DeepEX
Shoring Design Software

Design of Deep Excavations
DeepEX Software Application

DEEP EXCAVATION
Geotechnical Software & Solutions

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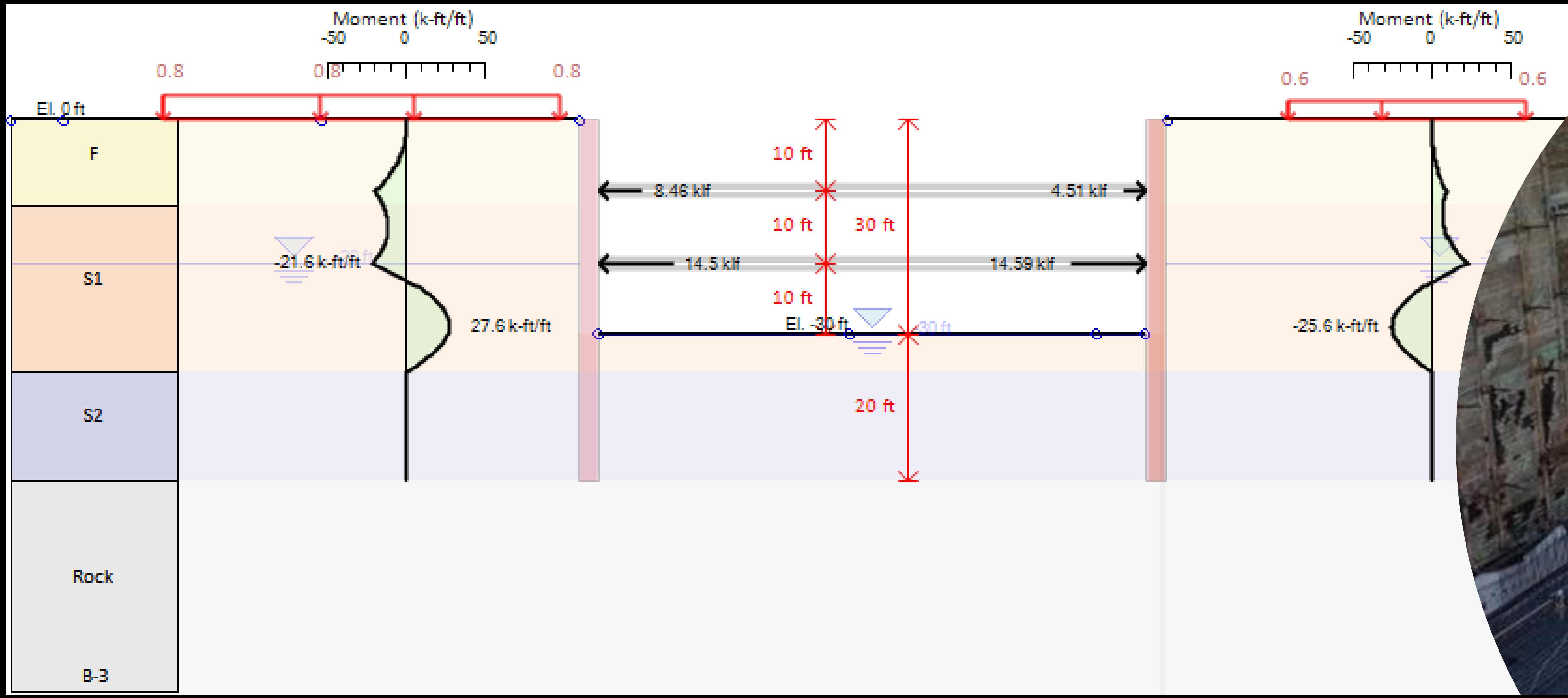
Seminar Notes & Demo: www.deepexcavation.com/en/workshops-seminars/seminar_auth



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Our Company

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www.deepex.com

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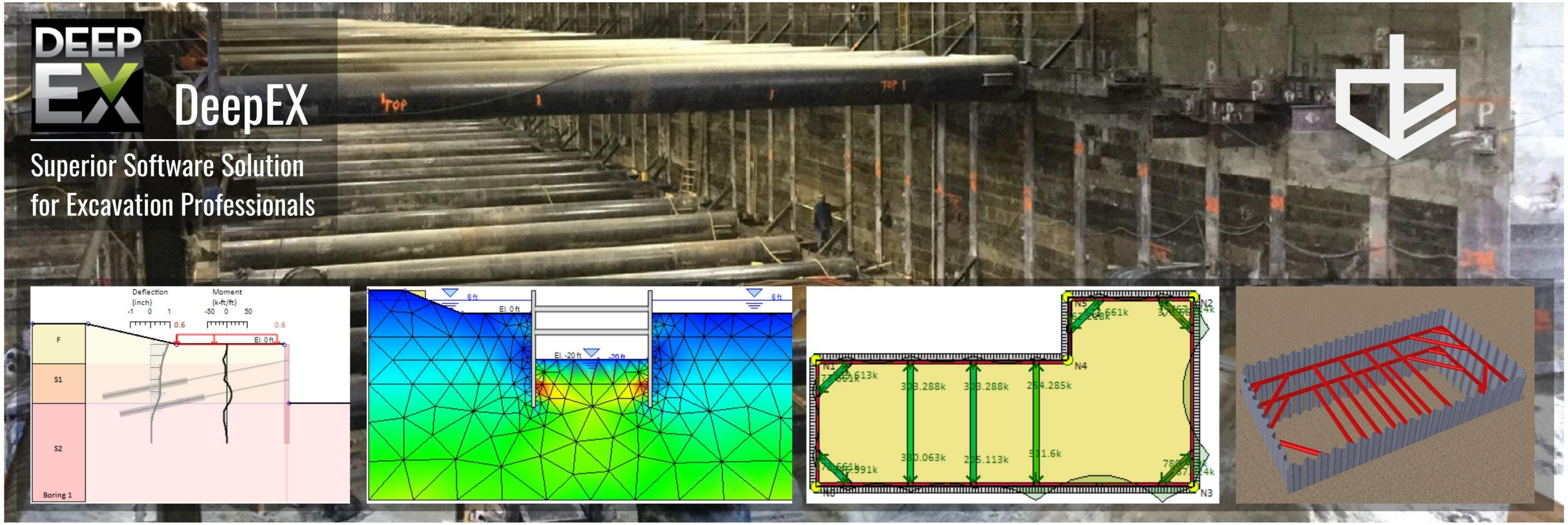
training@deepexcavation.com

- ✓ Software solutions for excavation and foundation professionals
- ✓ Consulting Services - Design of deep excavations and pile foundations
- ✓ Virtual Reality applications for geotechnical engineers and contractors

Introduction to Deep Excavations - DeepEX Features

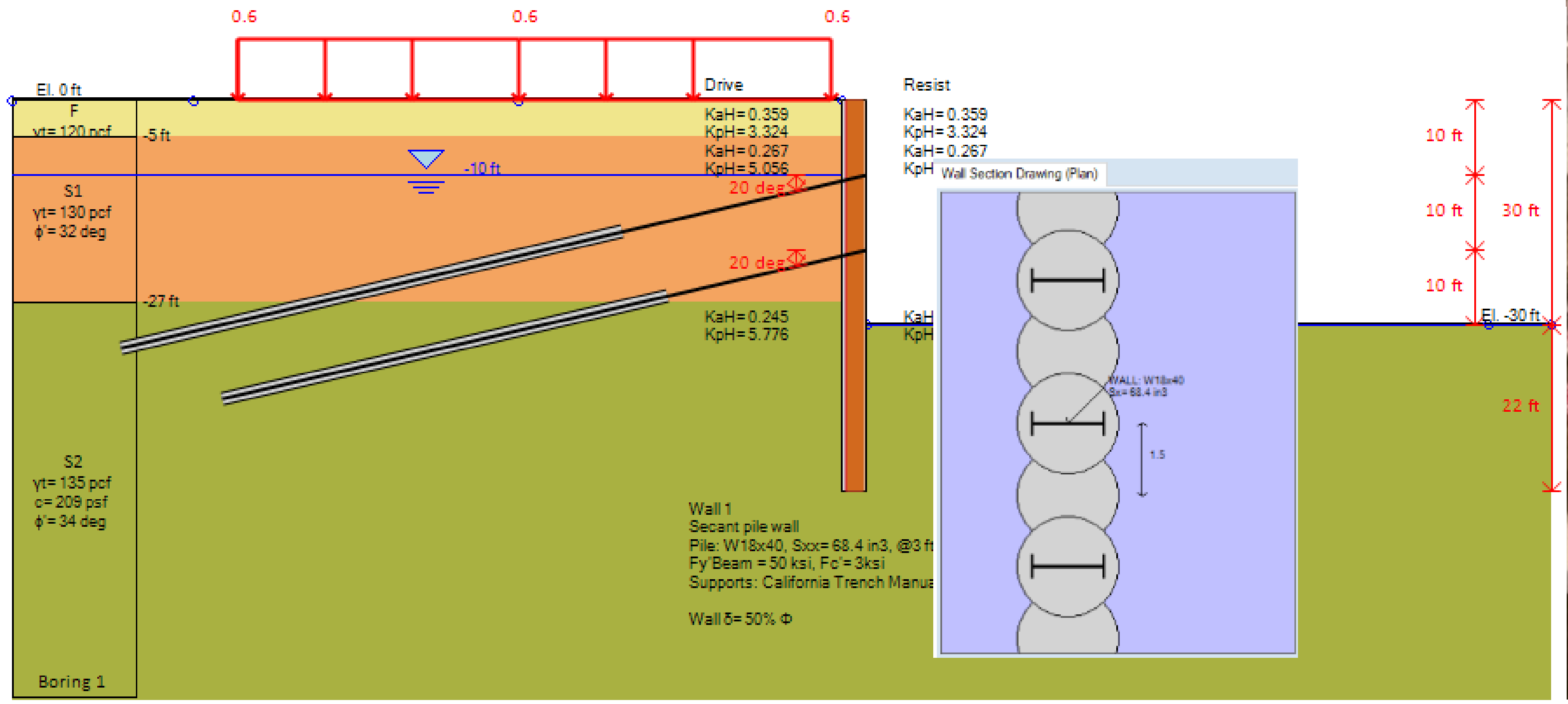


Access deepexcavation.com
DeepEX Features & Capabilities

DeepEX Software - General Capabilities

Deep Excavation: Typically deeper than 3.5m, that requires structural support.

- A deep excavation system has to retain earth, water, and neighboring structures
- Unknown factors and risks
- Soil properties estimation
- Protect adjacent properties
- Design issues and Code issues
- Economy
- Constructability



DeepEX Software - General Capabilities

Full Structural and Geotechnical Design of any Deep Excavation Model

Wall Types in DeepEX

- ✓ Soldier Pile and Lagging Walls
- ✓ Sheet Pile Walls
- ✓ Secant / Tangent Pile Walls
- ✓ Concrete Diaphragm Walls (Slurry Walls)
- ✓ Soldier Pile and Tremied Concrete Walls
- ✓ Combined Sheet Pile Walls (King Piles)
- ✓ Box Sheet Pile Walls
- ✓ Custom Walls

Support Systems in DeepEX

- ✓ Anchored Walls (Tiebacks and Helical Anchors)
- ✓ Braced Excavations (Steel Struts and Rakers)
- ✓ Top/Down Excavations with Concrete Slabs
- ✓ Dead-man Walls
- ✓ Bin-Type Walls
- ✓ Cofferdams
- ✓ Circular Shafts
- ✓ Cantilever Walls

ANALYSIS METHODS: LIMIT EQUILIBRIUM ANALYSIS

Soil Pressures: Active/Passive, At-rest, Apparent Pressures (FHWA, Peck, Adaptive, Custom Trapezoidal +more)

Beam Analysis: Blum's, FHWA Simple Span, CALTRANS +more

NON-LINEAR ANALYSIS (SOIL SPRINGS)

Moments and Reactions from Spring Analysis

Cumulative Results from Stages

Realistic Displacements

FINITE ELEMENT ANALYSIS

Moments and Reactions from Finite Elements

Full Soil-Structure Interaction

Calculate Surface Settlements

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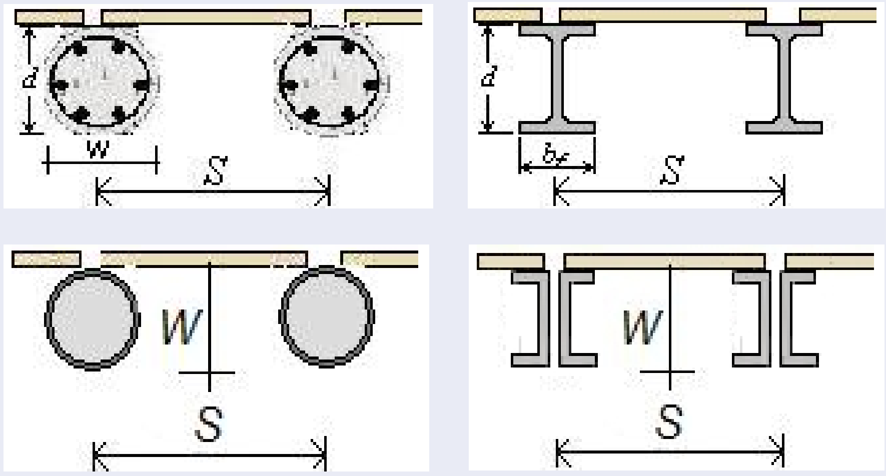
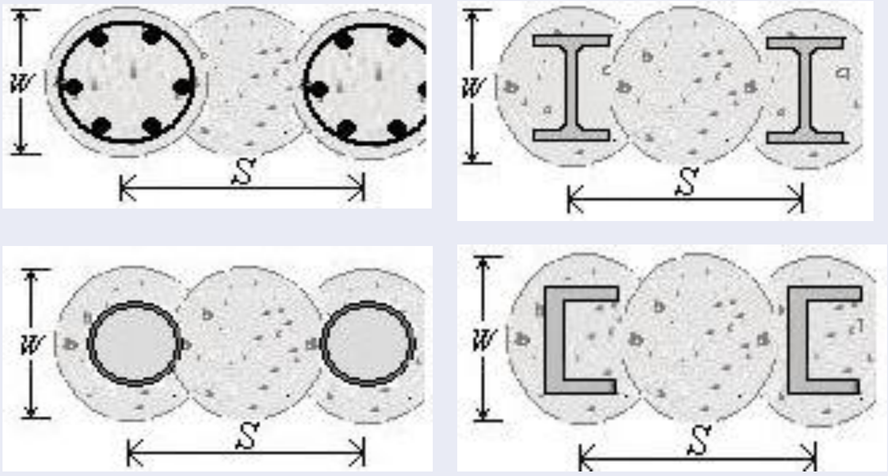
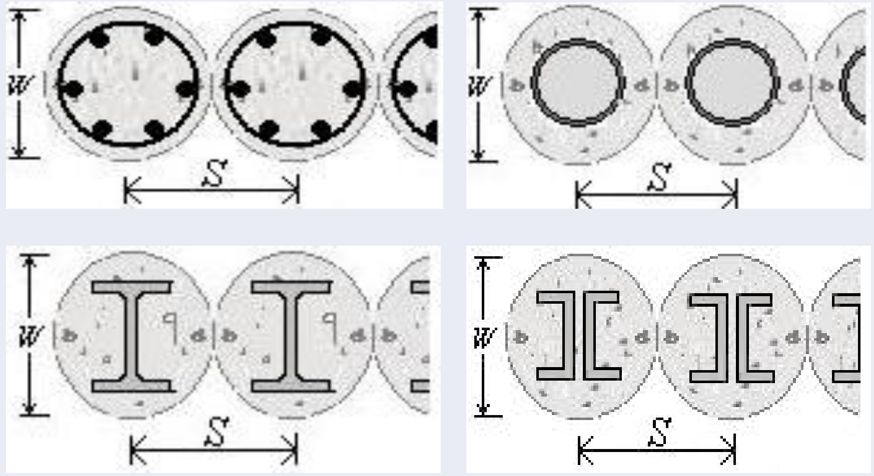
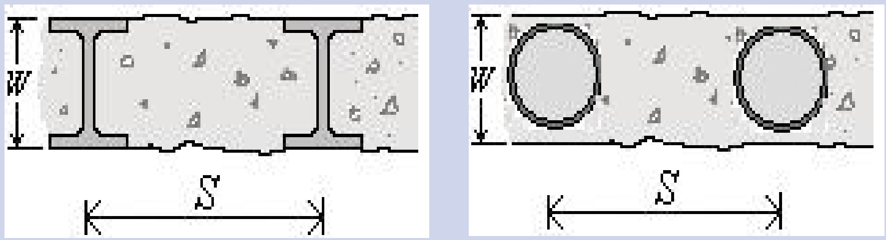
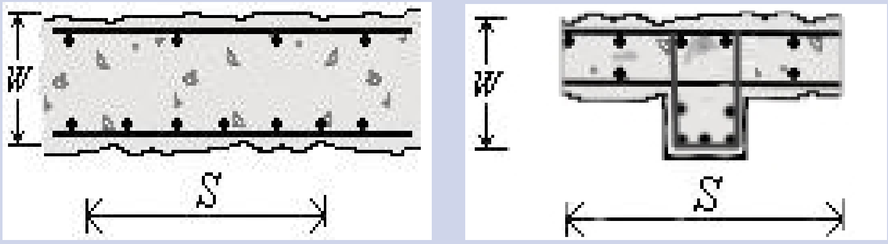
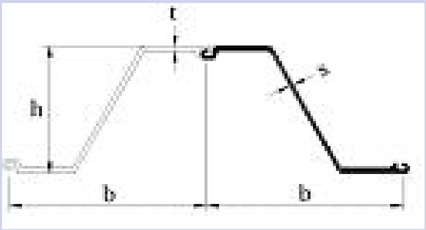
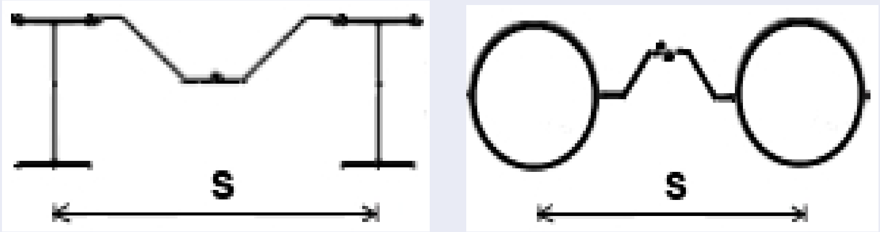
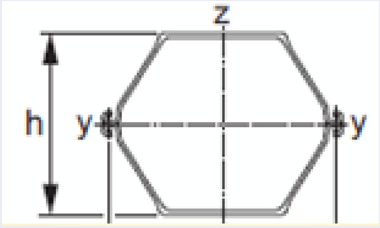
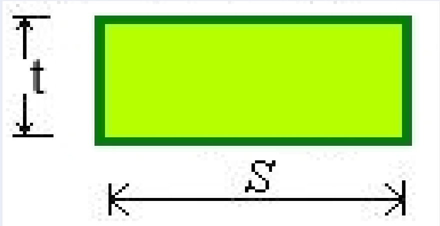
Common Wall Types in DeepEX

Soldier pile and lagging walls	Secant pile walls	Tangent pile walls
		
SPTC walls	**Diaphragm (slurry) walls**	**Sheet pile walls**
		
Combined sheet pile walls	**Box sheet pile walls**	**Custom walls**
		

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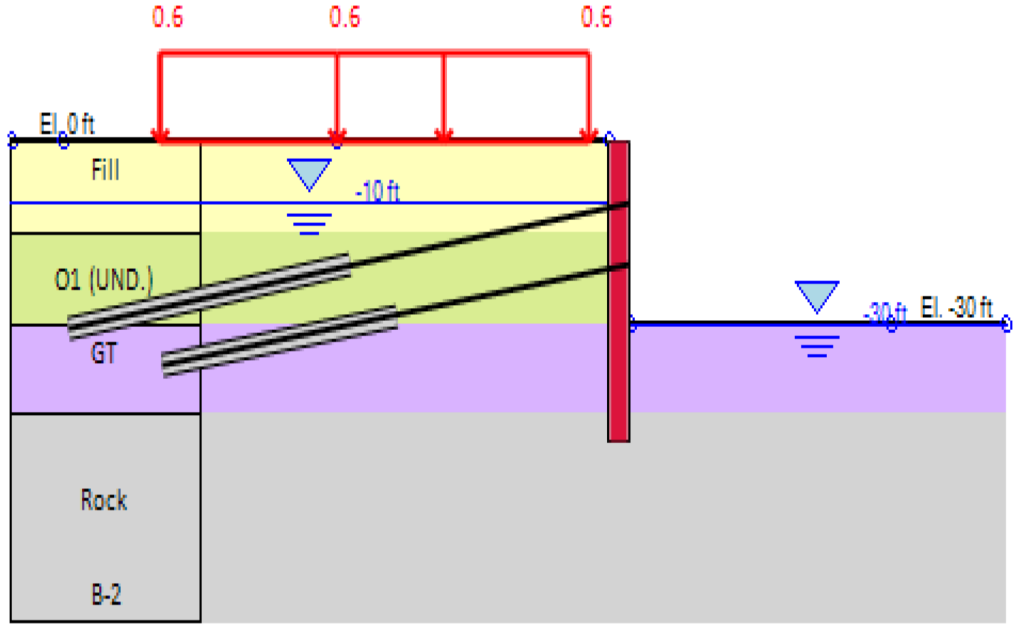
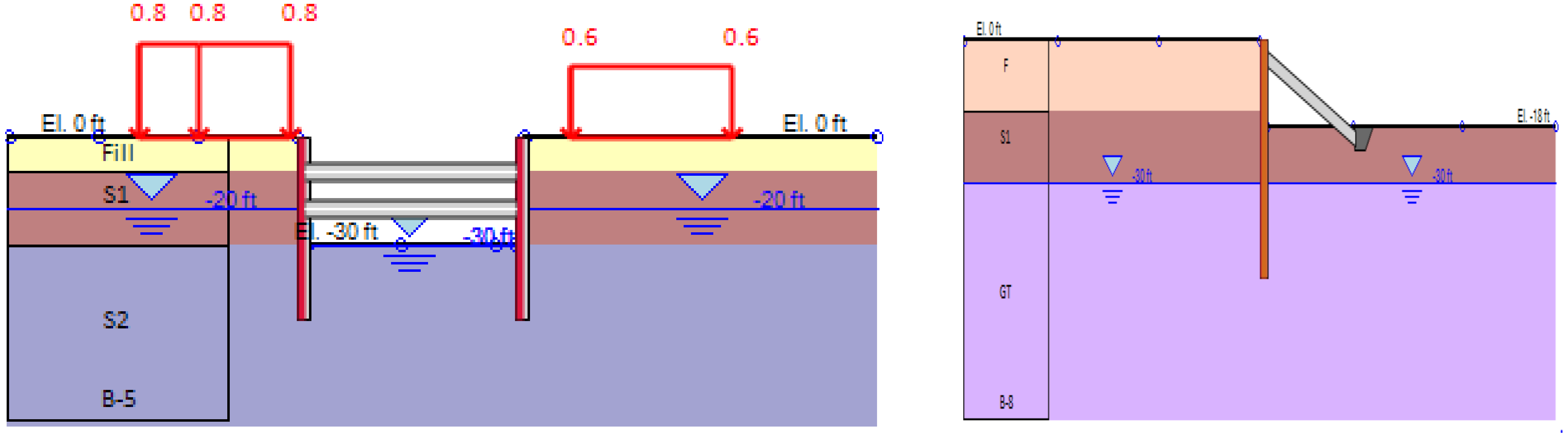
Support Systems in DeepEX

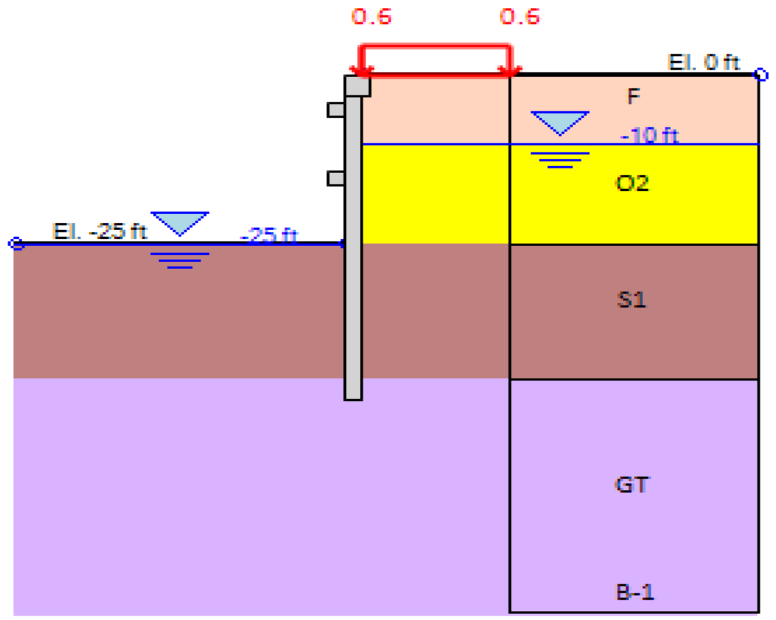
Anchored Walls (Tiebacks)



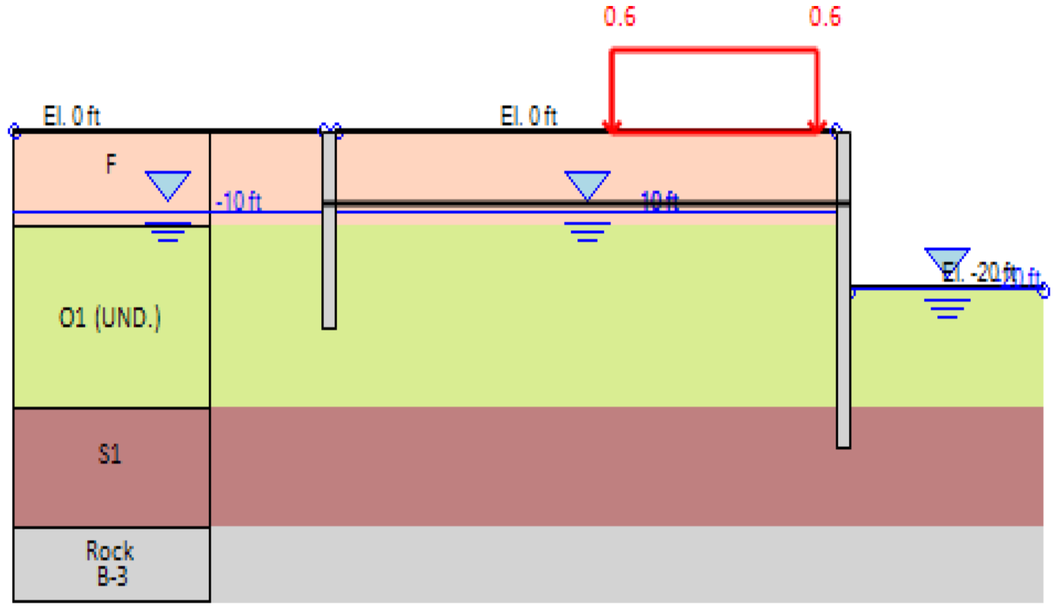
Braced Excavations (Struts and Rakers)



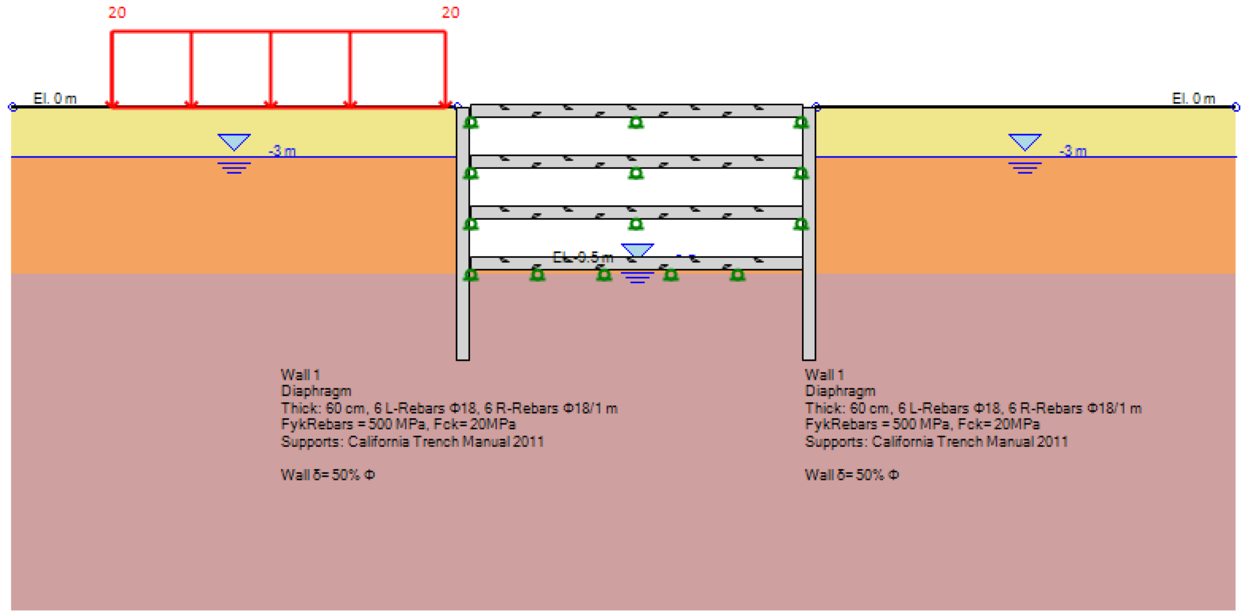
Circular Shafts (Ring Beams)



Dead-man Walls (Tierods)

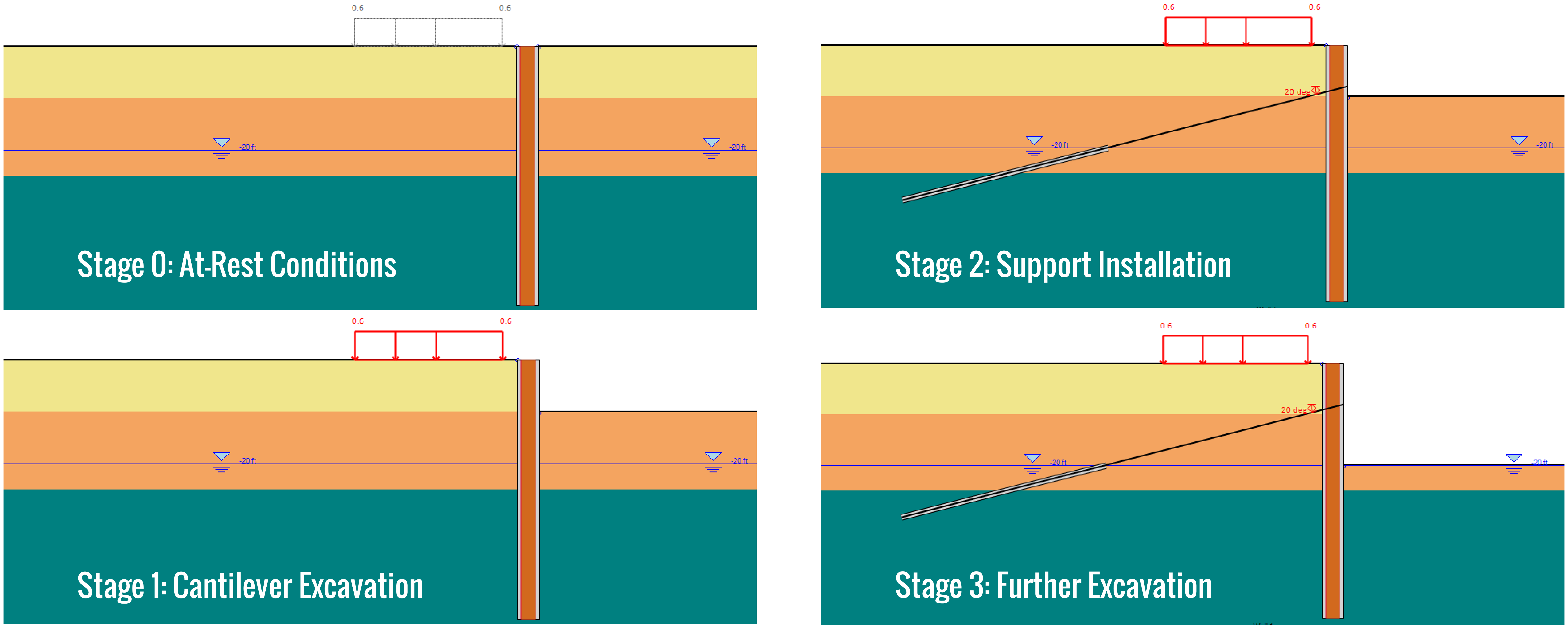


Top-Down Excavations (Concrete Slabs)



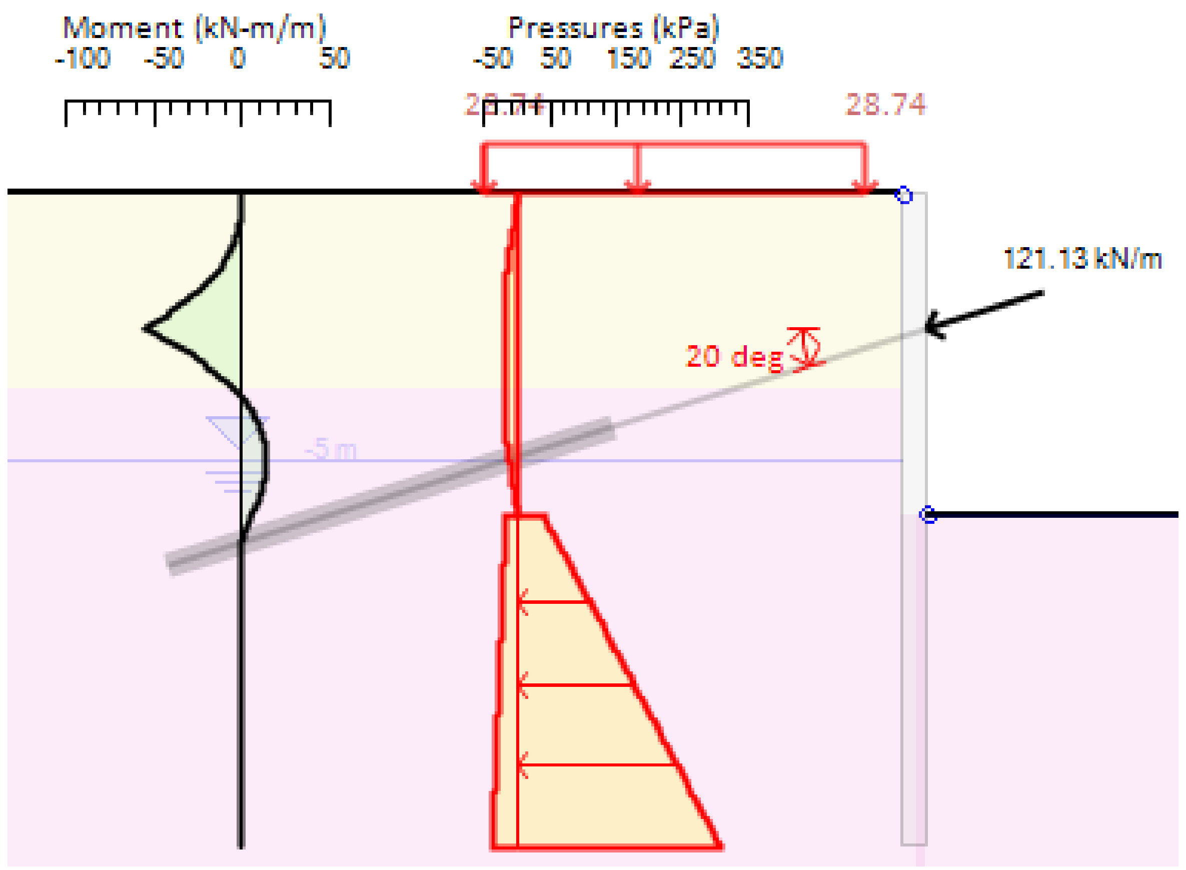
Include All Construction Stages

- ✓ Create all intermediate construction stages
- ✓ Review the results for each stage & recognize the critical stages
- ✓ Perform an efficient model optimization
- ✓ Get more realistic results for methods that consider staging (NL, FEM)

