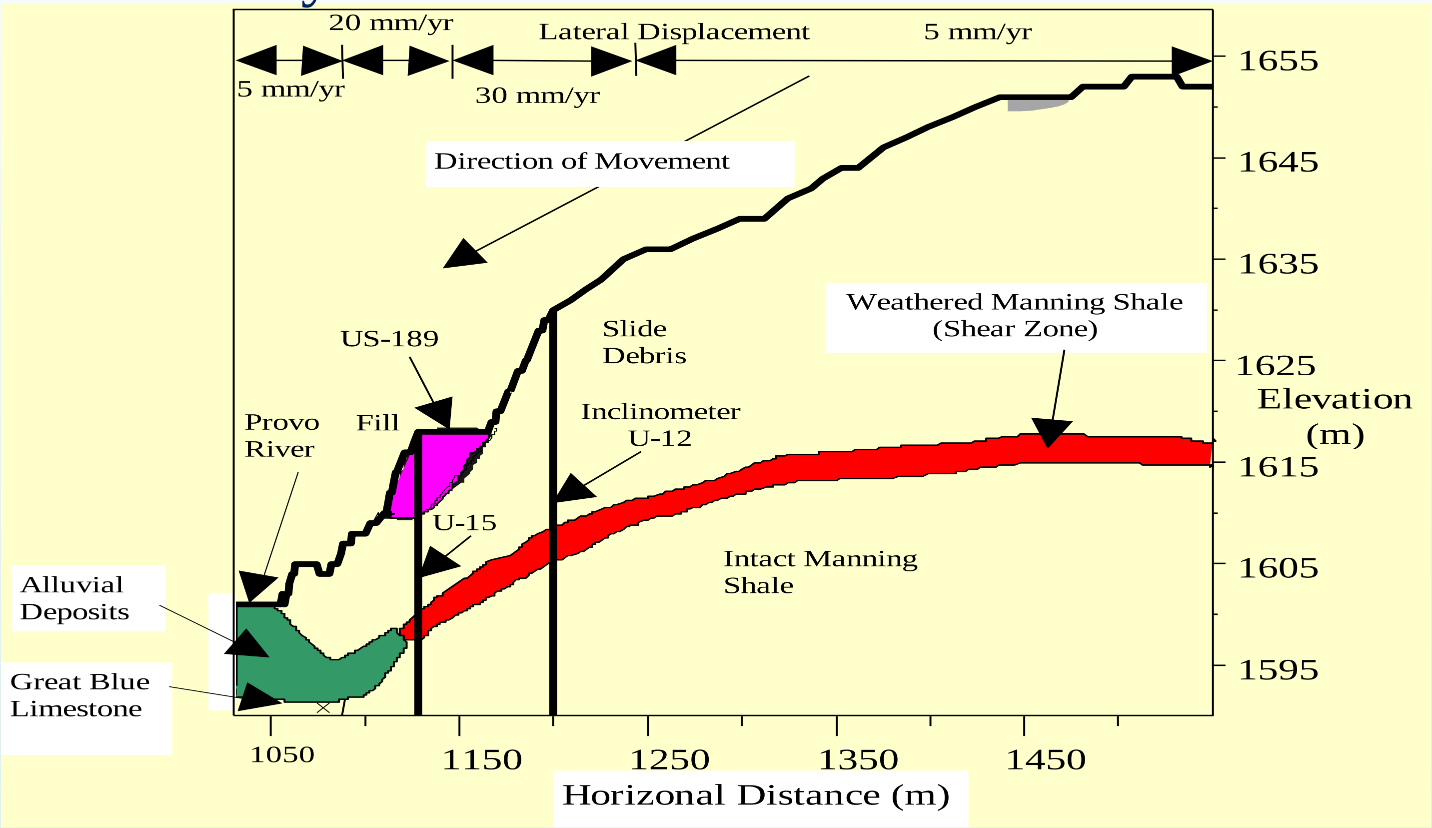
Hoover Slide, Upper Provo Canyon, Utah

Design Problem:

-load on drilled caissons

-reduction in ground movement

-Impact of roadway construction



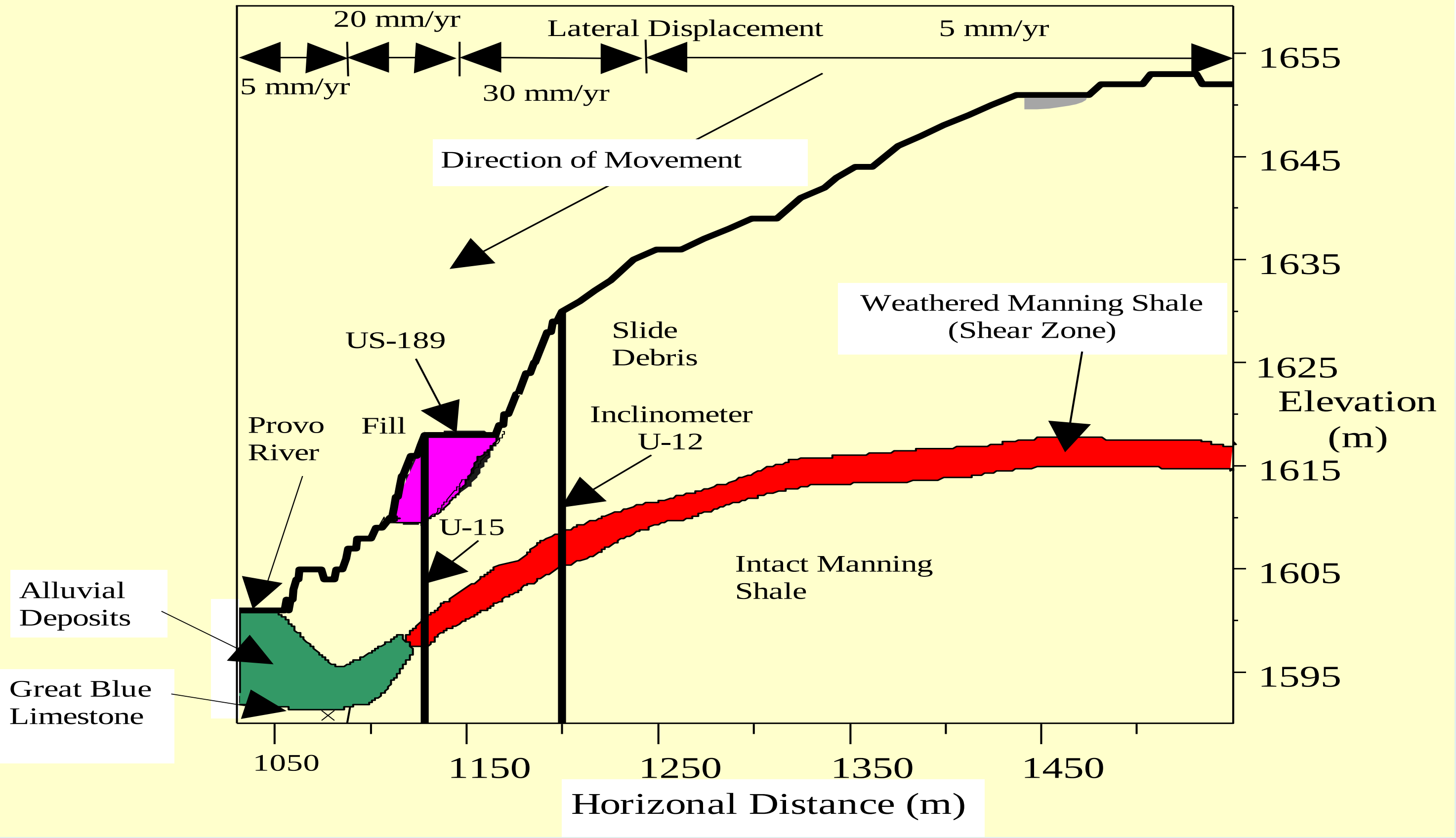
Stabilization of an Ancient Landslide

Approach:

-Empirical relations: engineering estimate, similar cases in Washington

-Simplified/closed form/Analytical solutions: ??

-Numerical solutions: construction staging, coupled stress-pile analysis



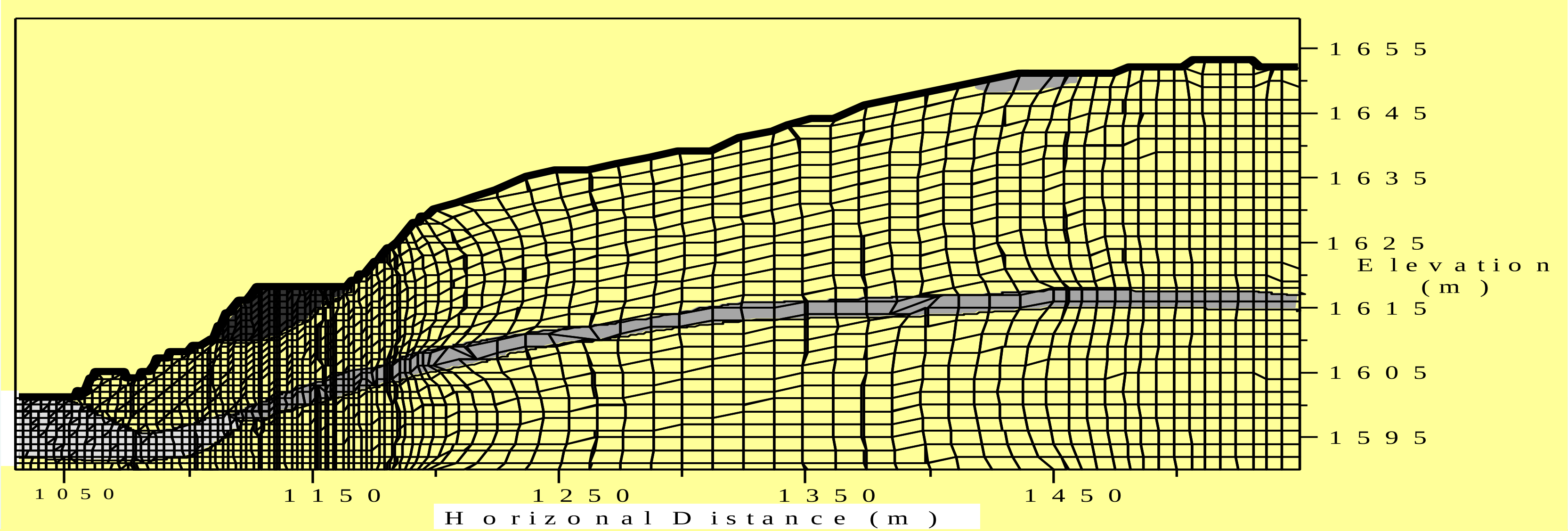
Stabilization of an Ancient Landslide

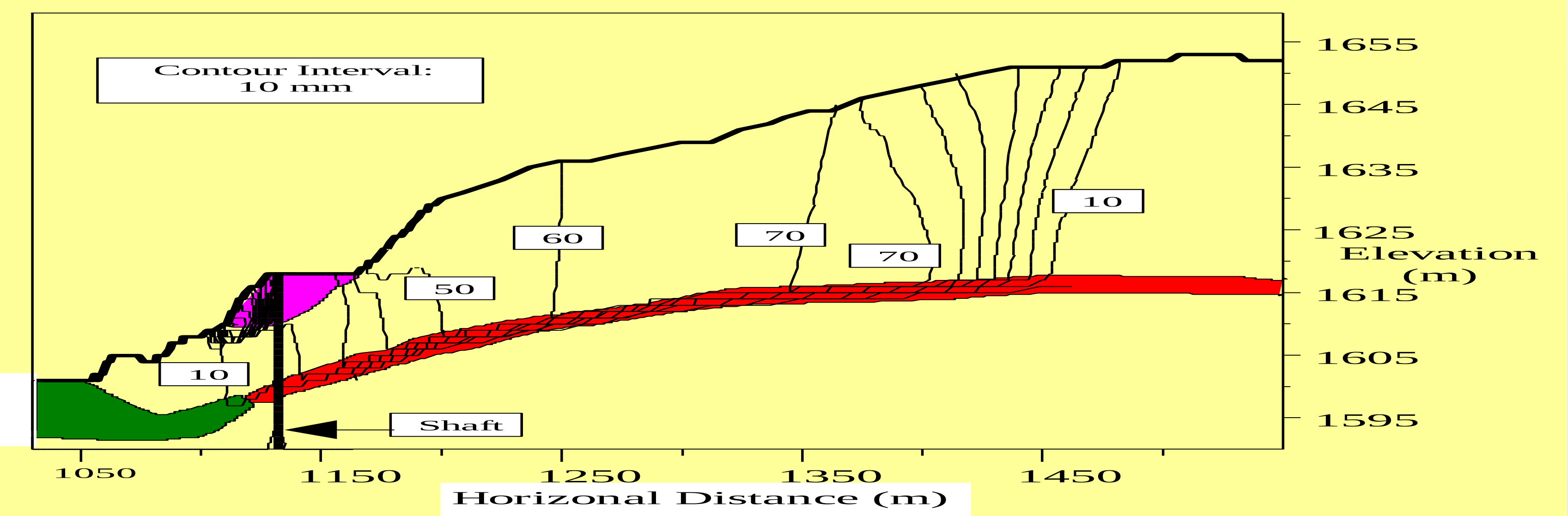
Hoover Slide, Upper Provo Canyon, Utah

- Calibrate creep model without stabilization measures and roadway.
- Add roadway fill and compute deformations
- Add stabilizing shaft and compute deformations

Stabilization of an Ancient Landslide

Hoover Slide, Upper Provo Canyon, Utah





Ground Freezing in a Uranium Mine

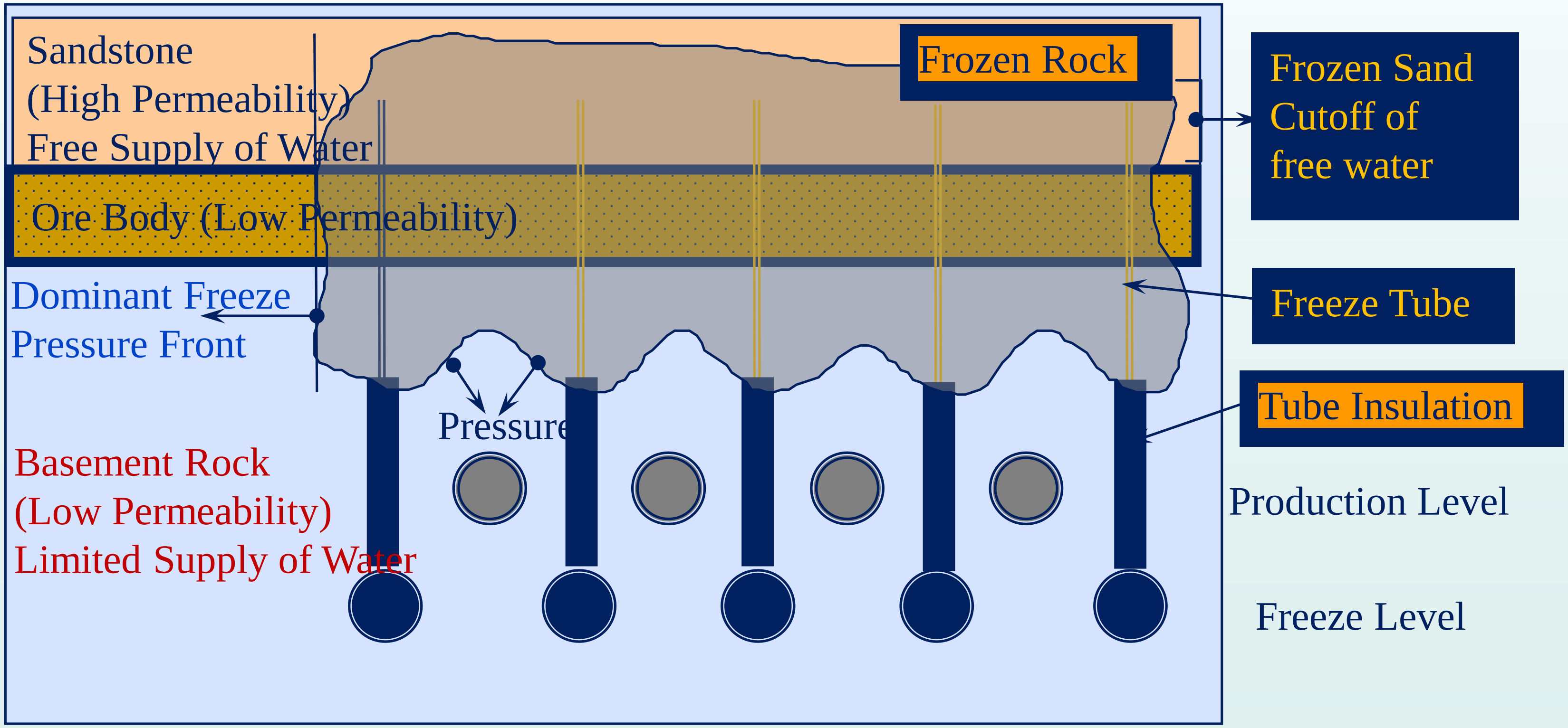
Cigar Lake mine, Saskatchewan, Canada

Design Problem:

-load on adit support system

-extent of freeze zone

-deformations



Ground Freezing in a Uranium Mine

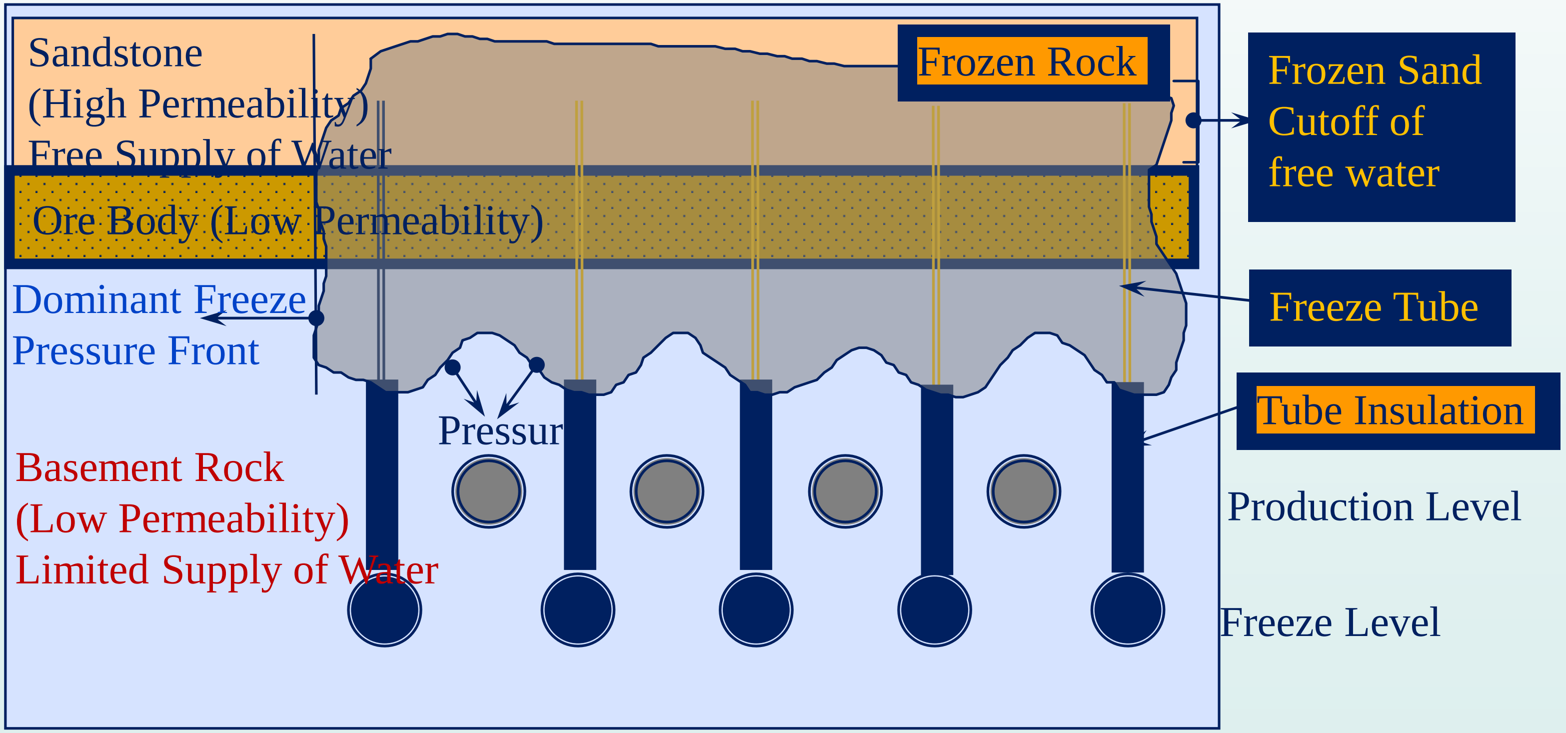
Cigar Lake mine, Saskatchewan, Canada

Approach:

-Empirical relations: some charts, no precedence

-Simplified/closed form/Analytical solutions: None

-Numerical solutions: construction staging, coupled stress-flow analysis

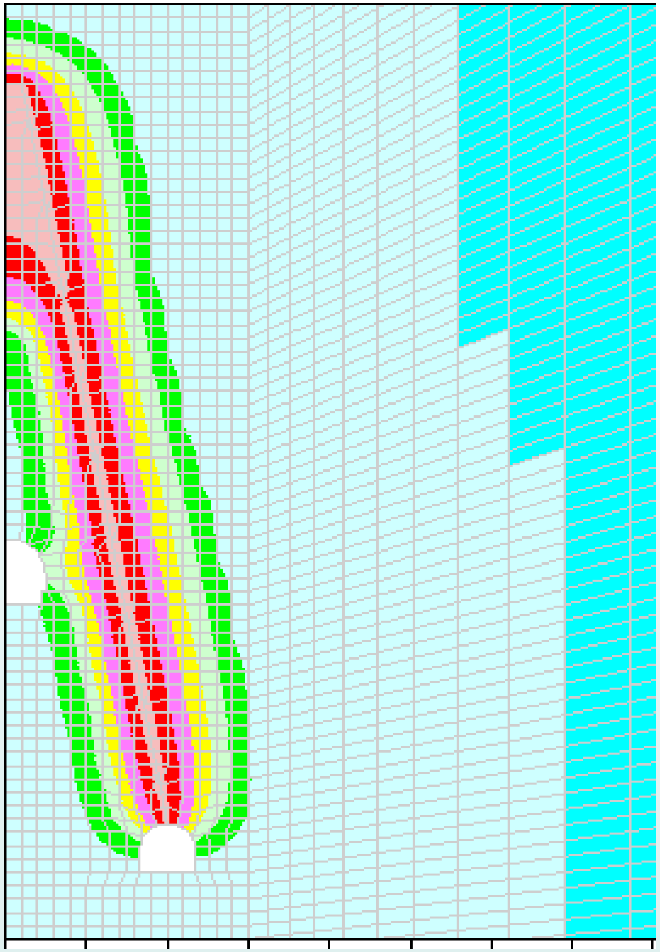


Ground Freezing in a Uranium Mine

Cigar Lake mine, Saskatchewan, Canada

- Experimental freezing program
- Temperature measurements
- Lining stress measurements

- Calibrate a user developed temperature dependent water freezing model

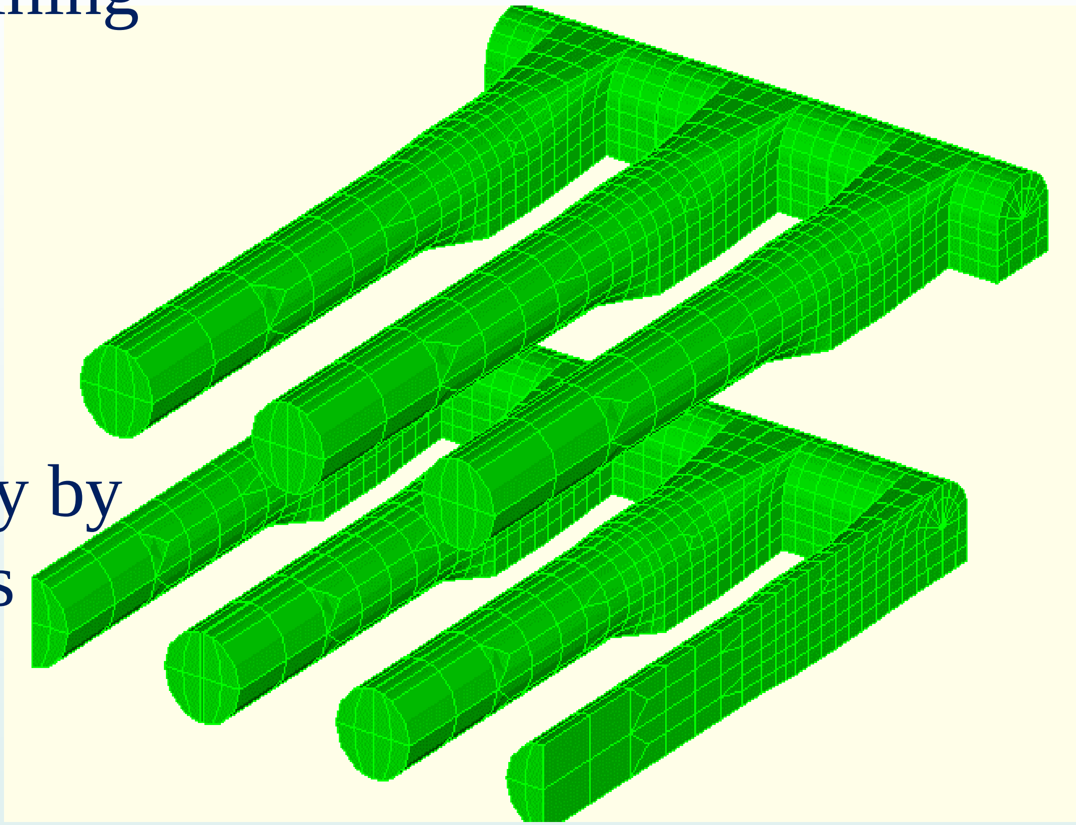


Temperature contours

Ground Freezing in a Uranium Mine

Cigar Lake mine, Saskatchewan, Canada

- Compute forces on lining in multi adit configuration
- Forces limited mostly by overburden pressures

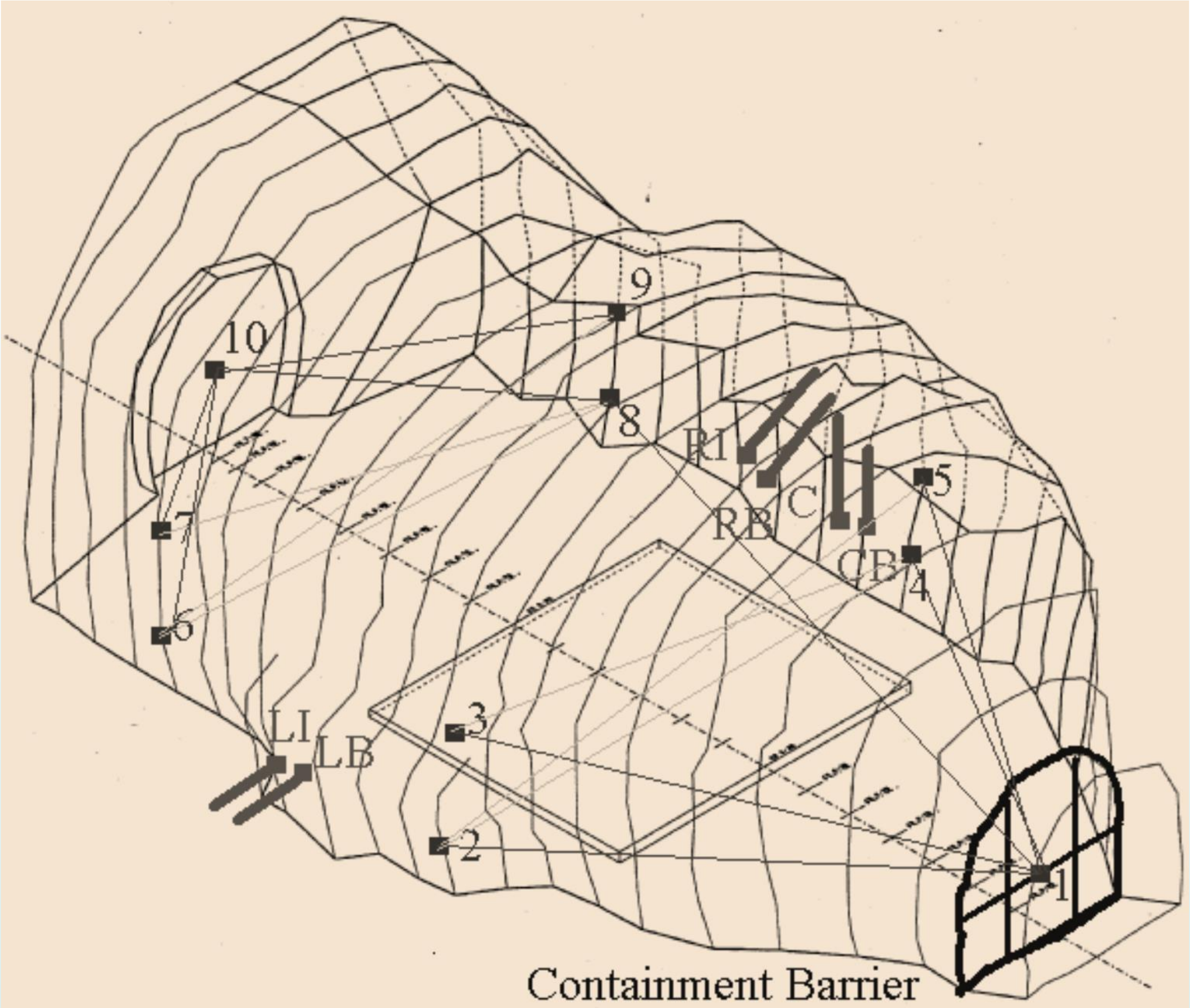


Adit Intersections

Munitions Disposal in an Adit : Nevada Test site

Design Problem:

Effect of repeated blasting on integrity of tunnel walls.



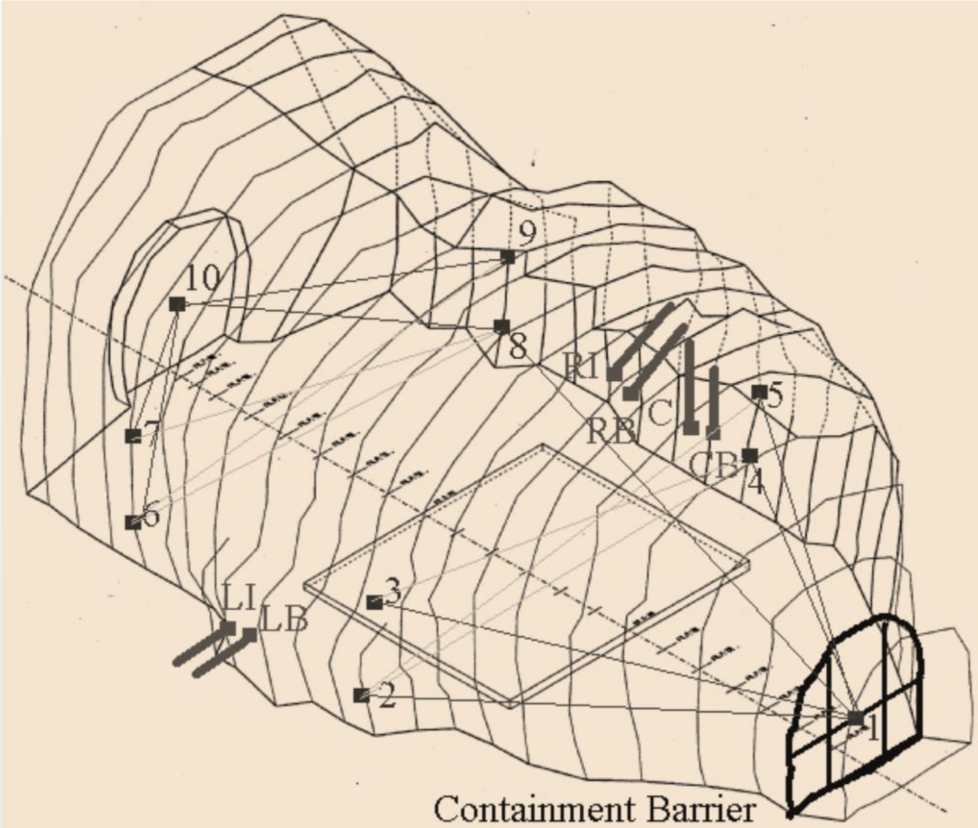
Munitions Disposal in an Adit : Nevada Test site

Approach:

-Empirical relations: no precedence, perform full scale field trials

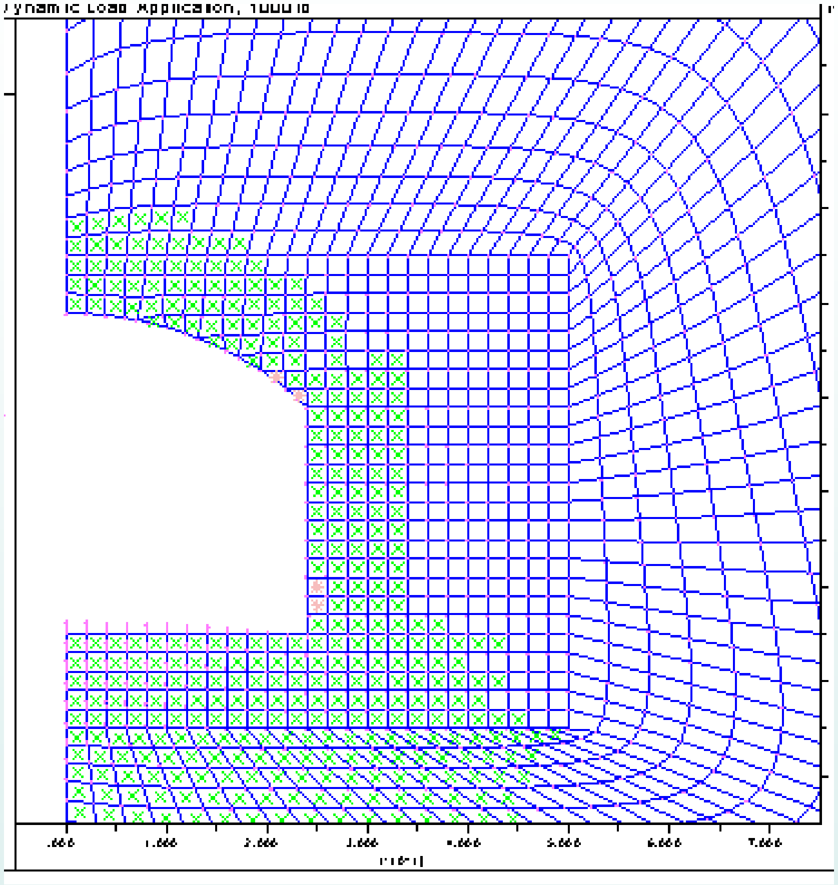
-Simplified/closed form/Analytical solutions: 1-D wave propagation

-Numerical solutions: tunnel geometry & blast pressure distribution



Munitions Disposal in an Adit

Nevada Test site

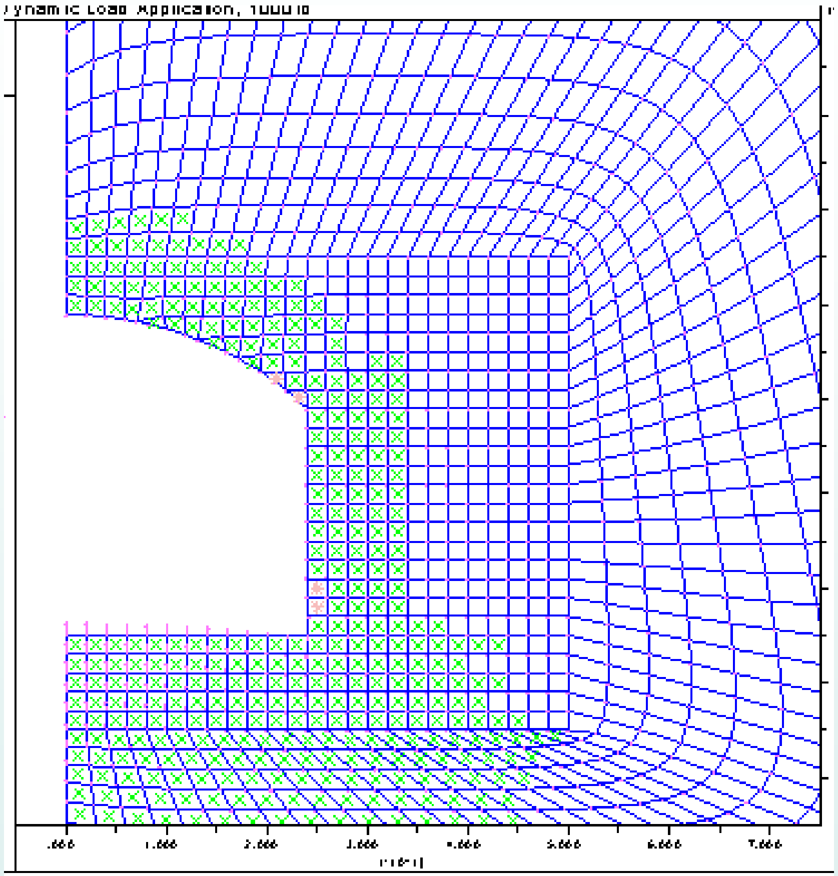


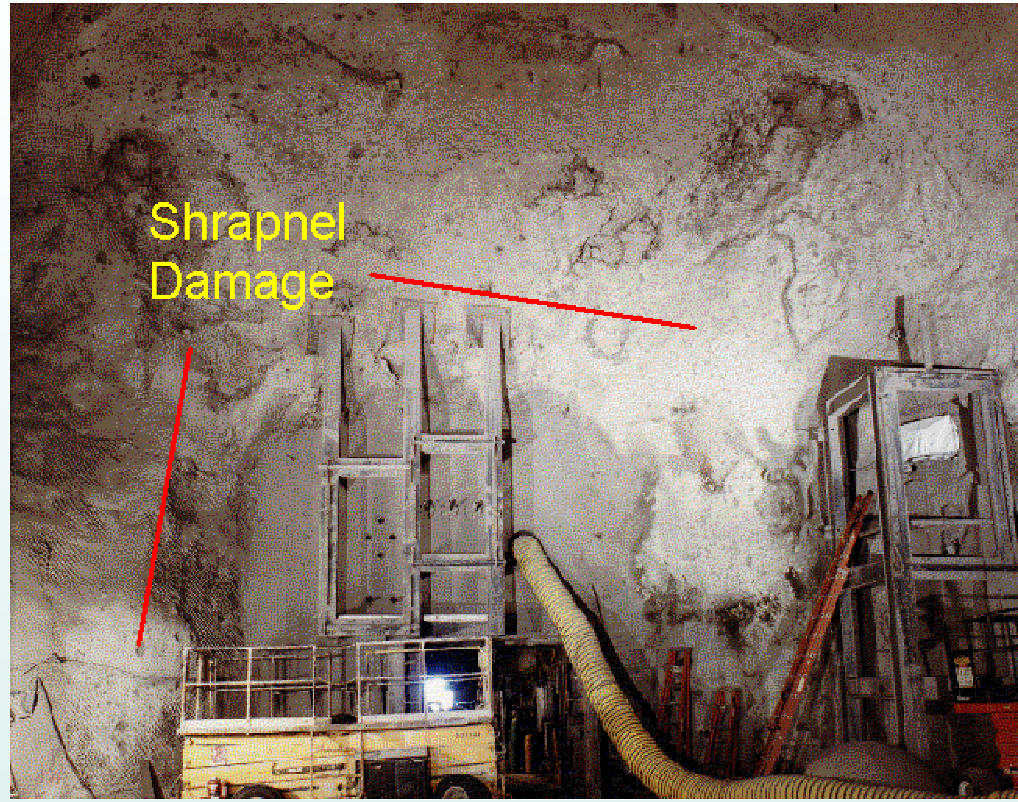
Yielding of Rock
Tensile failure

- Model of the tunnel
- Model of the pressure wave development
- Results:
  - Areas of tensile failure
  - Invert uplift
- Is this reasonable?