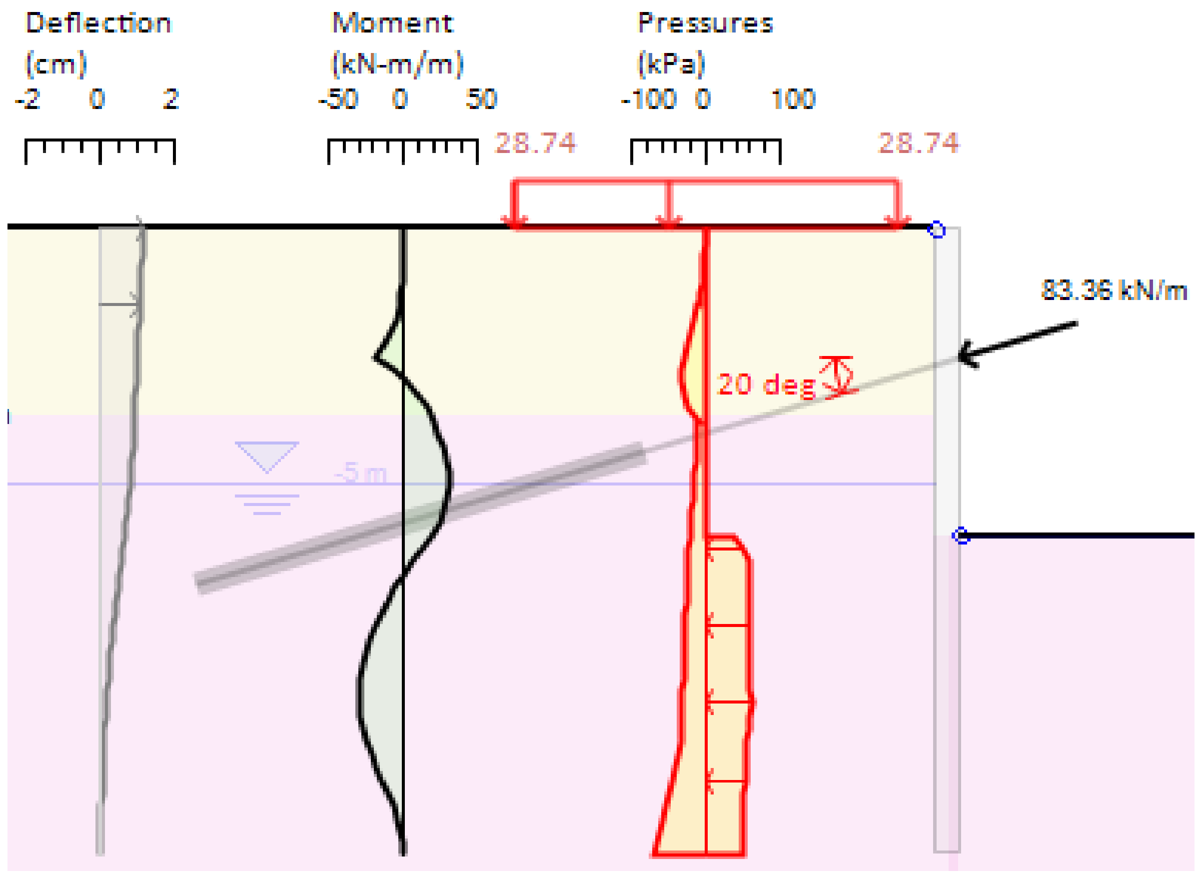


Multiple Analysis Methods

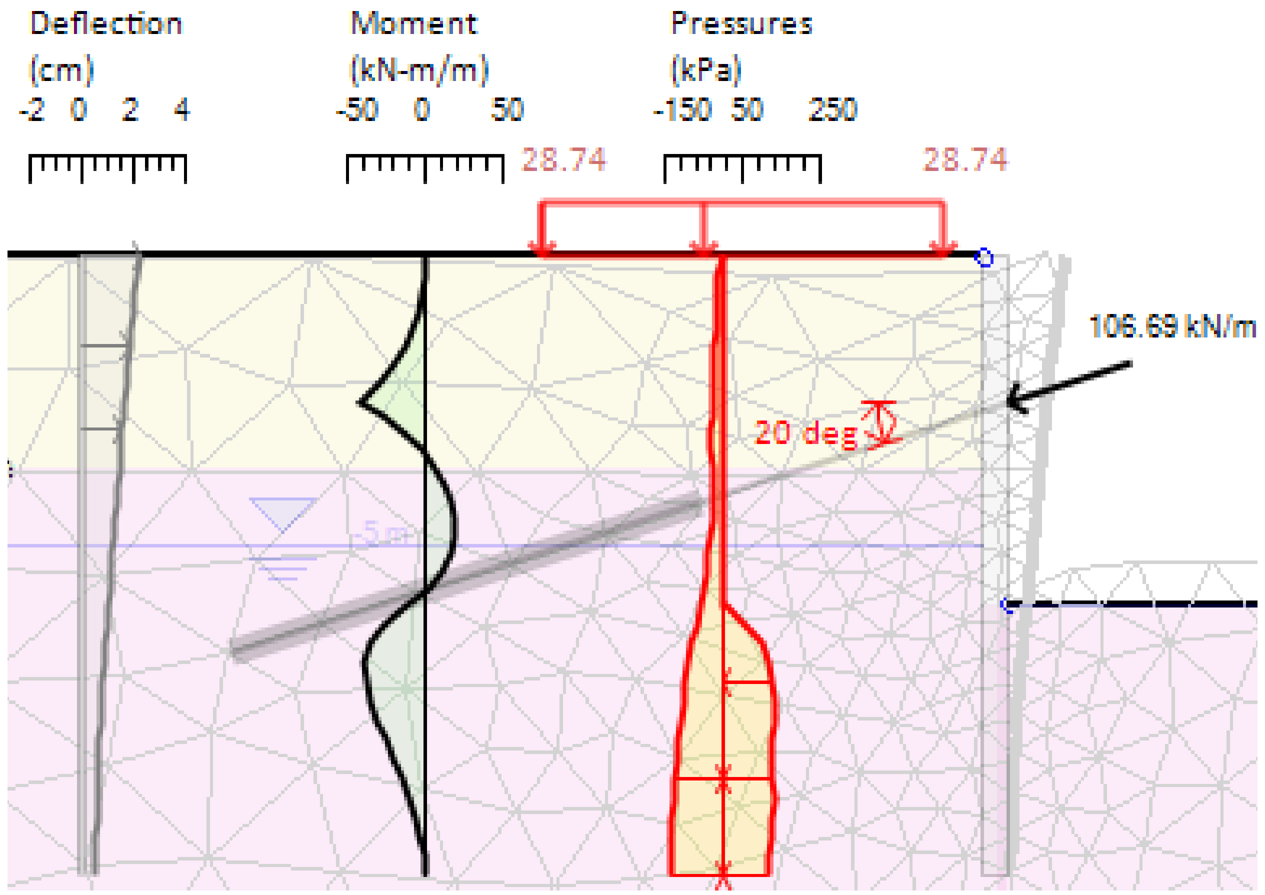
Limit Equilibrium Analysis (LEM)



Non-Linear Analysis (NL) (Elastoplastic Springs)



Finite Element Analysis (FEM)



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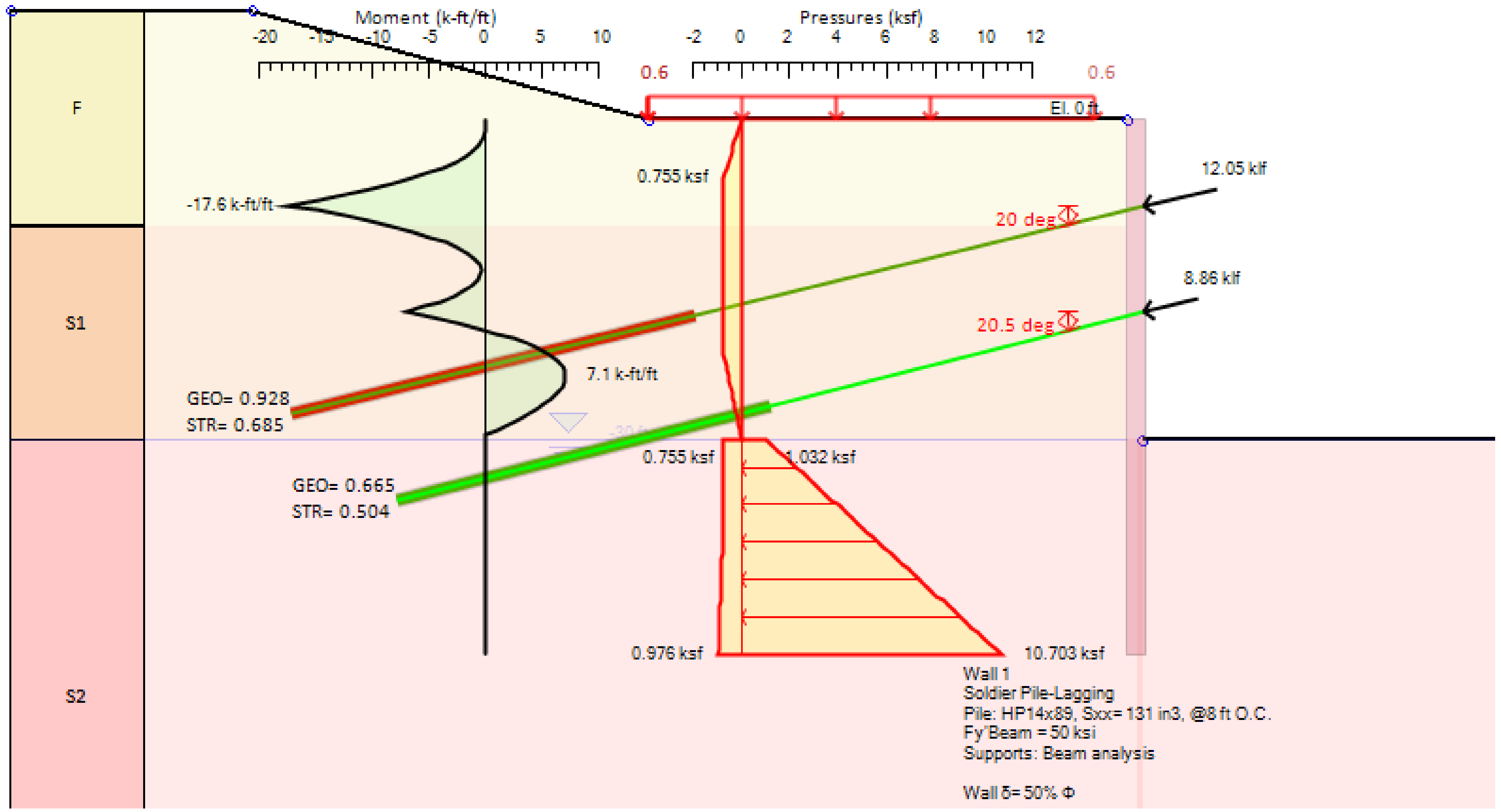
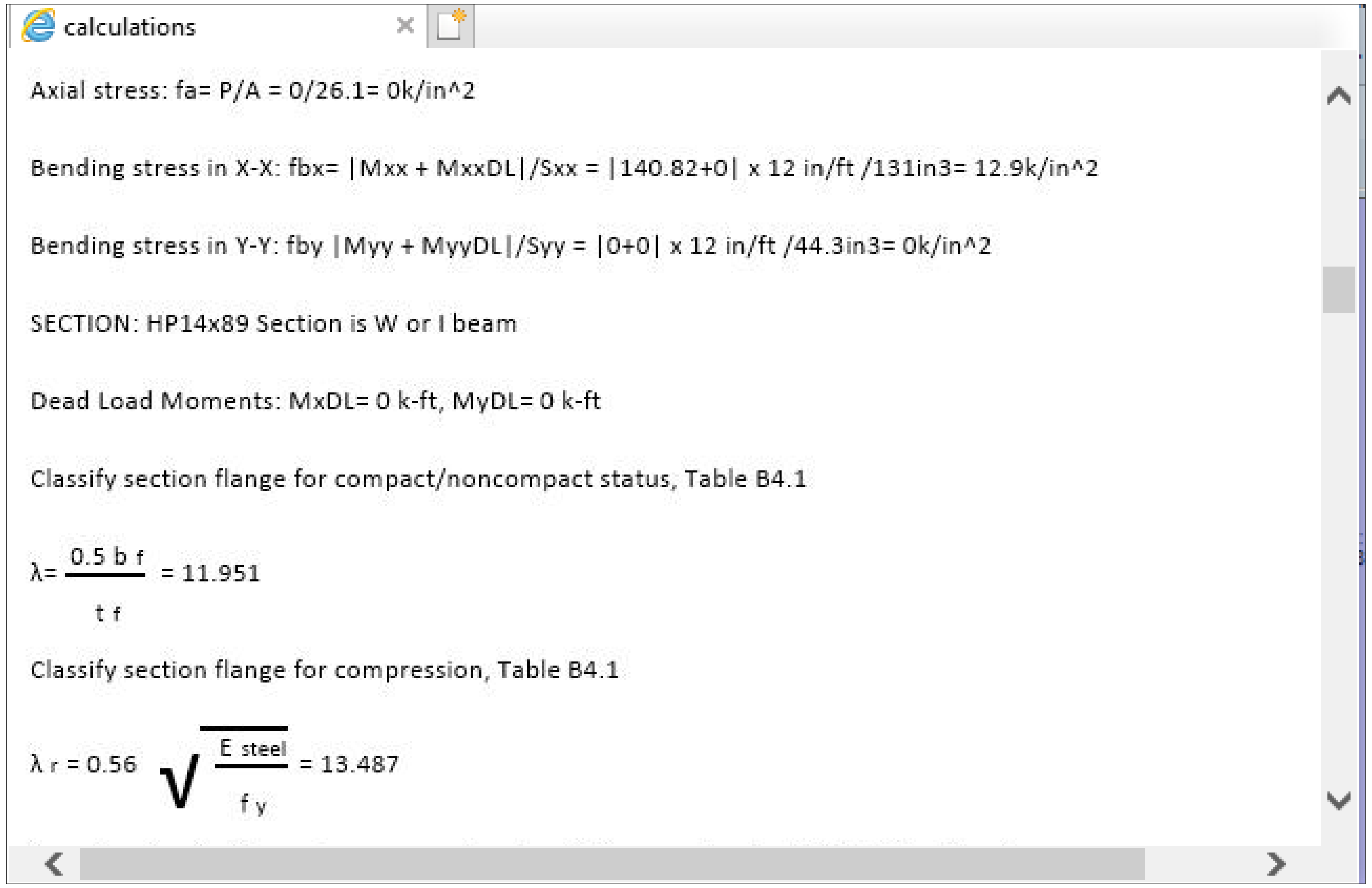
Structural & Geotechnical Design

Diagrams, Reactions & Check Ratios:



Structural Checks & Design Calculations:



Structural Codes: Eurocodes 1,2 & 8, ACI, LRFD, AISC, AS 3600 & 4100, CN (China) + more

Design Standards: Eurocode 7, DIN, BS, XP, AASHTO LRFD, CALTRANS, CN (China) + more

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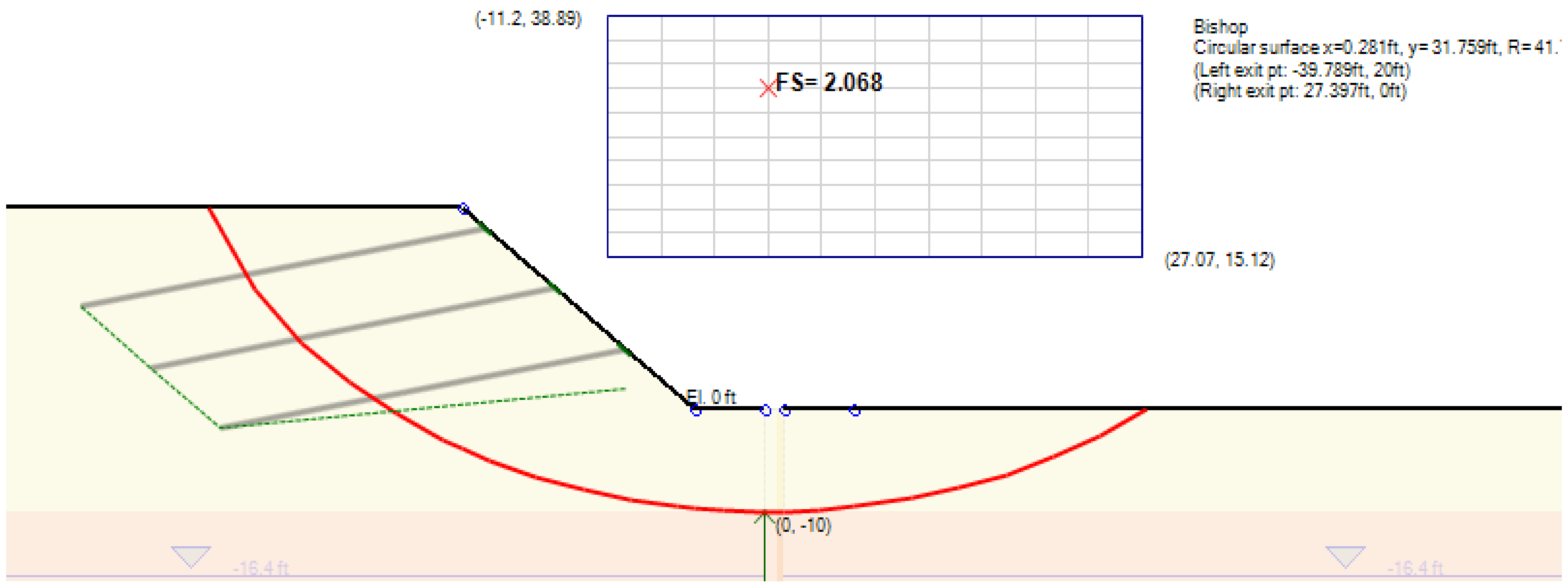
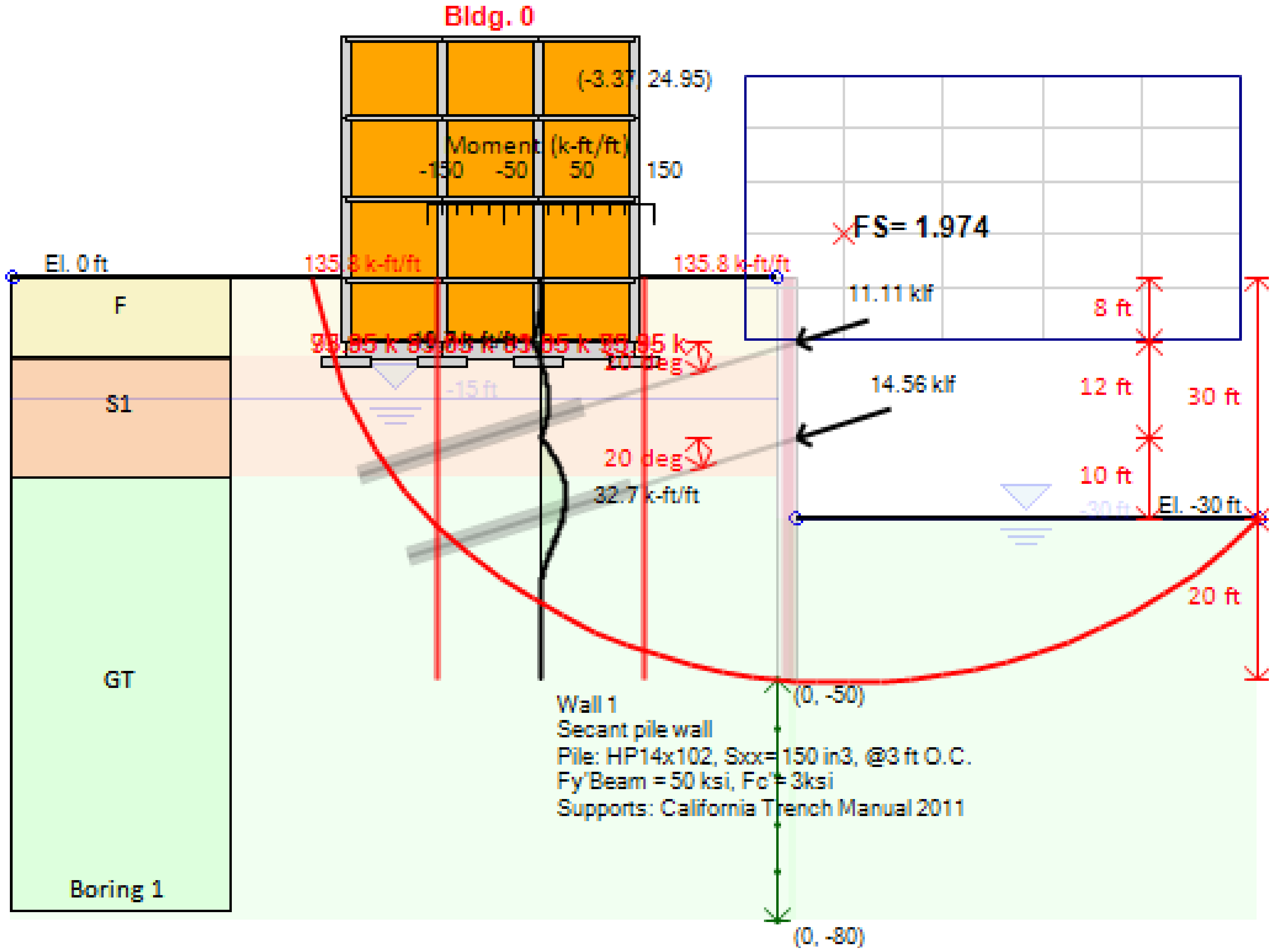
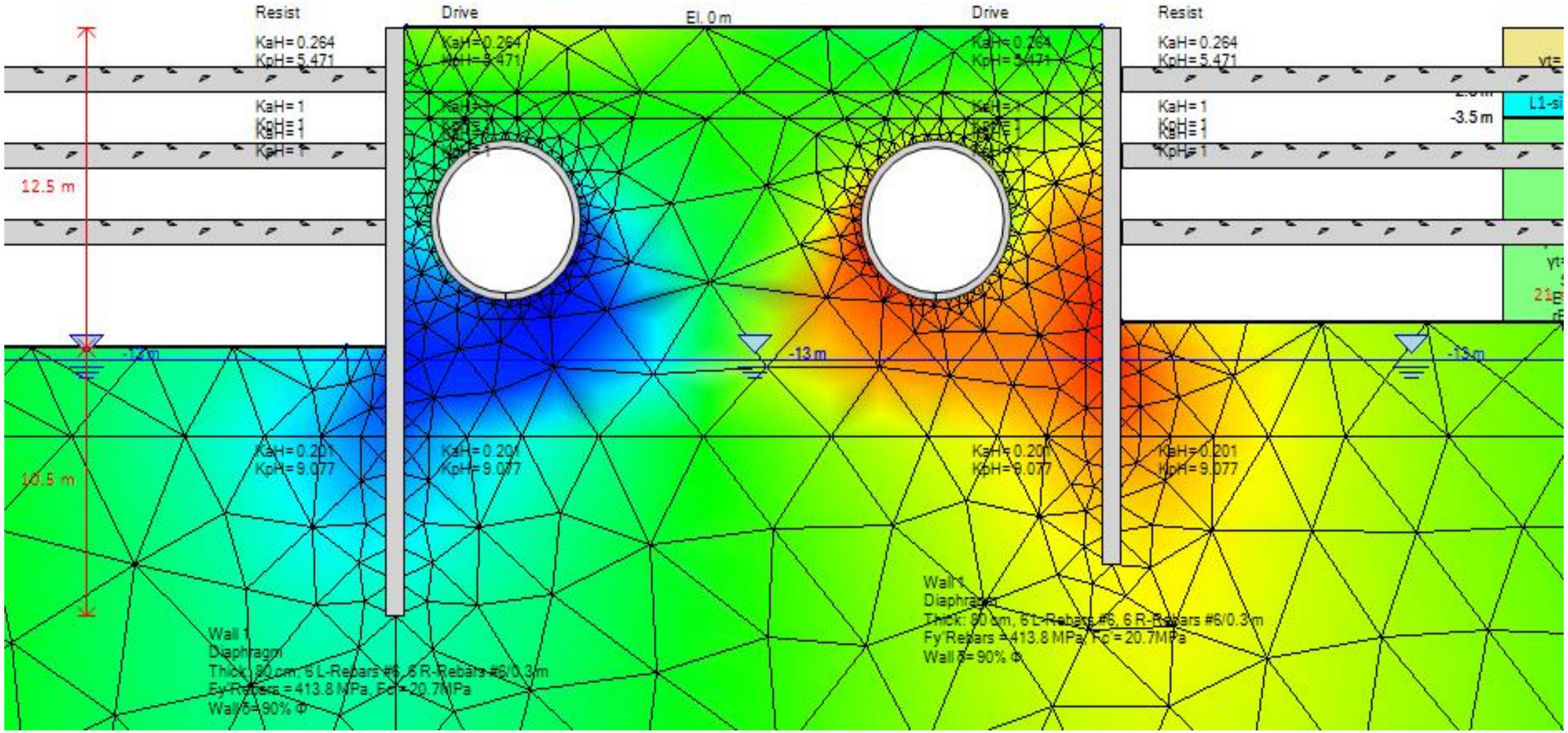
Slope Stability Analysis Options



- ✓ Bishop Method
- ✓ Morgenstern Price Method (G.L.E.)
- ✓ Spencer Method
- ✓ Ordinary (Swedish) Method
- ✓ Automatic Slope Search Method
- ✓ Single Point Slope Center
- ✓ Rectangular Slope Center
- ✓ Define Radius Search Limits
- ✓ Clouterre Standards for Soil Nails



Finite Element Analysis and Tunnels



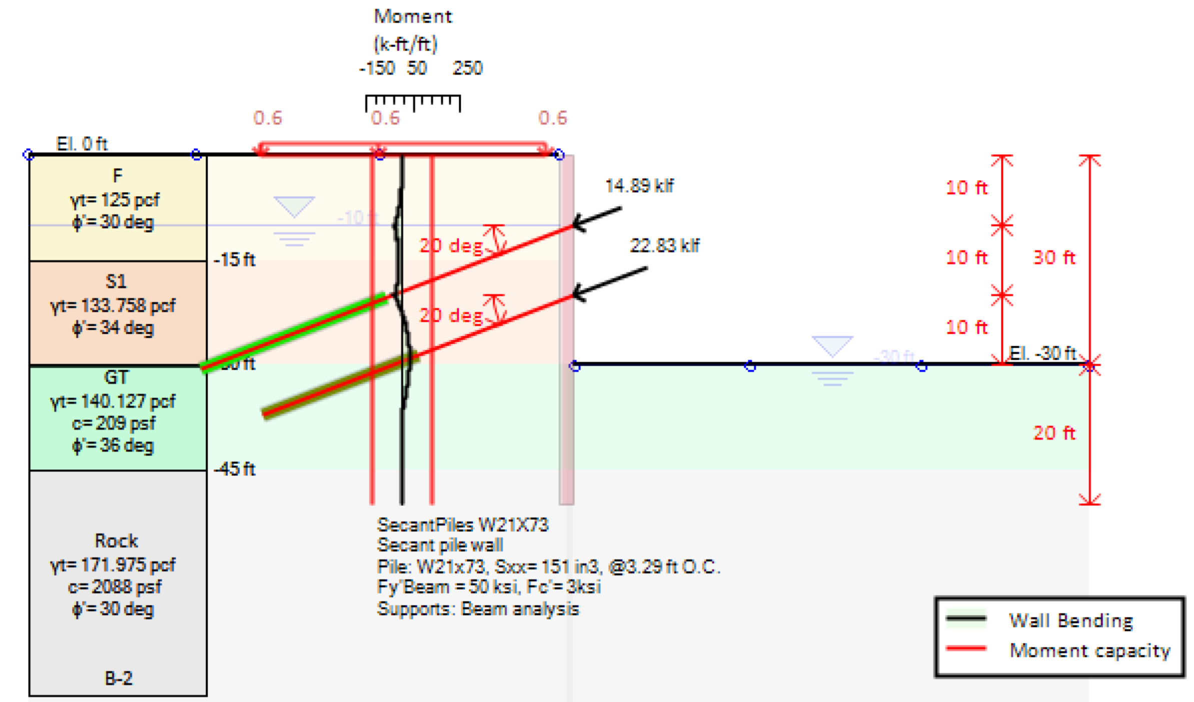
- ✓ DeepEX 2D FEM Engine (DeepFEM)
- ✓ Consider full soil-structure interaction
- ✓ Automatic FE options
- ✓ Soil Models for FEM
- ✓ Include Tiedowns & Foundation Piles

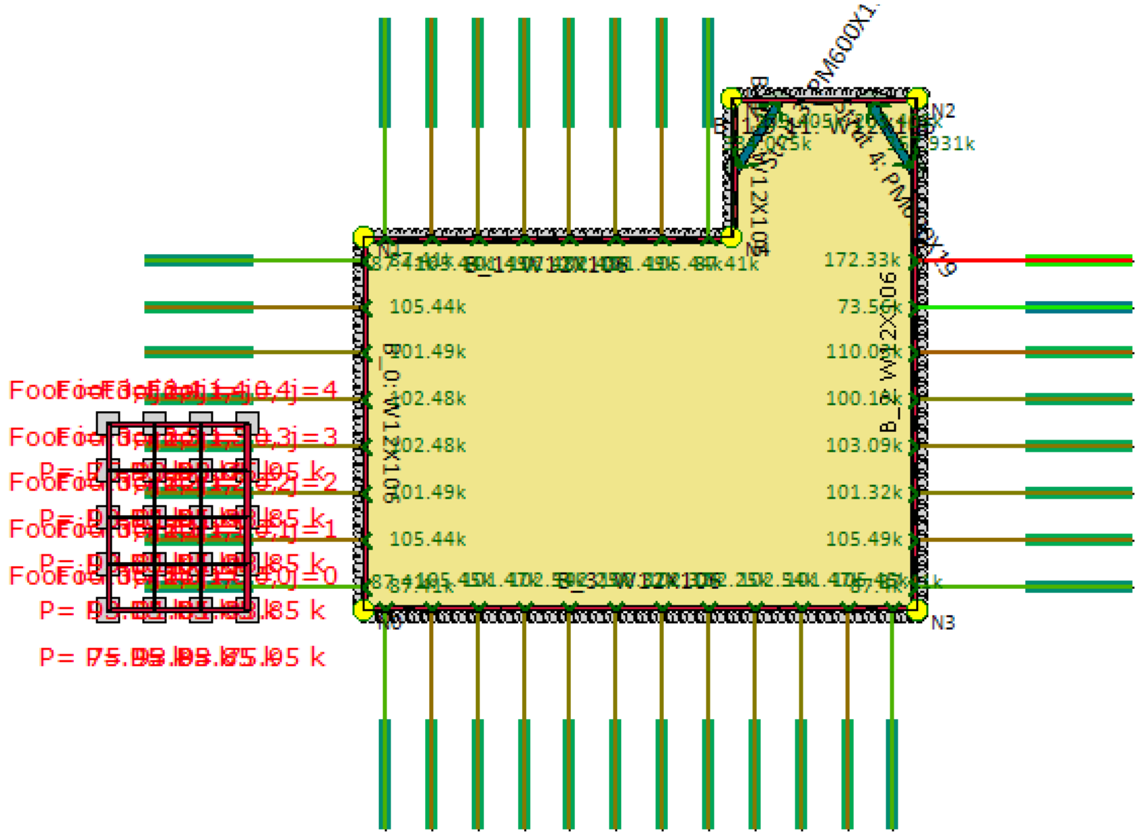
Tunnel Options:

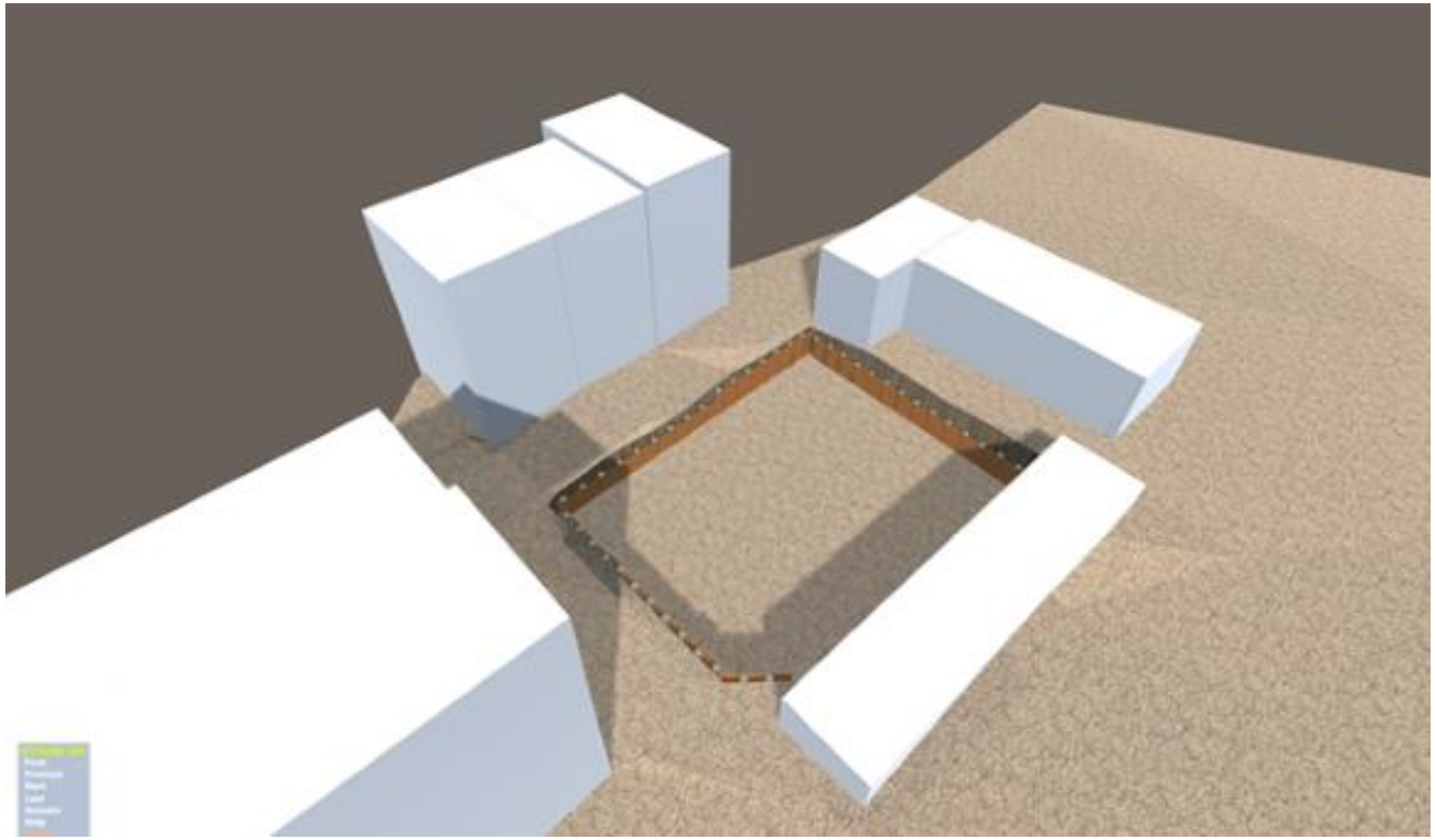
- ✓ Tunnel Analysis with FEM
- ✓ TBM Tunnels
- ✓ NATM - SEM Tunnels
- ✓ Oval and Complex Tunnel Shapes
- ✓ Tunnel Model Wizard
- ✓ Cut-and-Cover Tunnels

2D Sections & 3D Models, 3D Holograms

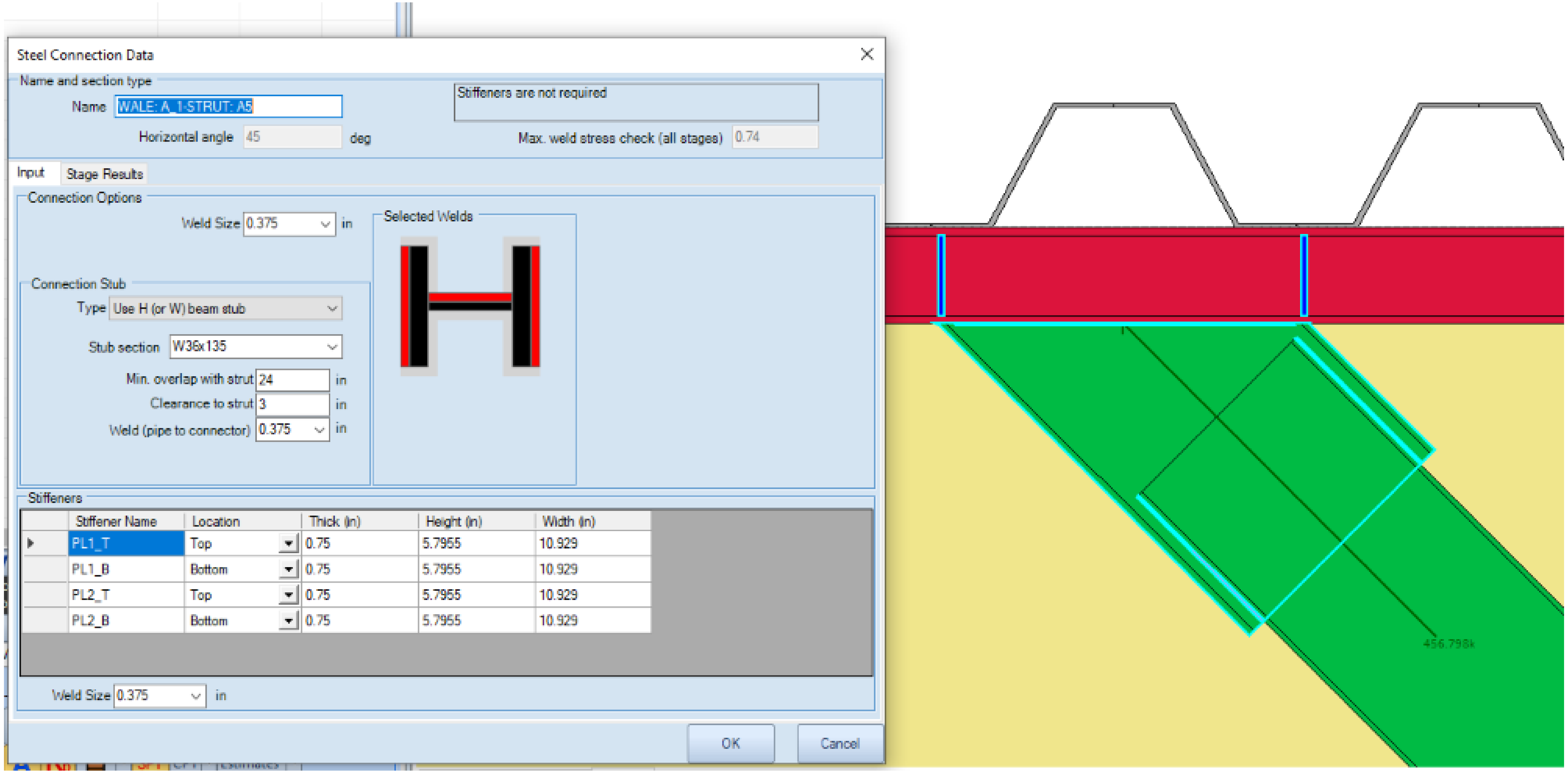
- ✓ Full Design - 2D Sections and 3D Model
- ✓ Structural & Geotechnical design of Tiebacks and Struts
- ✓ 3D Building Loads
- ✓ Full Model Optimization (Walls and Supports)
- ✓ Virtual Reality Model Visualization - Export Model to HoloDeepEX







Check & Optimize Steel Connections

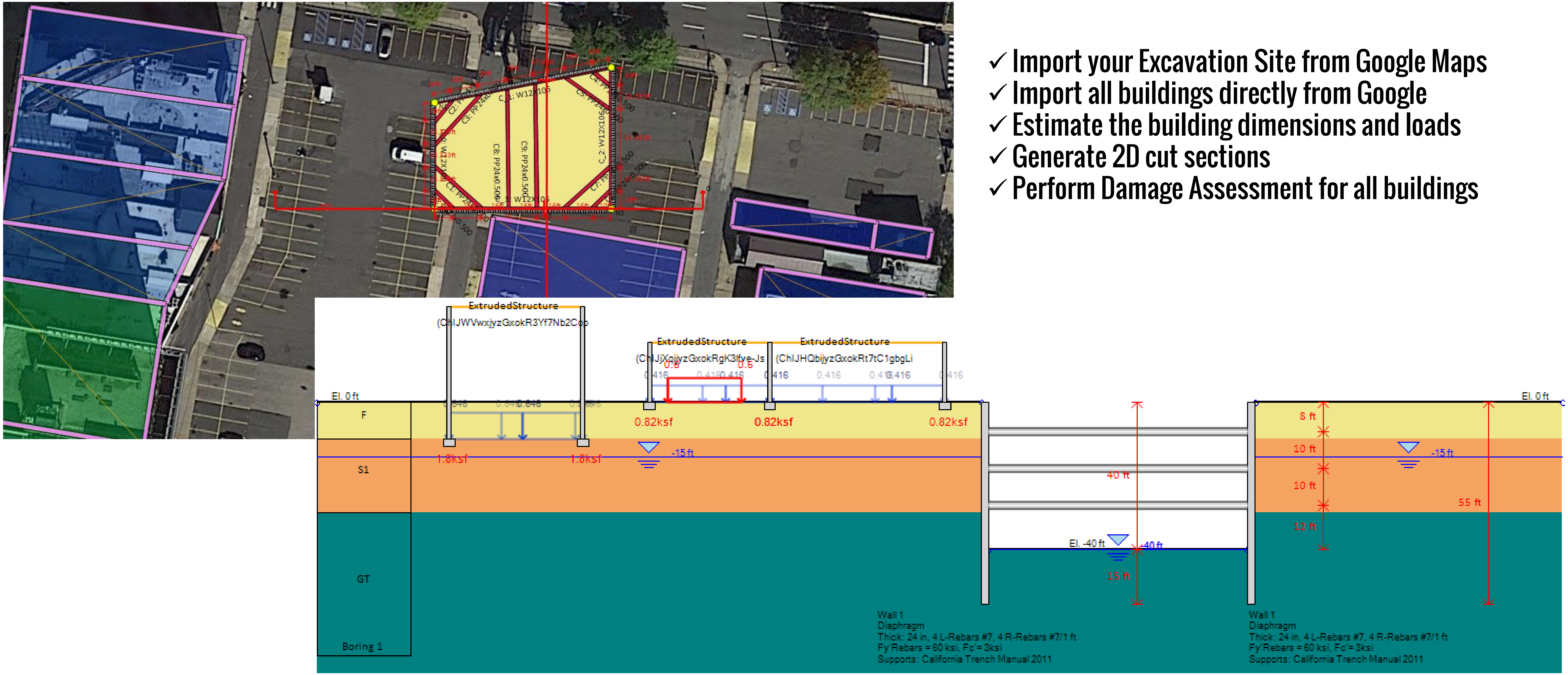


- ✓ Generate all steel connections
- ✓ Check Steel Connections (Struts and Walers)
- ✓ Optimize Steel Connections with a Click
- ✓ Adjust weld sizes and apply plate stiffeners

DeepEX Shoring Design Software

Import Site Map & Buildings from Google

- ✓ Import your Excavation Site from Google Maps
- ✓ Import all buildings directly from Google
- ✓ Estimate the building dimensions and loads
- ✓ Generate 2D cut sections
- ✓ Perform Damage Assessment for all buildings



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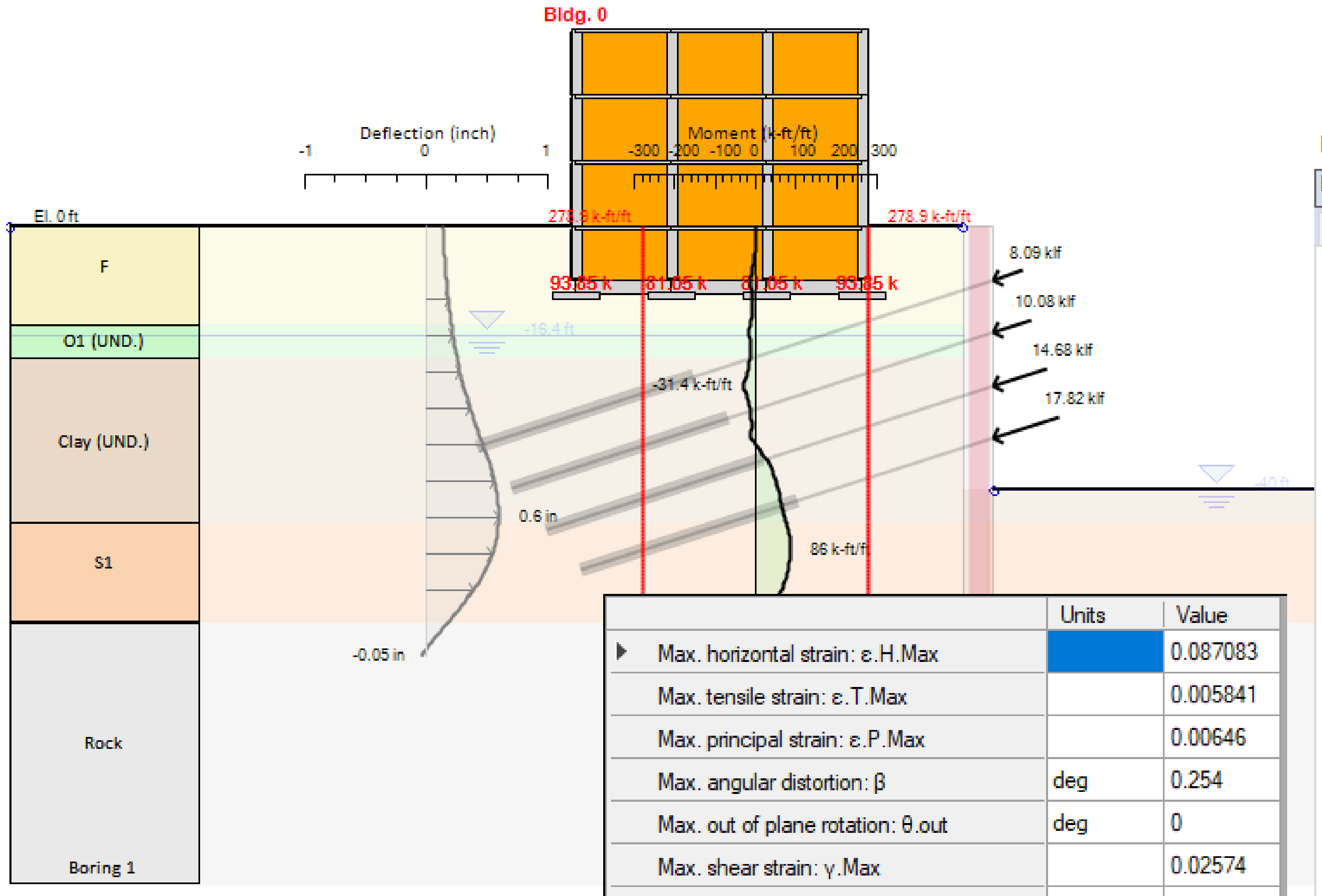
Building Damage Assessment

- ✓ Perform Damage Assessment of all Buildings close to an excavation site
- ✓ Review Crack widths, Damage Categories, Strains etc. for all building walls.



	Units	Value
Max. horizontal strain: ε.H.Max		0.087083
Max. tensile strain: ε.T.Max		0.005841
Max. principal strain: ε.P.Max		0.00646
Max. angular distortion: β	deg	0.254
Max. out of plane rotation: θ.out	deg	0
Max. shear strain: γ.Max		0.02574
Ave. shear strain: γ.Ave		0.003359
Cumulative principal crack width C.p	in	0.2936
Cumulative tensile crack width C.t	in	0.3409
Max principal crack width Cr.p.Max	in	0.1957
Max tensile crack width Cr.t.Max	in	0.2273
Max. damage category		Moderate
Damage category crack width		Moderate
Damage category Boscardin Cording		Moderate

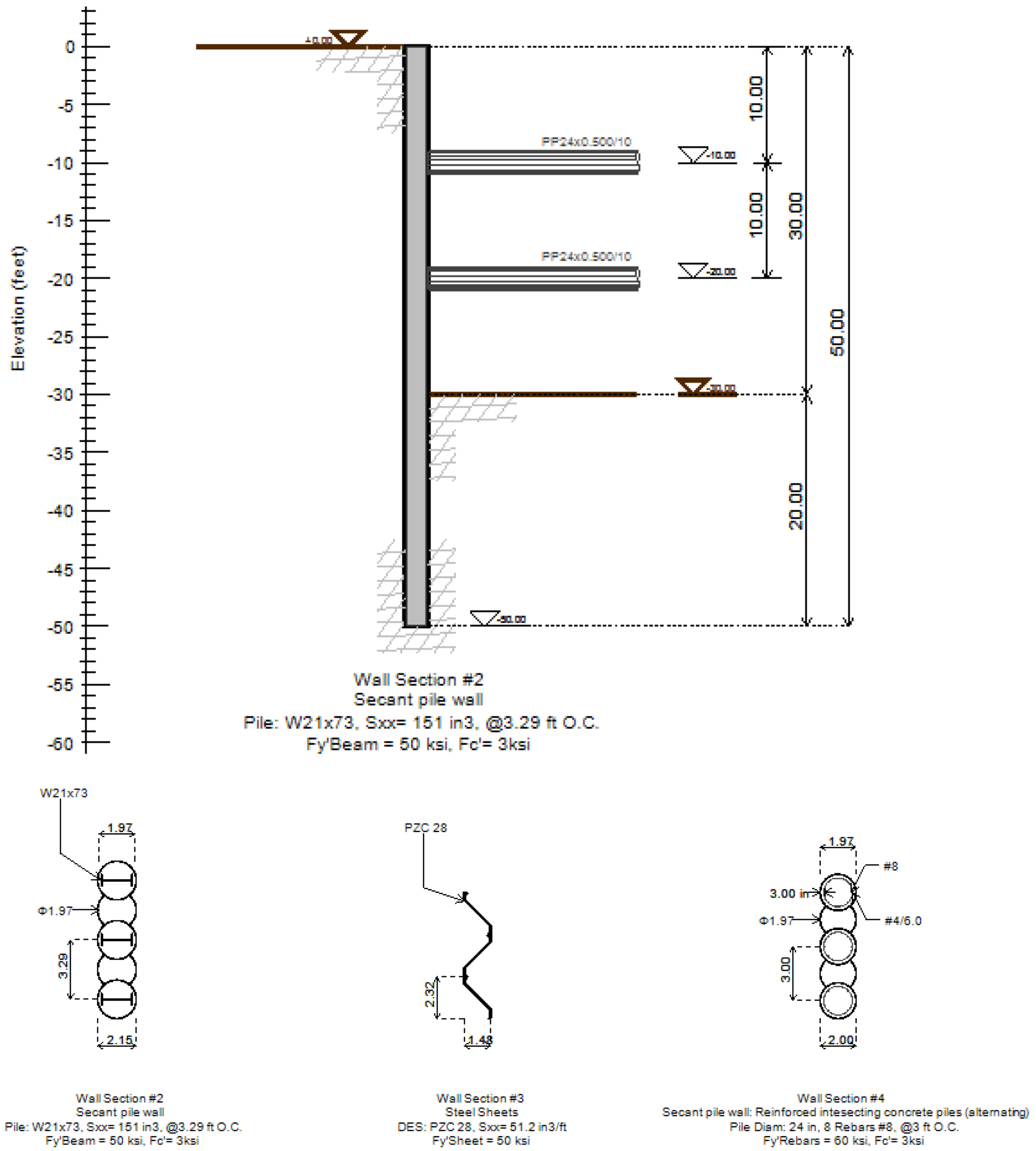
Building Damage Results

Bldg. 0

Maximum values | All elements | Individual elements | Horizontal movement | Settlement | Boscardin-Cording Chart | Hogging Chart (Burland 1979)

		θ.out	γ.Max	γ.Ave	C.p (in)	C.t (in)	Cr.p (in)	Cr.t (in)	Damage Cat	Dam. Crack width	Dam. Boscardin
Bottom side continuous basement wall	203	0	0.005103	0.002551	0	0	0	0	Moderate	Negligibe	Moderate
Left side continuous basement wall	277	0	0.000752	0.000376	0	0	0	0	Negligibe	Negligibe	Negligibe
Right side continuous basement wall	926	0	0.002511	0.001256	0	0	0	0	Negligibe	Negligibe	Negligibe
Top side continuous basement wall		0	0	0	0	0	0	0	Negligibe	Negligibe	Negligibe
Exterior wall at floor 1El. 0, (-10.67, 30 to -20.67,30)	407	0	0.025554	0.001561	0.2327	0.3337	0.1551	0.2225	Moderate	Moderate	N/A
Exterior wall at floor 1El. 0, (-20.67, 70 to -10.67,70)		0	0	0	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 1El. 0, (-20.67, 30 to -30.67,30)	872	0	0.022453	0.002095	0.0798	0.0299	0.0532	0.0199	Slight	Slight	N/A
Exterior wall at floor 1El. 0, (-30.67, 70 to -20.67,70)		0	0	0	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 1El. 0, (-30.67, 30 to -40.67,30)	558	0	0.014831	0.001949	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 1El. 0, (-40.67, 70 to -30.67,70)		0	0	0	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 1El. 0, (-10.67, 40 to -10.67,30)	439	0	0.02574	0	0.153	0.2154	0.102	0.1436	Slight	Slight	N/A
Exterior wall at floor 1El. 0, (-40.67, 30 to -40.67,40)	34	0	0.007772	0.001901	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 1El. 0, (-10.67, 50 to -10.67,40)	169	0	0.02417	0	0.2936	0.1803	0.1957	0.1202	Slight	Slight	N/A
Exterior wall at floor 1El. 0, (-40.67, 40 to -40.67,50)	391	0	0.002266	0	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 1El. 0, (-10.67, 60 to -10.67,50)	336	0	0.013545	0	0.0476	0	0.0317	0	Very slight	Very slight	N/A
Exterior wall at floor 1El. 0, (-40.67, 50 to -40.67,60)		0	0	0	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 1El. 0, (-10.67, 70 to -10.67,60)		0	0	0	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 1El. 0, (-40.67, 60 to -40.67,70)		0	0	0	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 2El. 10, (-10.67, 30 to -20.67,30)	407	0	0.025554	0.001561	0.1975	0.2805	0.1317	0.187	Slight	Slight	N/A
Exterior wall at floor 2El. 10, (-20.67, 70 to -10.67,70)		0	0	0	0	0	0	0	Negligibe	Negligibe	N/A
Exterior wall at floor 2El. 10, (-20.67, 30 to -30.67,30)	872	0	0.022453	0.002095	0.1566	0.2011	0.1044	0.1341	Slight	Slight	N/A

Export All Project Sketches to DXF

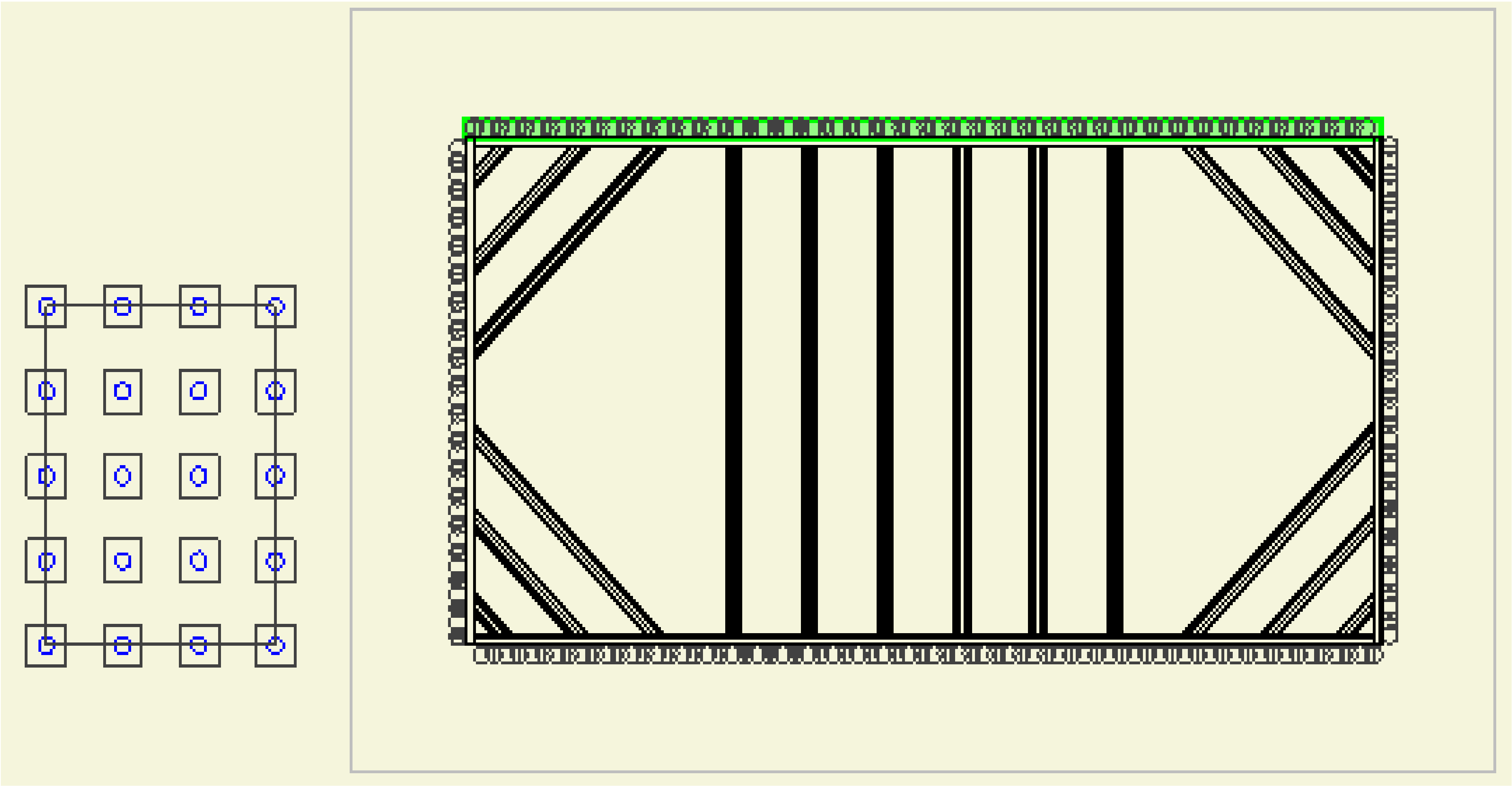


2D Sections:

- ✓ Export all 2D Sections Sketches for each Construction Stage
- ✓ Export Wall Section Details
- ✓ Export 2D Sections with Result Diagrams

3D Models:

- ✓ Export all 2D Sections and Wall Details
- ✓ Export Full Project Plan Sketches
- ✓ Export Elevation Sketches for each Project Wall



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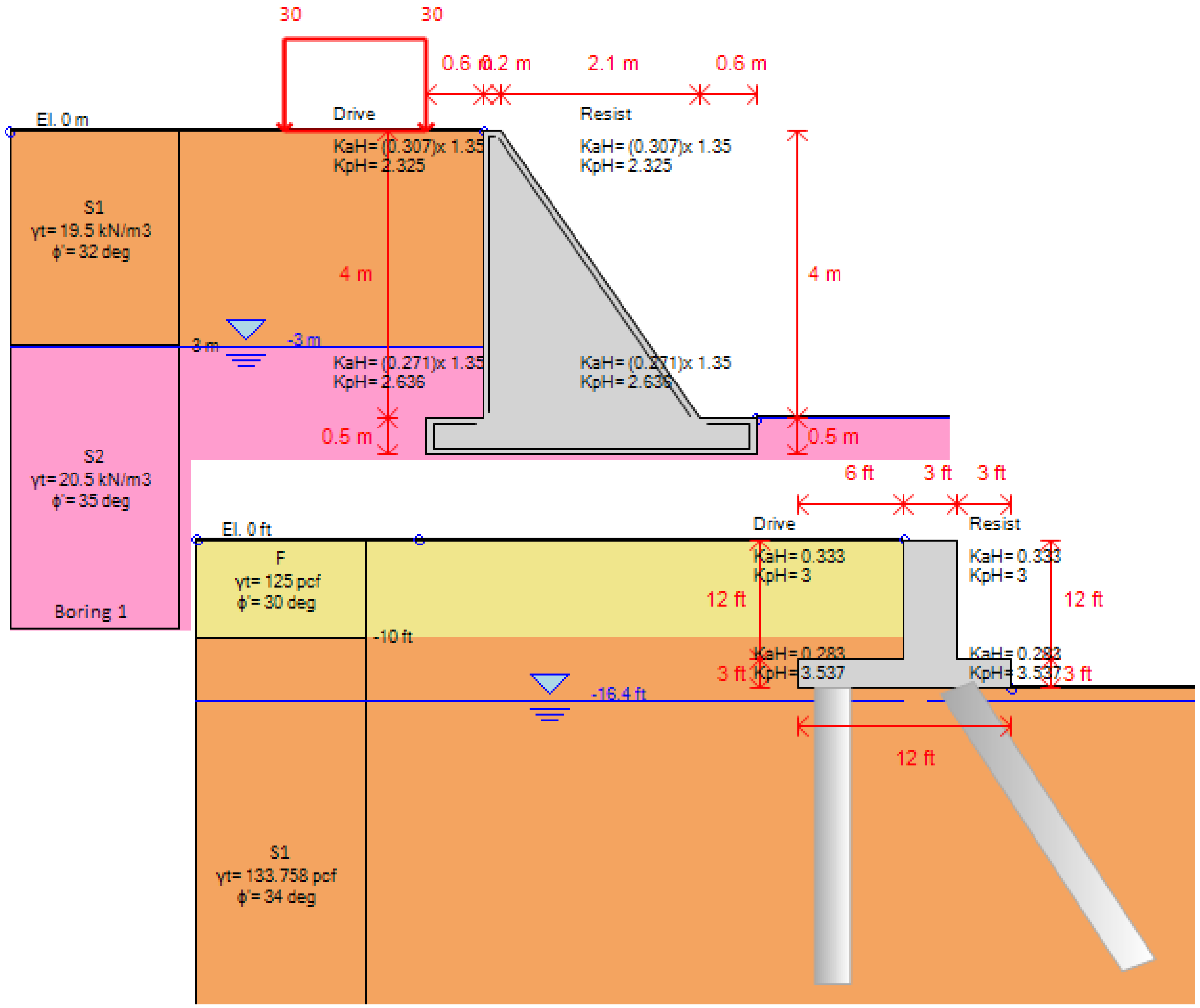
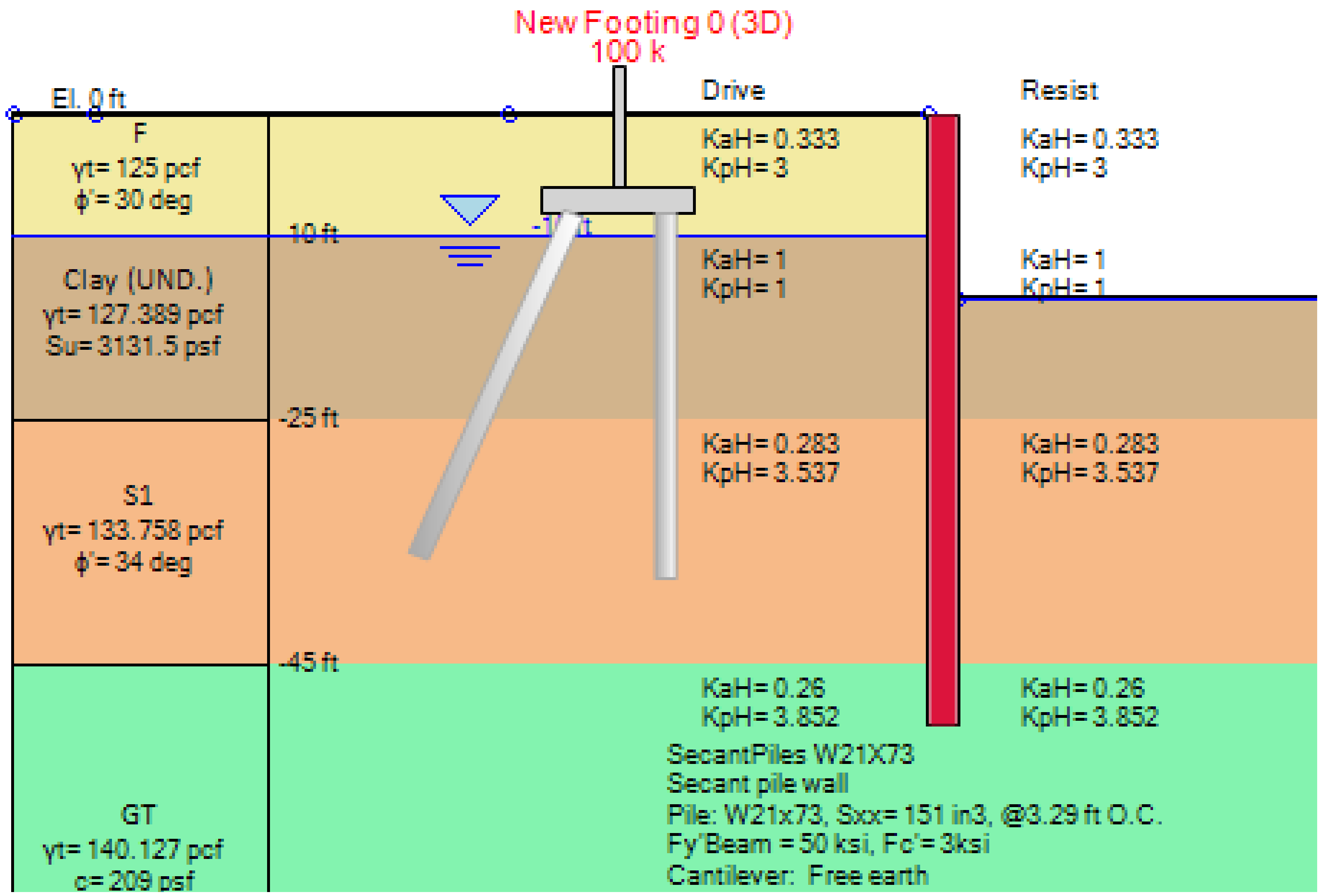
Gravity Walls & Pile Abutments

- ✓ Design gravity walls (any shape)
- ✓ Design pile supported abutments
- ✓ Use footings (3D loads) and design the foundation piles





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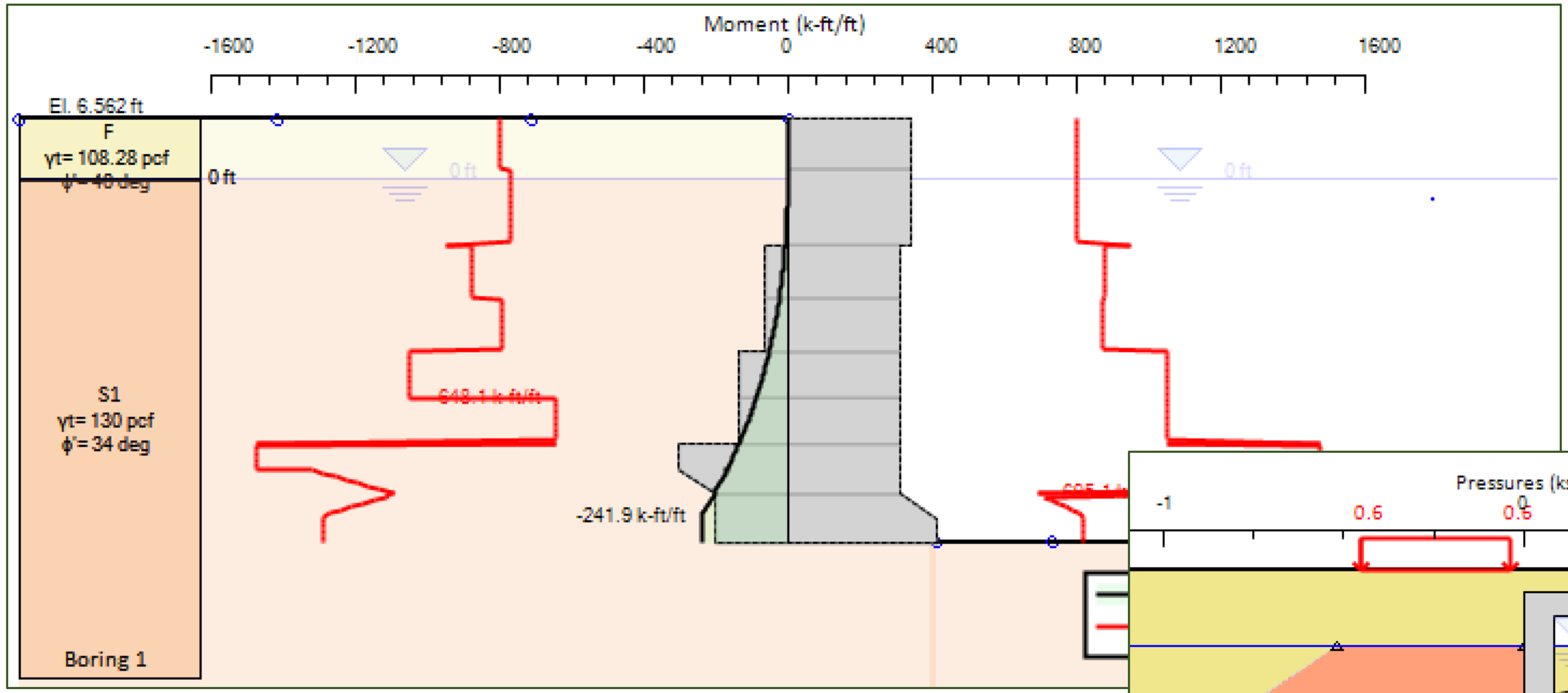
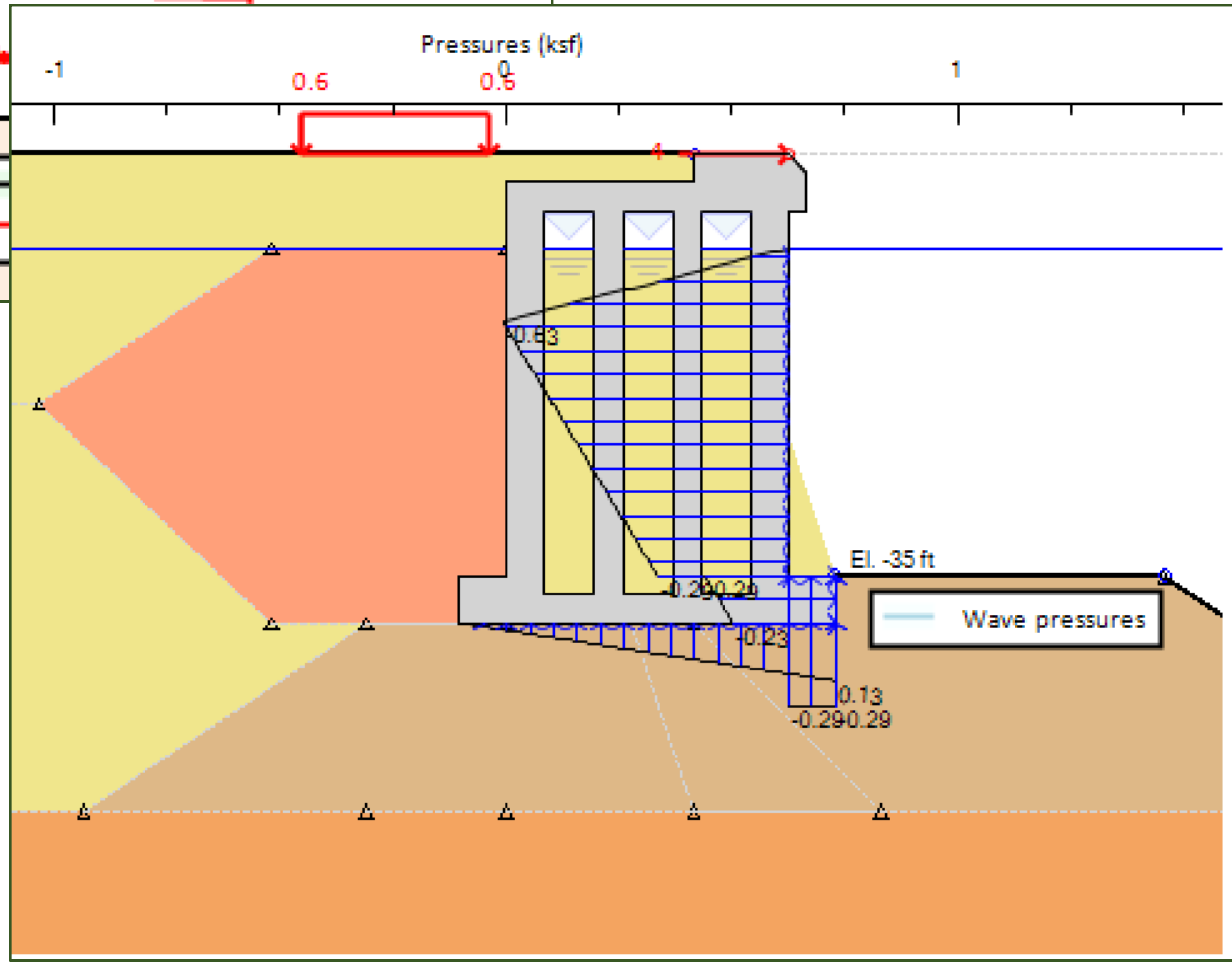
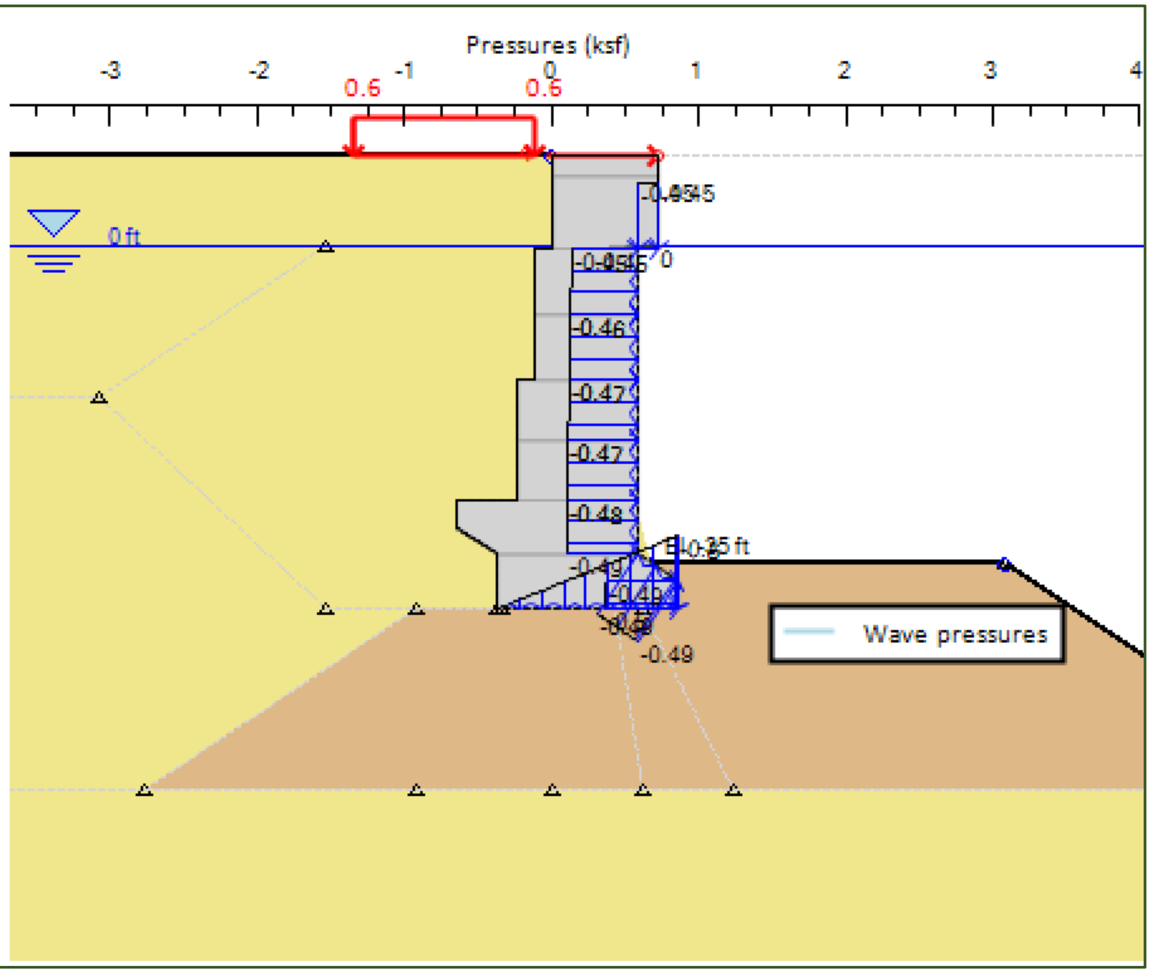
Sea Walls - Quay Walls - Wave Pressures