Munitions Disposal in an Adit

Nevada Test site





Yielding of Rock - Tensile failure

Observed damage – Shotcrete spalling

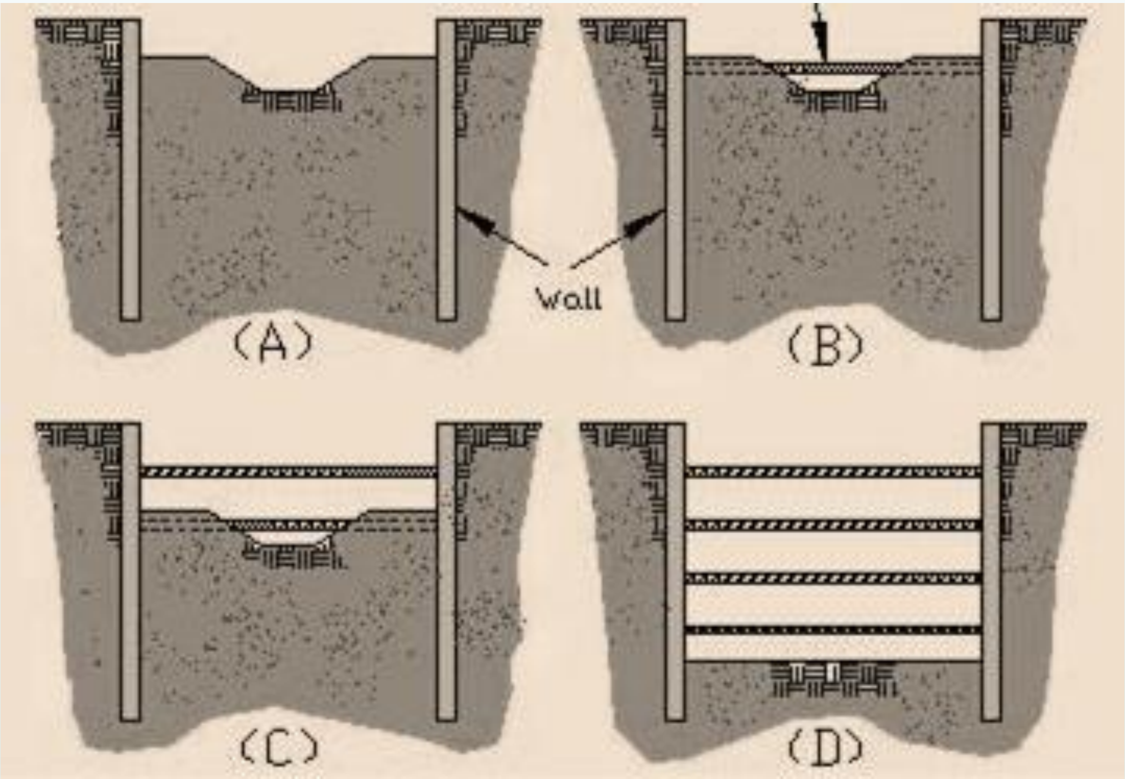
Significant damage caused by reflected (tensile) wave

Ex: Misuse of Numerical Modeling

- Excavation
- Ground Improvement

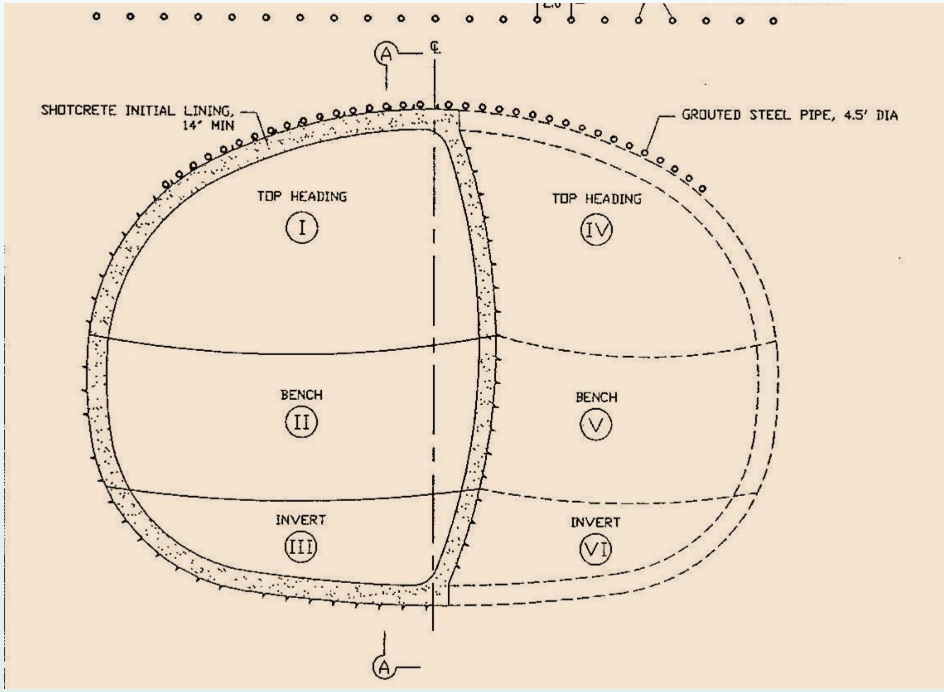
Case 1: Braced Excavation vs SEM

- Congested urban area
- Many historic structures, sensitive to deformations
- Design: braced excavation, T-wall (for added stiffness) and bracing at 6-8 ft vertical spacing



Case 1: Exc. vs SEM – Value Eng'g

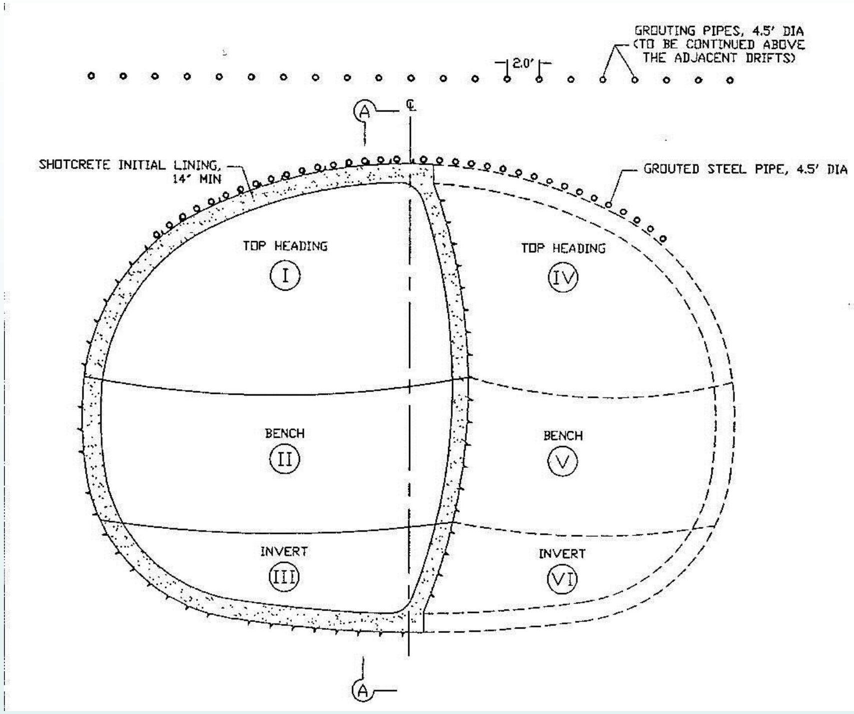
- Value Engineering Proposal:
  - Sequential excavation method
  - Roof with pipe Stabilize face, and shotcrete
  - Deformations less than those from braced excavation
  - Backed up with boxes of Finite Element Analysis output

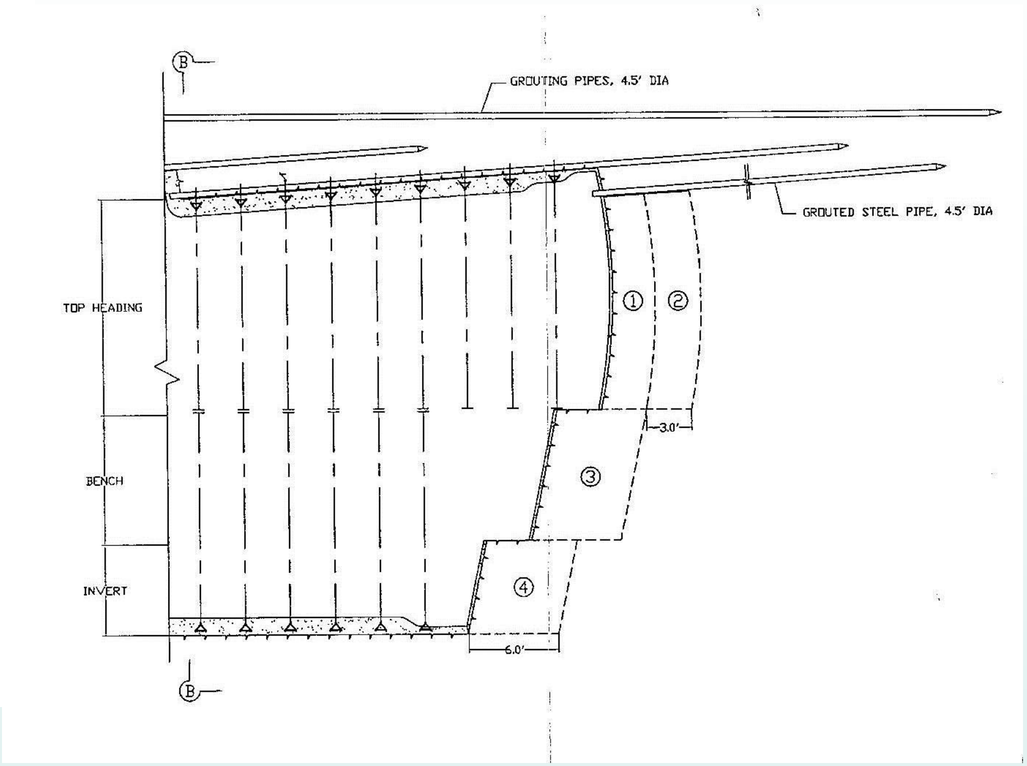


Case 1: Exc. vs SEM - Reviewers

- Braced diaphragm walls – Stiff ground support system
- SEM- relies on ground relaxation – Flexible Support system
  - Therefore, $\delta_{SEM} > \delta_{Braced}$
- However, Numerical model says $\delta_{SEM} < \delta_{Braced}$
- Contractor confident that numerical analysis is correct
- Is there a disconnect?
- Who is right, wrong, both or neither?

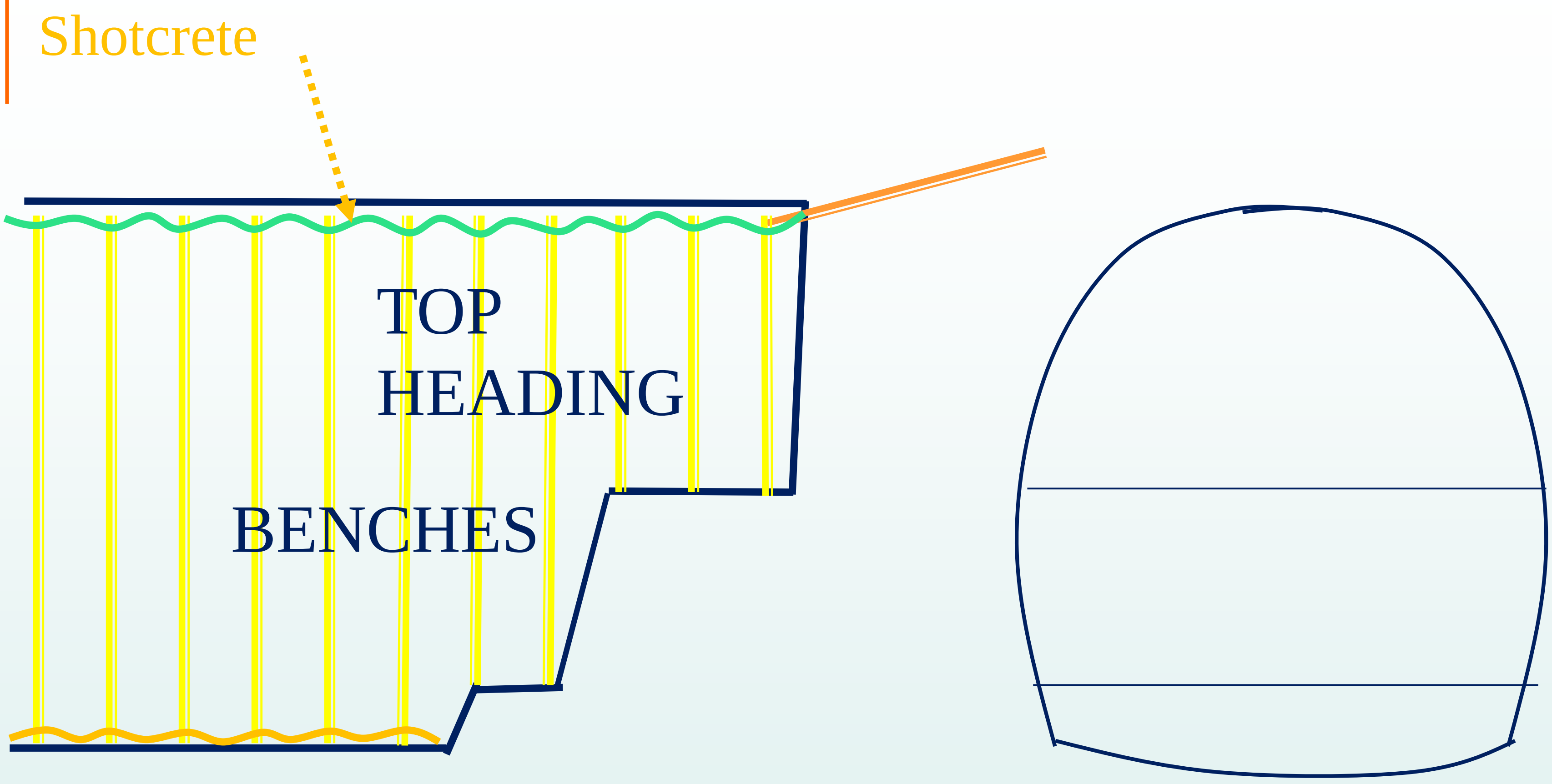
Let us review SEM





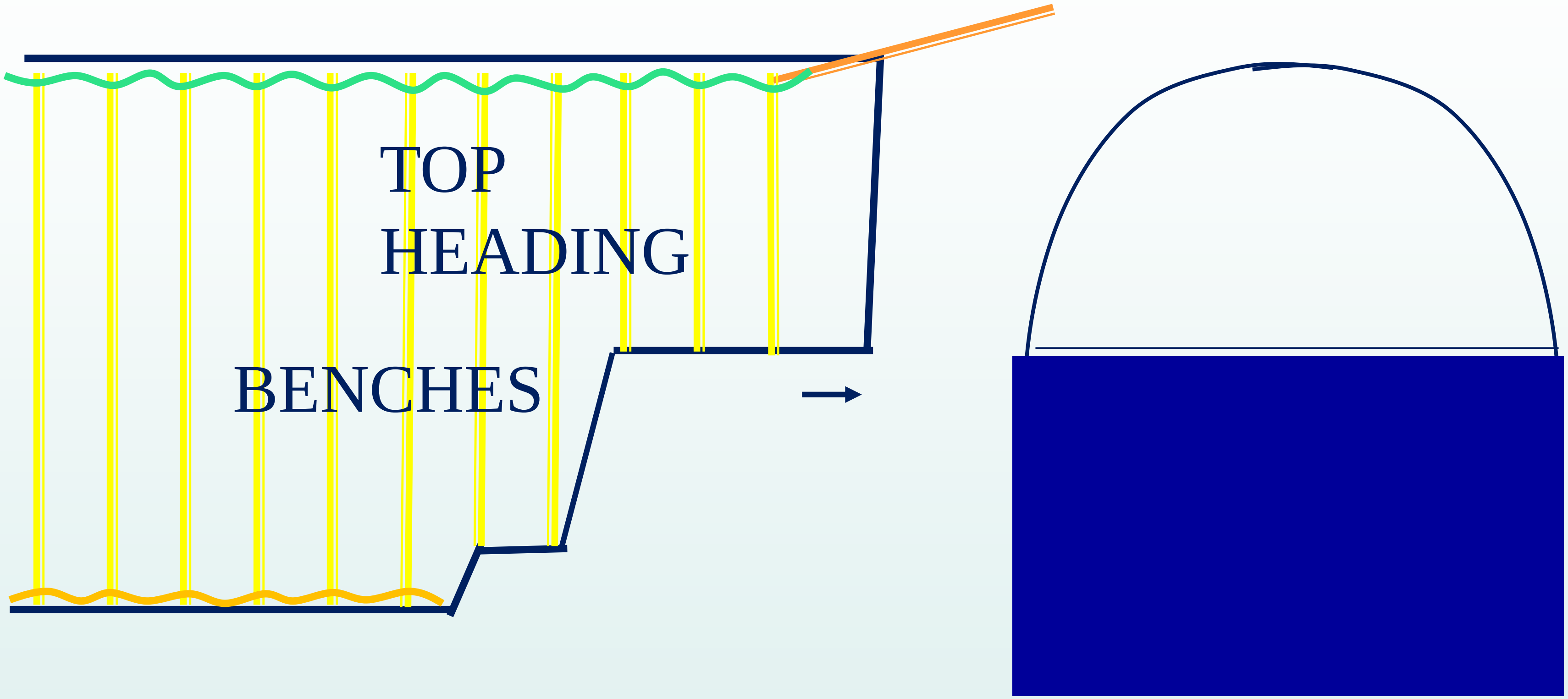
Heading and bench carried together
(I, II, III) or (IV, V, VI)

SEM



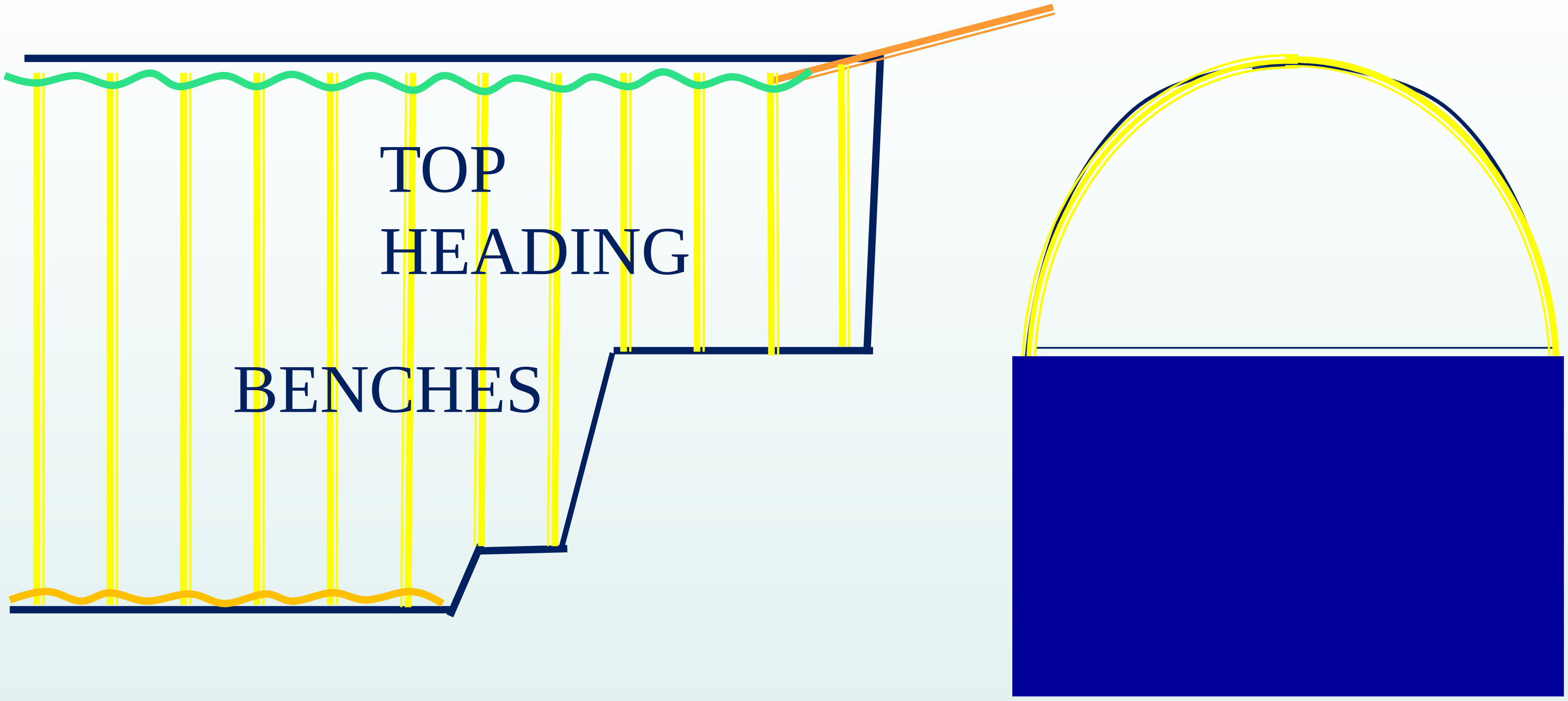
Heading and bench excavation,
Shotcrete and lattice girder support

SEM



Excavate top heading: one round

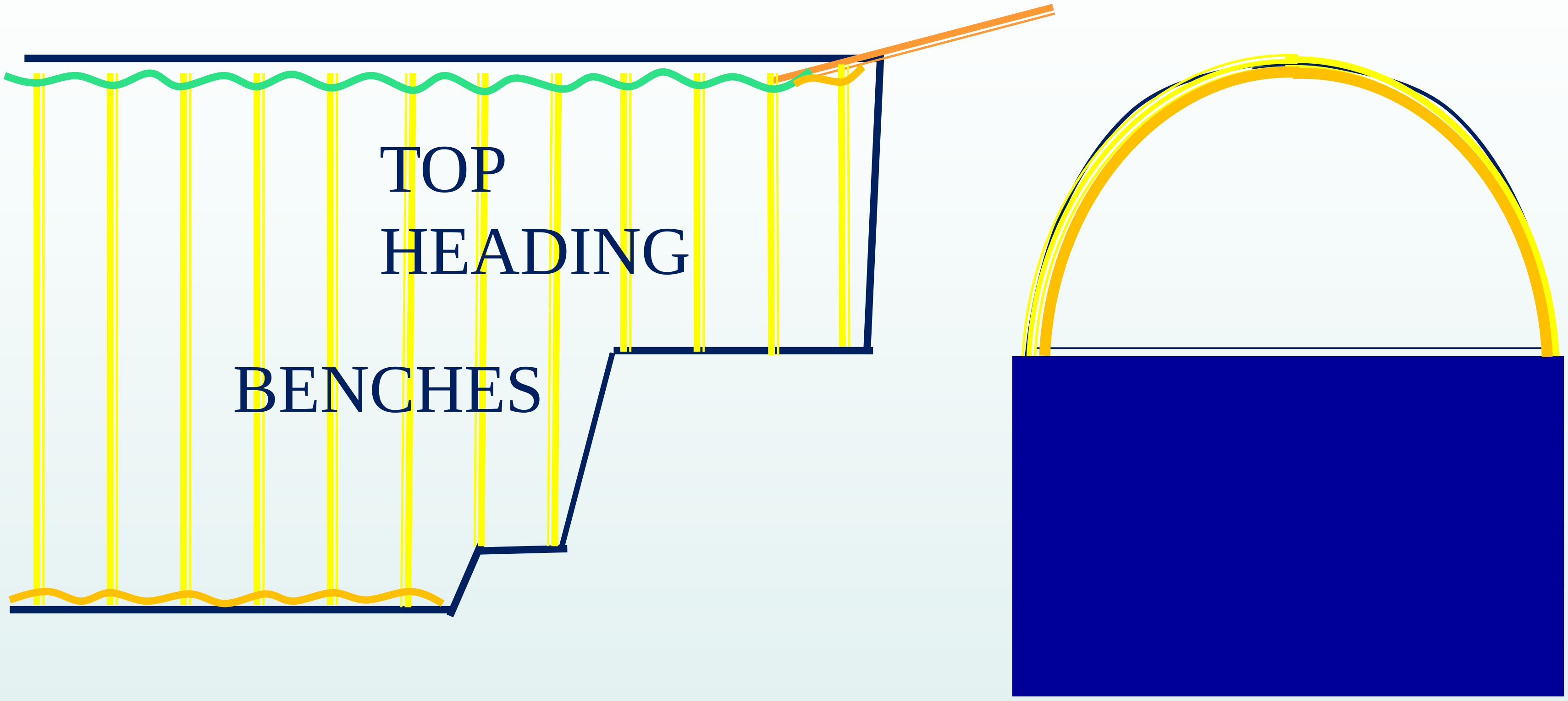
SEM



Place initial layer of shotcrete: 1 to 2 in.

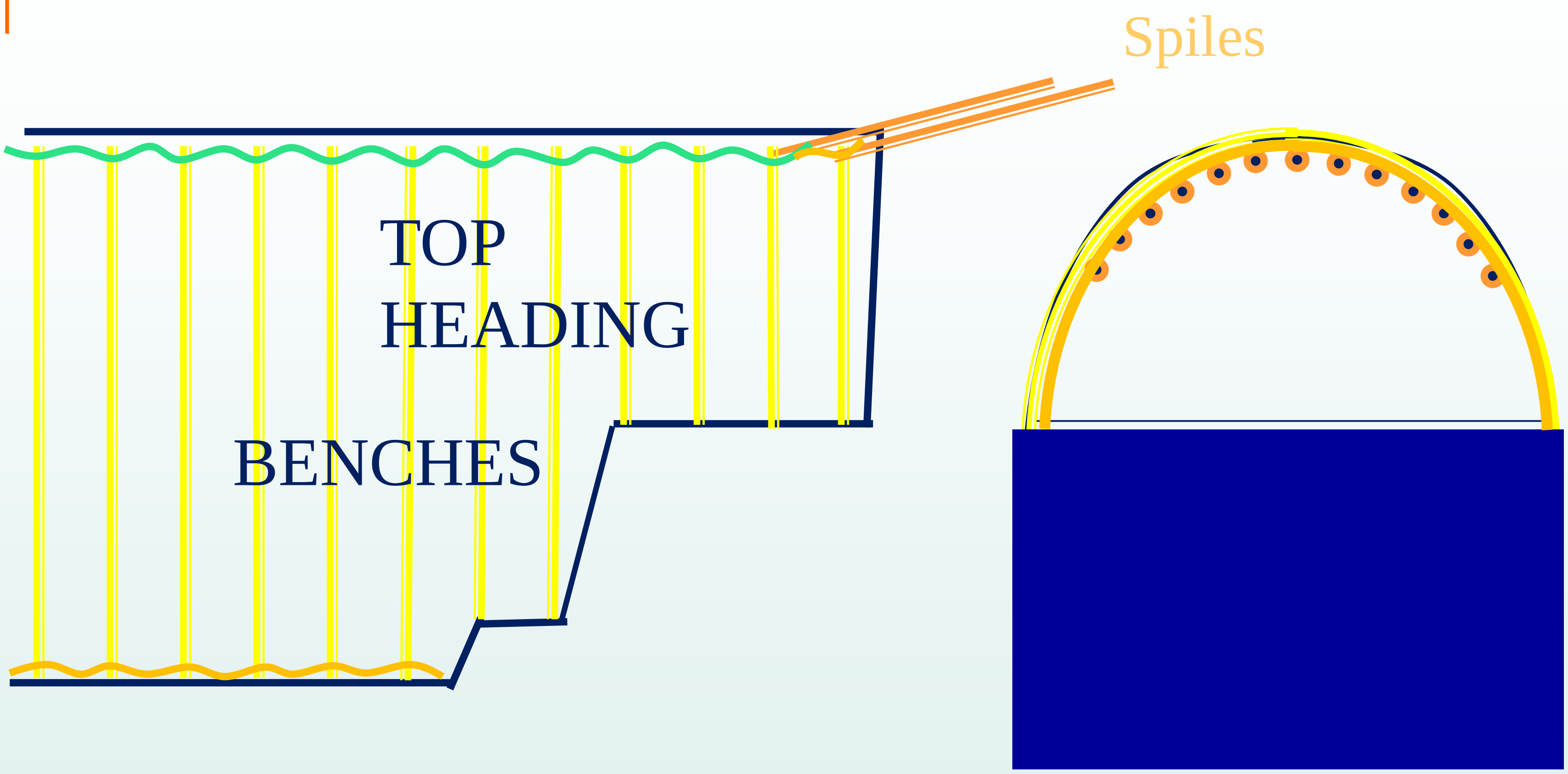
Set lattice girder

SEM



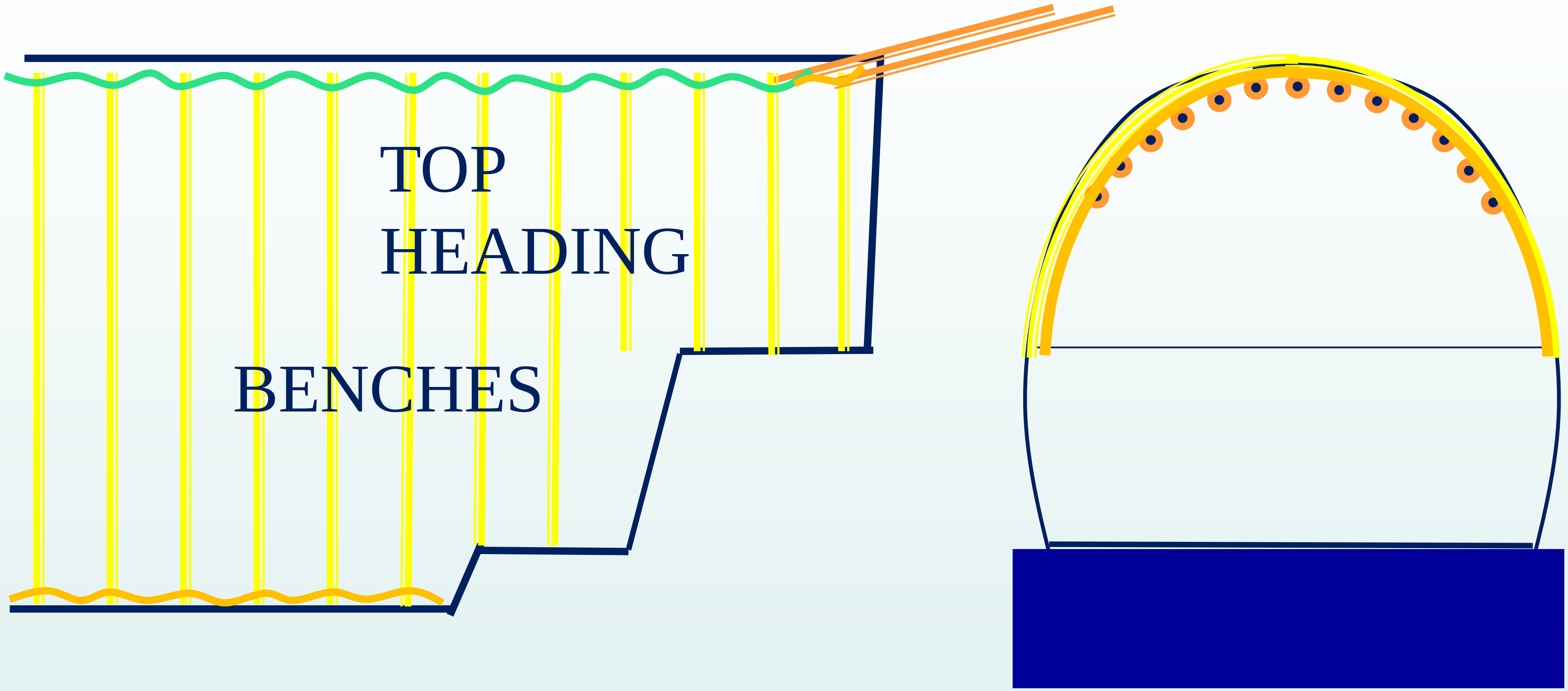
Encapsulate lattice girder with shotcrete: ~ 8 in. +

SEM



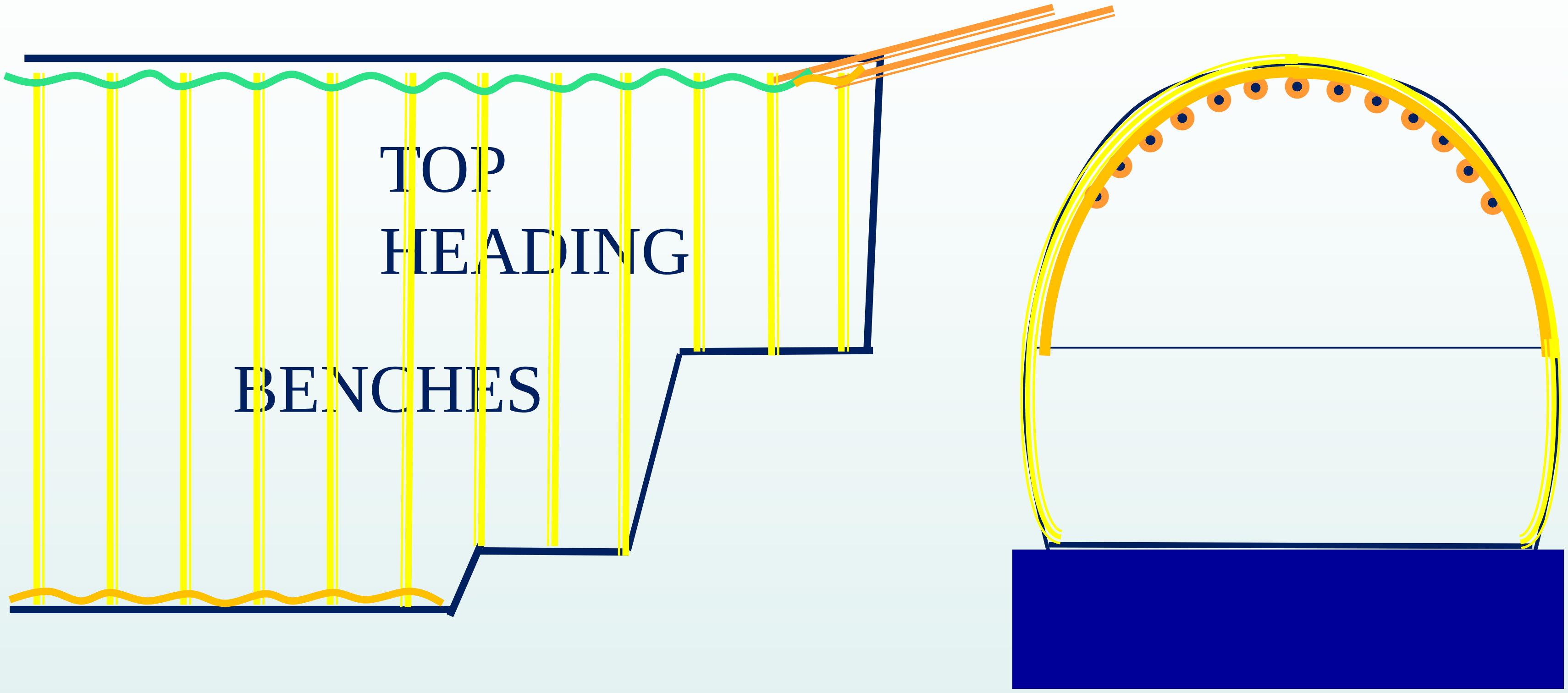
Drive, or drill and grout, spiles ahead of face