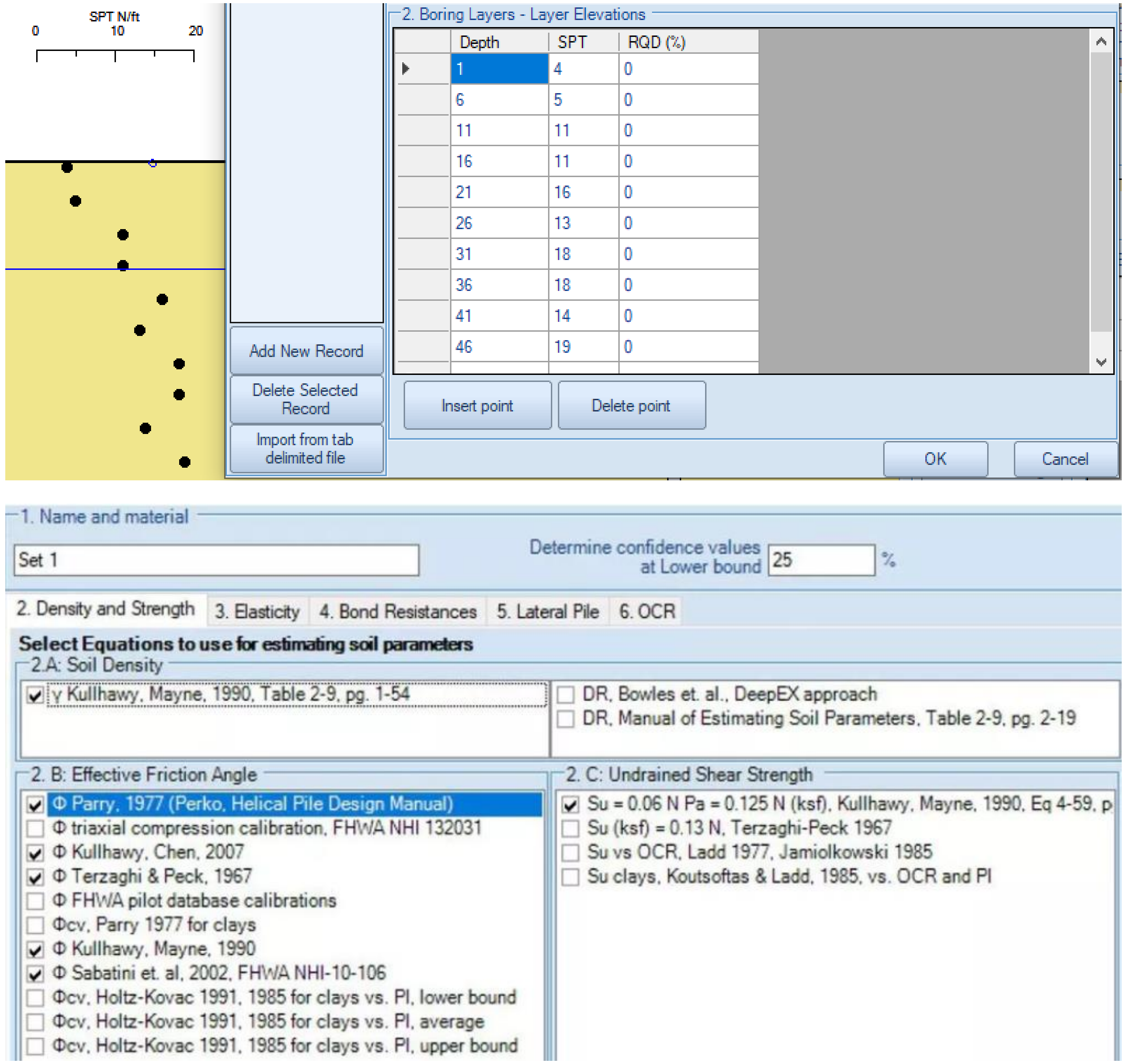
- ✓ Load combinations for British Standards 6349 Parts 1-2 (Marine Structures-Quay Walls)
- ✓ Wave pressures with Sainflou, McConnel, Proverbs
- ✓ Average overtopping volume calculations
- ✓ Block/segmental walls with individual shear resistances and densities
- ✓ Quay caisson walls (3D) with infill zones. The program can calculate the 3D weight
- ✓ Quay wall wizard - Create a model in minutes



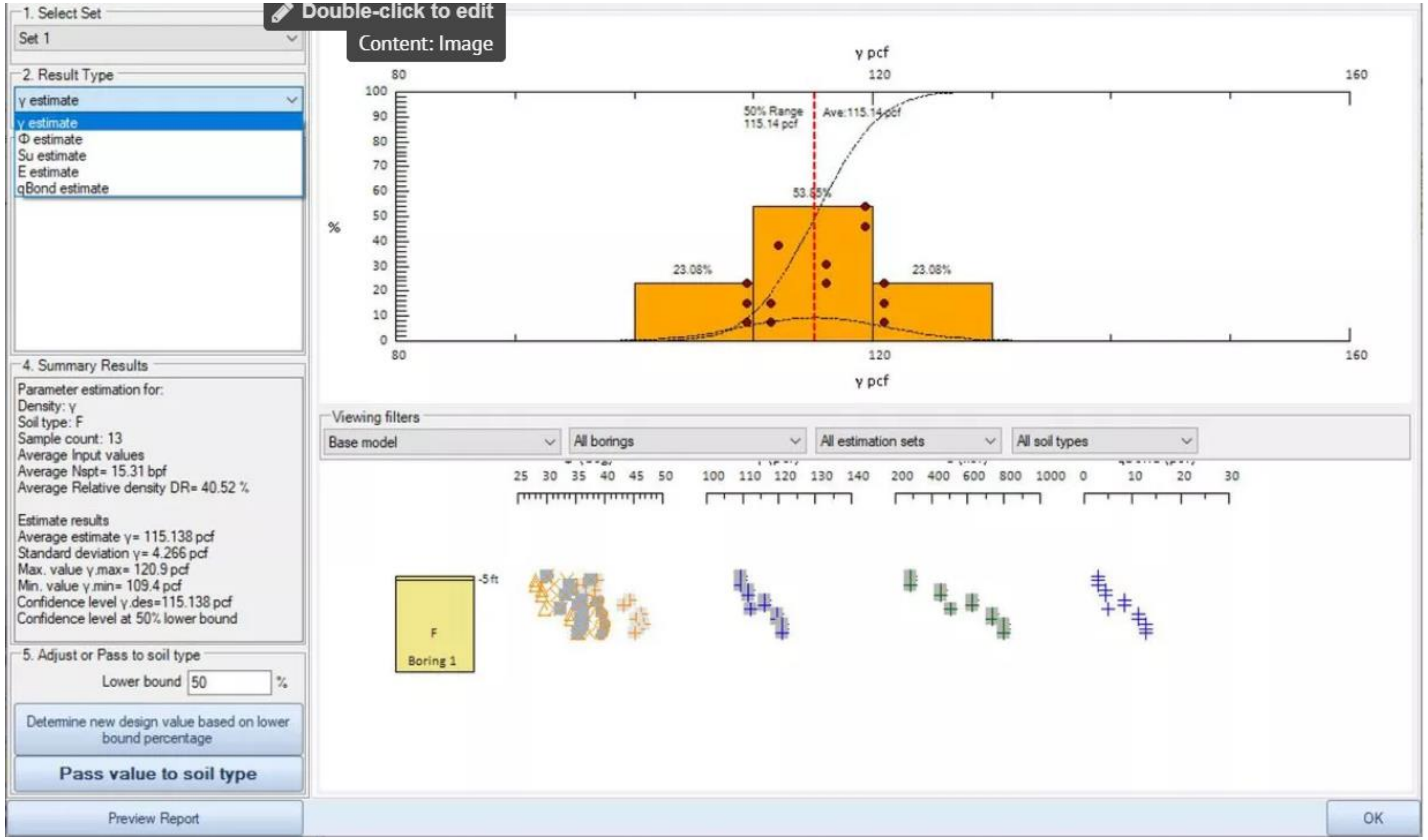




Soil Estimation - Statistical Analysis



- ✓ Estimate Soil Properties with different methods
- ✓ Review a statistical analysis of the estimated properties
- ✓ Select the project values with a high level of certainty



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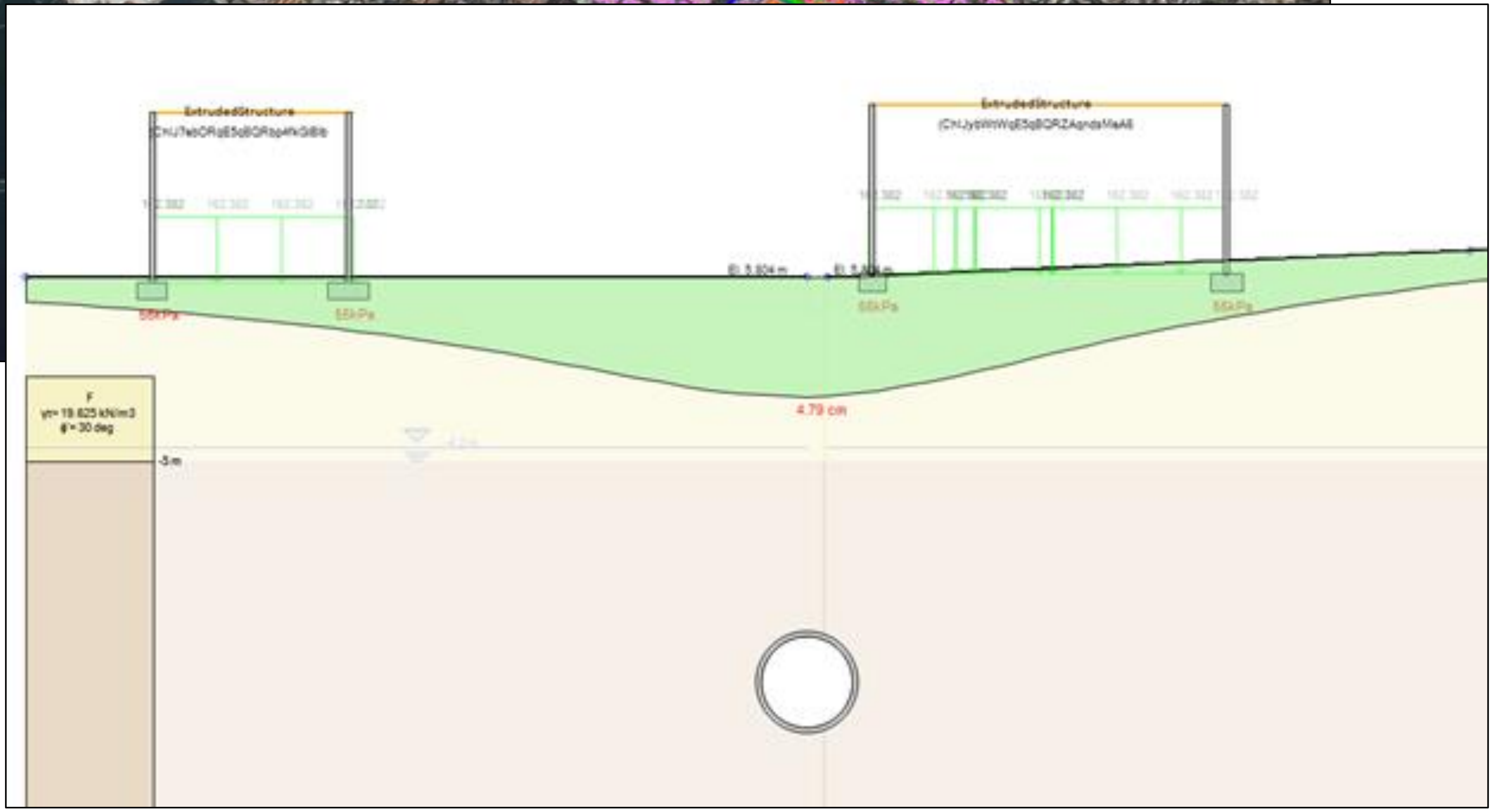
Citywide Tunnels Damage Assessment

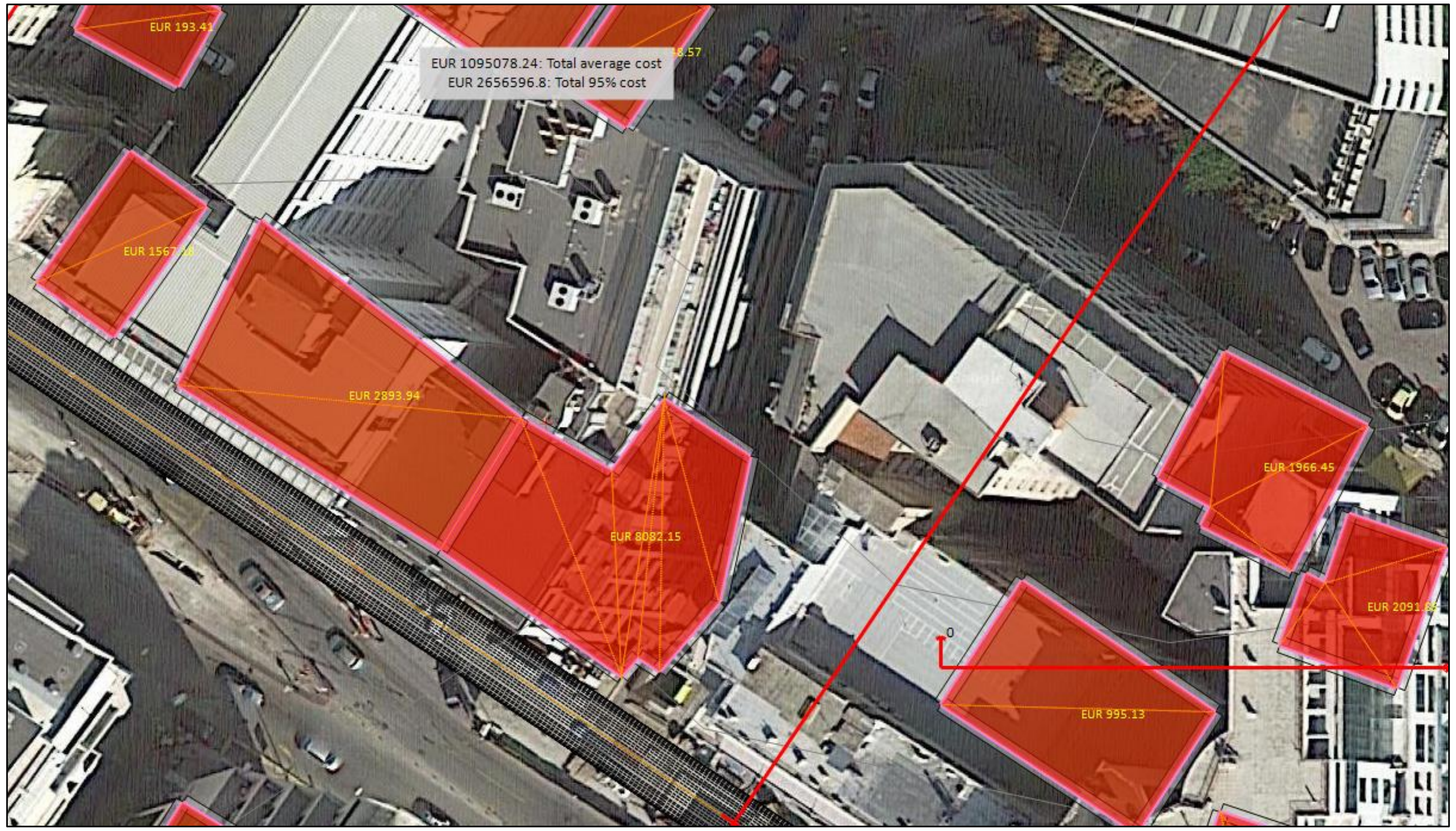
www.deepexcavation.com

The Future is Here!

- ✓ Import your City Map with all Structures from Google
- ✓ Define your Tunnel Construction Stages and Location on the Map
- ✓ Automatically Generate 2D Cut Sections along your Tunnel
- ✓ Define your Metro Station Locations on the Map and Design Them
- ✓ Analyze the Tunnel, Calculate Settlements considering Soil Volume Loss, Consolidation and Water Drawdown
- ✓ Estimate the Damage Cost for all Imported Buildings

And more!





Projects Designed with DeepEX

Sweet Home Alabama! Uncommon Auburn

Courtesy of Russo Construction

Southbank Soil Nail Wall, Tempe AZ

PB&A + Deep Excavation

Secant Pile Wall For Maspeth Avenue Station, NY

Courtesy of Skanska

Javits Center Expansion, NY

EE Cruz + Deep Excavation

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10000+ Projects Worldwide!

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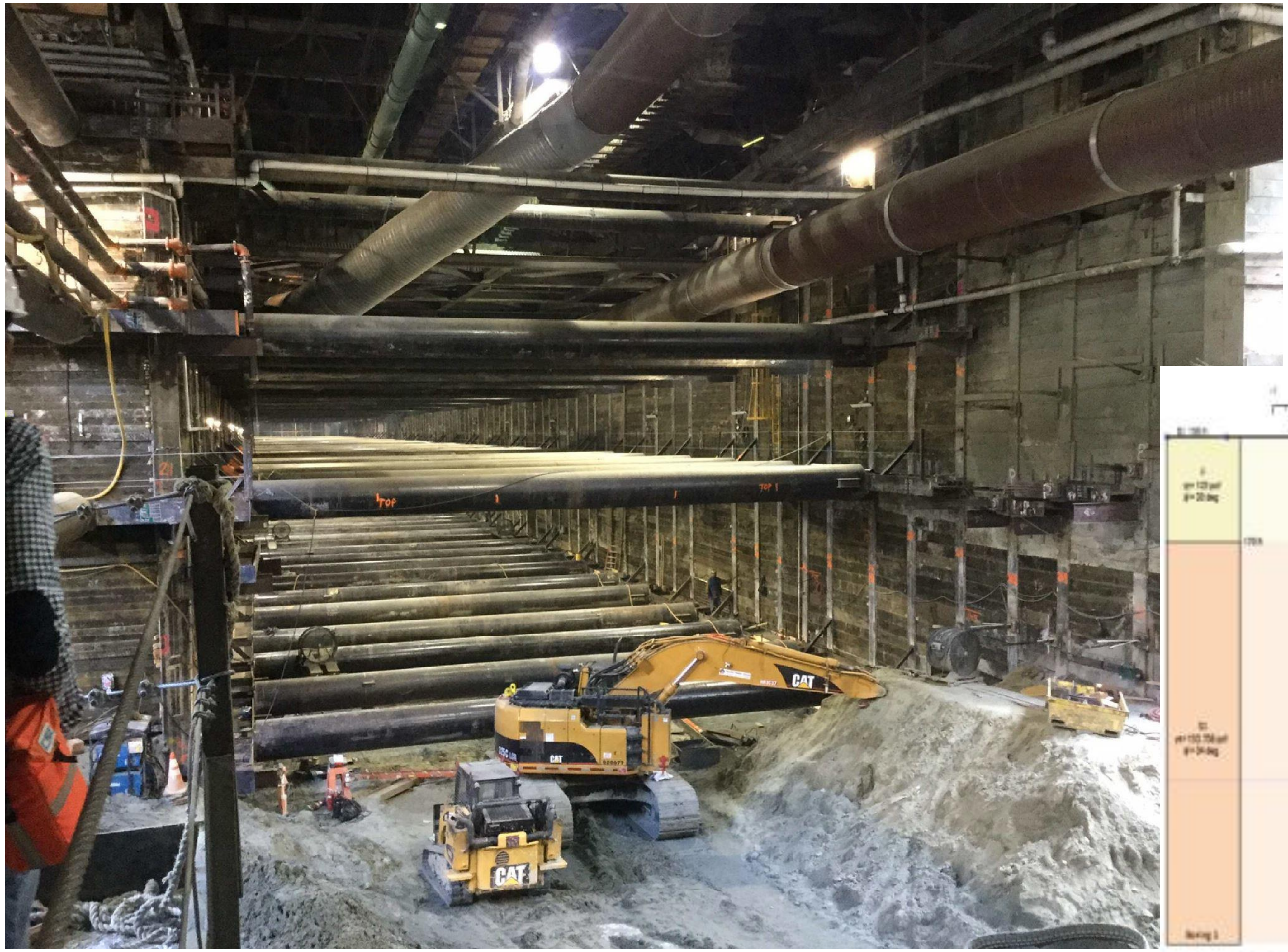
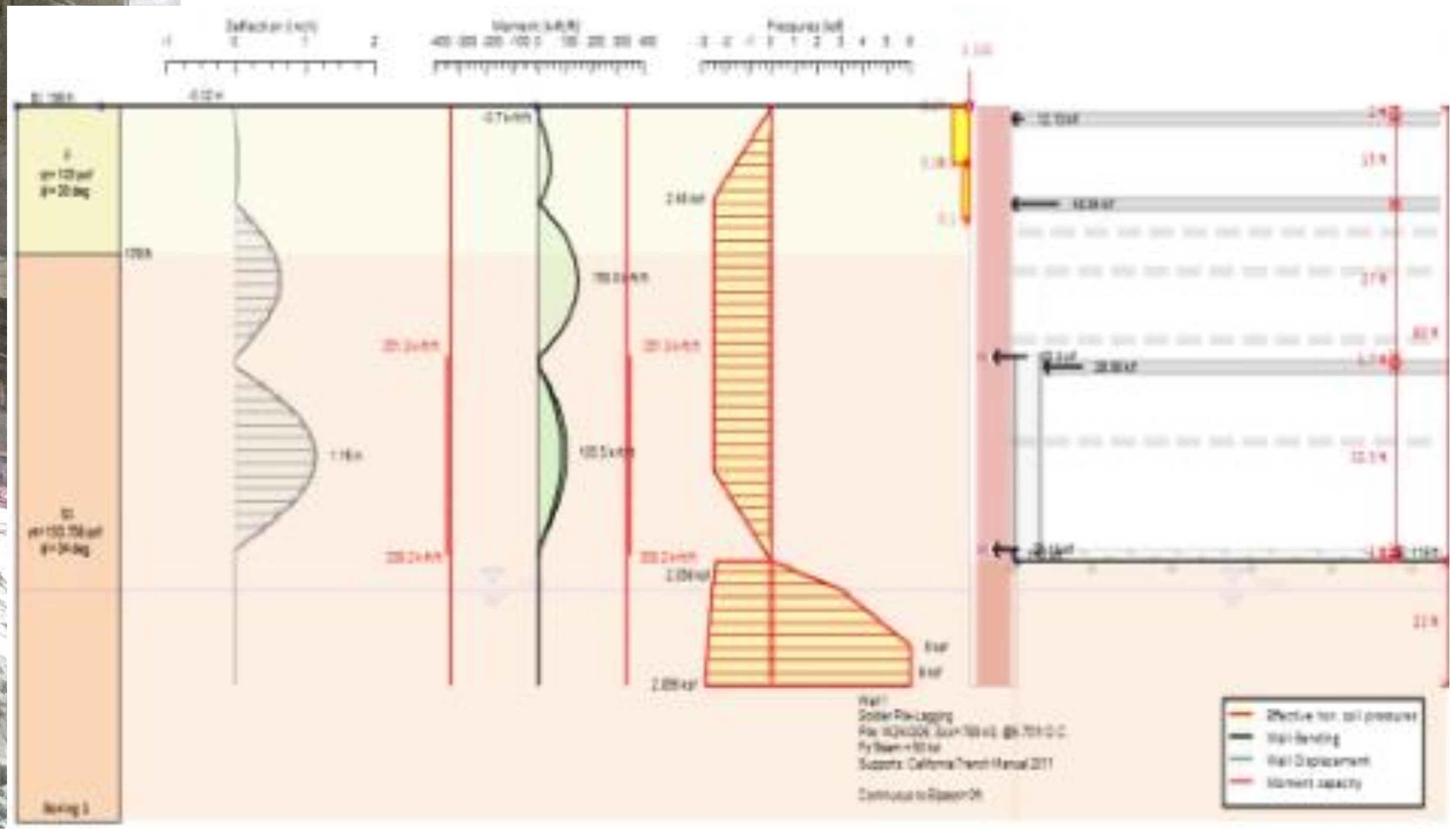
Review Project Gallery

Sample DeepEX Projects

LaBrea Metro Station, Los Angeles, California, USA

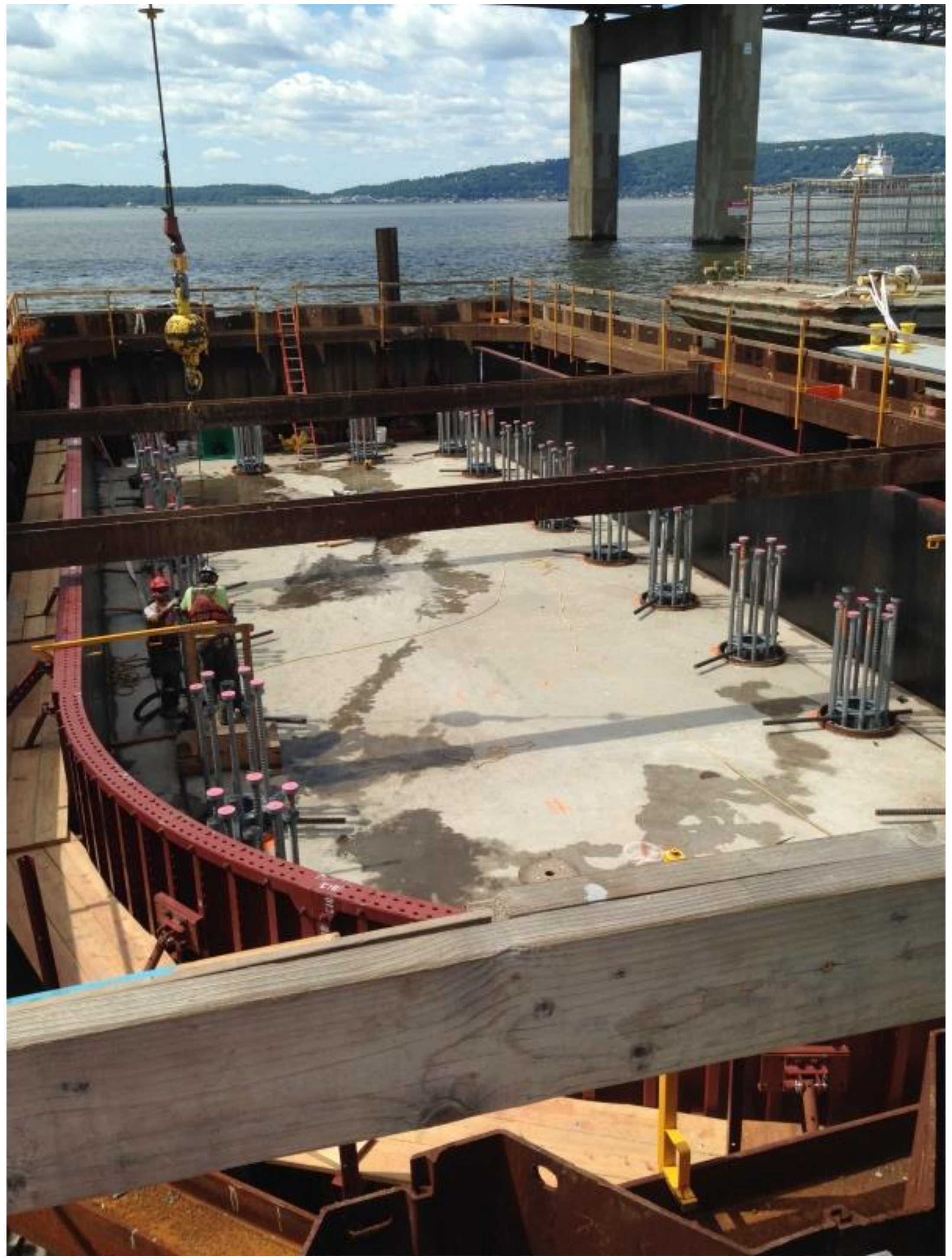


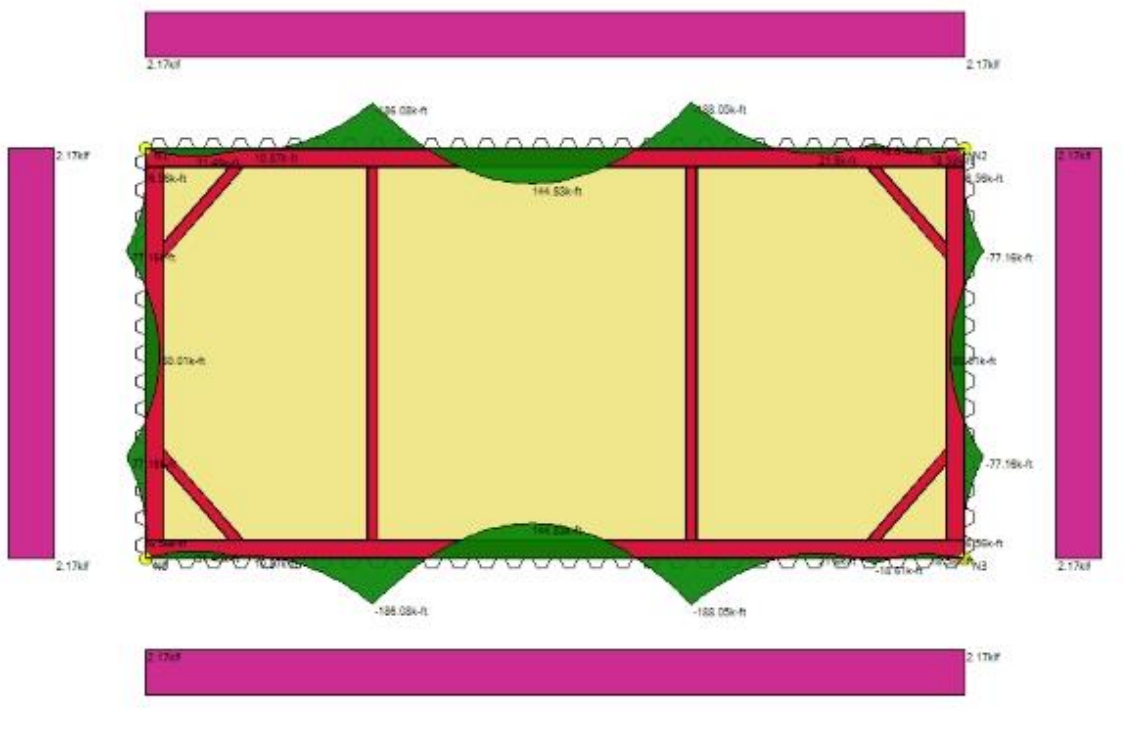


- ✓ 100 ft (30.5 m) Excavation
- ✓ Soldier Piles and Lagging
- ✓ Lateral Bracing (Struts)
- ✓ Full Design with DeepEX
- ✓ 5 Stations designed and under construction

Sample DeepEX Projects

New Tapan Zee Bridge Cofferdams, New York, USA





- ✓ $3.9 billion project
- ✓ 90x45ft (27.5x13.7m) Cofferdams
- ✓ Lateral Bracing (Struts)
- ✓ Full Design with DeepEX

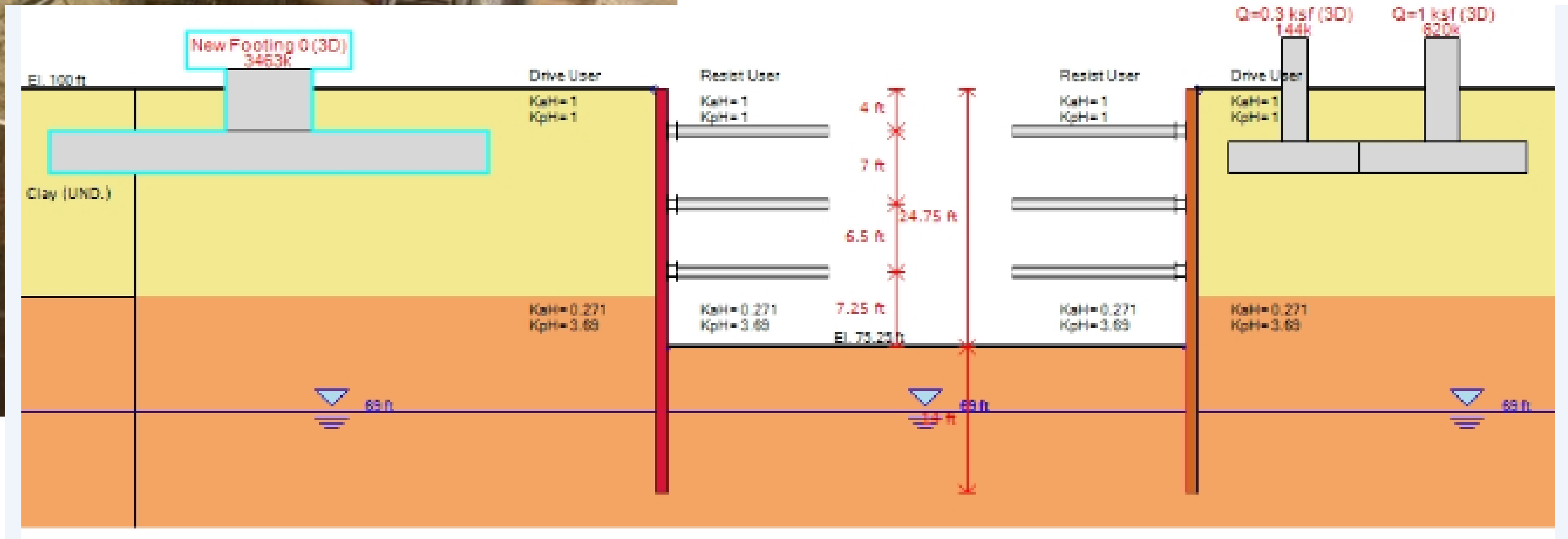
Sample DeepEX Projects

Soldier Pile Excavation Pits with Diagonal Struts and Tiebacks, Arkansas, USA

- ✓ 90 ft (27.5m) Excavation
- ✓ Soldier Piles and Lagging
- ✓ Pipe Struts
- ✓ 9 rows of Tiebacks

Sample DeepEX Projects

Soldier Pile Excavation Pits with Diagonal Struts, Arkansas, USA



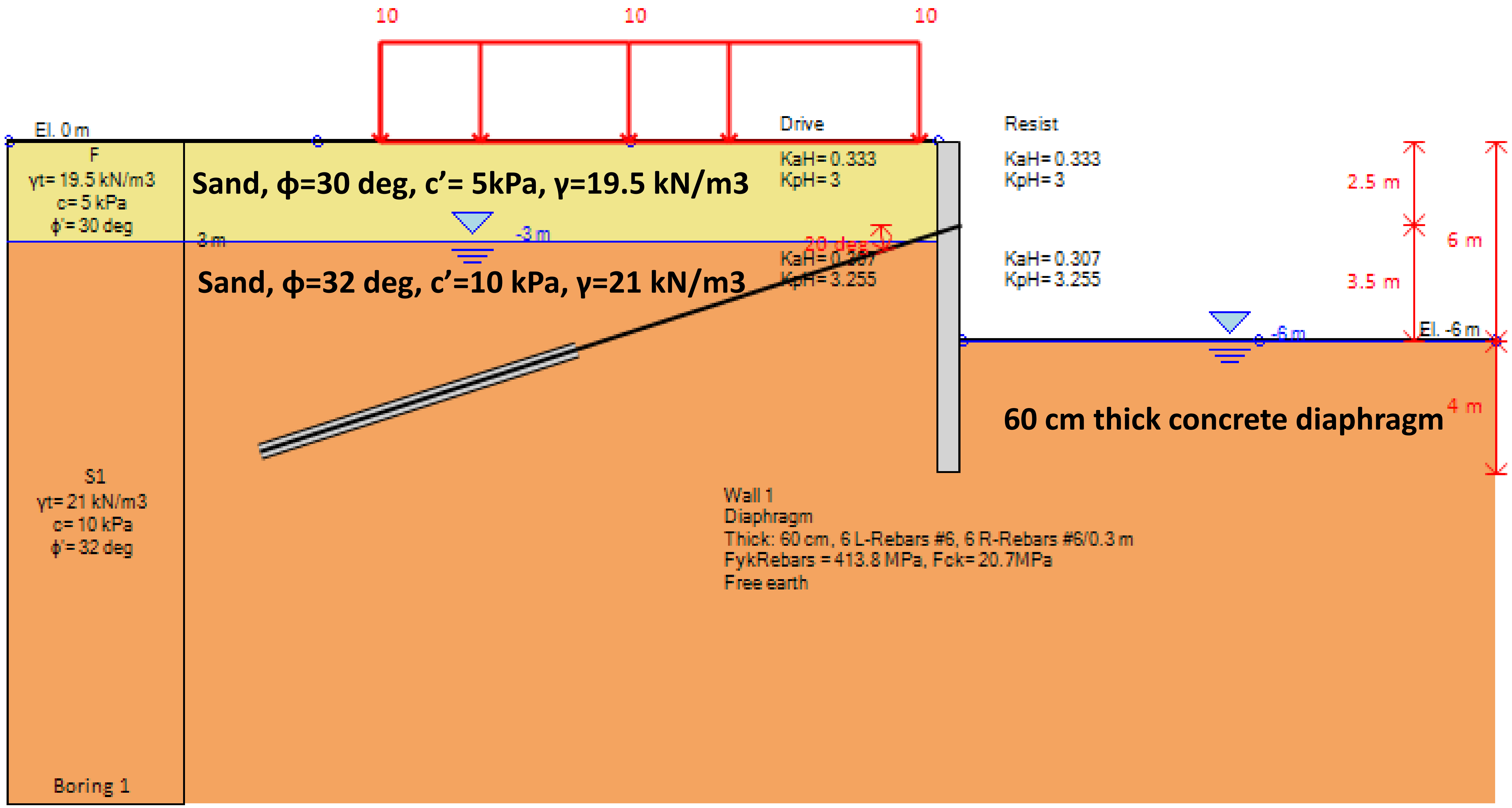
- ✓ 24 ft (7.3m) Excavation
- ✓ Soldier Piles and Lagging
- ✓ Pipe Struts
- ✓ Full Design with DeepEX