SEM



Excavate first bench

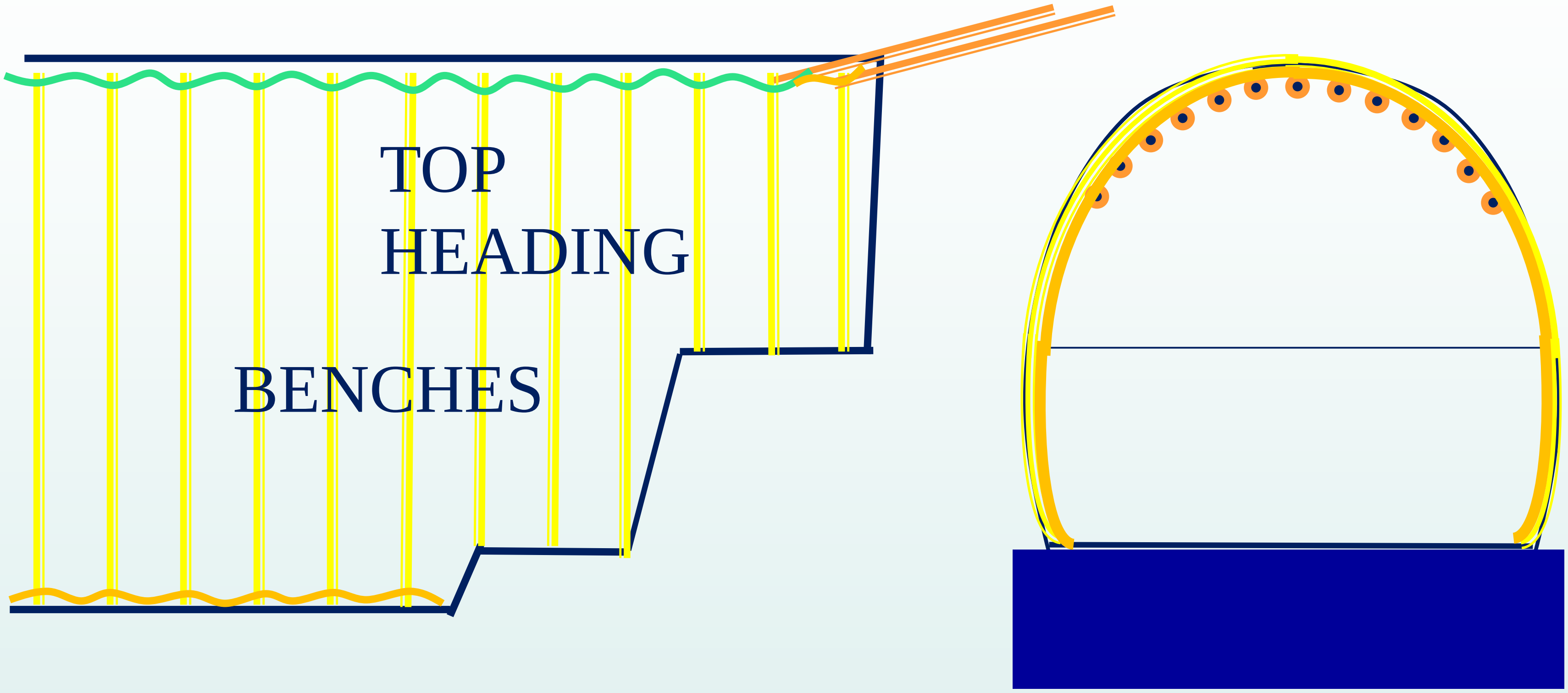
SEM



Place initial layer of shotcrete:

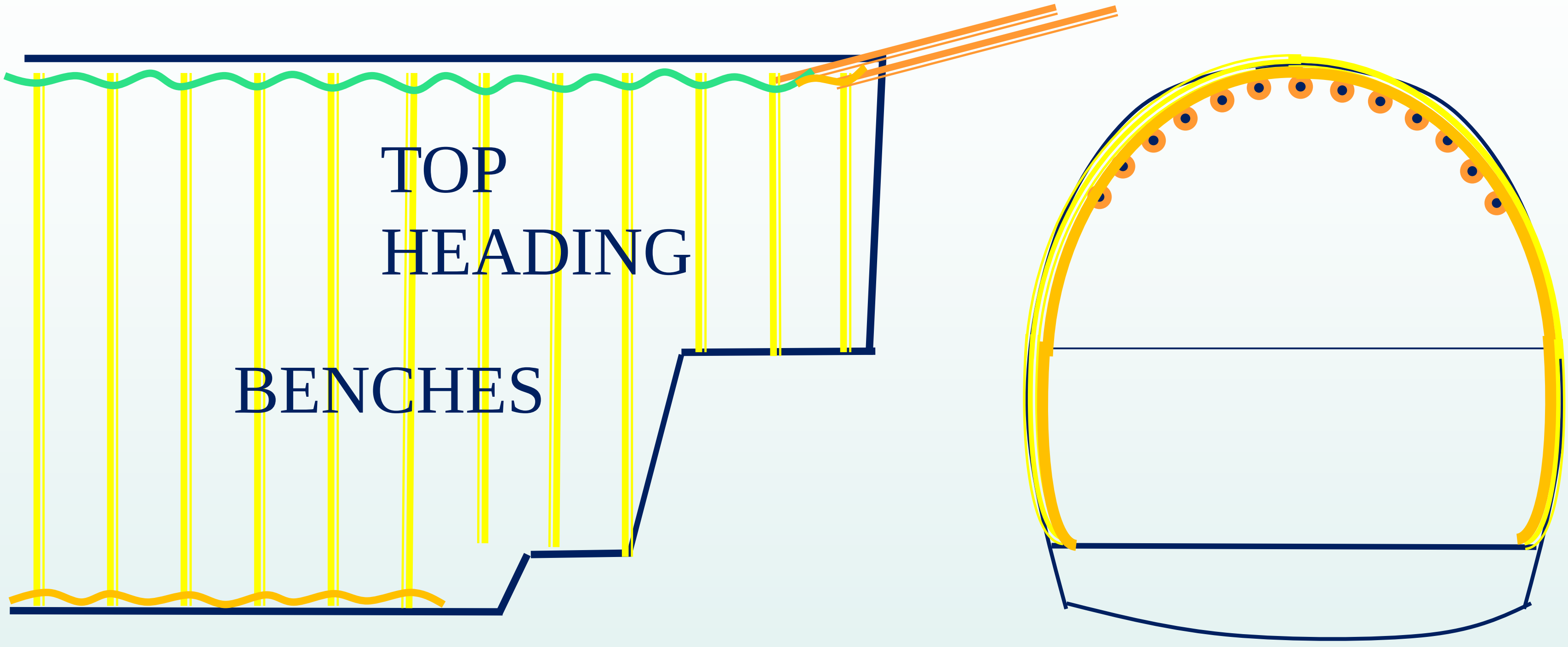
Extend lattice girders

SEM



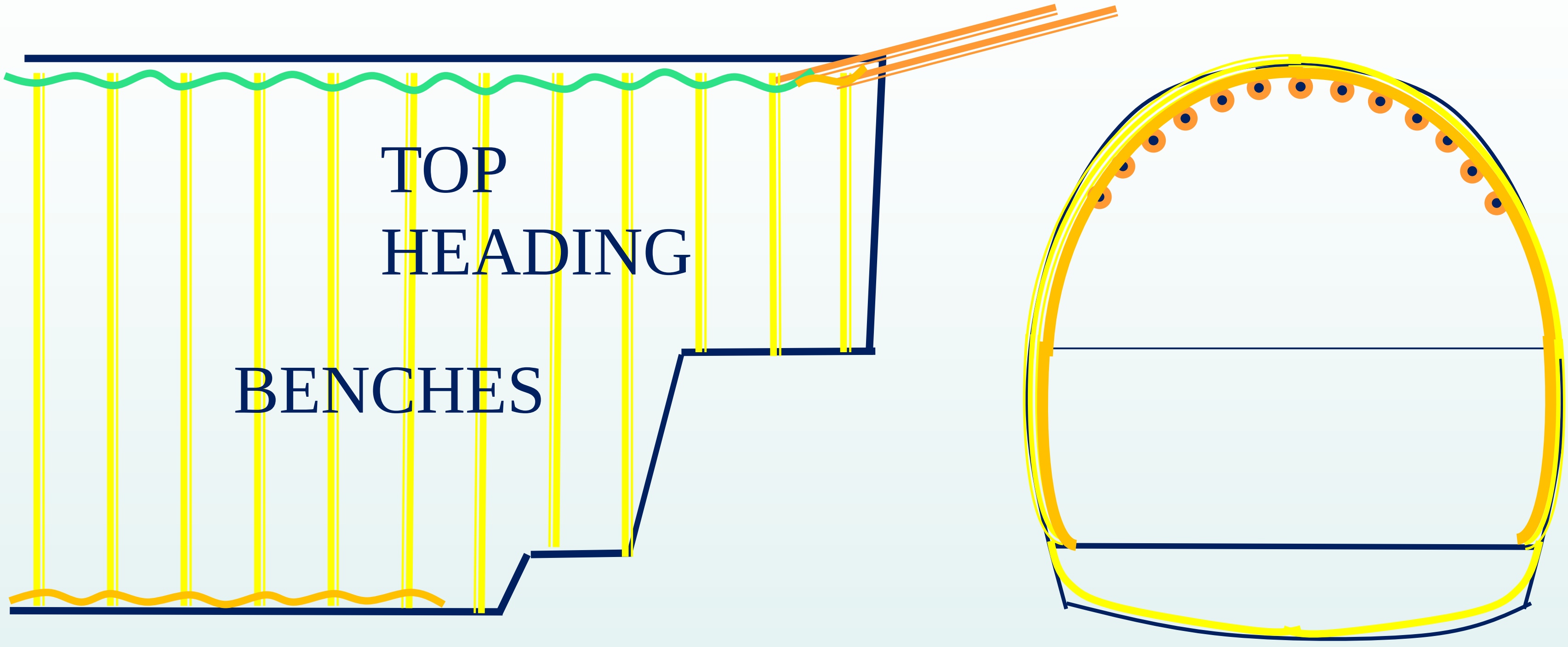
Encapsulate lattice girder with shotcrete

SEM



Excavate second bench

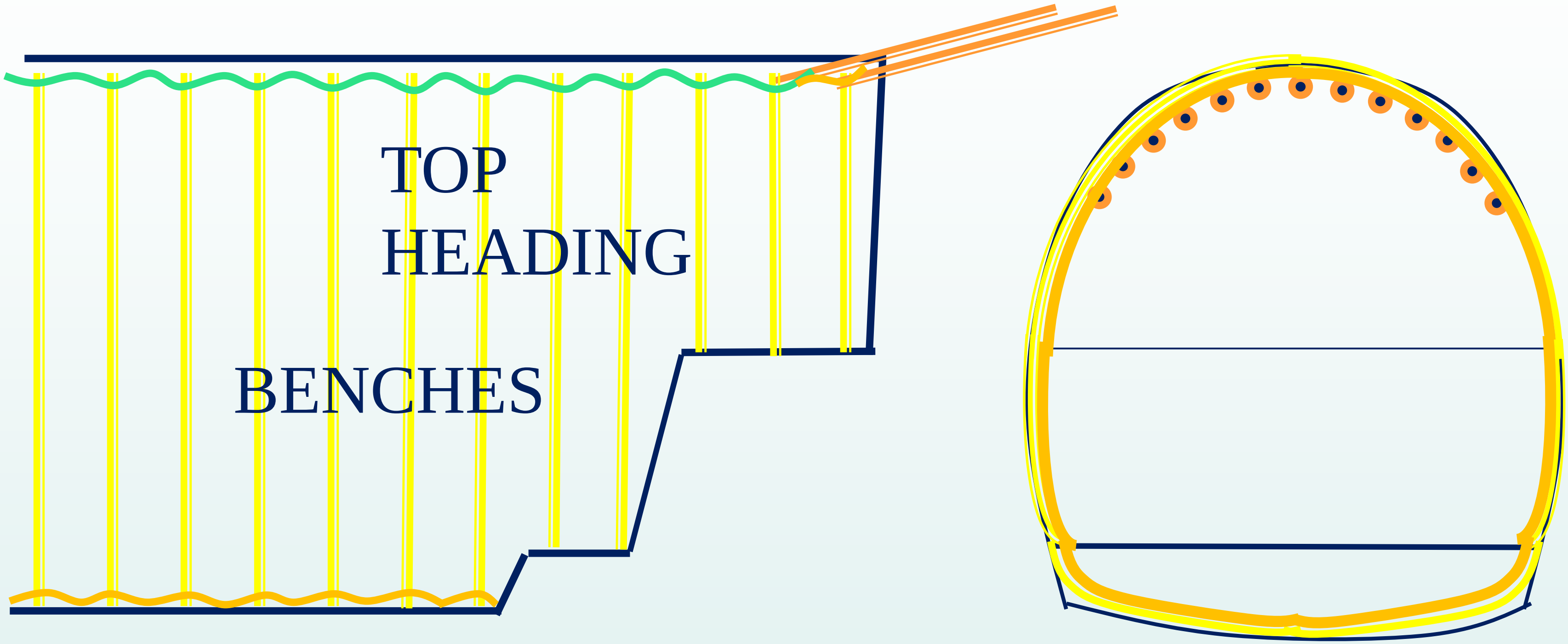
SEM



Place initial layer of shotcrete:

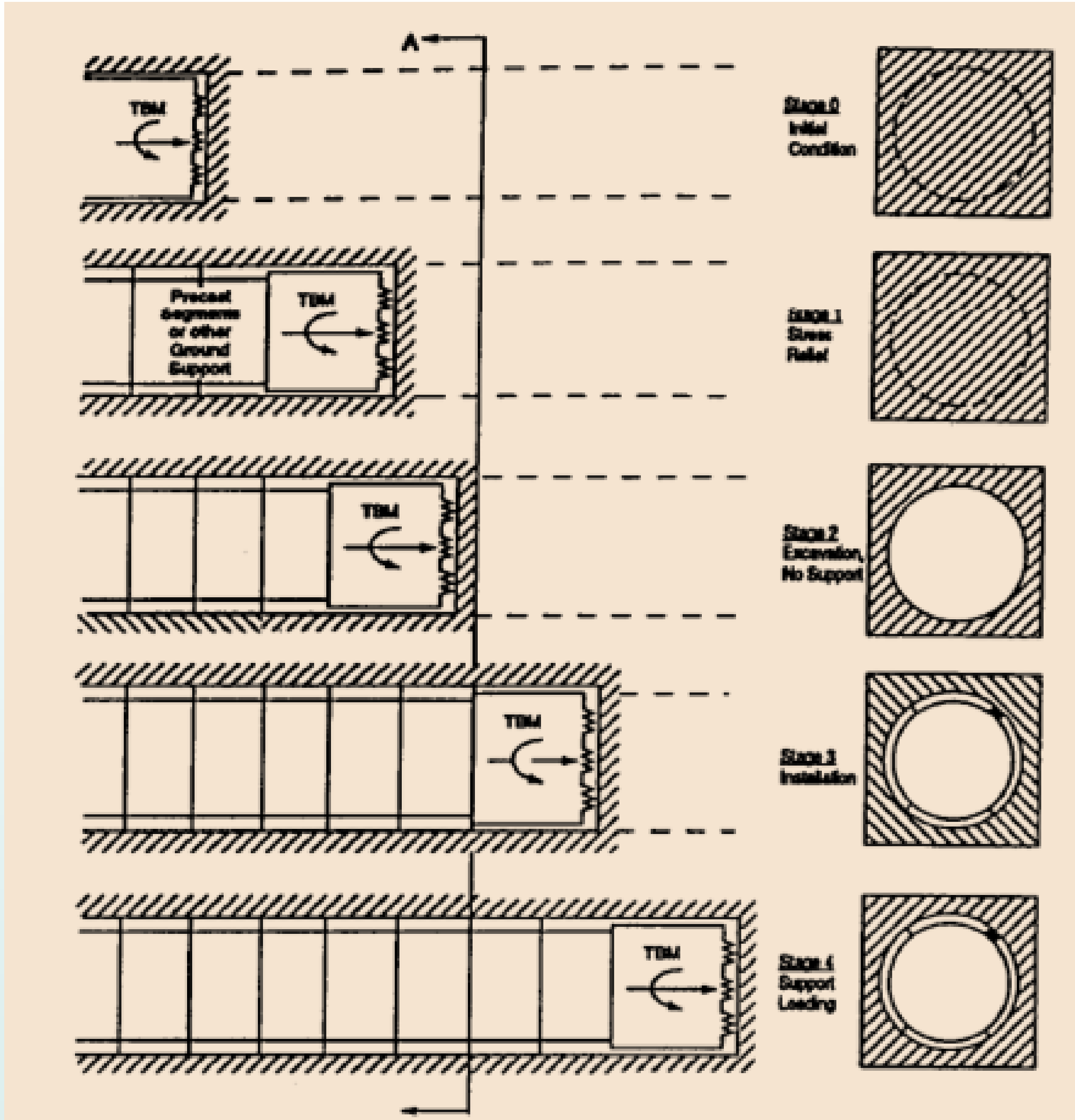
Extend lattice girders

SEM

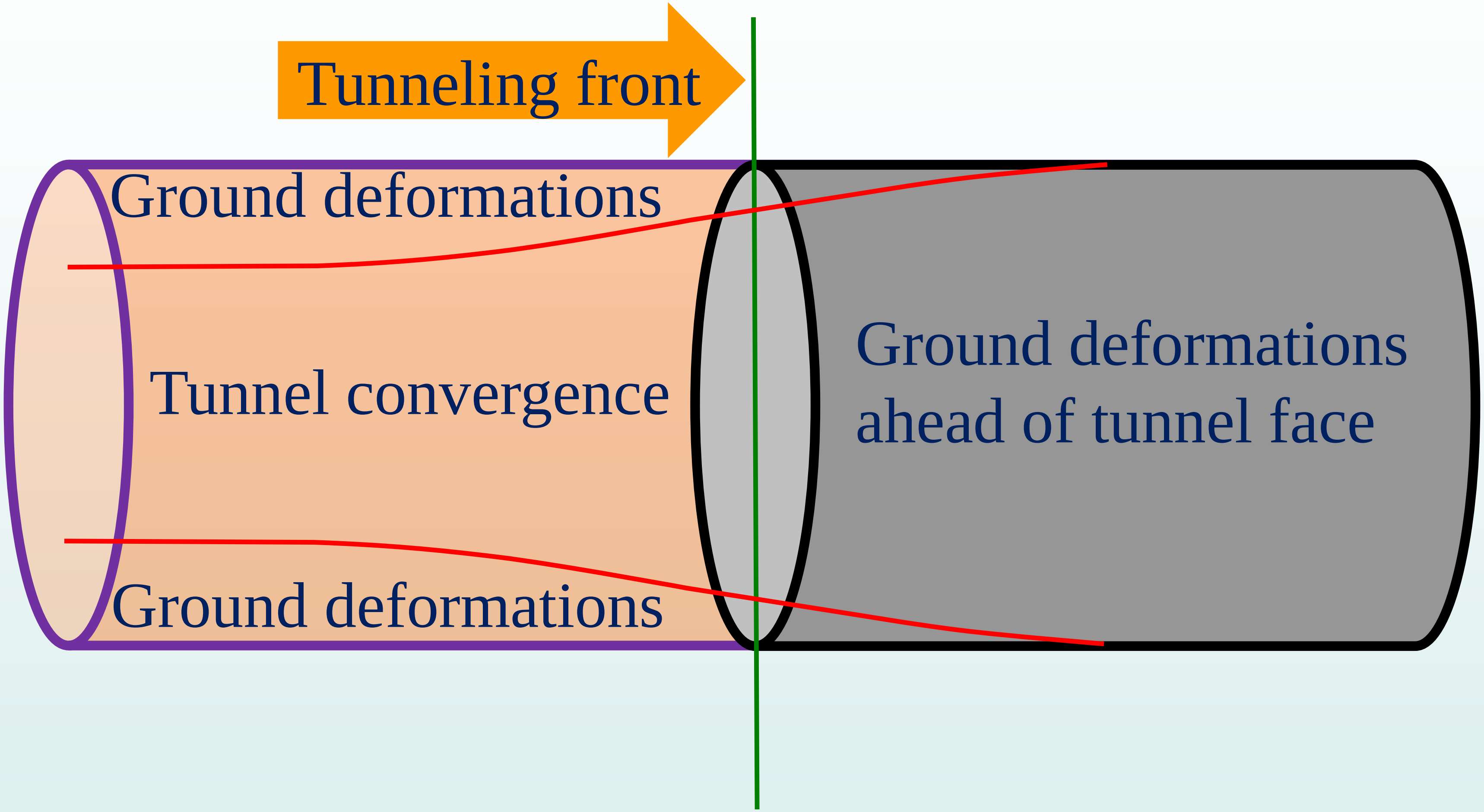


Encapsulate lattice girder with shotcrete

Tunnel- Ground Interaction



Tunnel- Ground Interaction

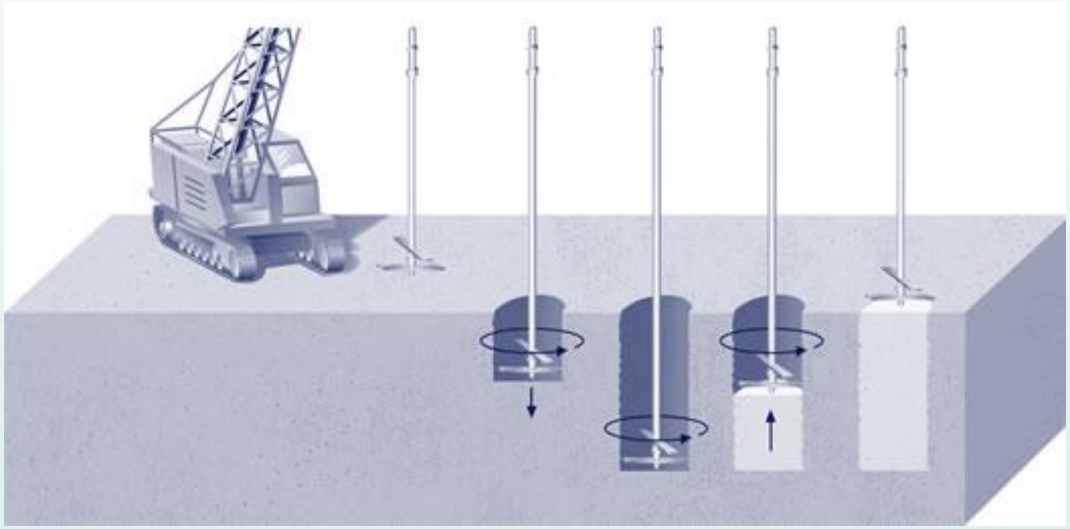


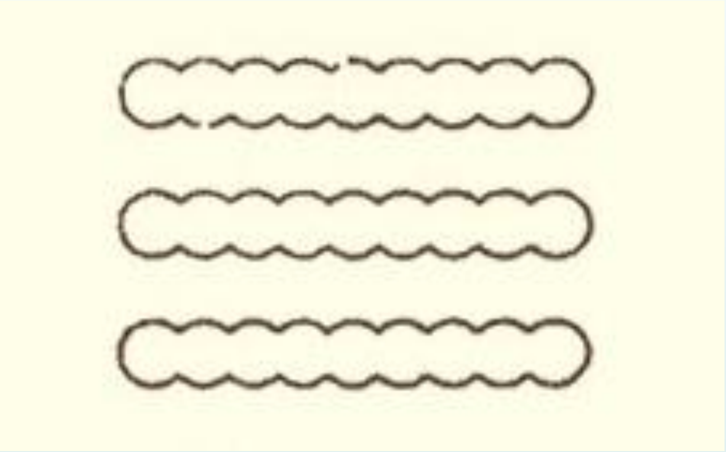
Case 1: Exc. vs SEM – It's in the Details

- Numerical model of tunnel was 2-D
- Tunnel supports installed in the same analysis step of tunnel excavation.
- Analyses did not incorporate the 3-D ground relaxation.
- Analysis wishes the tunnel support in place, hence minimal deformations are computed.
- Analysis results are correct… based on the input
- Input to the analysis is incorrect.
- *It's not the software, it's the engineer*

Case 2: Soil Mixing for Excavation

- Excavation in soft marine soils.
- Soil Mixing in support of excavation and unbalanced load.

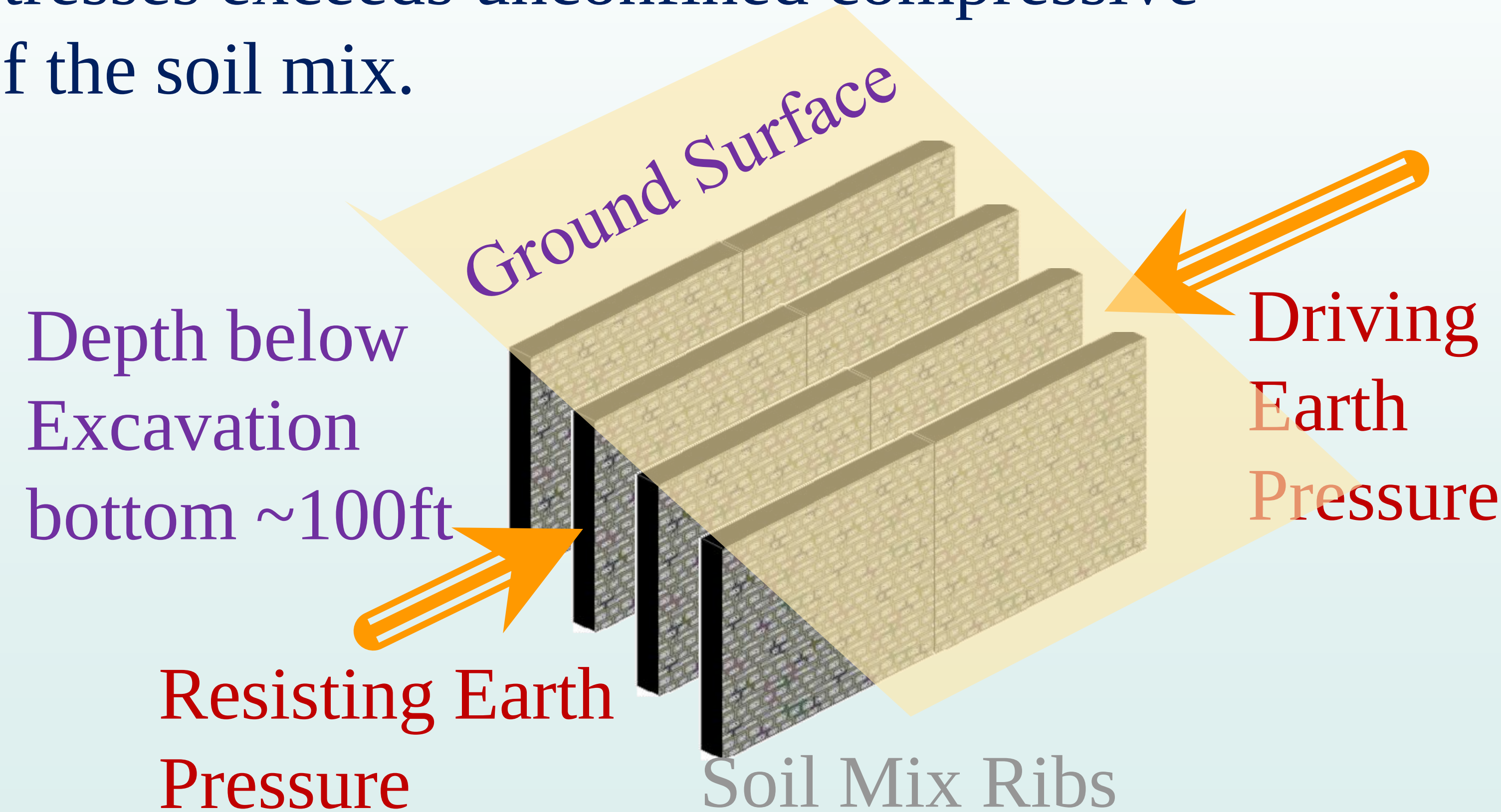




Plan view – Ribs/walls

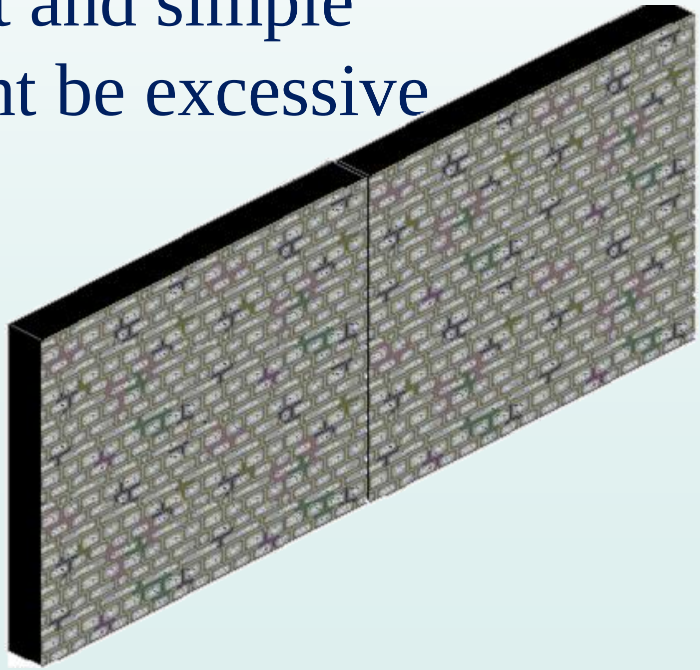
Case 2: Soil Mixing for Excavation

- Numerical modeling to estimate stresses in soil mix ribs
- Required soil coverage let us say 50%
- Criteria: stresses exceeds unconfined compressive strength of the soil mix.



Case 2: Soil Mixing for Excavation

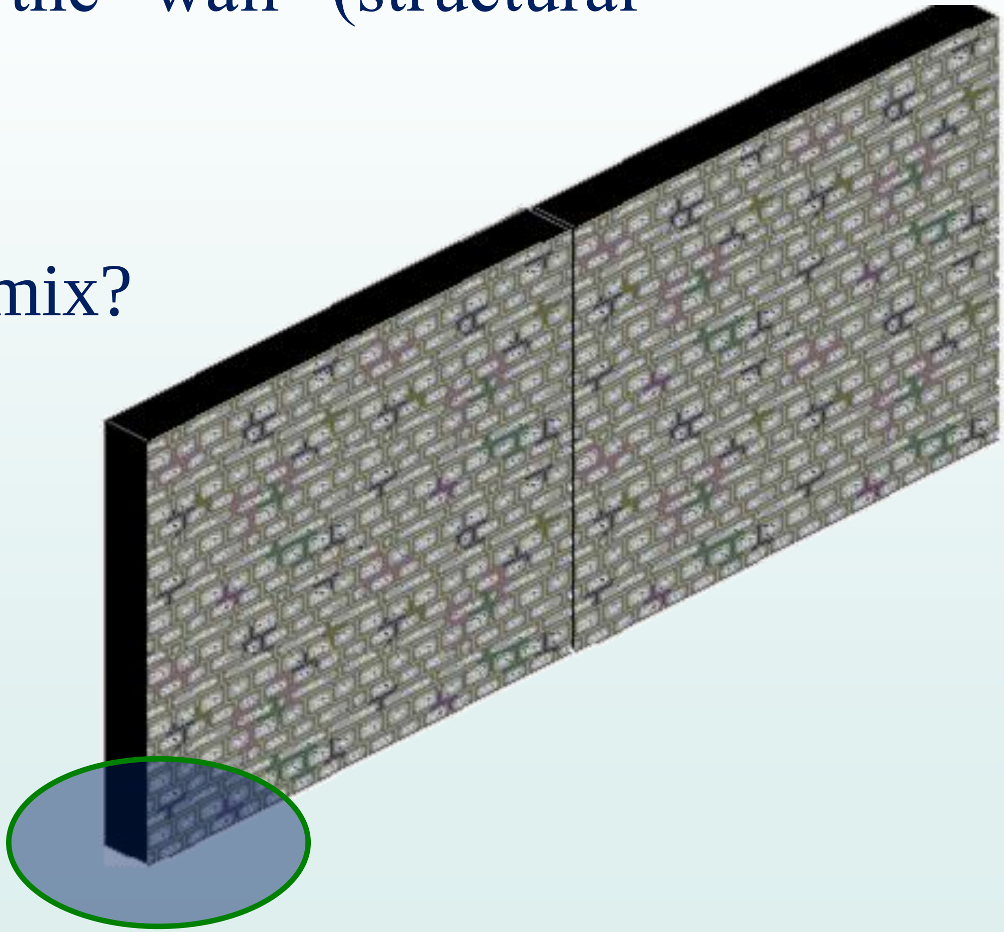
- Interpretation: maximum/major principle stress larger than unconfined compressive strength of the soil mix mass.
- Concern: cost, expensive to do so much treatment
- Peer review: engineering judgement and simple calculation would indicate this might be excessive
- Are we missing something?



Case 2: Soil Mixing for Excavation

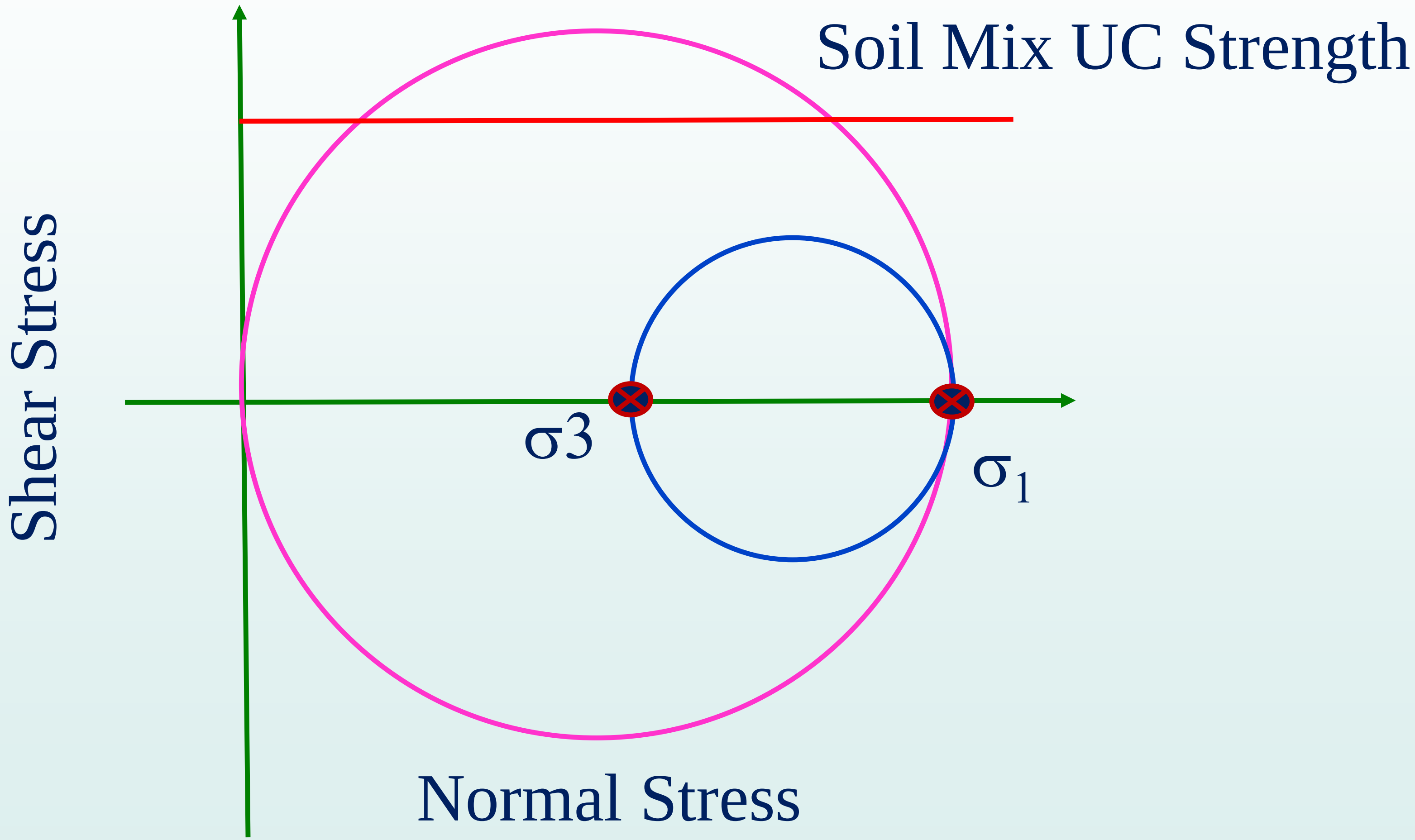
- Where is the controlling maximum principles stress?
- At the bottom corner of the "wall" (structural engineering view)
- Is it a wall or deep soil mix?

Zone of maximum principle stress



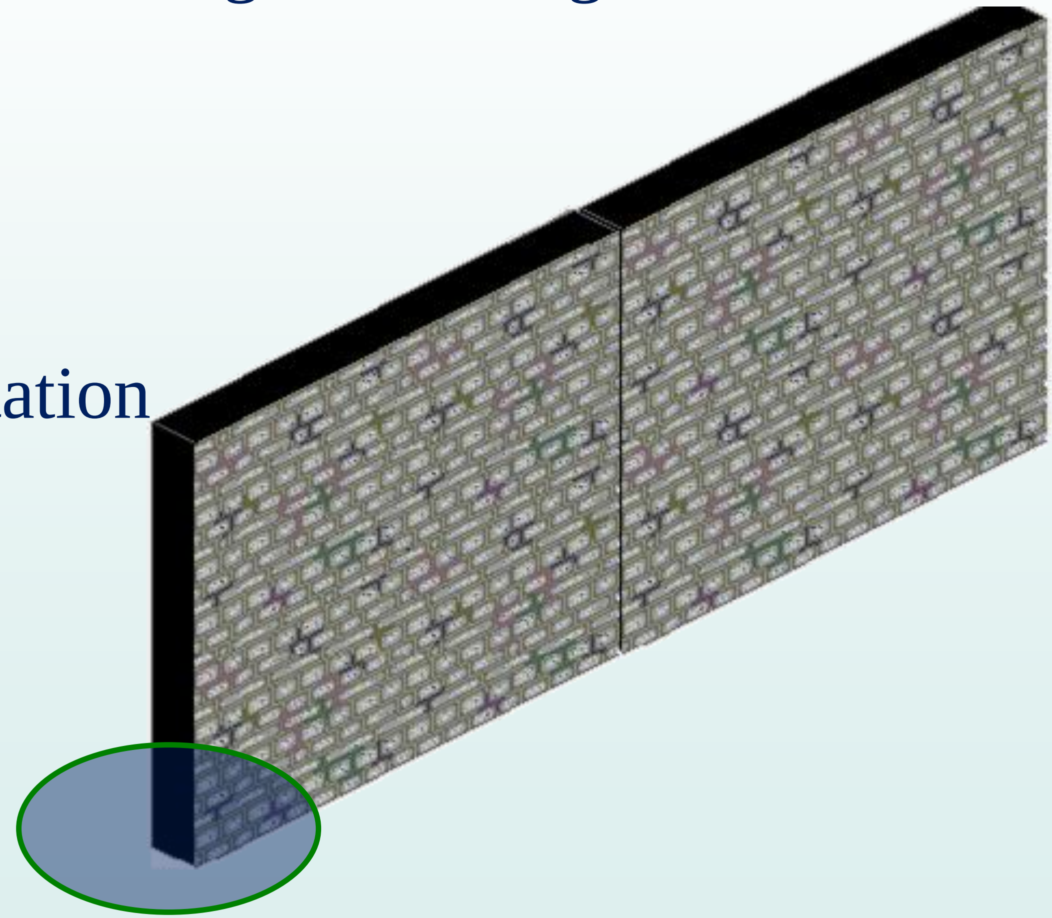
Case 2: Soil Mixing for Excavation

- Recall Mohr Circle of stress



Case 2: Soil Mixing for Excavation

- It's a deep mixed soil – confining pressure
- Significantly reduced % coverage of mixing
- Saving ~$10 Million
- Lesson: proper interpretation



Zone of maximum
principle stress

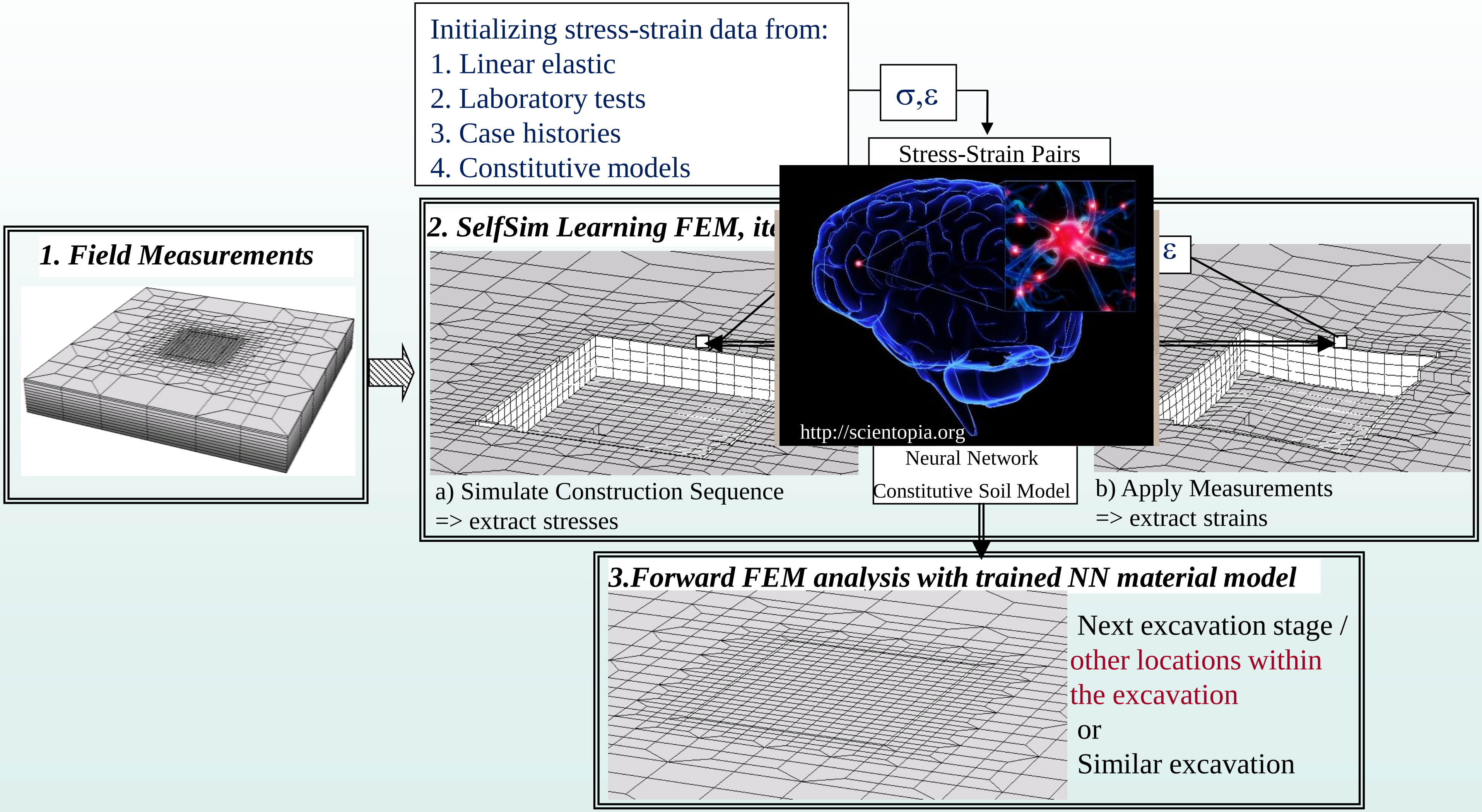
Looking Ahead

Deep Learning- Inverse Analyses

- Strong relationship between soil model and displacements around an excavation
- Parameter Optimization
  - Optimize parameters of a pre-existing soil model
  - Limited by the versatility of the existing model
  - Can use readily available commercial software
- Self learning simulations
  - Soil behavior evolves from measurements
  - Can learn new soil behavior such as anisotropy and small strain-nonlinearity
  - Requires greater user expertise

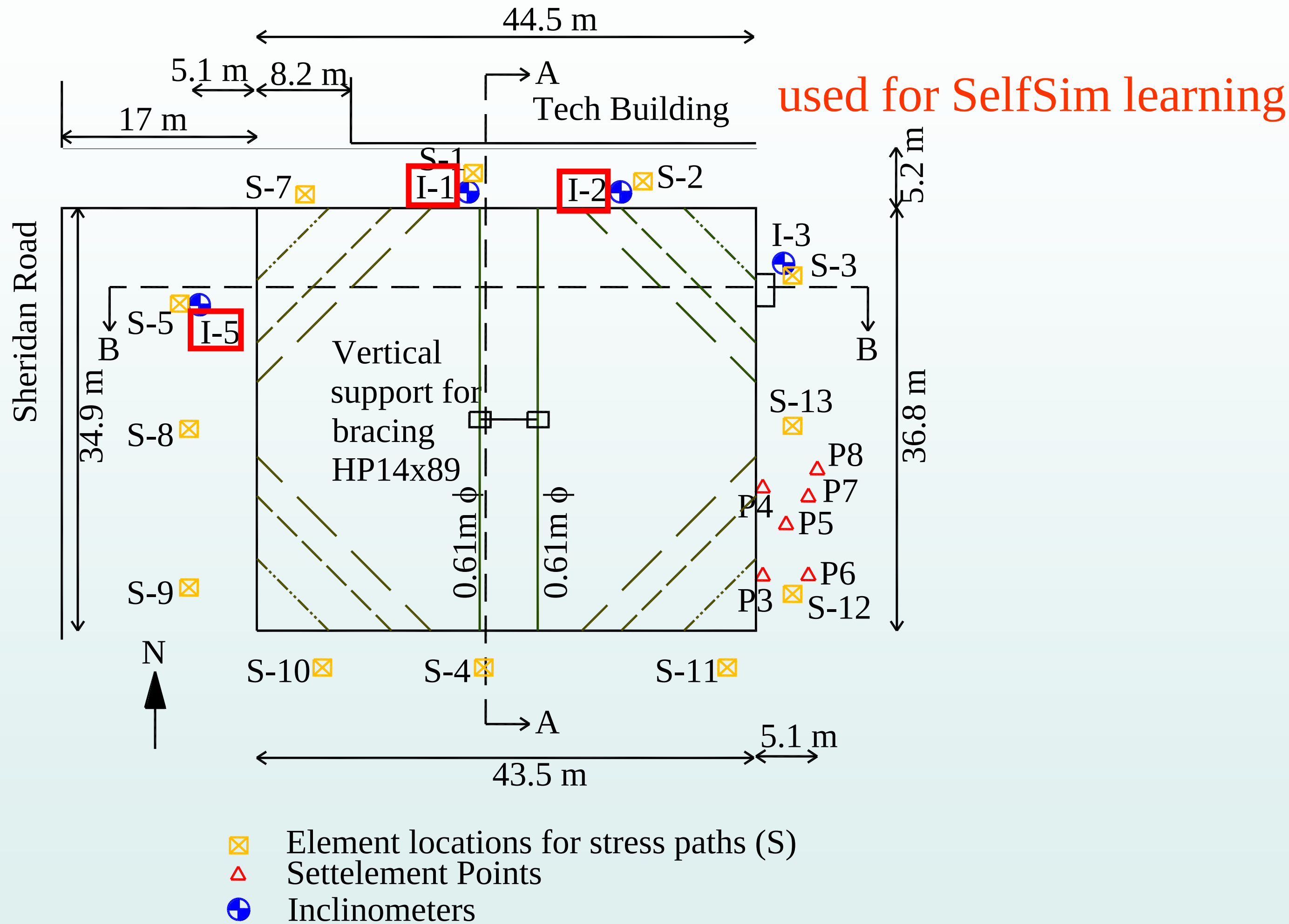
Self-Learning Simulations

- Inverse analysis framework to learn soil behavior from field measurements



Ford Center Excavation – 3-D Modeling

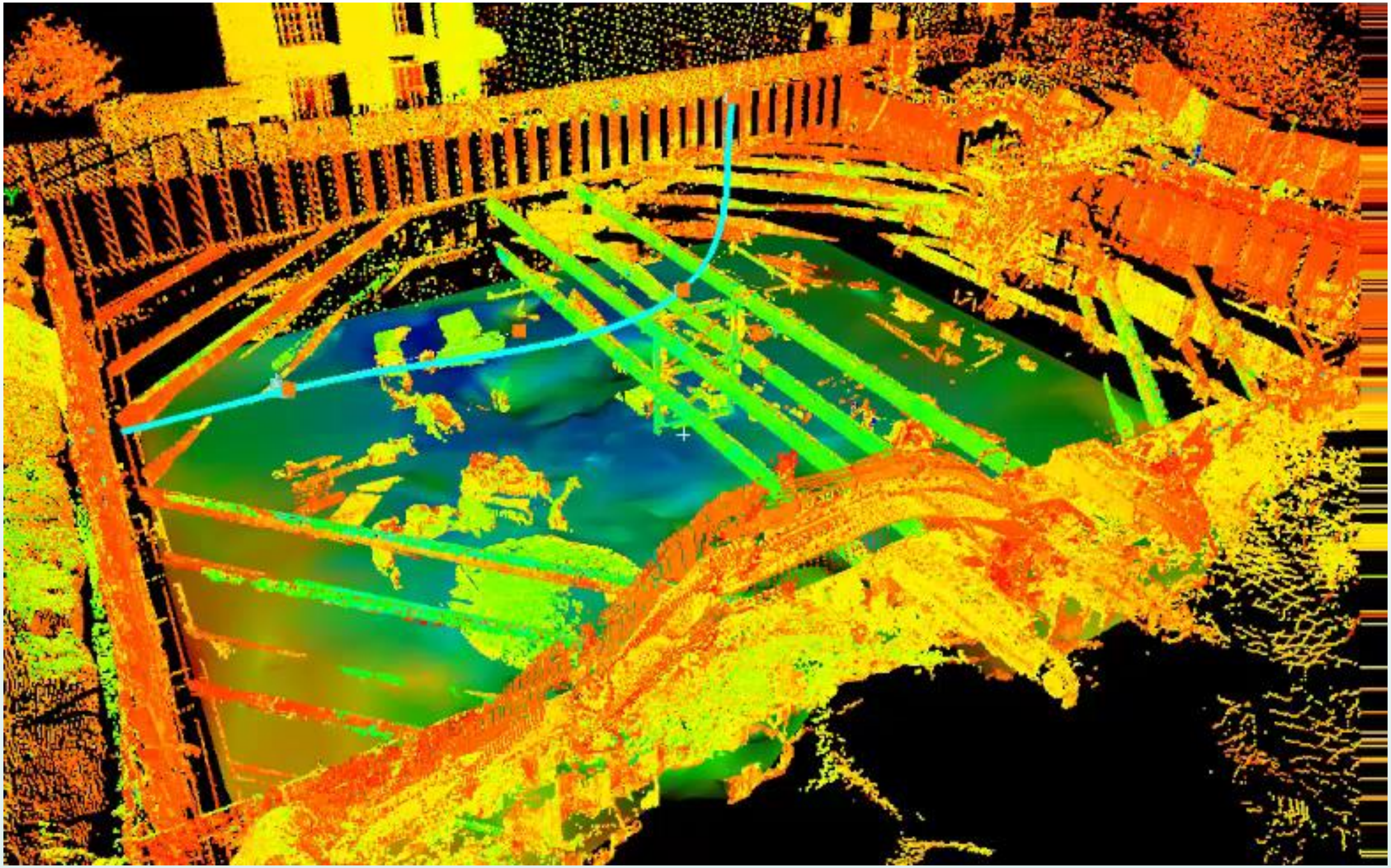
- Plan view



Hashash, Y. M. A., H. Song and A. Osouli (2011). "Three-dimensional inverse analyses of a deep excavation in Chicago clays." International Journal for Numerical and Analytical Methods in Geomechanics **35**(Compendex): 1059-1075