Sample DeepEX Projects

All American Canal, Imperial Irrigation District, Yuma, Arizona

- ✓ Cofferdam
- ✓ Water Wall Design
- ✓ Water Depth up to 20’ (6m)
- ✓ Sheet Pile System
- ✓ Post Tension cable Ties
- ✓ Full Design with DeepEX

Example: A 6m Excavation - Anchored Diaphragm Wall

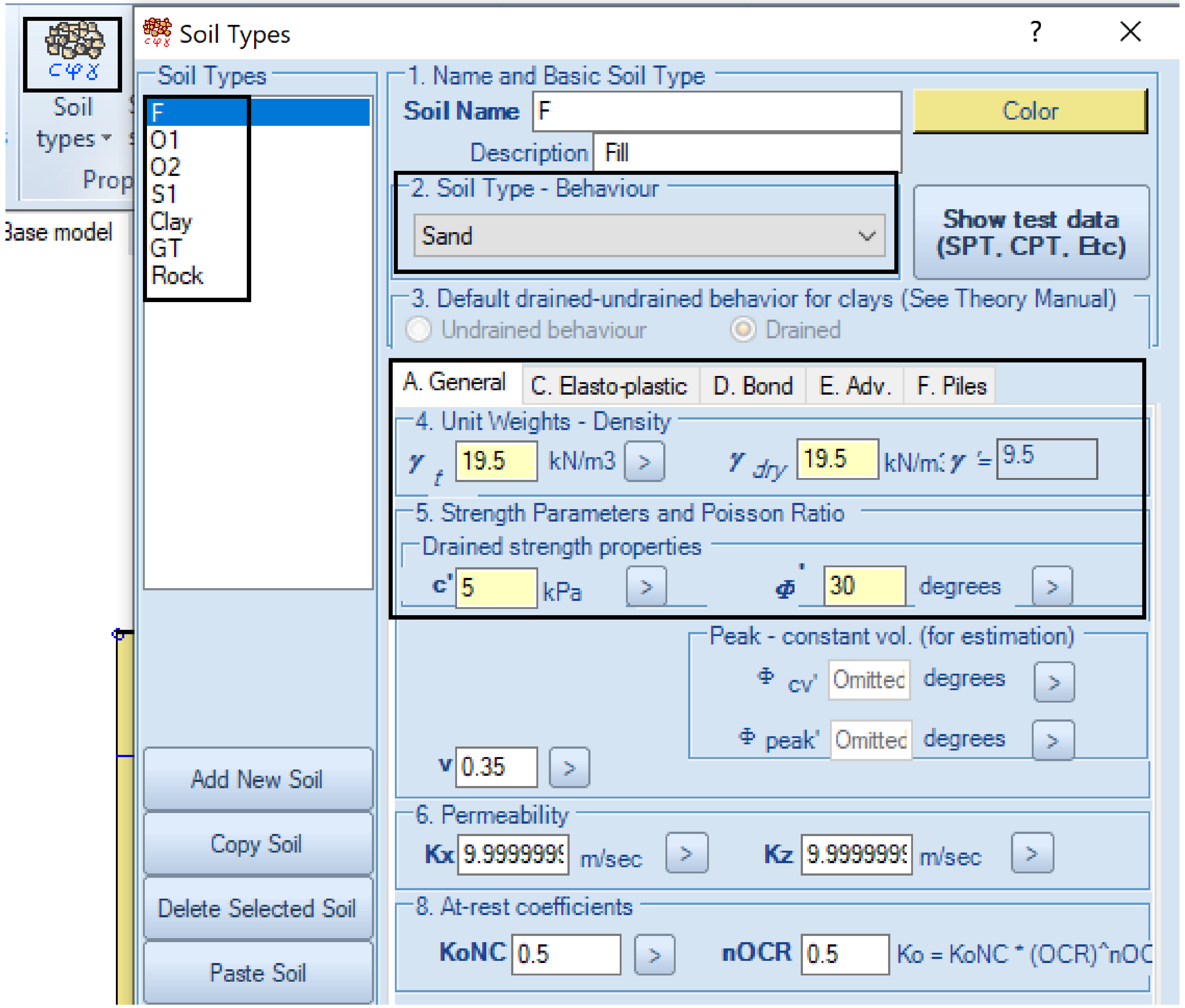


- ✓ Create model in DeepEX (all stages)
- ✓ Apply Eurocode 7 Specifications
- ✓ Run model with Limit Equilibrium Method
- ✓ Run model with Non-Linear Analysis Method
- ✓ Run model with Finite Element Analysis Method

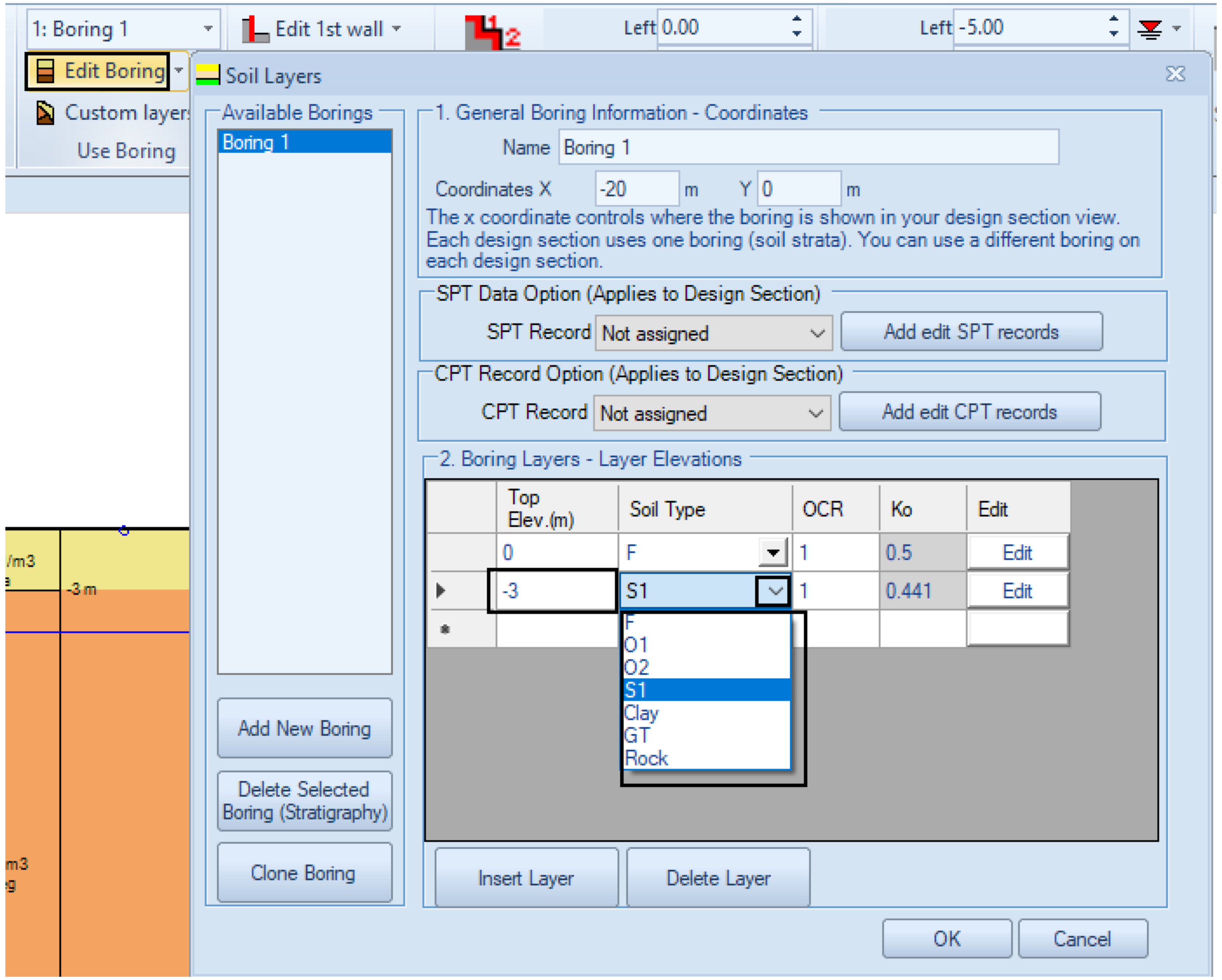
- ✓ Review calculated results
- ✓ Optimize wall section
- ✓ Optimize support section
- ✓ Optimize anchor fixed length
- ✓ Optimize wall embedment

DeepEX
Shoring Design Software

Define Soil Properties & Stratigraphy



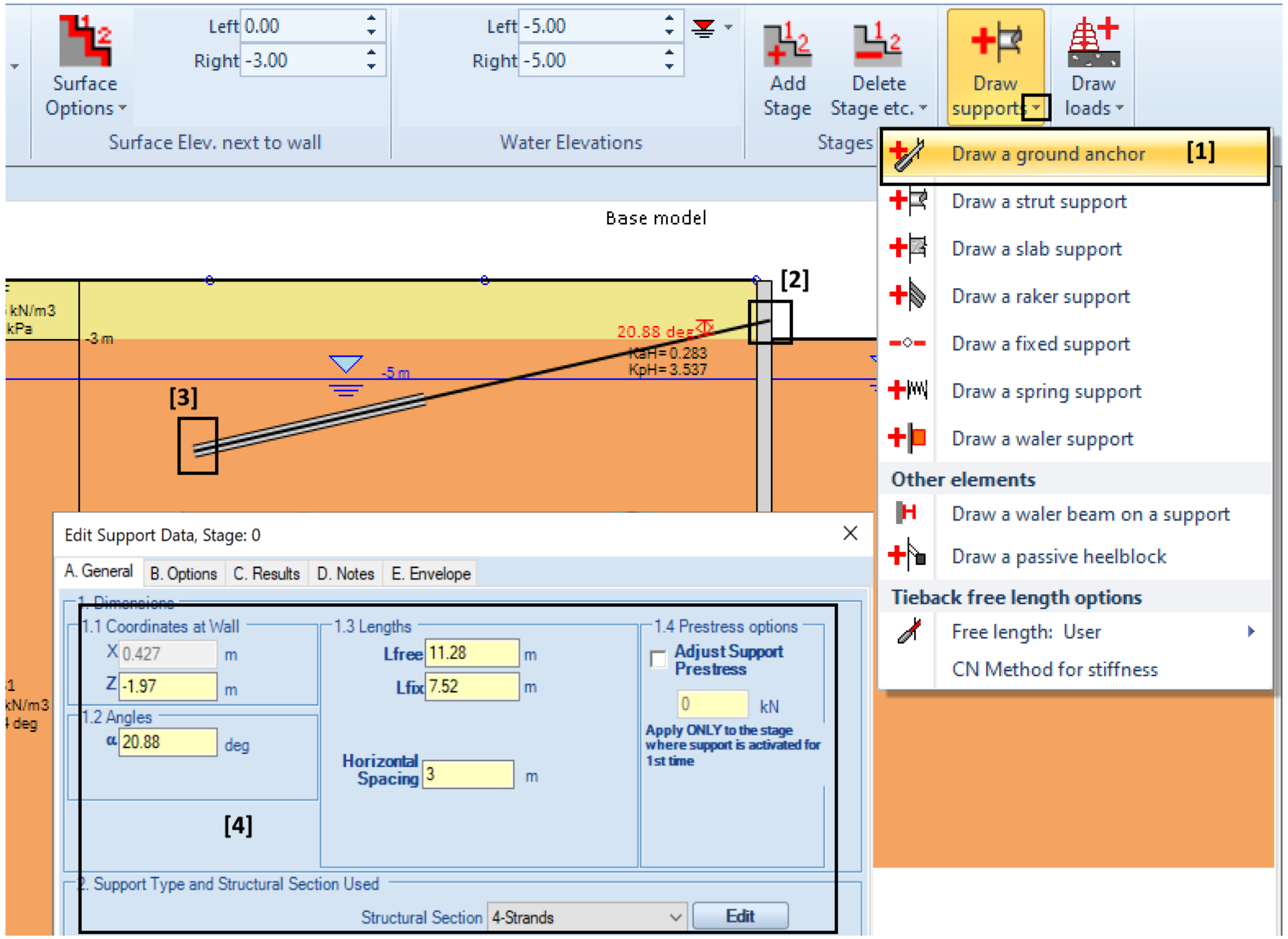
- Edit List of Soils
- Define Soil Properties for each soil



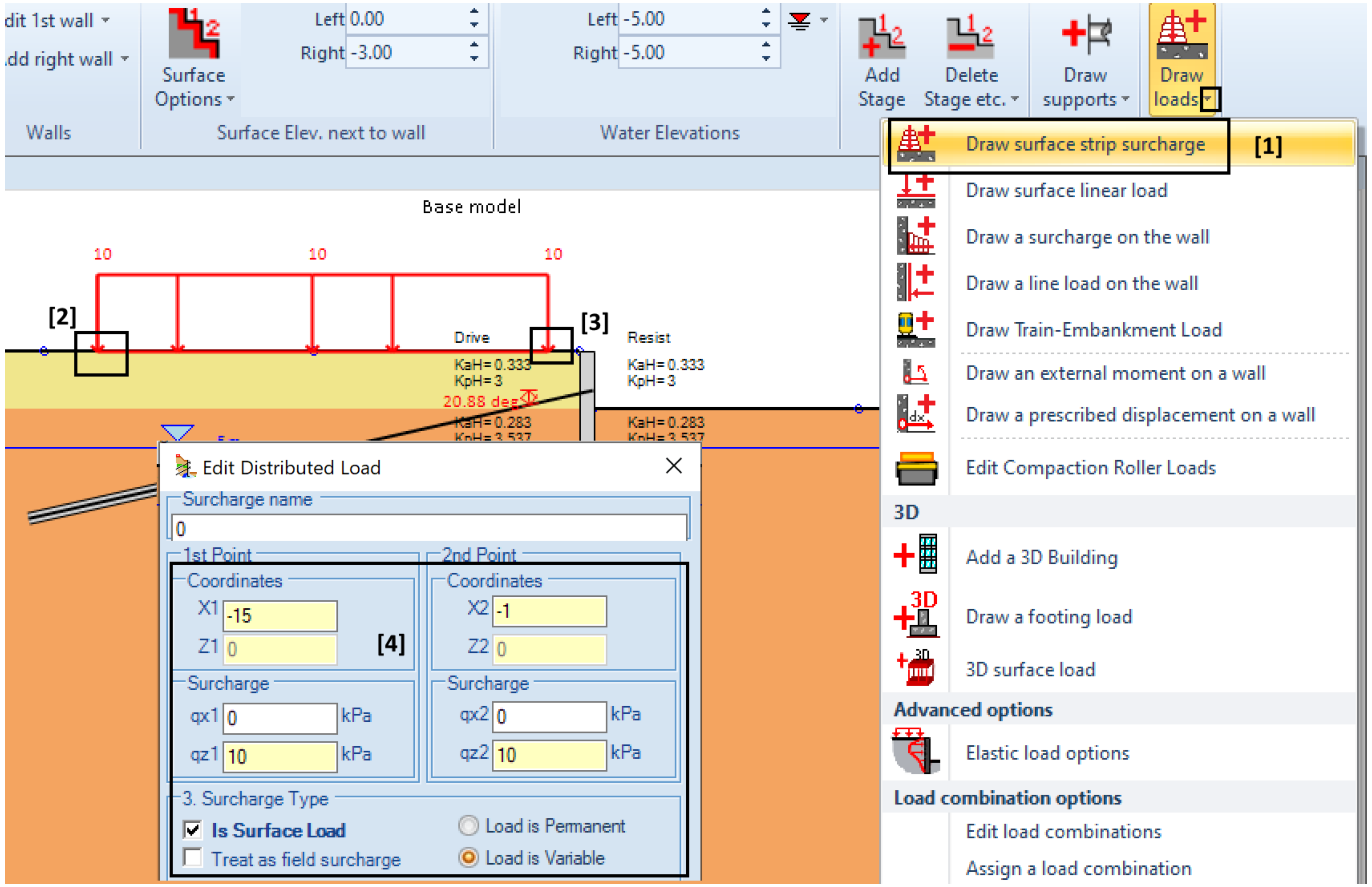
- Add Soil Layers
- Define Top Layer Elevation and Soil Type

DeepEX
Shoring Design Software

Add Supports & Loads Graphically

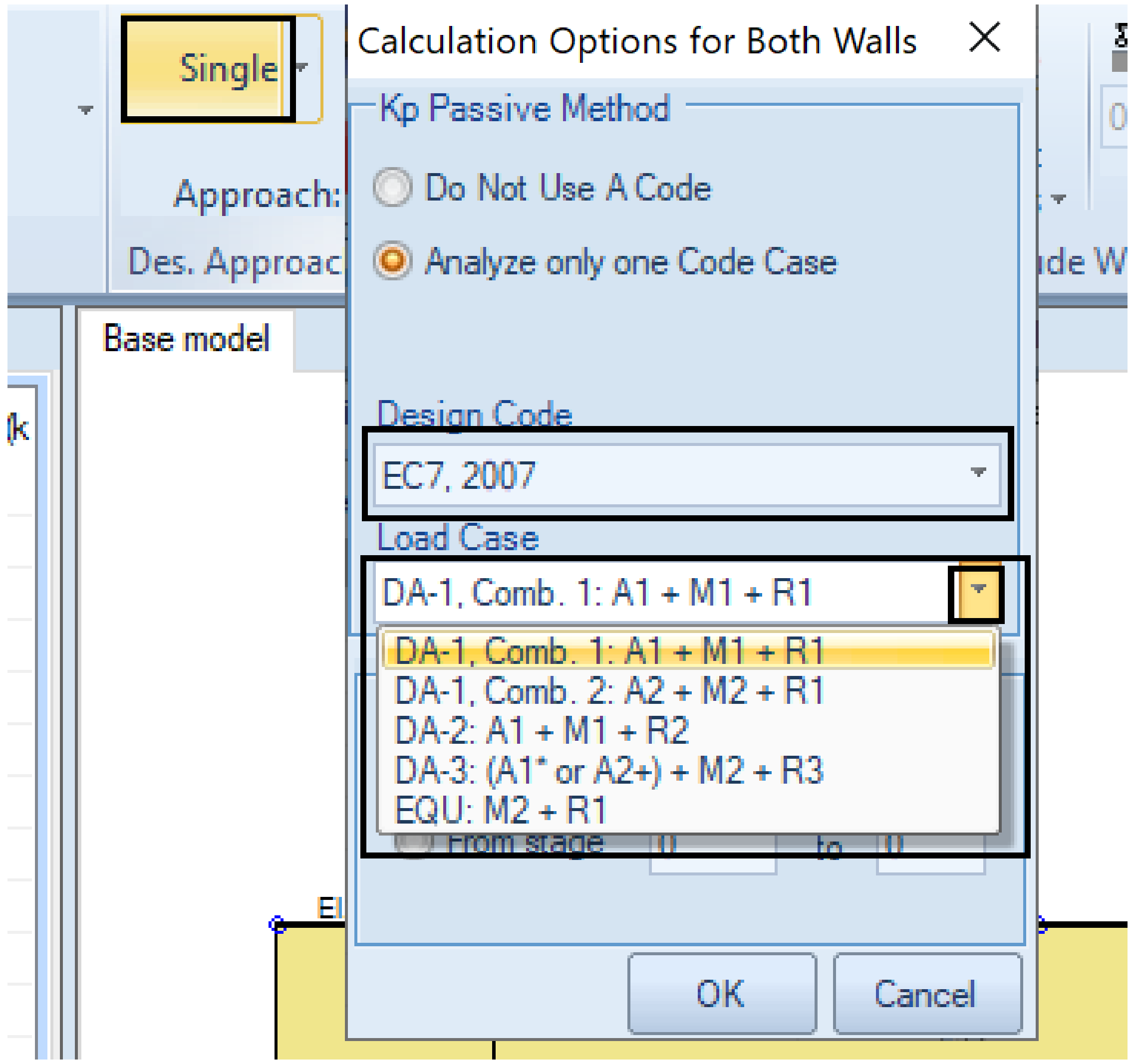


1. Select the Draw Support Tool
2. Click on the Wall
3. Click to the Ground
4. Define exact Support Location, Dimensions and Structural Section



1. Select the Draw Loads Tool
2. Click on the Ground (Start Load Point - Left)
3. Click to the Ground (End Load Point - Right)
4. Define exact Load Location, Type and Magnitude

Eurocode 7 Load Combinations



EC 7, DA-1, Comb.1

Code	EC7, 2007
Case	DA-1, Comb. 1: A1 + M1 + R1
Parameter	Safety Factor
Seismic multiplier	0
Variable loads	1.5
Permanent loads	1.35
Temporary anchors	1.1
Permanent anchors	1.1
tan(friction angle)	1
Eff. cohesion c'	1
Shear strength Su	1
Earth unfavorable	1.35 (STR)
Earth favorable	1
Water unfavorable	1.35
Water favorable	1
HYDraulic unfavorable	1.35
HYDraulic favorable	0.9
UPLift unfavorable	1.1
UPLift favorable	0.9
Used FS wall STR	1

EC 7 (GR), DA-2

Code	EC7-Greece
Case	DA-2*: A1 + M1 + R2
Parameter	Safety Factor
Seismic multiplier	0
Variable loads	1.5
Permanent loads	1.35
Temporary anchors	1.1
Permanent anchors	1.1
tan(friction angle)	1
Eff. cohesion c'	1
Shear strength Su	1
Earth unfavorable	1.35 (STR)
Earth favorable	1.4 (GEO)
Water unfavorable	1.35
Water favorable	1
HYDraulic unfavorable	1.35
HYDraulic favorable	0.9
UPLift unfavorable	1.1
UPLift favorable	0.9
Used FS wall STR	1

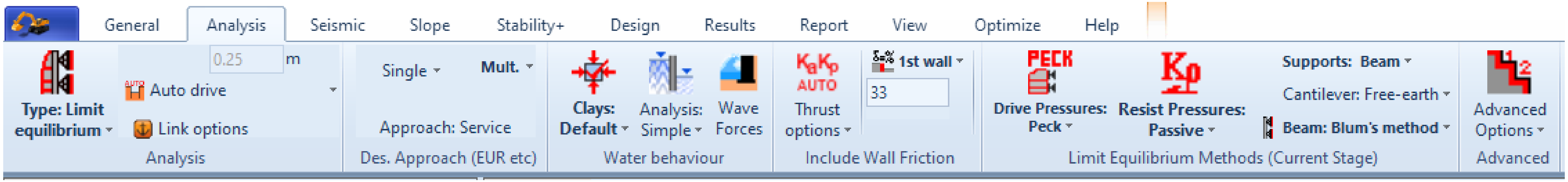
EC 7 (GR), EQU

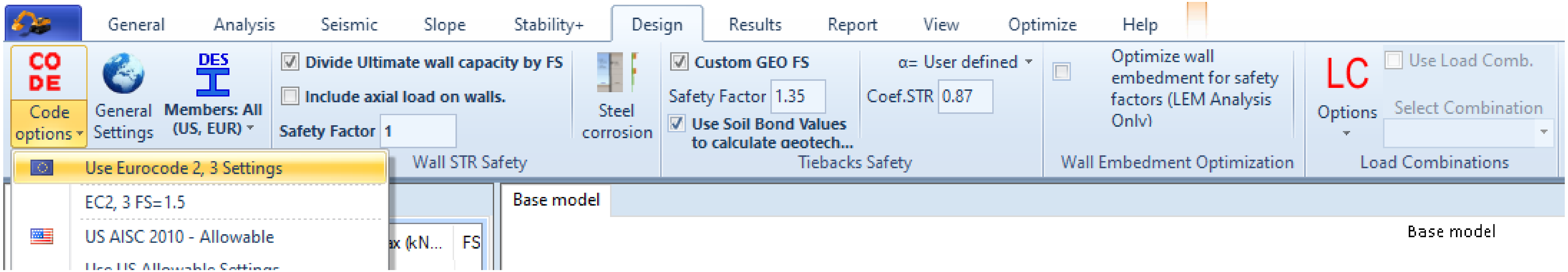
Code	EC7-Greece
Case	EQU: M1 + R1 (GR)
Parameter	Safety Factor
Seismic multiplier	1
Variable loads	1
Permanent loads	1
Temporary anchors	1.1
Permanent anchors	1.1
tan(friction angle)	1
Eff. cohesion c'	1
Shear strength Su	1
Earth unfavorable	1
Earth favorable	1
Water unfavorable	1
Water favorable	1
HYDraulic unfavorable	1
HYDraulic favorable	0.9
UPLift unfavorable	1.1
UPLift favorable	0.9
Used FS wall STR	1
FS tiebacks	1x R_anchor

Eurocode 7 Approach

- Select a Load Combination
- Factors on the external loads and soil pressures
- Use a design surface load of 10 kPa
- Target for a wall embedment FS > 1

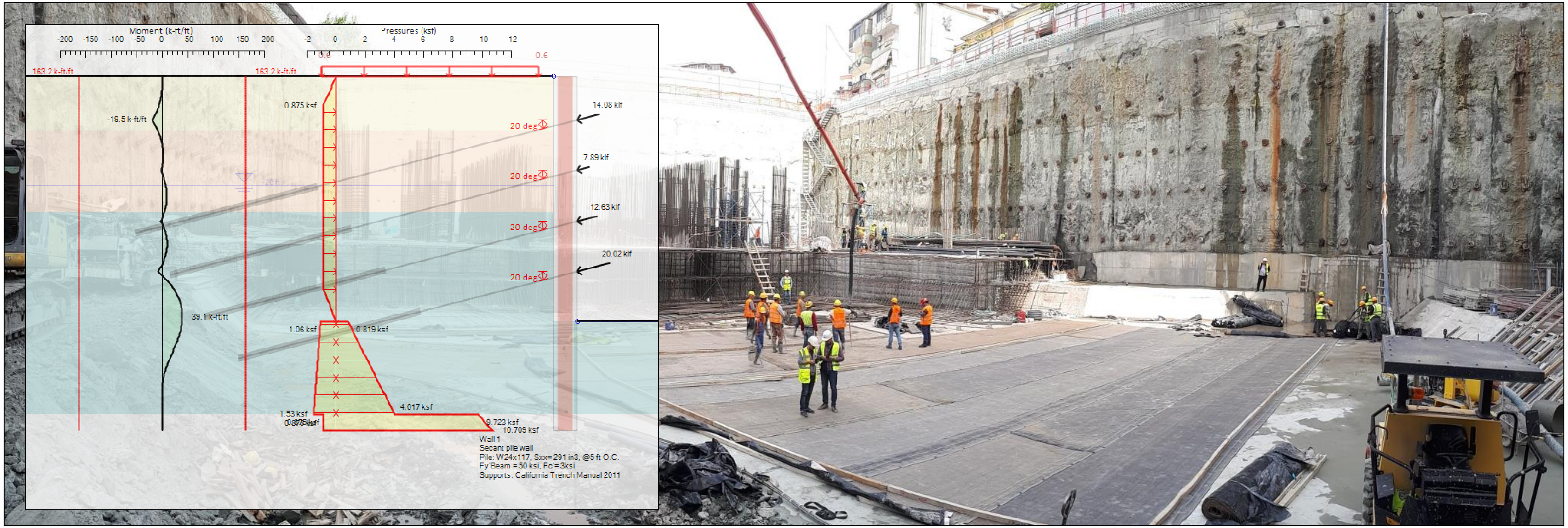
Analysis Settings





- ➢ Use Active pressures for the Cantilever excavation stage and Peck Apparent pressures for all stages with supports
- ➢ Examine Wall Friction (i.e. 33% of Soil Friction)
- ➢ Simplified Water Flow
- ➢ Cantilever Stage: Free Earth method
- ➢ Beam Analysis (stages with supports): Blum's Method
- ➢ Apply Eurocode 2,3 settings (Design Tab)

Theoretical Background & Methods



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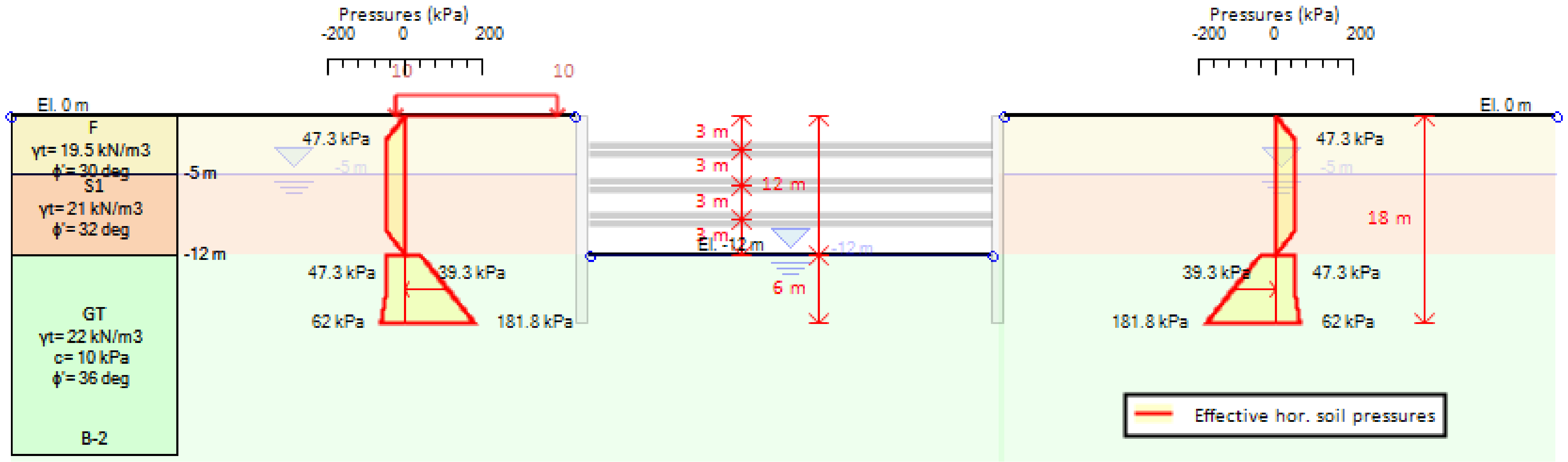
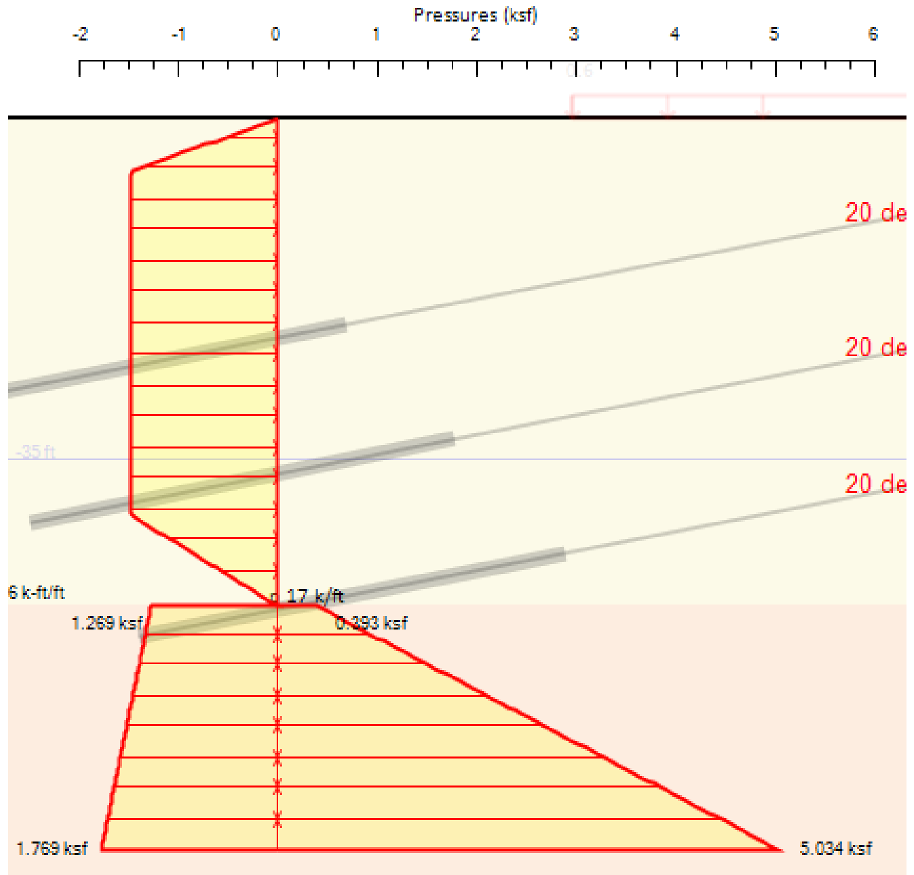
Use of DeepEX - Wall Types & Support Systems

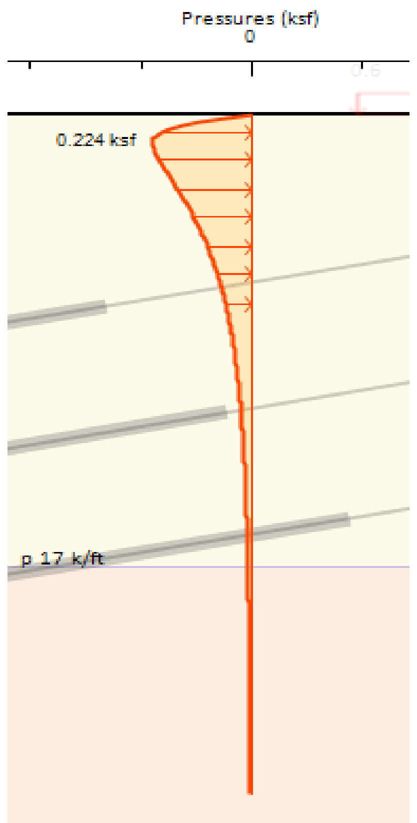
Limit Equilibrium Analysis Concept (LEM)

- ✓ Assume lateral earth pressures.
- ✓ Determine fixity locations for forces at subgrade.
- ✓ Analyze wall beam with assumed loads.
- ✓ Advantages: Easy method to verify. Gives a back check for more rigorous methods.
- ✓ Disadvantages: Soil-structure interaction ignored.

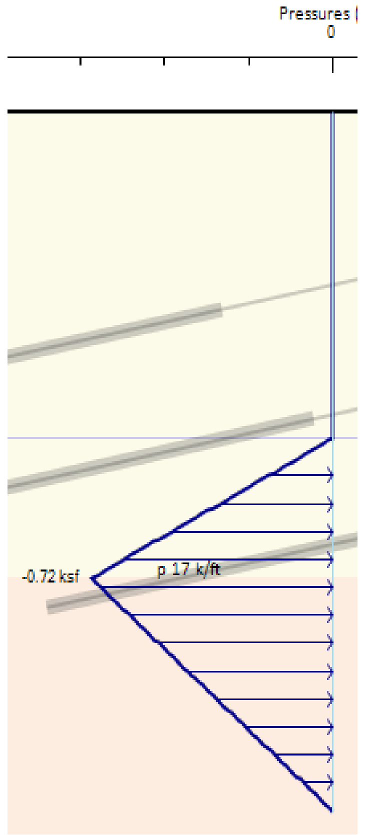




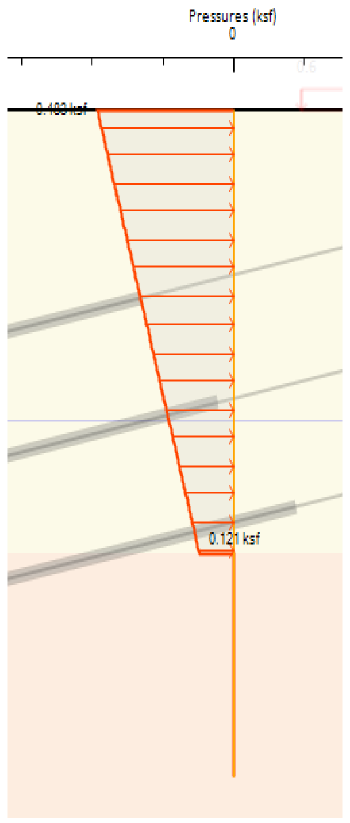
Soil Pressures

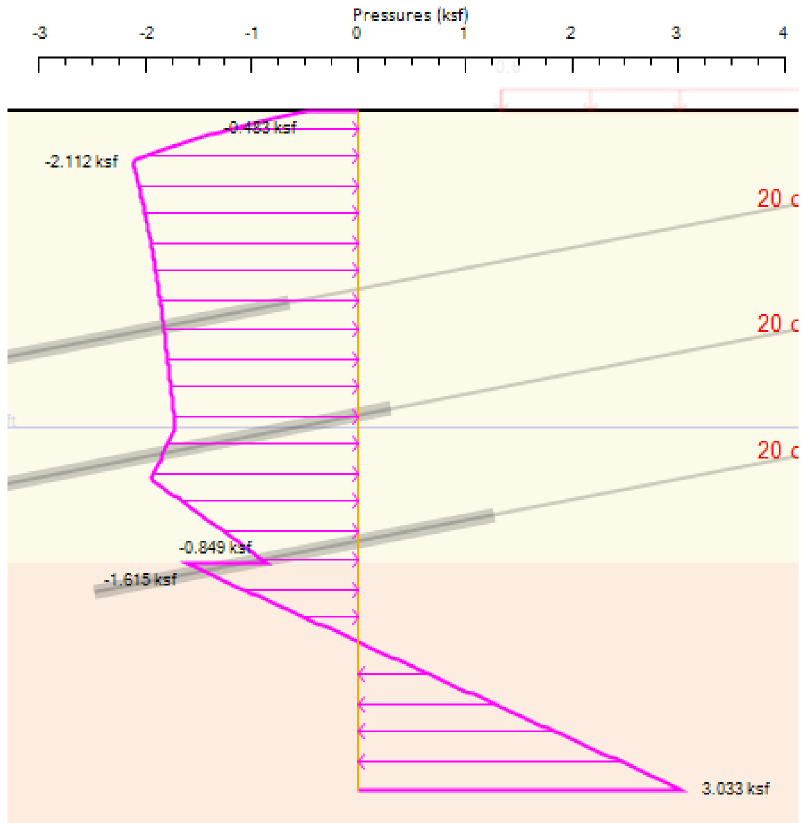


Surcharge



Water Pressures


Seismic Pressures

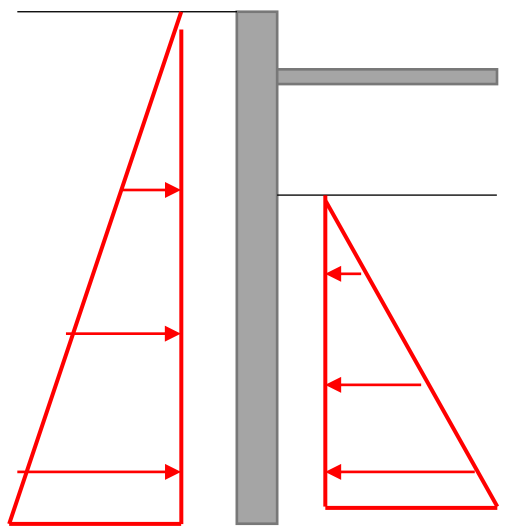


Net Pressures

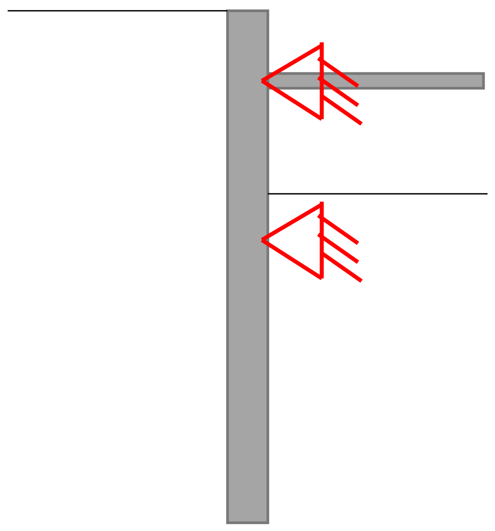
Limit Equilibrium Analysis Concept (LEM)

Limit Equilibrium Method (LEM) :

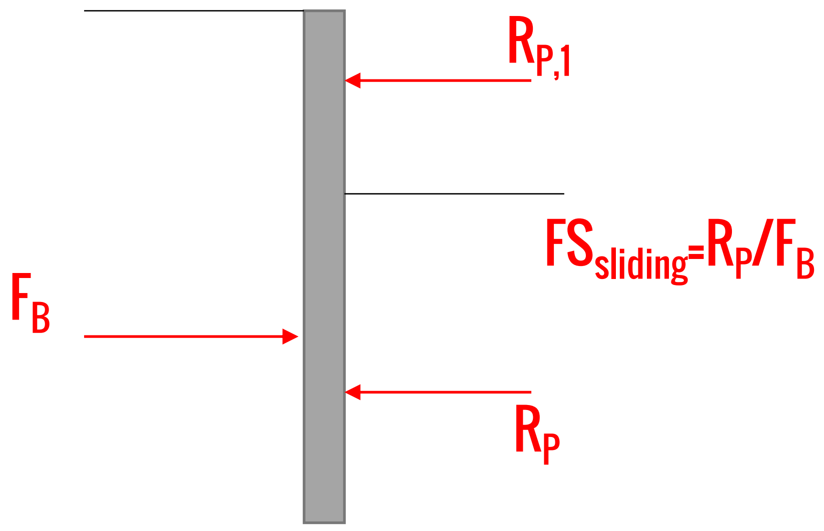
- Easy method to verify. Gives a back check for more rigorous methods.
- pre-failure strain is ignored
- Soil-structure interaction ignored



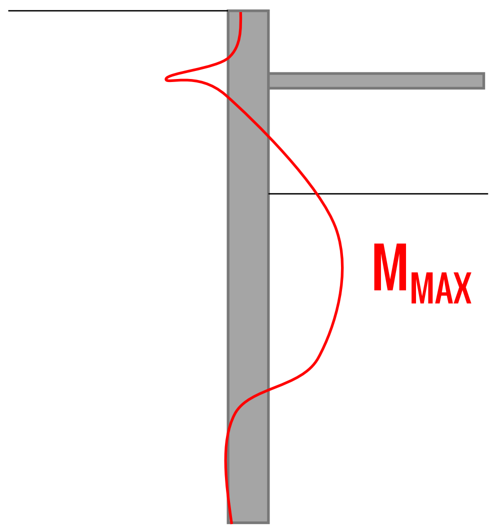
Calculation of lateral earth pressures.



Determine fixity locations and run beam analysis.



Calculate stability checks
on the wall

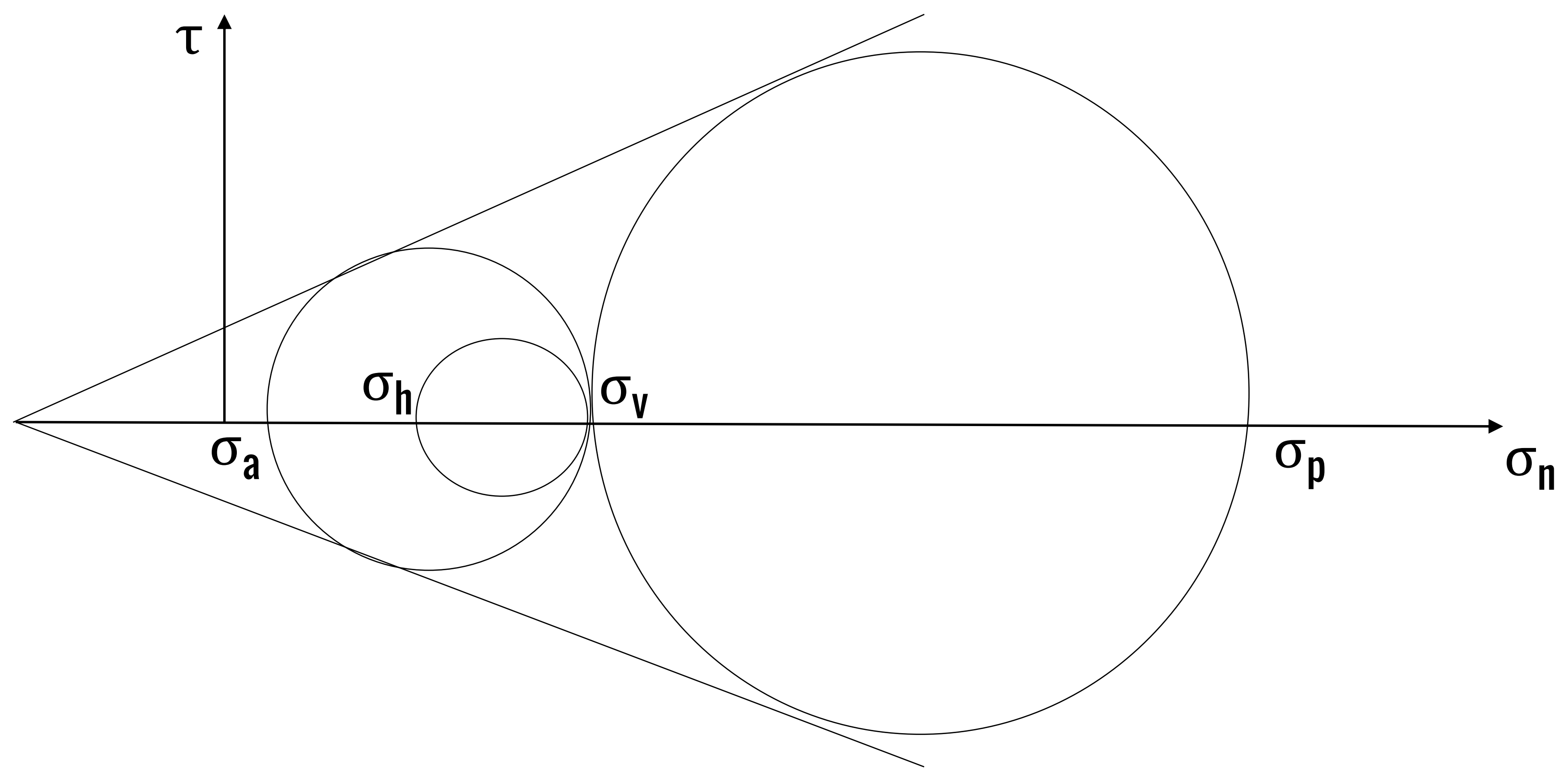


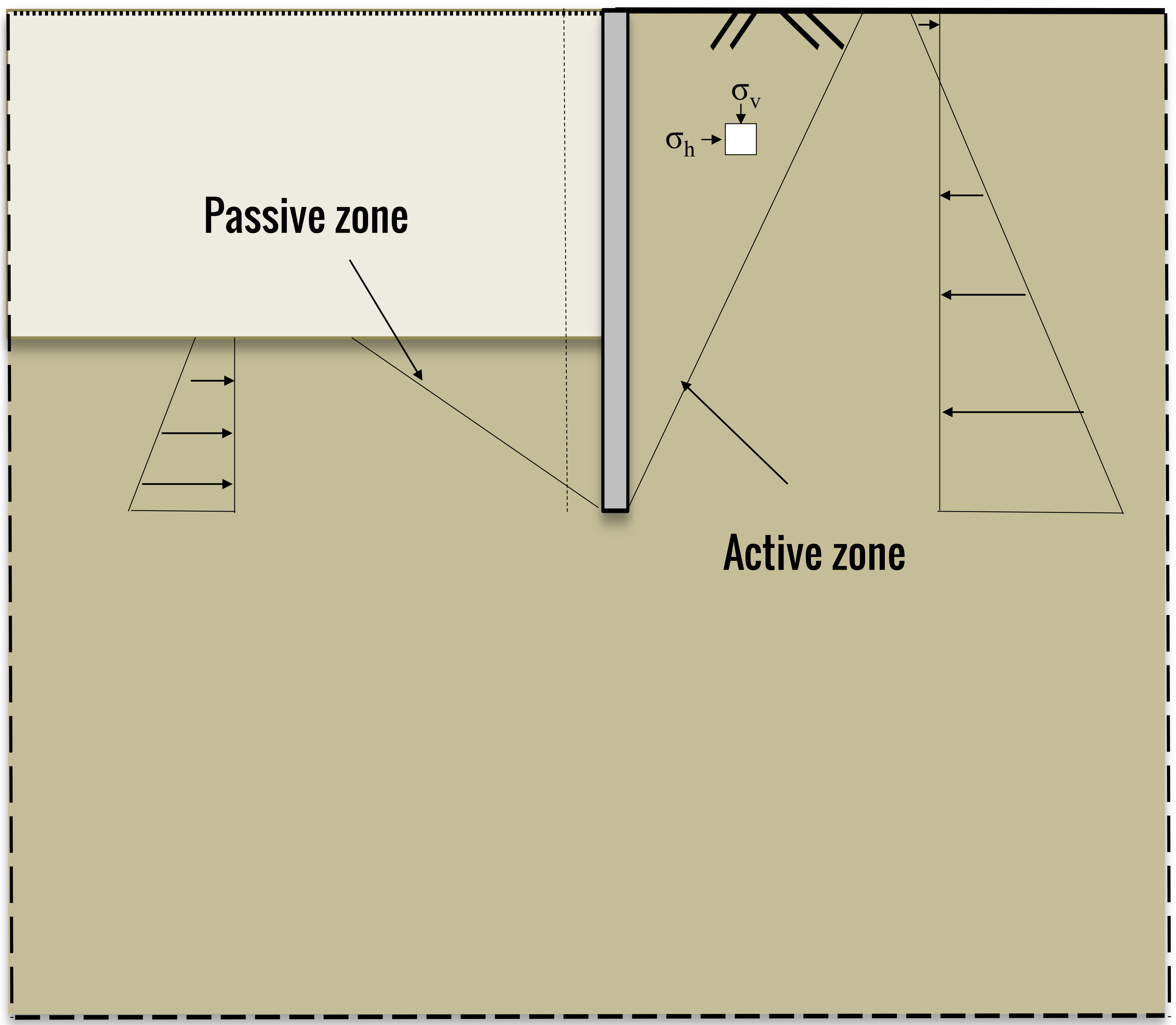
Calculate structural design checks

Earth Coefficients in DeepEX

Rankine earth pressure theory (1857):

- Based on plastic equilibrium concept
- No friction between wall and soil

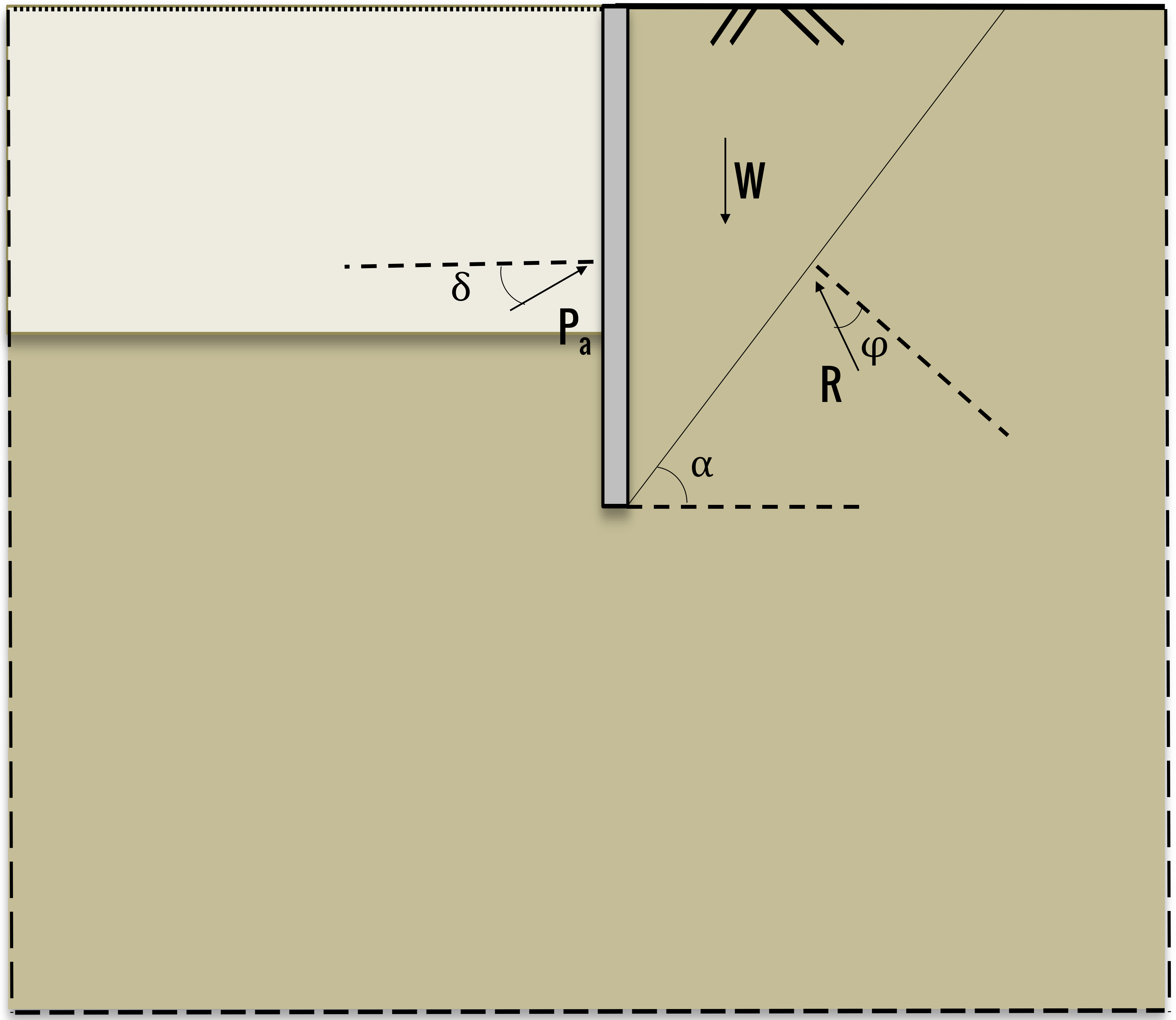




Earth Coefficients in DeepEX

Coulomb earth pressure theory (1776):

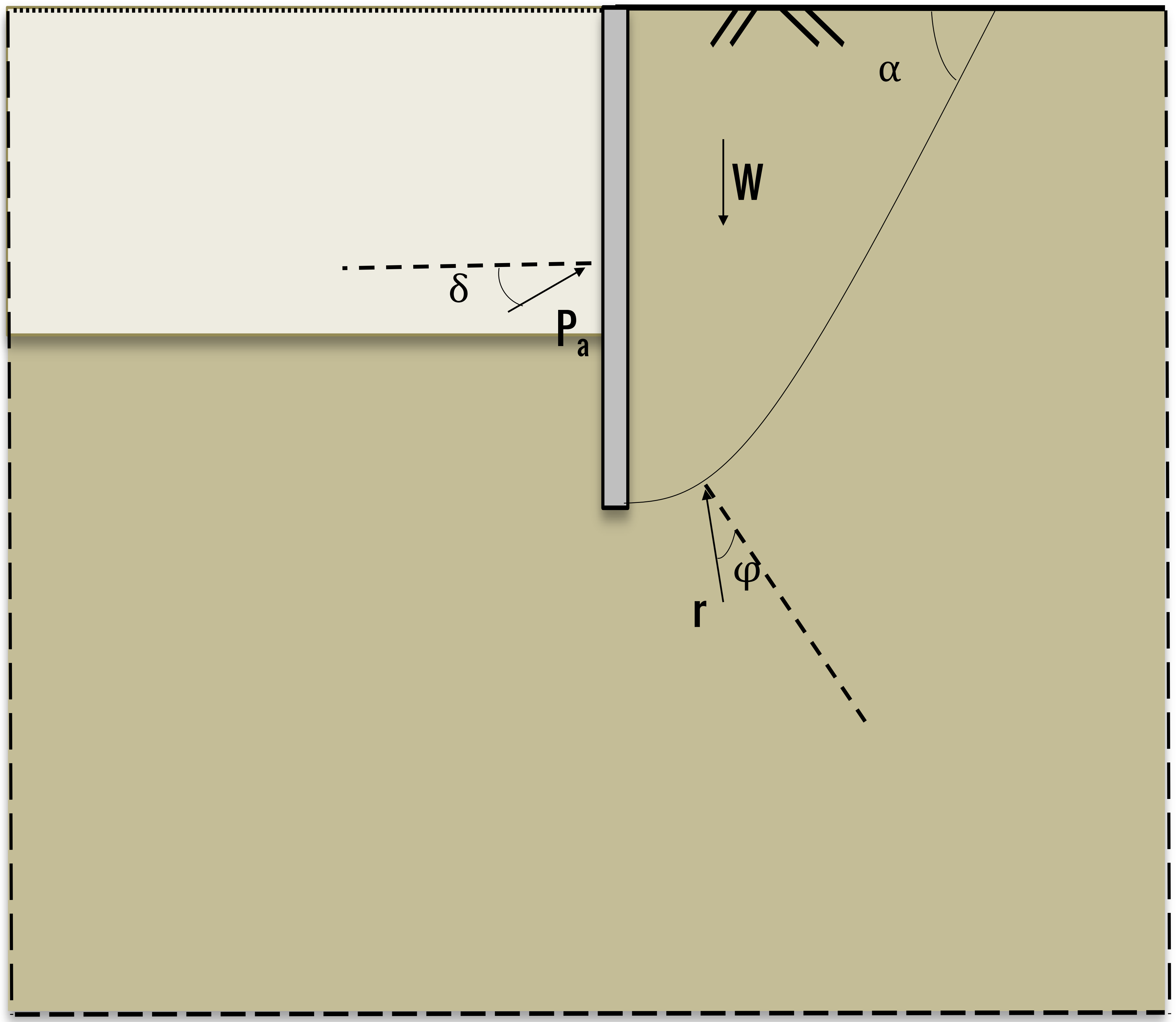
- Failure surface is a plane
- friction between wall and soil can be considered
- Arbitrary slope at the sides of the wall



Earth Coefficients in DeepEX

Caquot and Kerisel earth pressure theory (1948):

- Failure surface is an elliptical curved plane
- Eurocode 7 and NAVFAC charts based on the theory

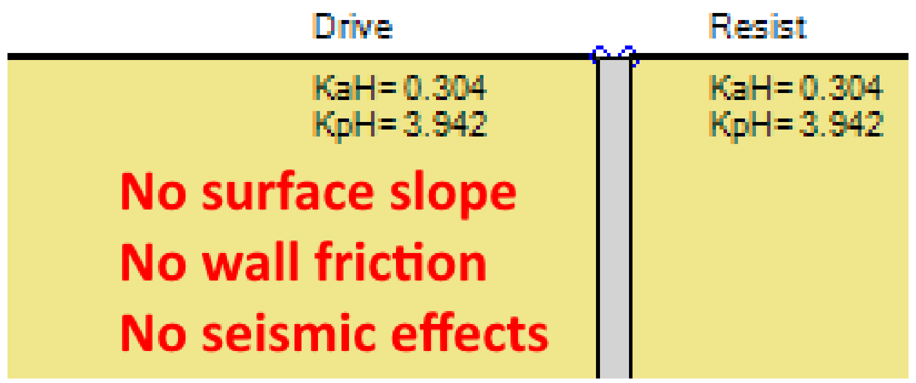


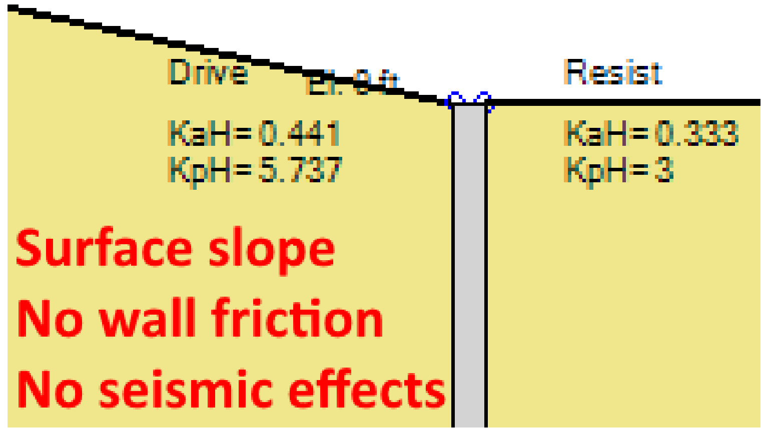
Earth Coefficients in DeepEX

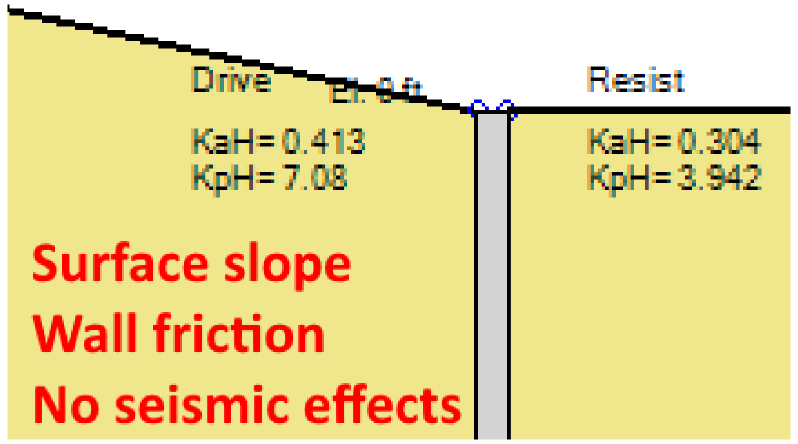
DeepEX Automatic Method Selection According to Project Parameters

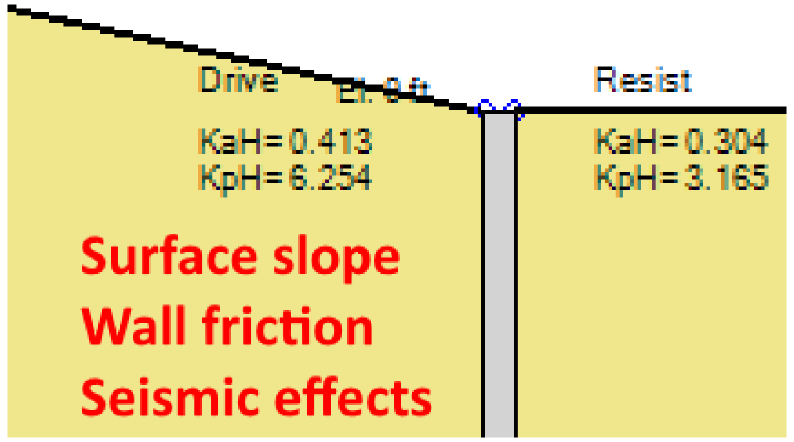
Active Coefficient Ka				
Parameters	Horizontal Surface	Inclined Surface	Wall Friction Considered	Seismic Effects Applied
Method	**Rankine**	**Coulomb**	**Coulomb**	**No Effect**

Passive Coefficient Kp				
Parameters	Horizontal Surface	Inclined Surface	Wall Friction Considered	Seismic Effects Applied
Method	**Rankine**	**Coulomb**	**Caquot-Kerisel**	**Lancelotta**





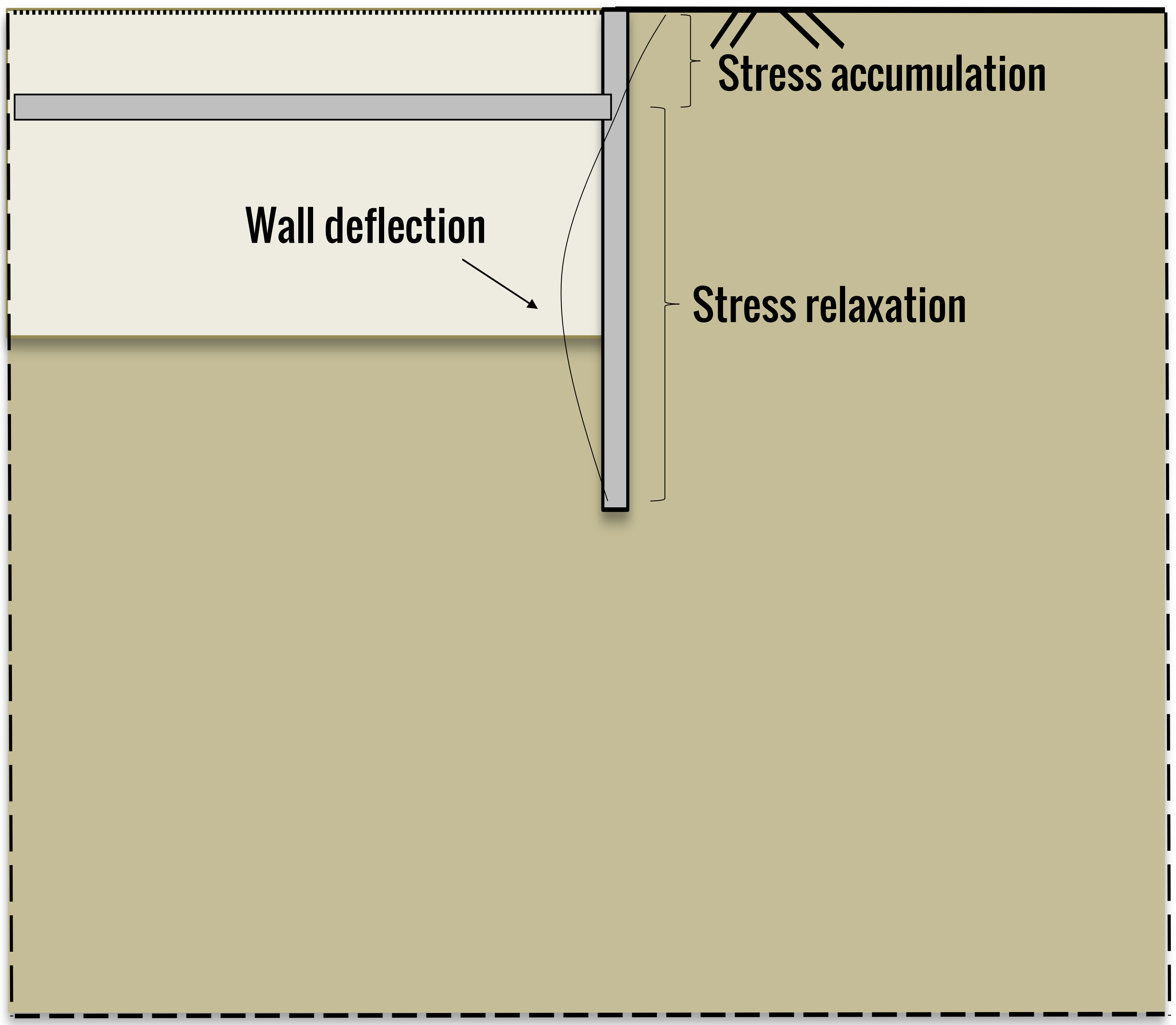




Earth Coefficients in DeepEX

Apparent earth pressures

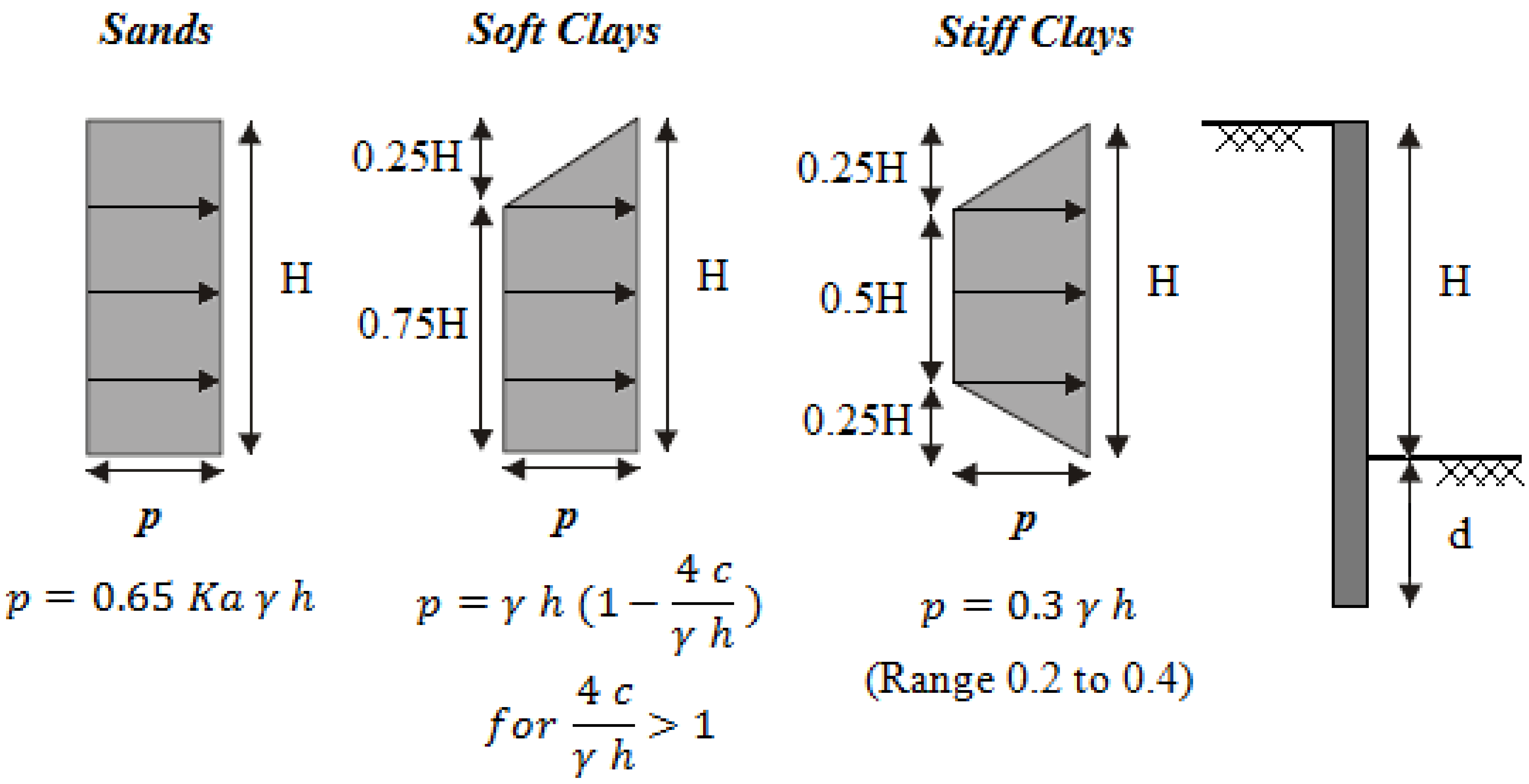
- Multilevel supported excavations experience different earth pressures
- Effective active pressures multiplied by a factor and redistributed.