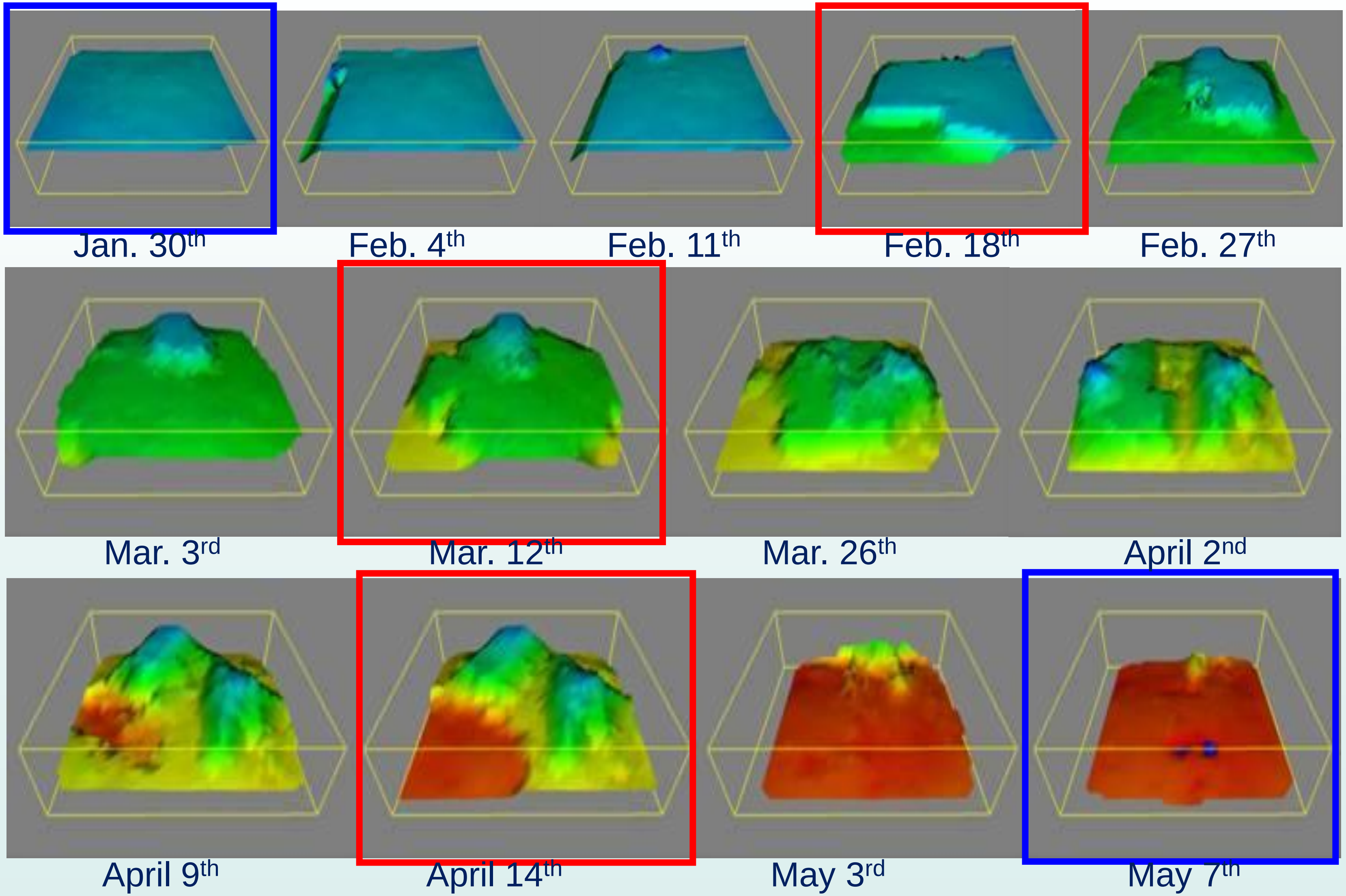
Data Courtesy of Prof. R. Finno, NWU

Fly Through – Ford Center, NWU



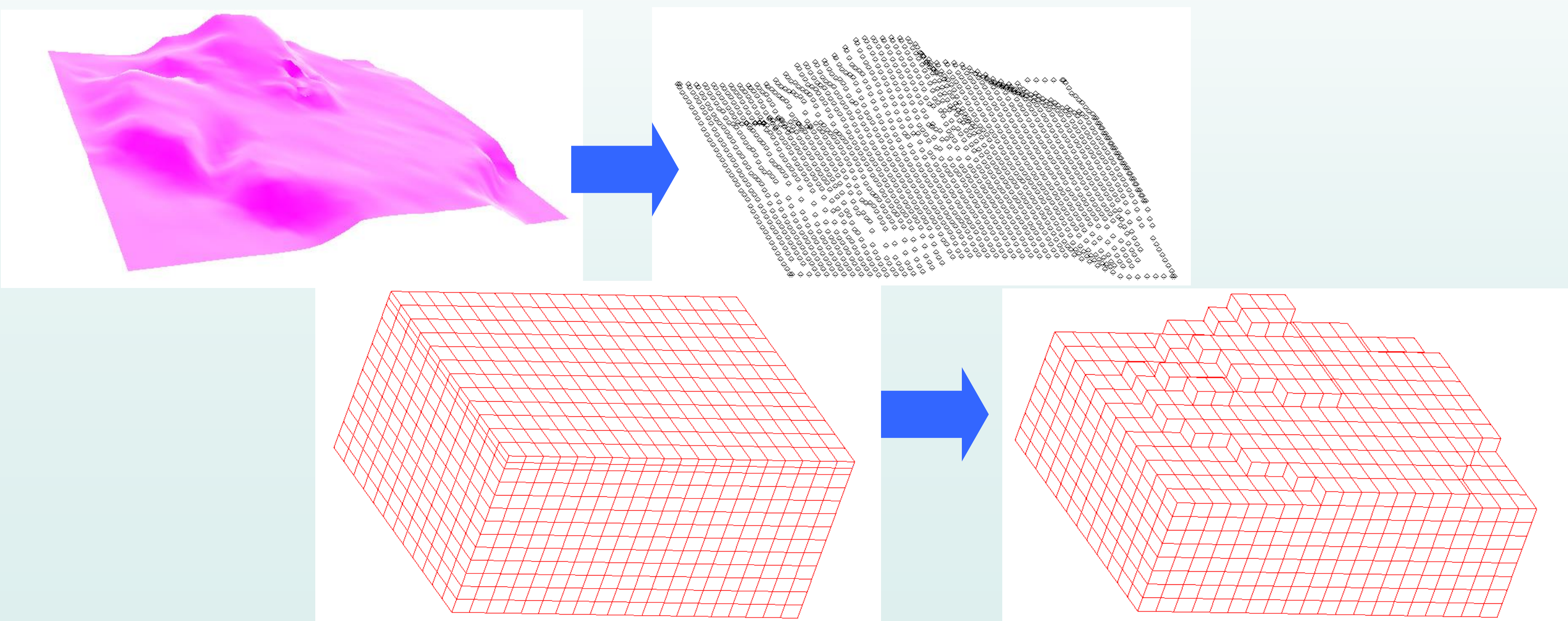
3-D Laser Scanning

- 13 scan sessions and 5 selected stages



FE Mesh Modeling Techniques

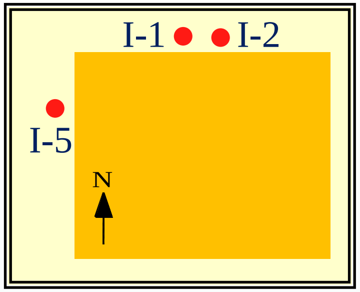
- 3D excavation model from laser scanned data
  - No Direct ways of importing/exporting
  - Finite element modeling: Brick element deleting scheme (C++)
  - Choose mesh dimension/density first → remove/add element according to the 3DLS data



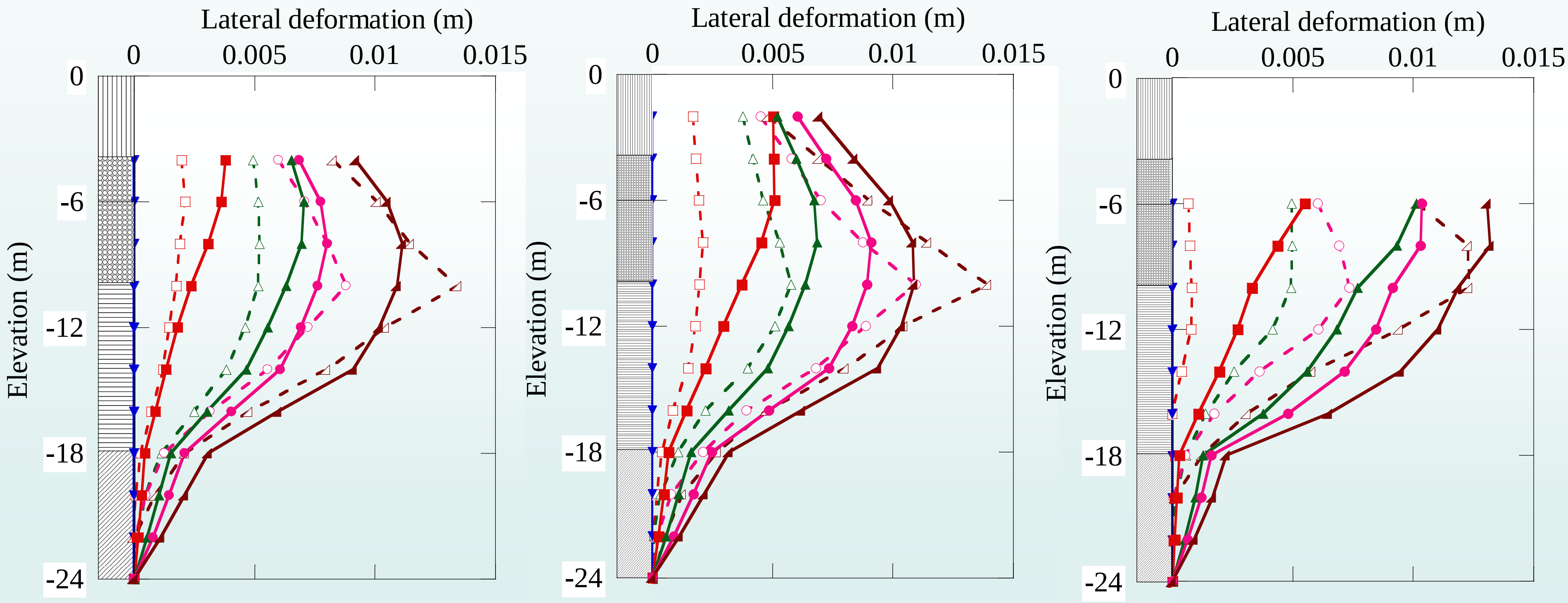
Ford Center Excavation

- Learning from I-5, I-1 and I-2

After SelfSim



Exc Stage	Target	SelfSim
Jan. 30th		
Feb. 18th		
March 12th		
April 14th		
May 7th		

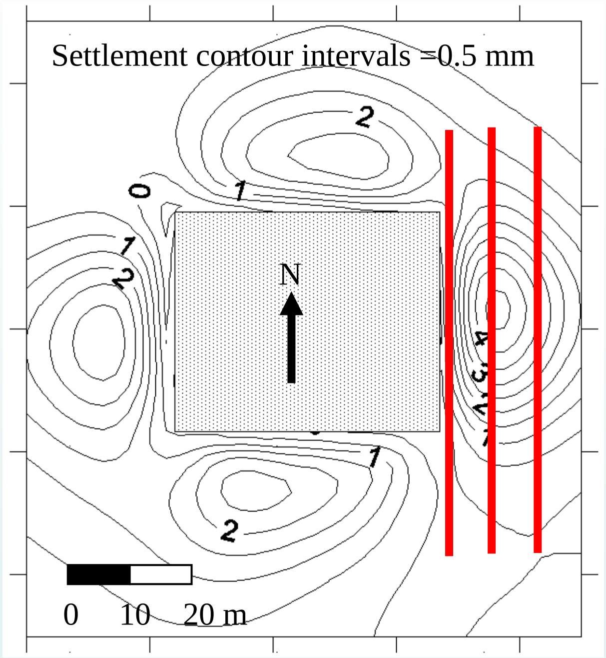


Data Courtesy of Prof. R. Finno, NWU

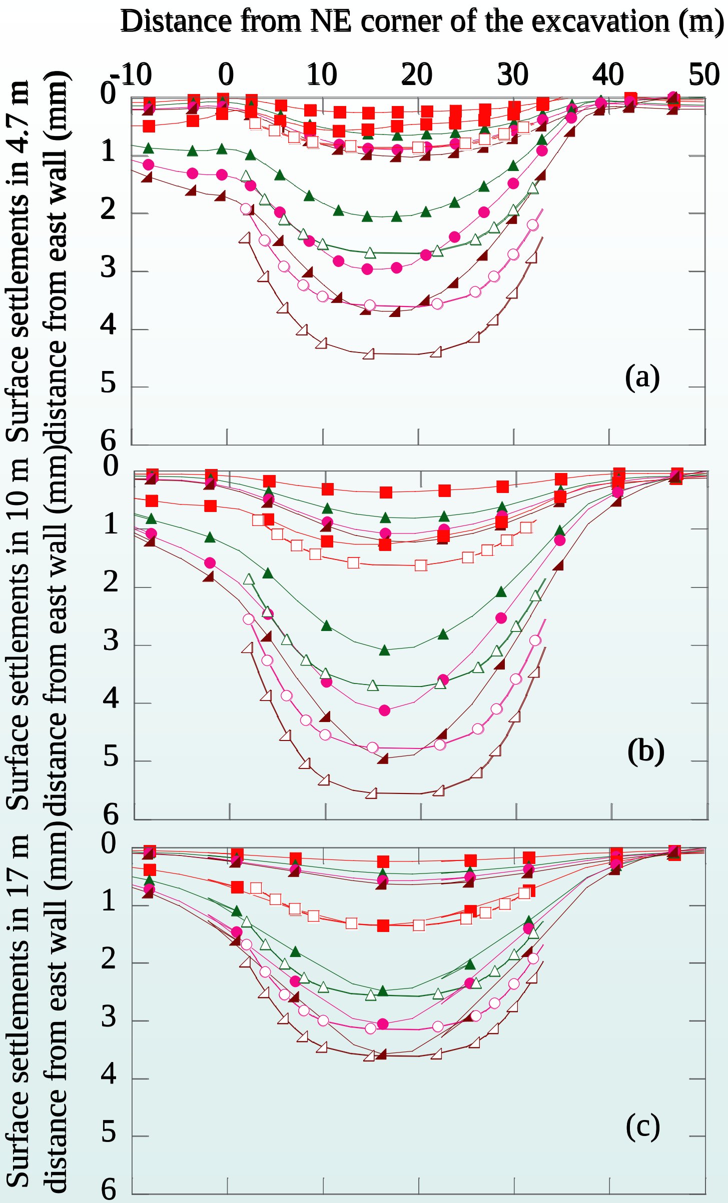
Ford Center Excavation

- Surface settlement profiles

After SelfSim



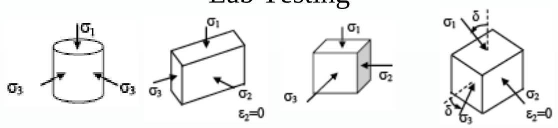
Stages	Predicted	Finno&Roboski (2005)
Feb. 18th	■ (filled square)	□ (open square)
March 12th	▲ (filled triangle)	△ (open triangle)
April 14th	● (filled circle)	○ (open circle)
May 7th	◢ (filled half-triangle)	◿ (open half-triangle)



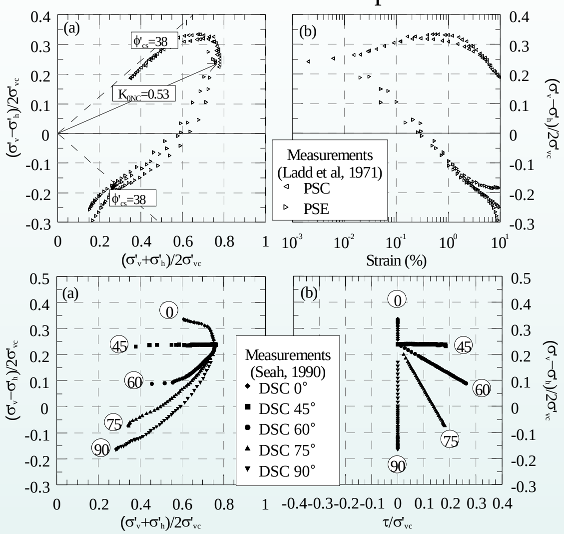
Direct Site Specific Soil Model Development

Multiple Laboratory Tests

Lab Testing



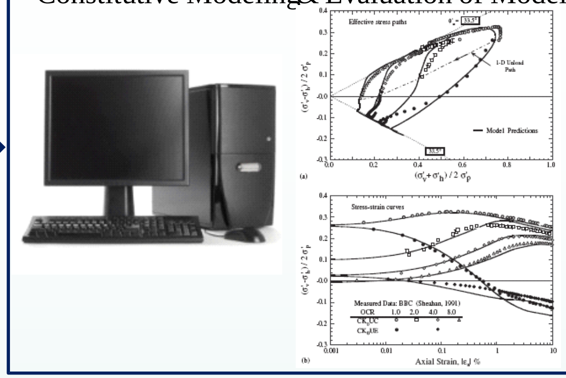
Stress Paths with Complex Behavior



Current approach

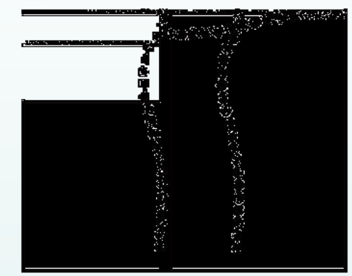
Development of Soil Model

Constitutive Modeling & Evaluation of Model



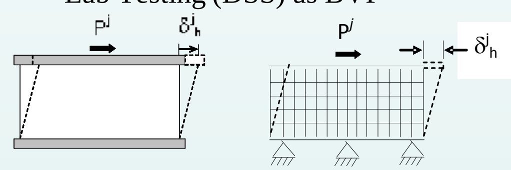
Solution of Boundary Value Problem

Application to BVP (Excavation)



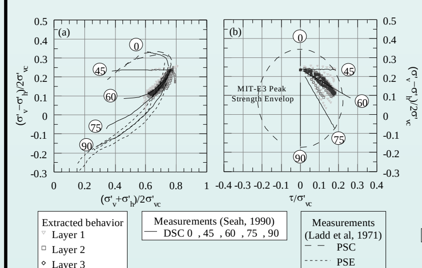
Inverse Analysis Soil Model

Lab Testing (DSS) as BVP

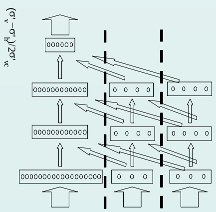


Inverse Analysis

Extracted Constitutive Behavior



NN Based Constitutive Model



Future approach

Modeling in Professional Practice

- Numerical modeling is an extension of conventional engineering calculations
- It is based on basic principles of equilibrium and compatibility
- It is a virtual representation of the planned structure.
- It is a versatile tool that complements available tools
- It may include 1, 2 and 3-D modeling, static and dynamic, multiphase, flow, thermal and chemical processes.
- It may provide higher fidelity estimates
- It supports performance based design

It's all about the user - example

- Excerpt for PLAXIS manual

- DISCLAIMER: PLAXIS …. **The accuracy at which reality is approximated depends highly on the expertise of the user regarding the modeling of the problem, the understanding of the soil models and their limitations, the selection of model parameters, and the ability to judge the reliability of the computational results. Hence, PLAXIS may only be used by professionals that possess the aforementioned expertise.** The user

Issues to consider

1. Processes and interaction and team composition
2. Interaction between modeling team and other engineering team members
3. Relationship between numerical modeling, field and laboratory investigation and engineering design. Design aided by numerical modeling vs design by numerical modeling.
4. Soil-structure Interaction
   a. collaborative process between geotechnical and structural engineers
   b. shared information needs
   c. iterative analysis and model compatibility

Processes, interactions and team composition

- Modeling team leader part of the proposal preparation team

- Modeling activity involves three individuals:
  - Modeler (person behind the computer)
  - Modeling advisor (daily or every other day interaction and guidance)
  - Project Engineer (weekly interactions)

- Model checking during model development

- All three co-author the analysis report (do not leave it to the modeler).

- For large or important projects, external modeling advisor, and peer reviewer/panel are highly recommended

Numerical Modeling and Field and Laboratory Testing

- Develop a field investigation program compatible with the planned numerical modeling.
- Shear wave velocity is a key parameter for static and dynamic problems.
- High quality field and laboratory tests.
- Parametric studies are not a substitute for a good and comprehensive site investigation program.
- Numerical modeling may identify additional site investigation needs.

Soil-Structure Interaction

- A collaboration of geotechnical and structural engineers.
- Soil is not a spring, structure is not a pendulum.
- Higher fidelity geotechnical models interacting with higher fidelity structural models.
- The problem does not care whether you are a geotechnical or structural engineer. Important to extend beyond traditional boundaries…

Numerical Modeling and Engineering Design

- Design aided by numerical modeling vs design by numerical modeling.
- Develop a modeling plan with clear objectives, prepare to modify.
- Modeling shall inform engineering design.
- *Calculation packages for numerical models*.

Numerical Modeling Guidelines

For Geotechnical Applications

Prepared by Youssef Hashash

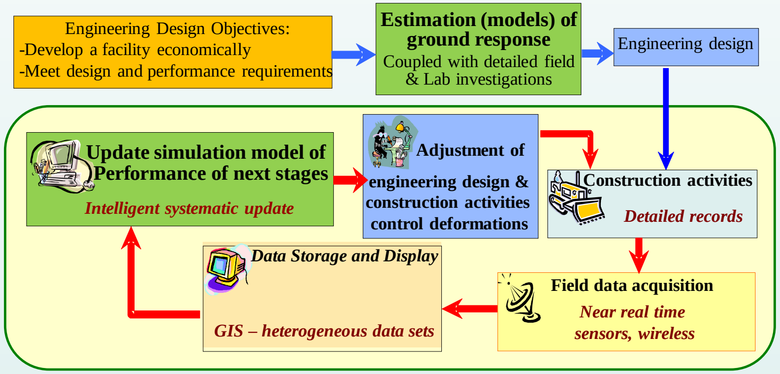
Saturday, October 8, 2016

Version 2.0

Table of Contents

Concluding Remarks

- Numerical modeling is a powerful tool available to our profession.
- Numerical modeling can be an integral element of design & construction processes – Use and misuse.



- Not a substitute for good engineering and judgment, and detailed investigation programs

Thank you.
Questions?