Earth Coefficients in DeepEX

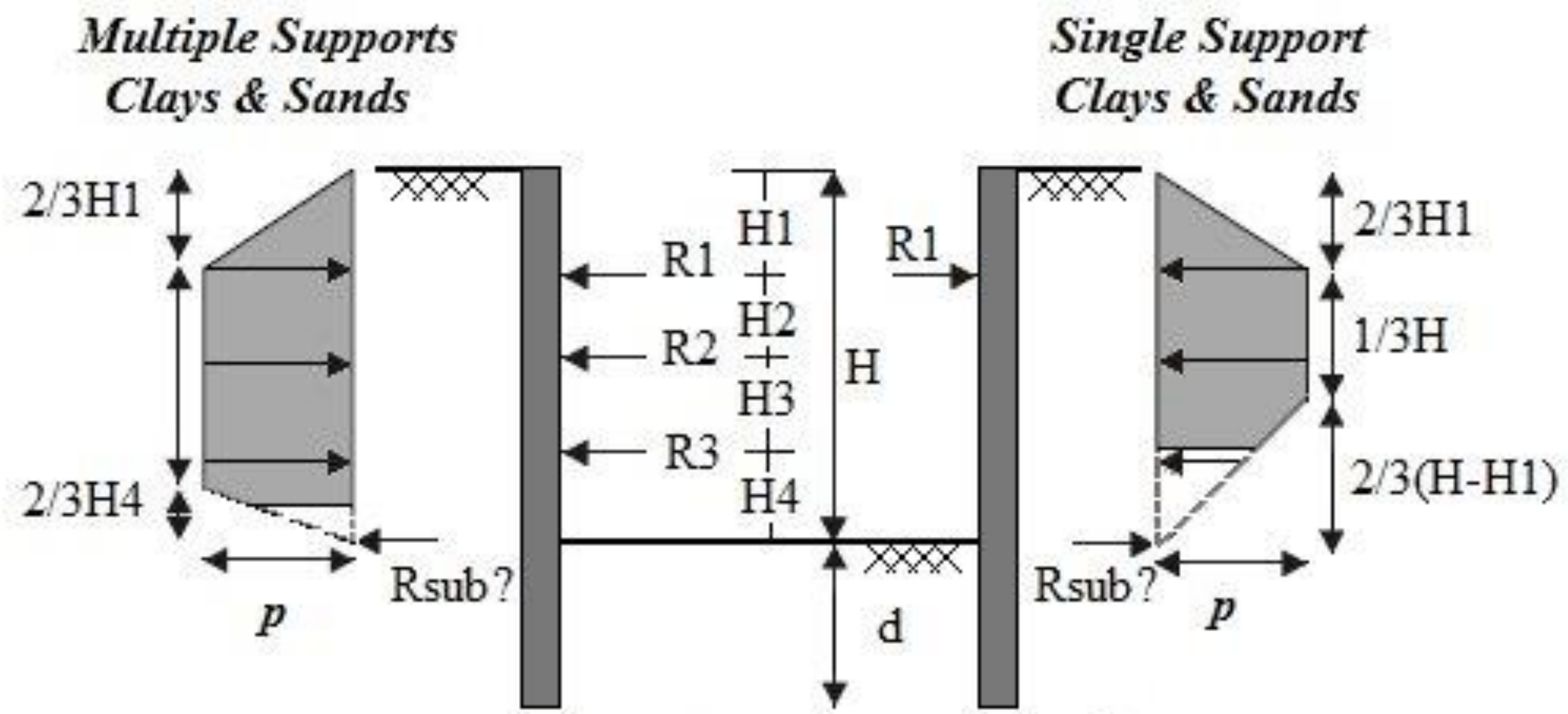
Peck (1969) Method:

- Based on multiple measurements of strut reactions of strutted excavations



FHWA Method:

- Based on multiple measurements of strut reactions of strutted excavations



Sands: Total Load = $0.65\ Ka\ \gamma\ h^2$

Clays: $p = 0.2\ \gamma\ h$ to $0.4\ \gamma\ h$

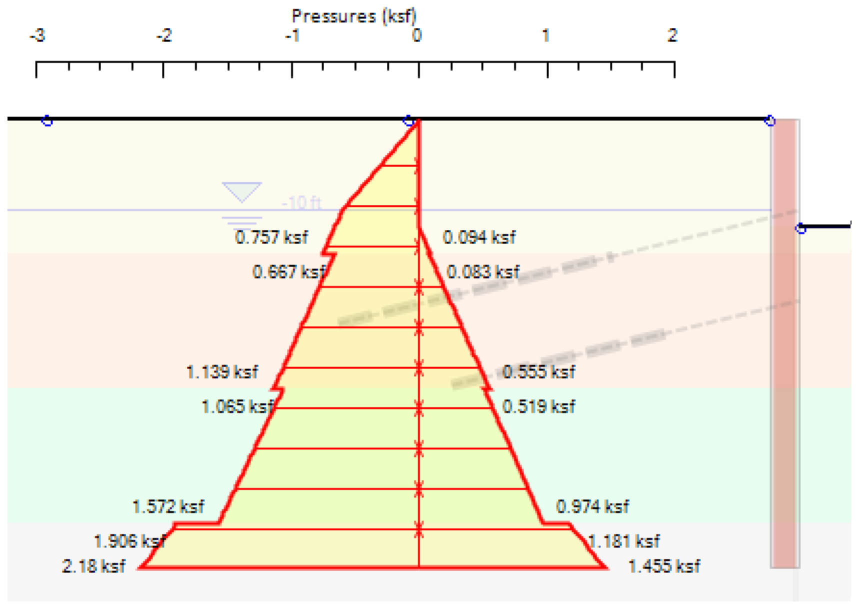
Rsub = Apparent virtual reaction at subgrade

DeepEX
Shoring Design Software

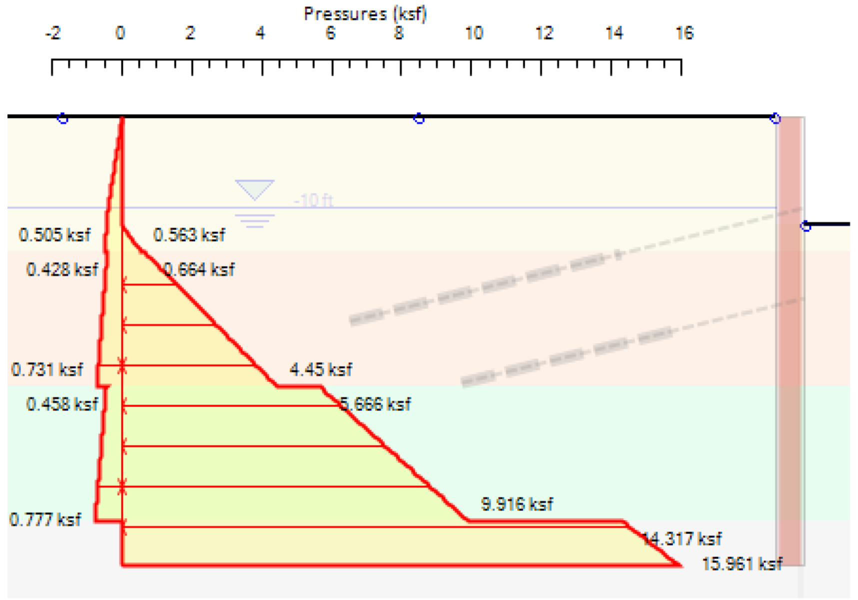
Soil Pressure Methods (LEM Analysis)

Cantilever Excavations

At-Rest Pressures

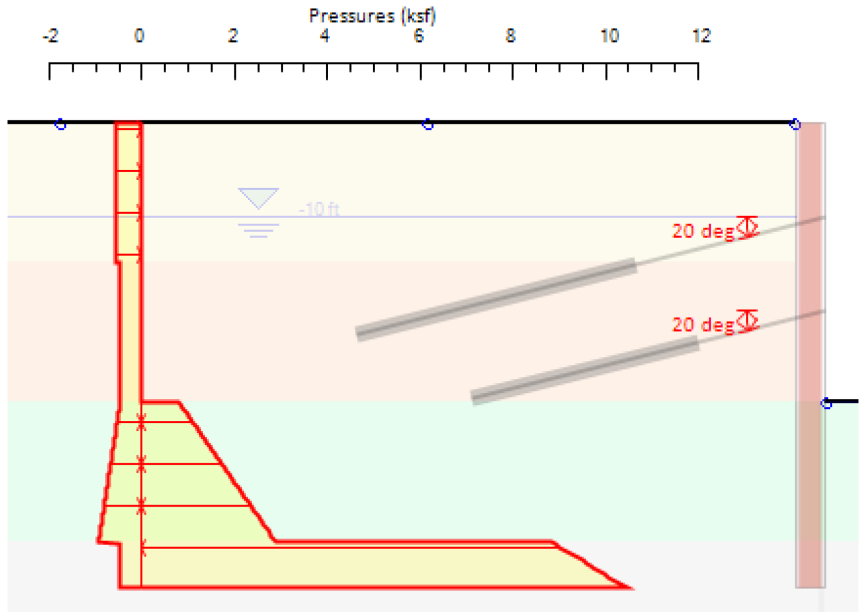


Active - Passive Pressures

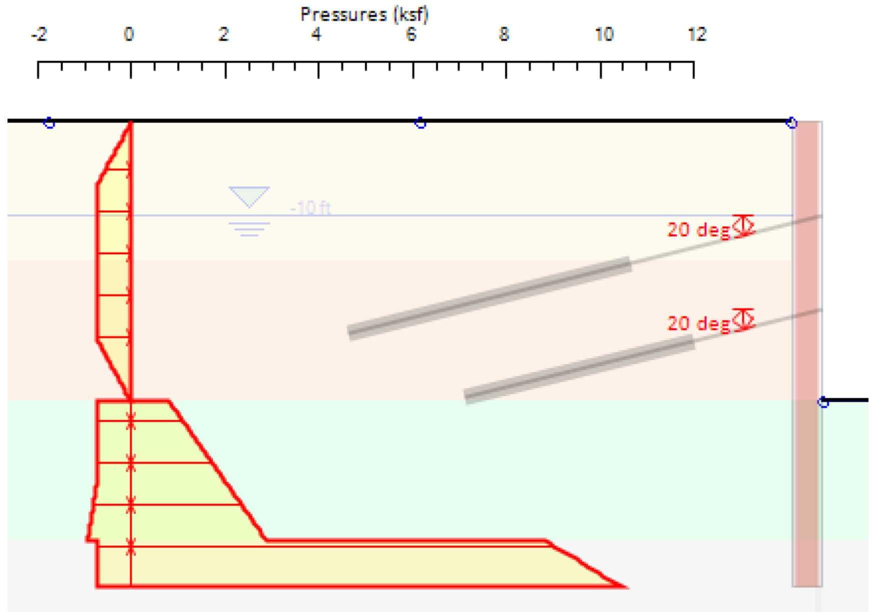


Construction Stages with multiple support levels

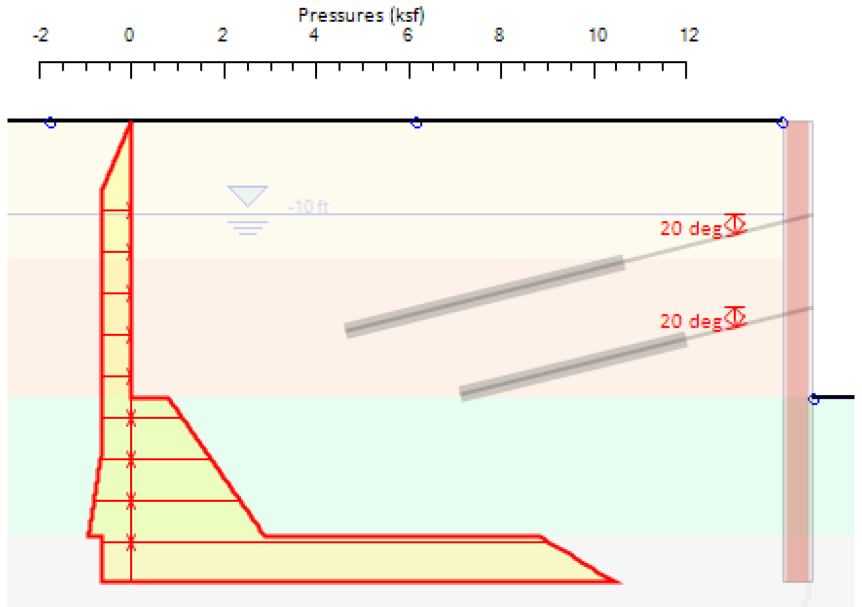
Peck 1969 Pressures



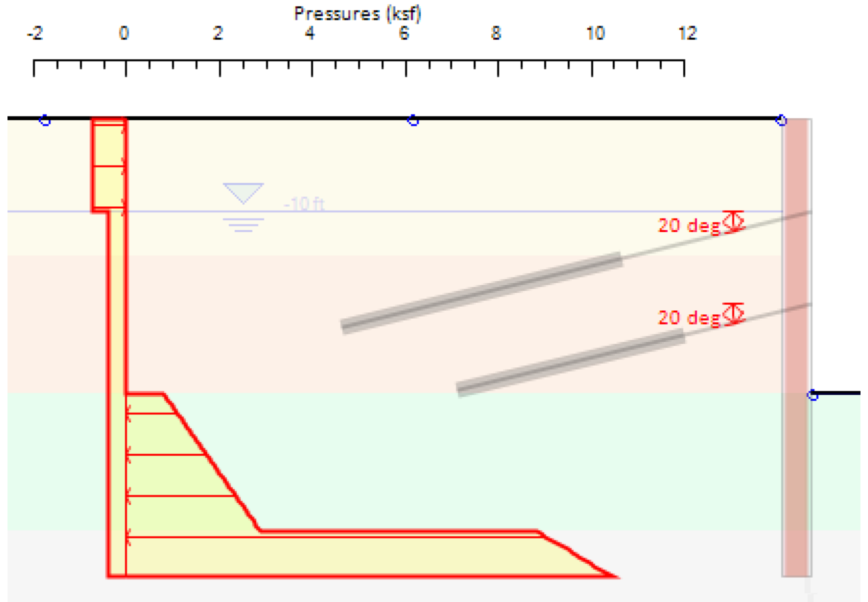
FHWA Apparent Pressures



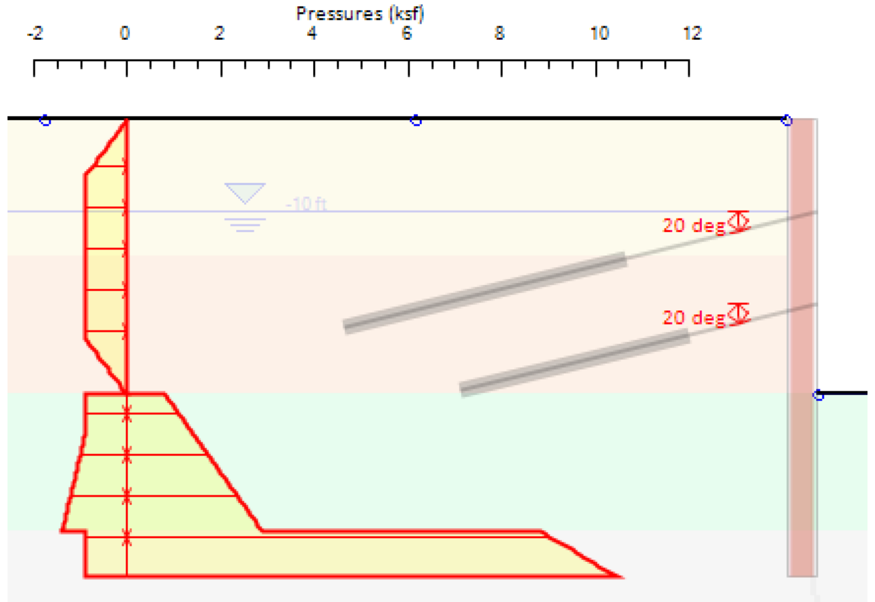
Custom Trapezoidal Pressures



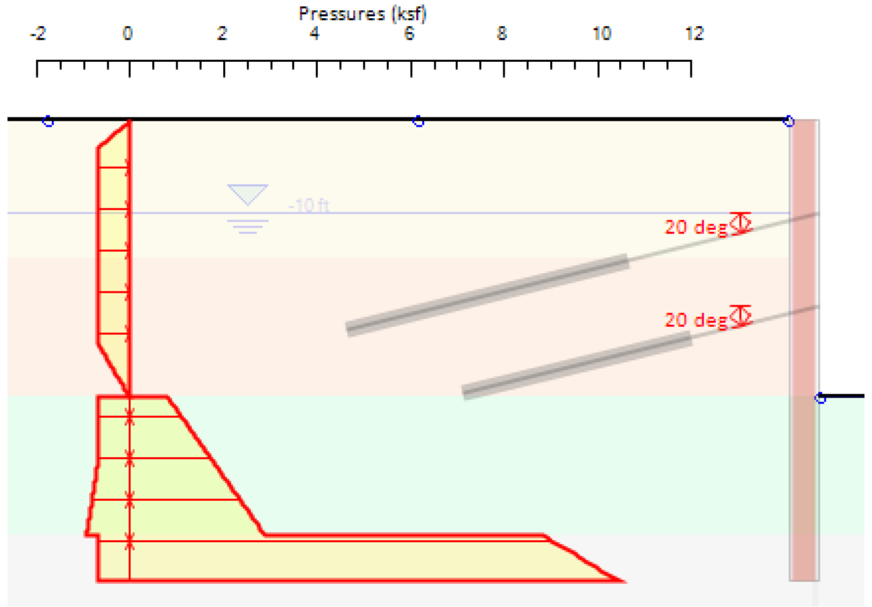
Two-Step Rectangular Pressures



WMATA Pressures

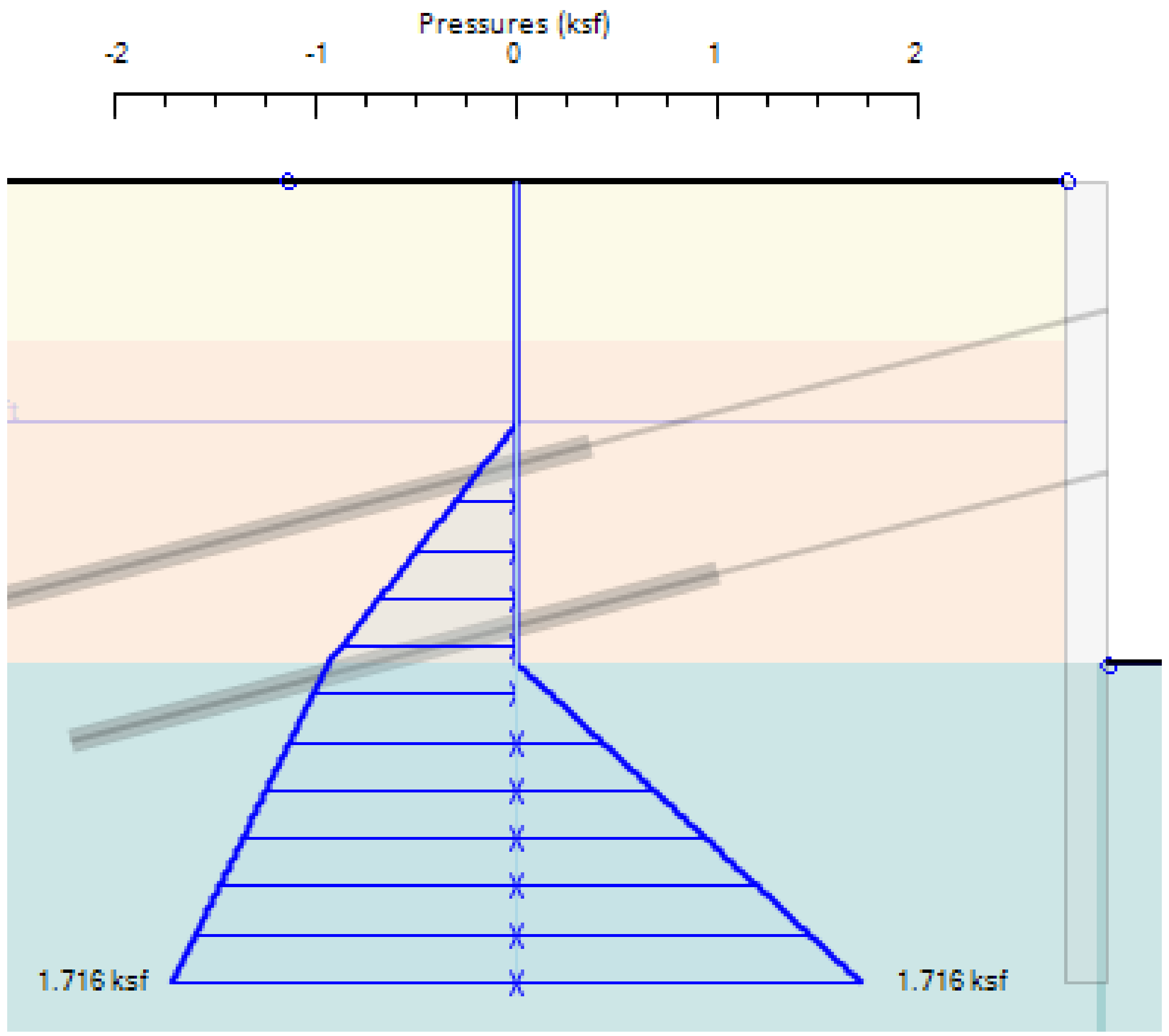


New York City DEP Pressures

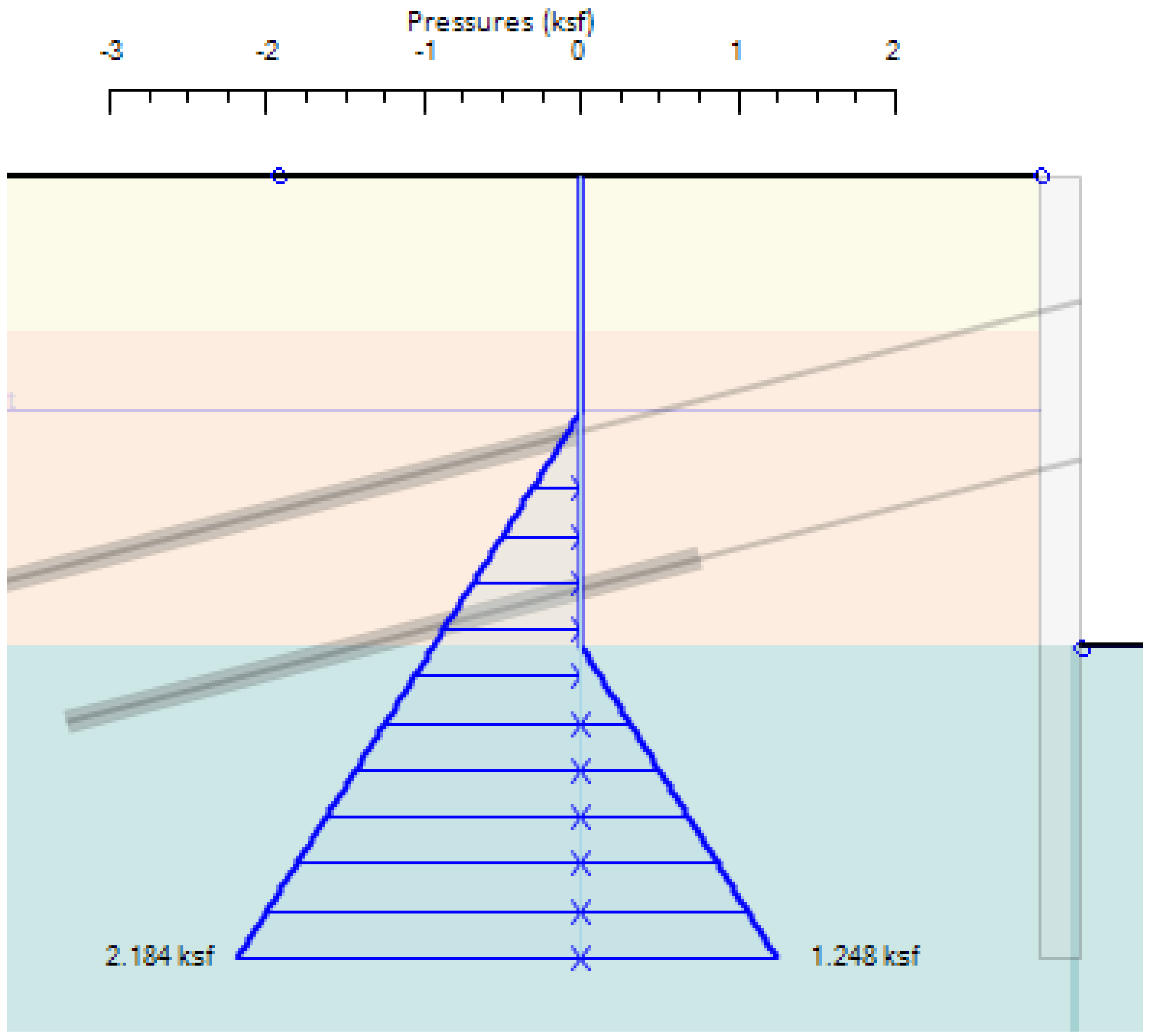


Water Pressure Methods

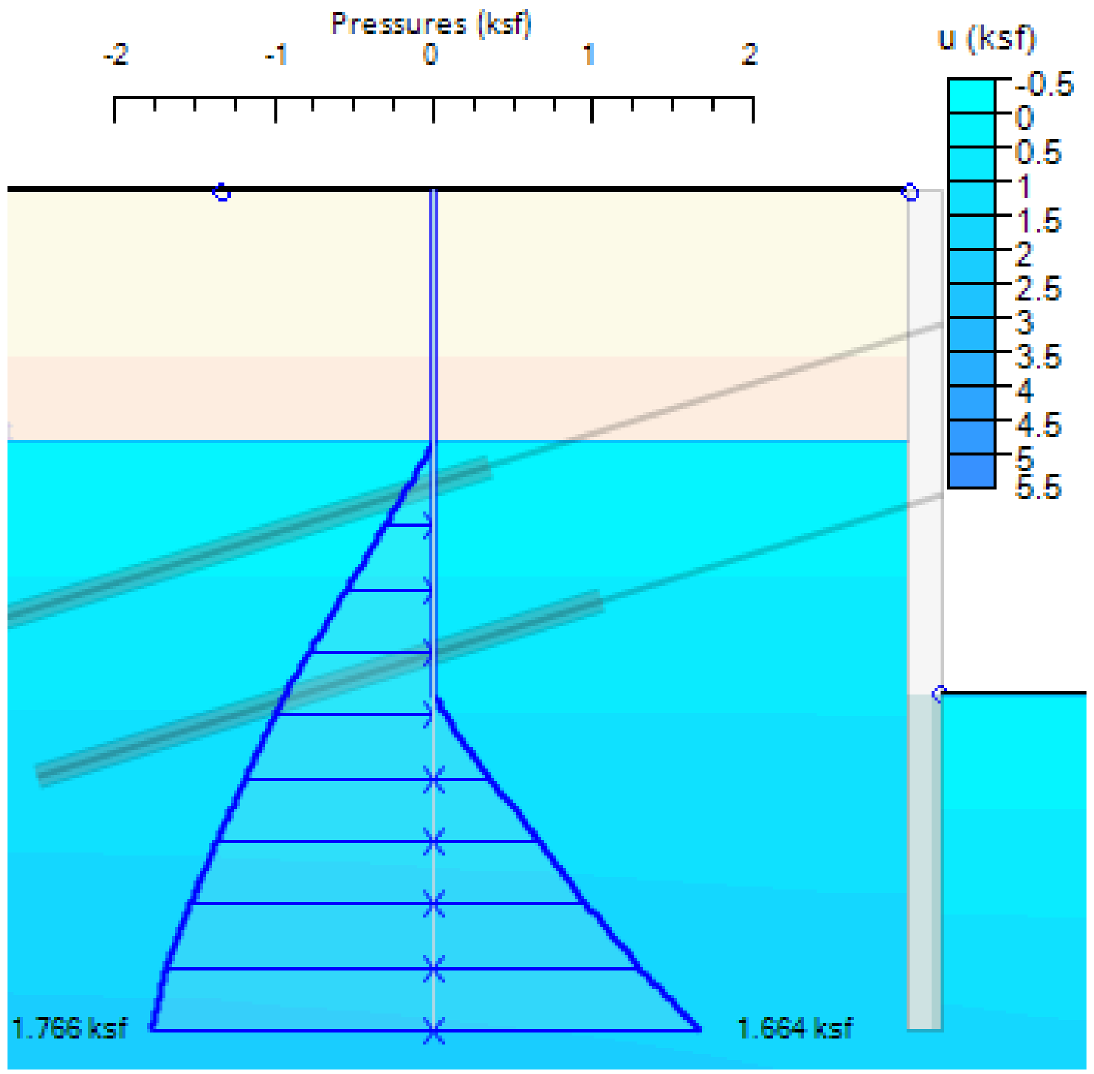
Simplified Flow



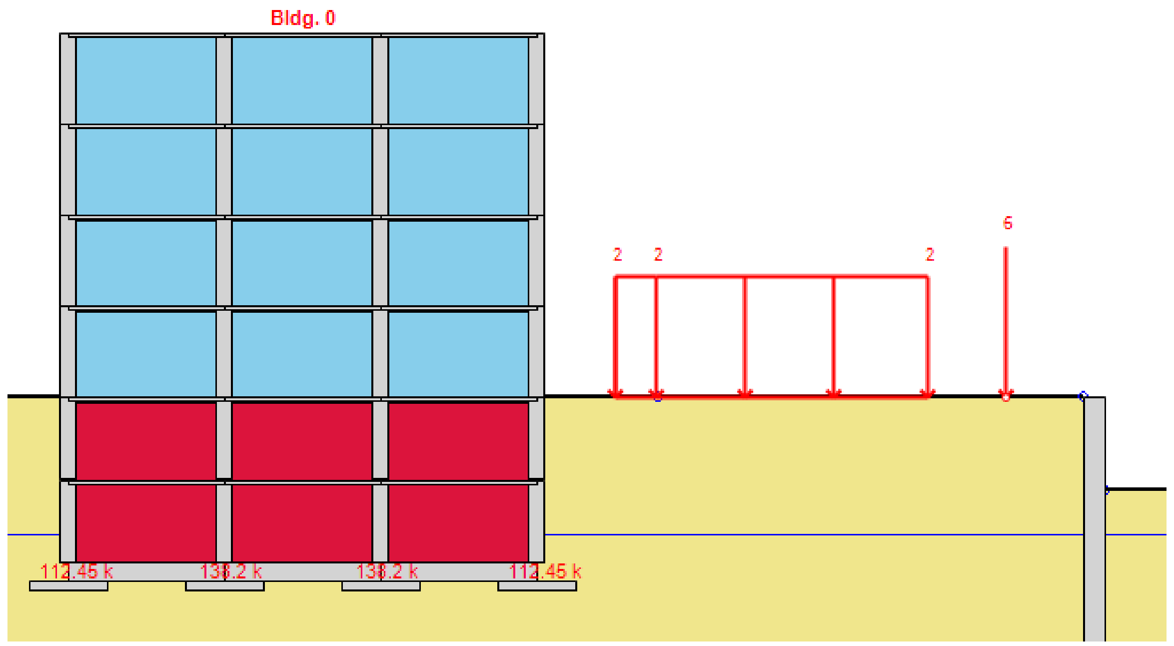
Hydrostatic

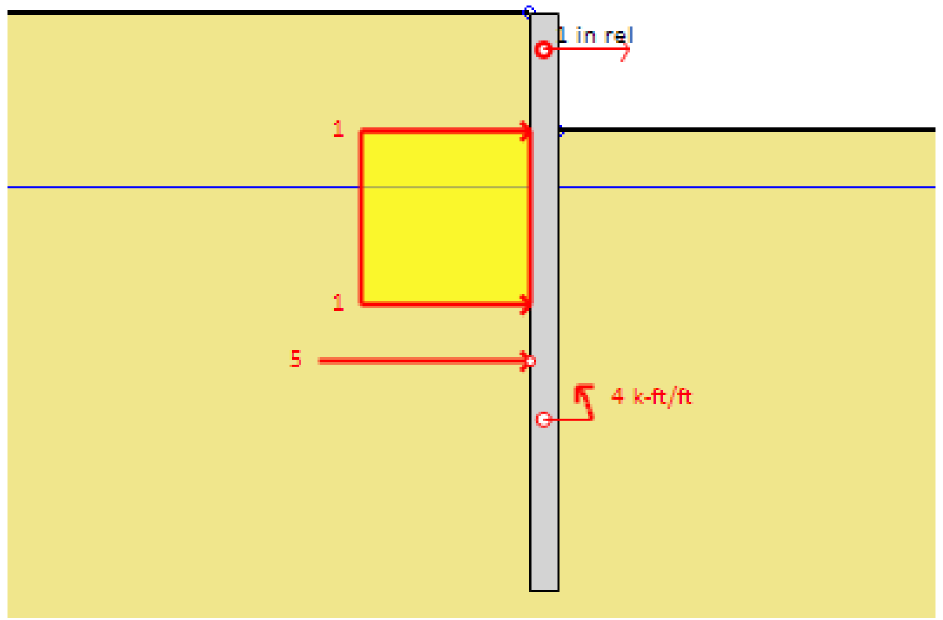


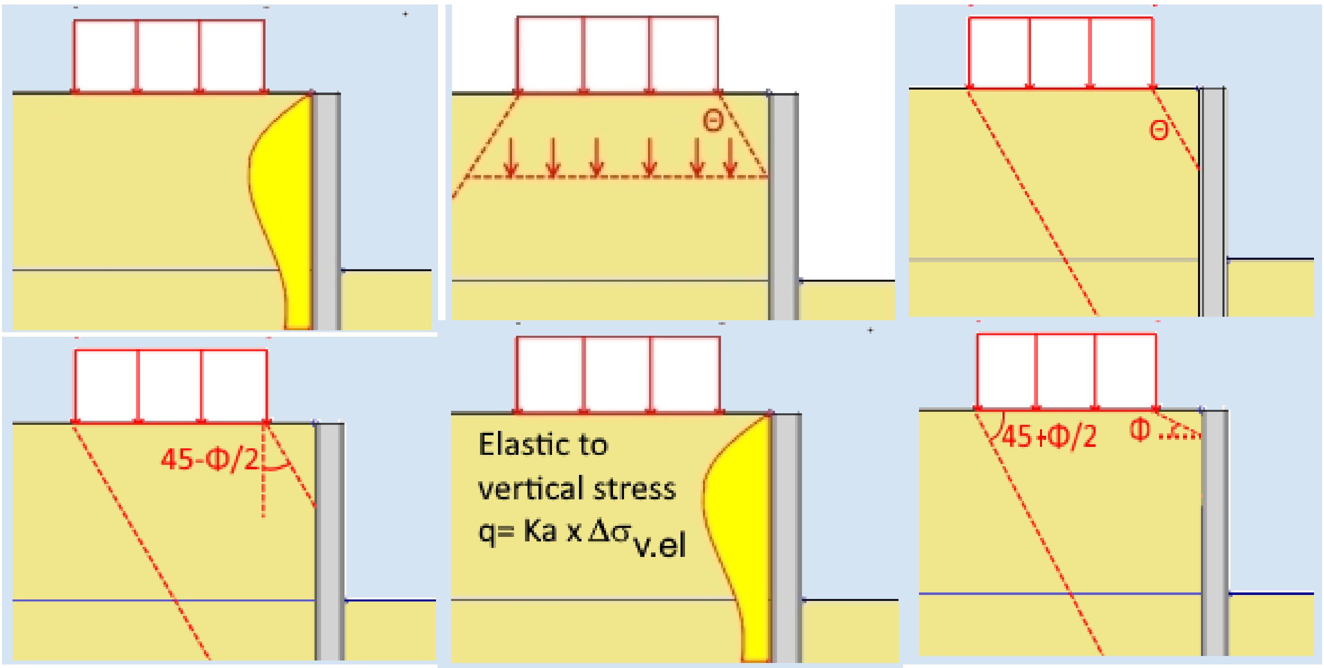
Full Flownet Analysis



External Loads: Types & Pressure Methods







Loads on ground surface:

- ✓ Strip surcharges
- ✓ Linear loads
- ✓ 3D loads (buildings, footings, 3D surface loads

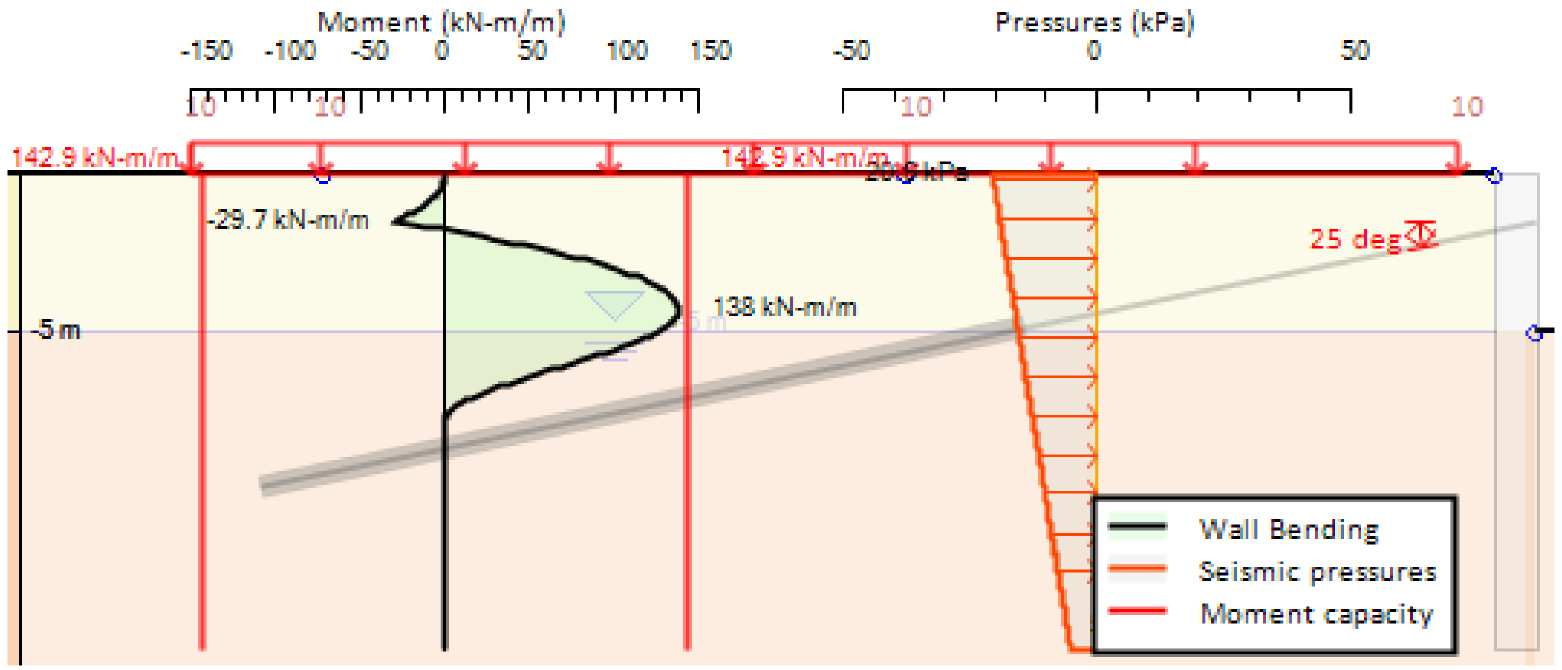
Loads on the wall:

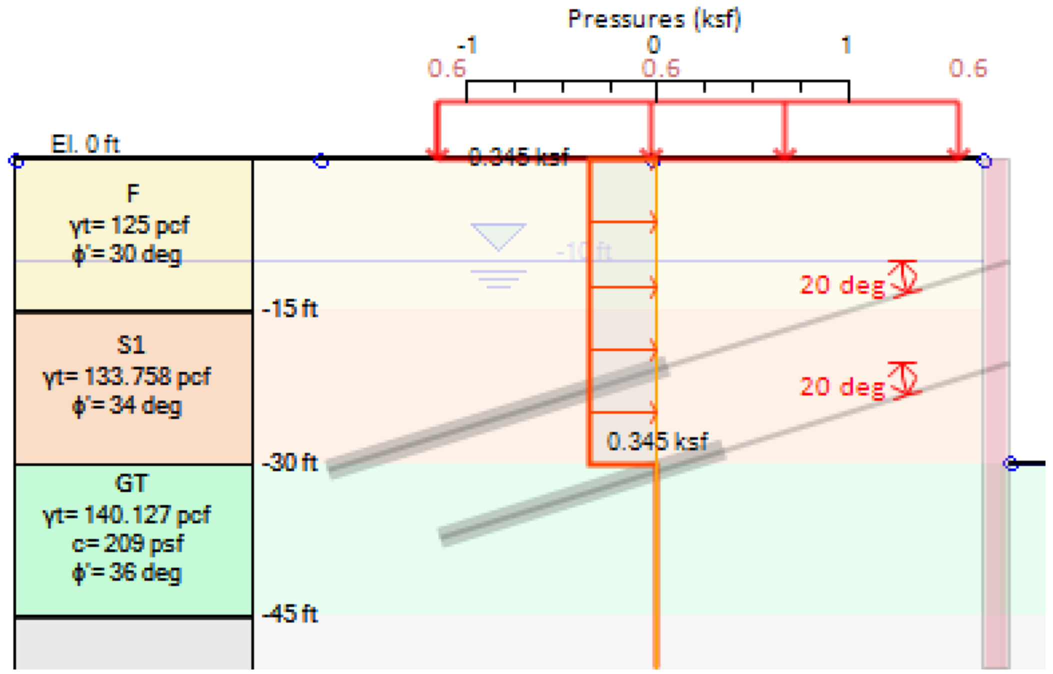
- ✓ Strip surcharges
- ✓ Linear loads
- ✓ External moments
- ✓ Prescribed displacements

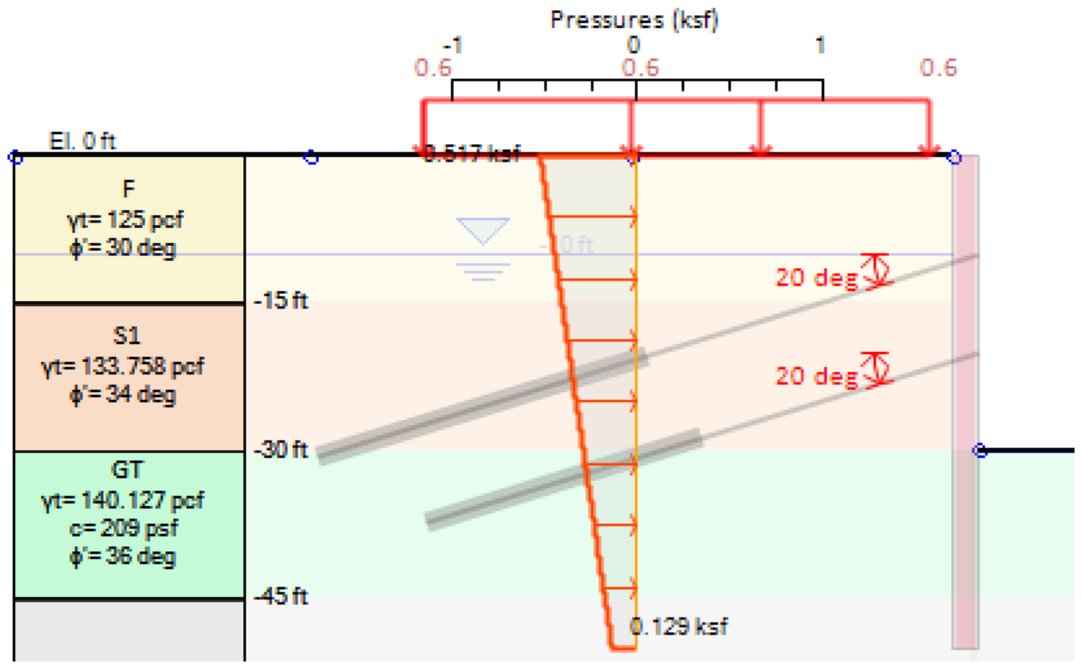
Load modeling options:

- ✓ Elasticity equations
- ✓ Two-way distribution angle
- ✓ One-way distribution angle
- ✓ One-way distribution angle from soil friction
- ✓ Elasticity to vertical stress x Ka (or Ko)
- ✓ CIRIA Special Pub 95 - 1993

Seismic Pressure Methods







Procedure in DeepEX

- Define Seismic Accelerations Ax and Az
- Select Seismic Pressures Calculation Method
- Select a Seismic Design Standard

Seismic Pressure Methods

- ✓ Semirigid
- ✓ Mononobe-Okabe (frictional soils)
- ✓ Wood Automatic
- ✓ Wood Manual

Semirigid Method

- Total Vertical Stress at Bottom of Wall x B
- B = 0.75 in DeepEX
- Rectangular Pressure Diagram

Mononobe-Okabe Method (Frictional Soils)

- Extension of the Coulomb Static Theory
- Accelerations added to a Coulomb Wedge
- Seed & Whitman (1970) Seismic Thrust Redistribution
- Inverse Trapezoid Pressure Diagram

DeepEX
Shoring Design Software

Cantilever Wall Analysis Concepts

Fixed earth method

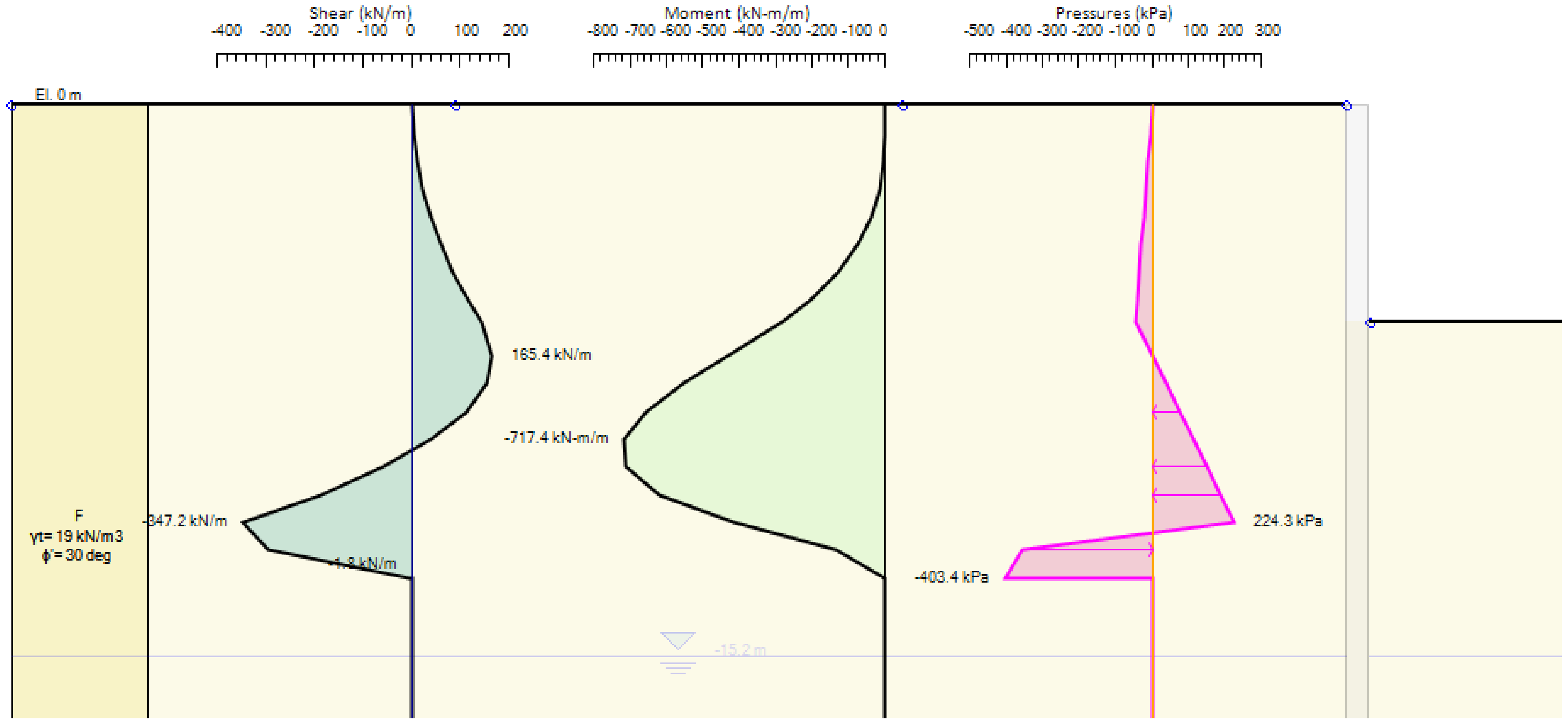
Balances out Moment and Shear

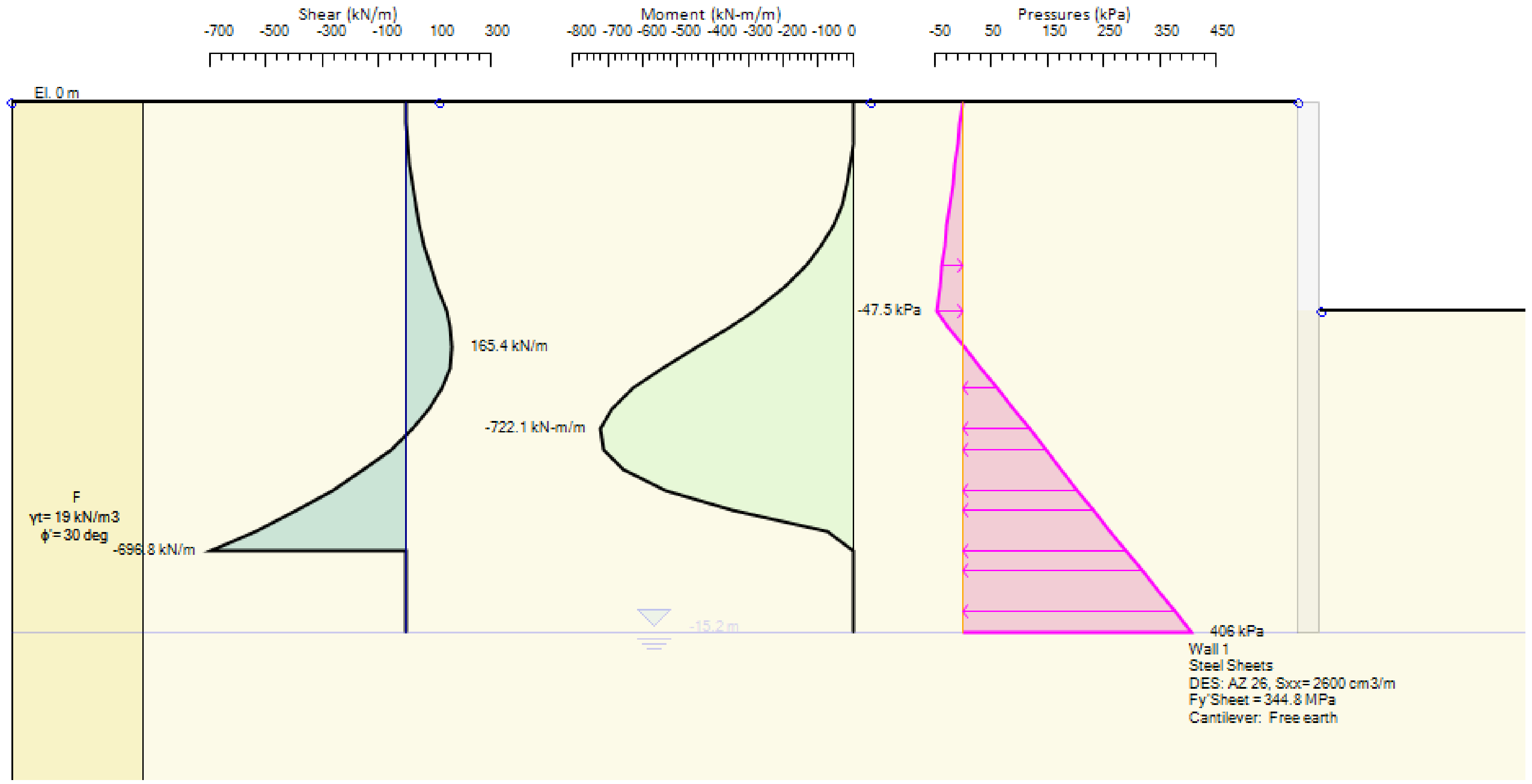
Free earth method

Balances out Moment - Shear not balanced

Increase length by 1.2 to get FS 1.0

Then apply additional safety factors



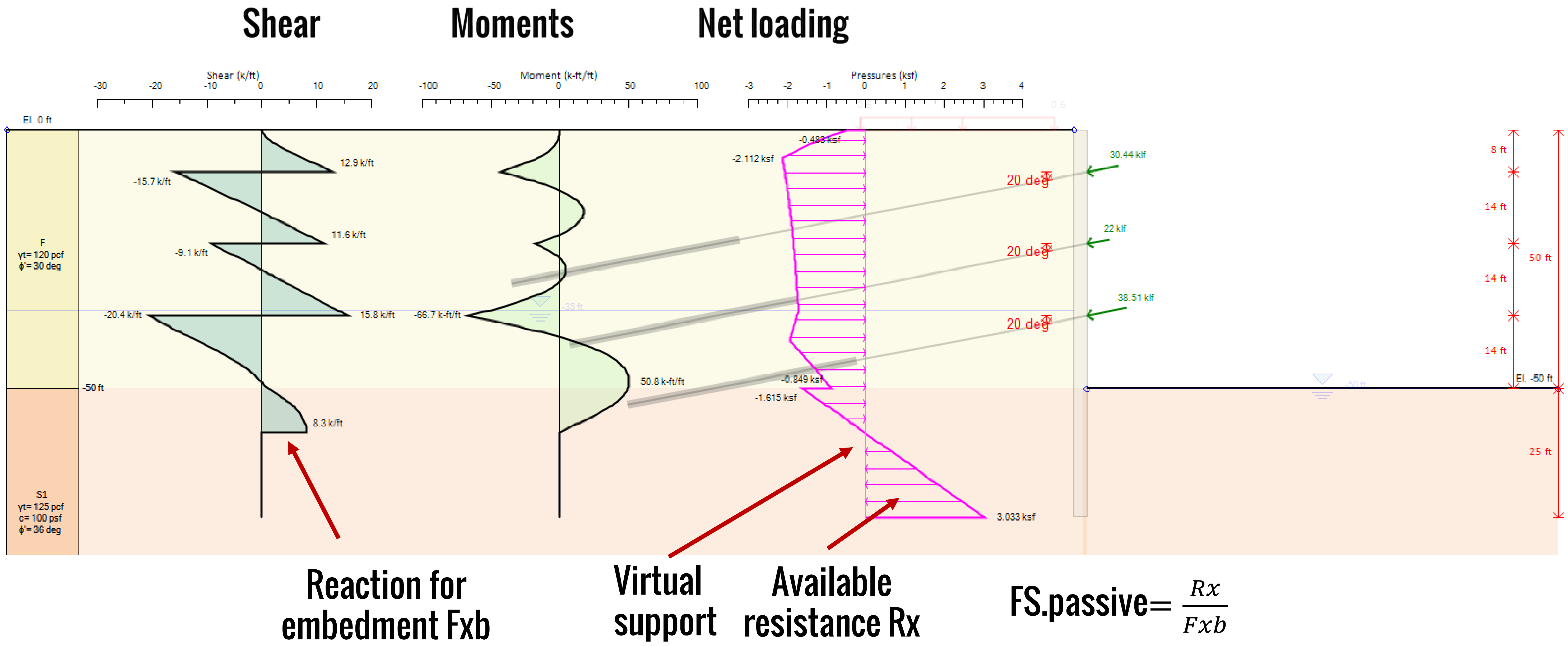


Beam Analysis: Blum's Method

Pinned supports - continuous beam

Point of zero net soil shear below subgrade.

Use point of zero shear as a virtual support.



$$FS.passive = \frac{Rx}{Fxb}$$

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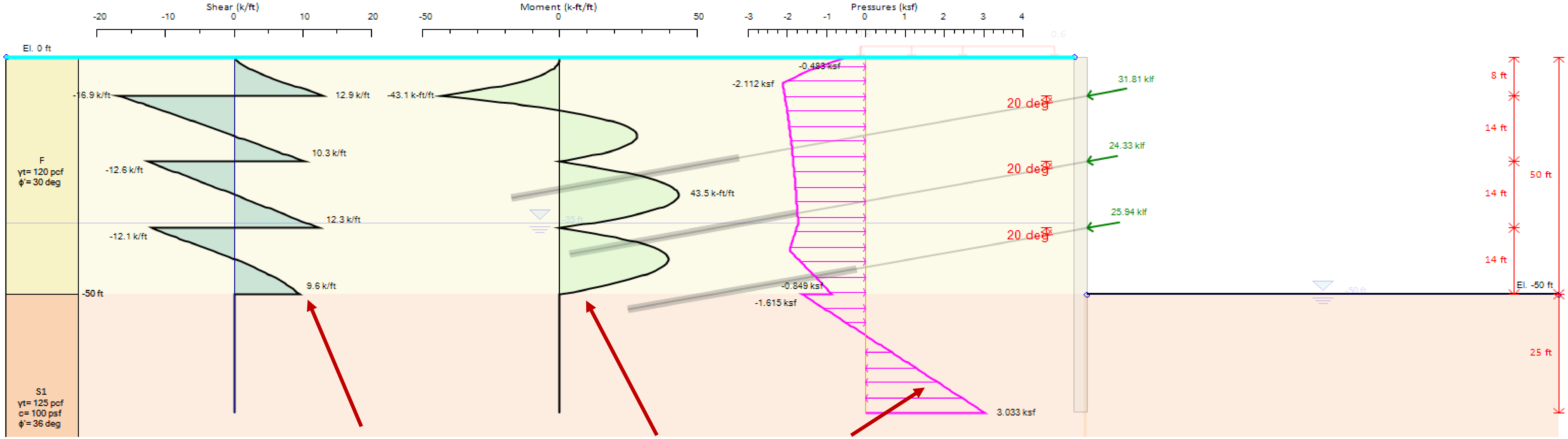
Beam Analysis: FHWA Simple Span Method

Pin support at excavation base, simple spans

Shear Moments Net loading



Reaction for embedment Fxb

Virtual support

Available resistance Rx

$$FS.passive = \frac{Rx}{Fxb}$$

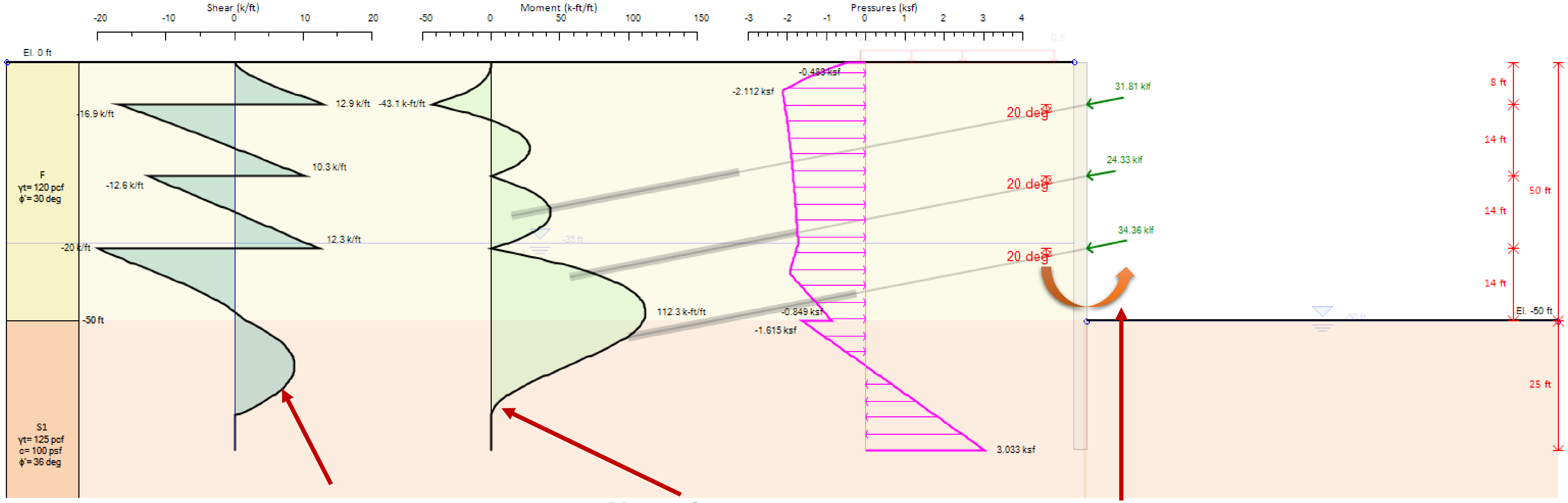
Beam Analysis: CALTRANS Approach

Pinned supports - simple span

Base at point of zero moment below bottom support

Shears and moments balance out

Shear Moments Net loading



No Embedment Reaction

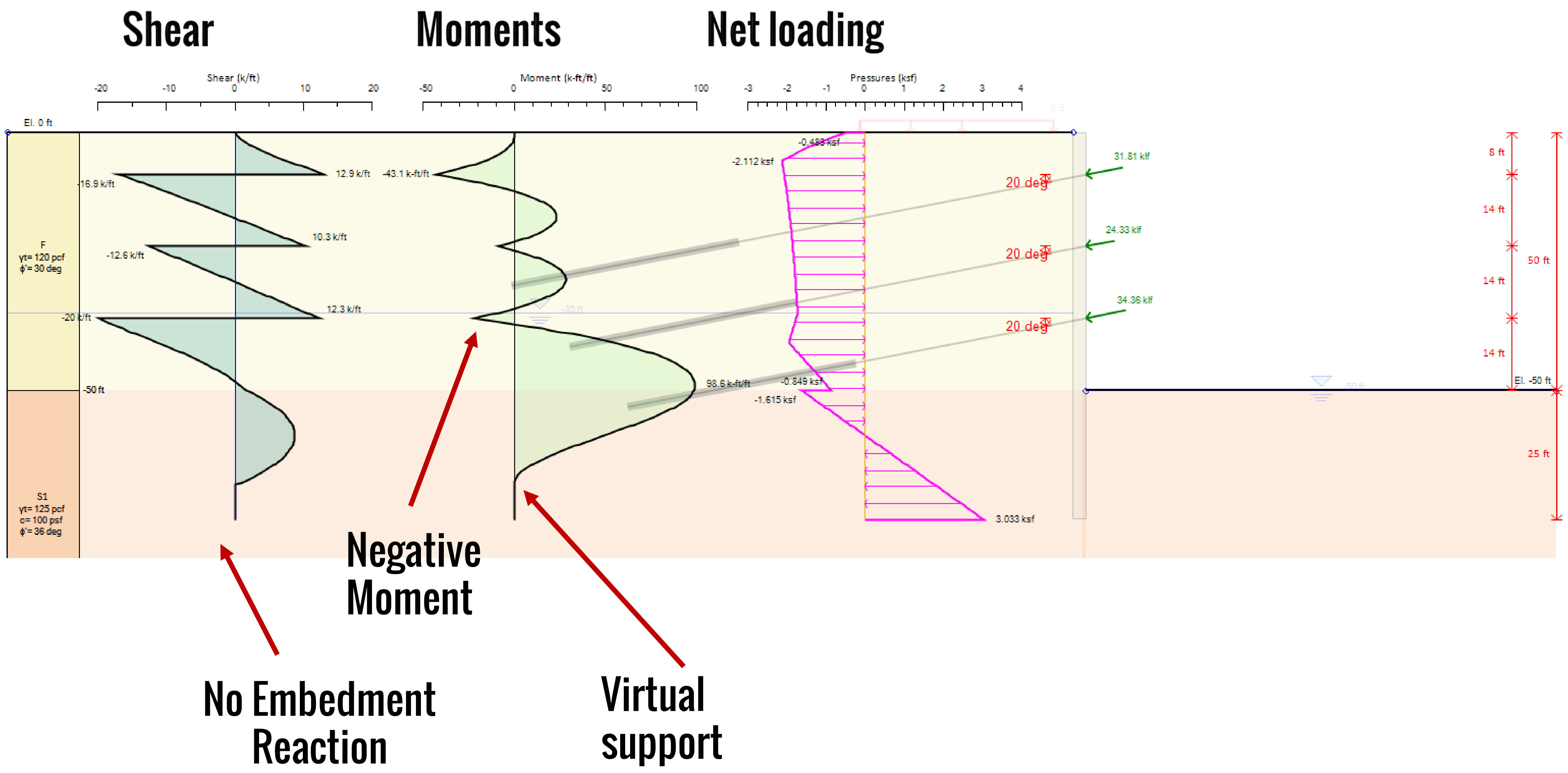
Virtual support

$$FS.rotation = \frac{Fresist}{Fdrive}$$

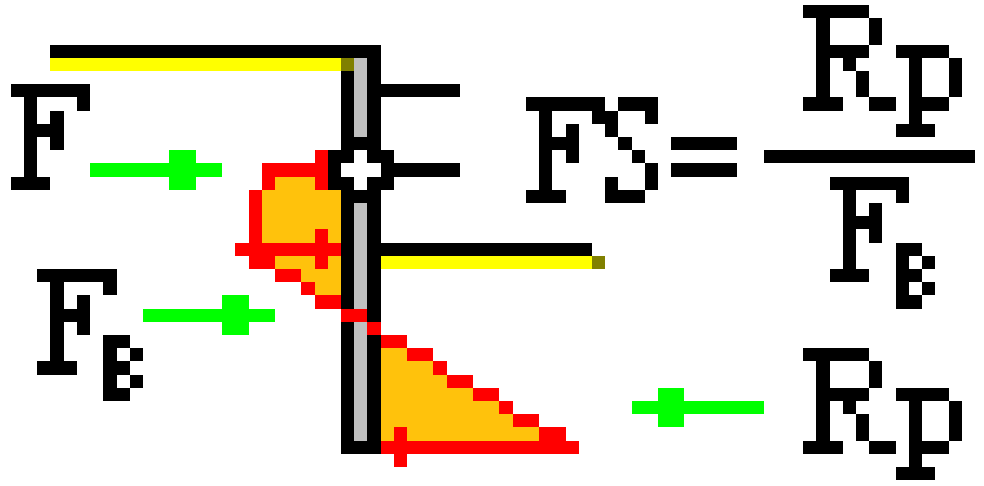
Beam Analysis: CALTRANS & Negative Moments

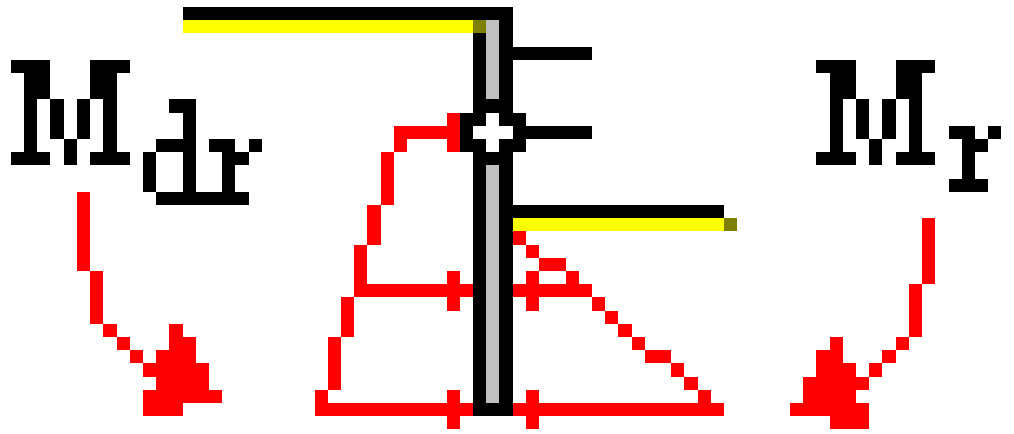
Simple span may be very conservative

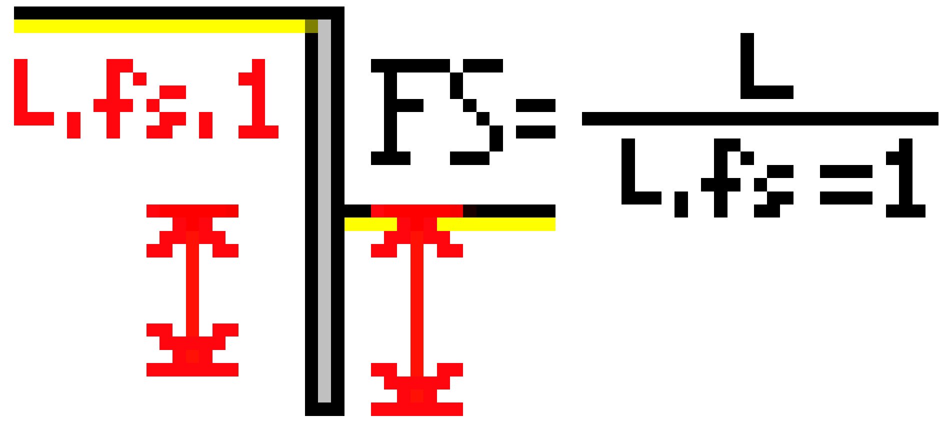
Assume negative moments (20% of simple span)



Wall toe Stability checks





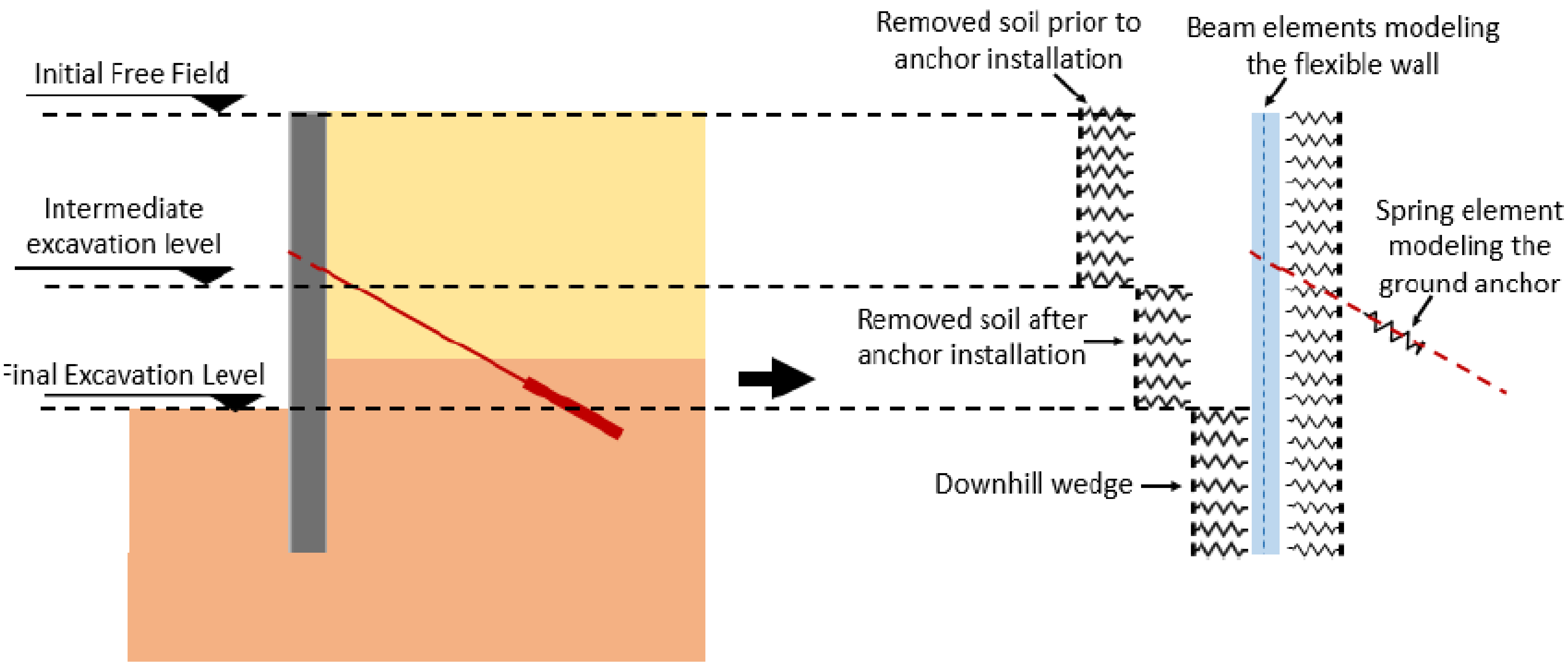


$$FSpas = \frac{Available\ Resistance\ beneath\ \text{virtual}\ fixity\ point}{Hor.reaction\ at\ virtual\ point + driving\ pressures\ beneath\ virtual\ fixity\ point}$$

$$FSrotation = \frac{Resisting\ moments\ about\ a\ point}{Driving\ moments\ about\ the\ same\ point}\ (Eq.\ 9.2)$$

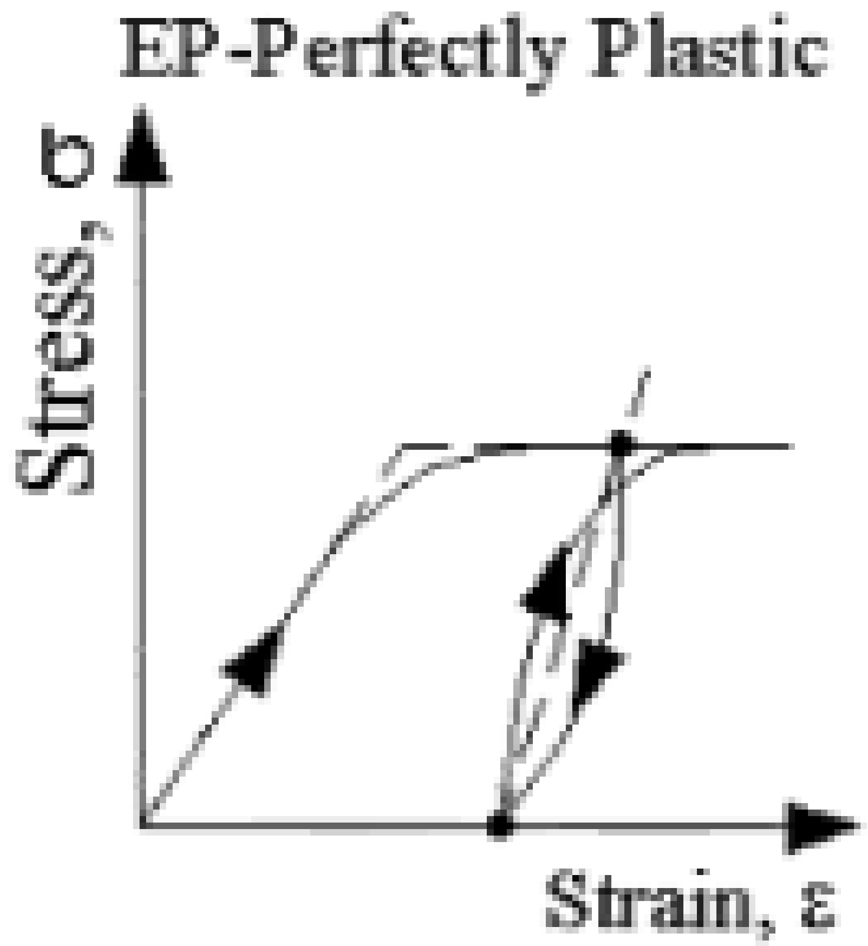
$$FSembed = \frac{Available\ wall\ embedment\ depth}{Max.Required\ embedment\ depth\ for\ FS = 1\ from\ Equations\ 1\&\ 2\ above}\ (Eq.\ 9.3)$$

Non-linear Analysis Concept (Soil Springs)



Linear Perfectly plastic Model

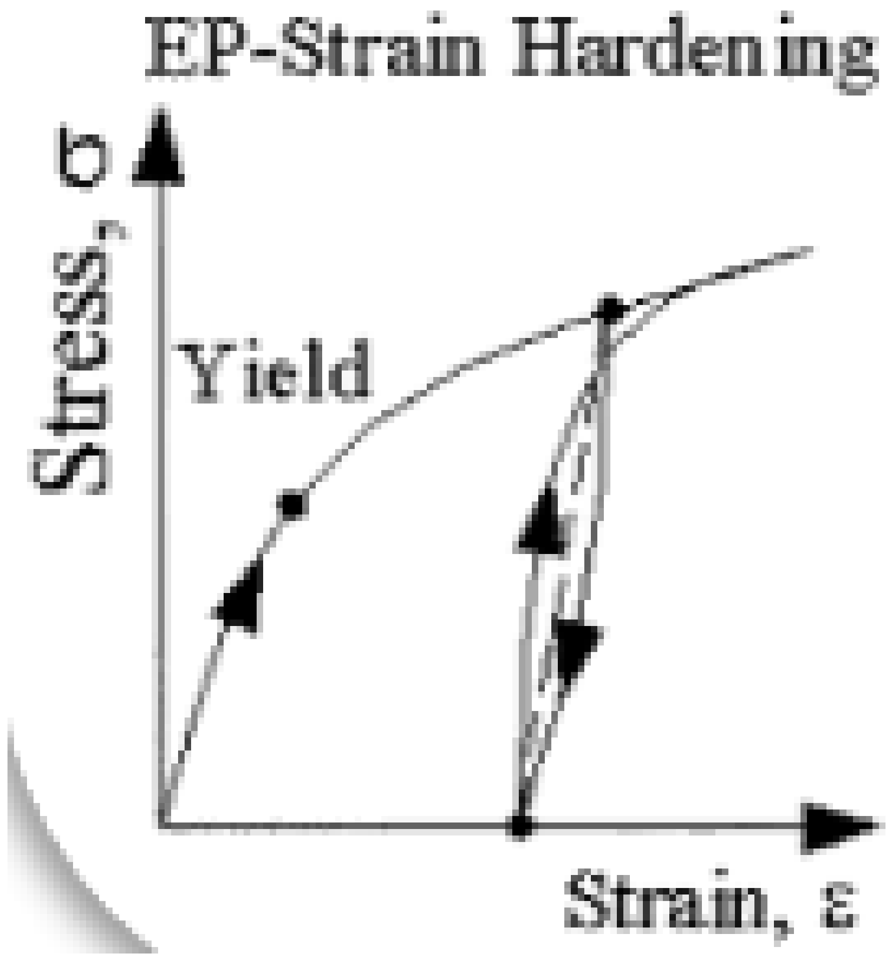
- Elastic behavior prior to yielding
- Detailed unloading reloading behavior



Non-linear Analysis Concept

Hyperbolic elastoplastic Model

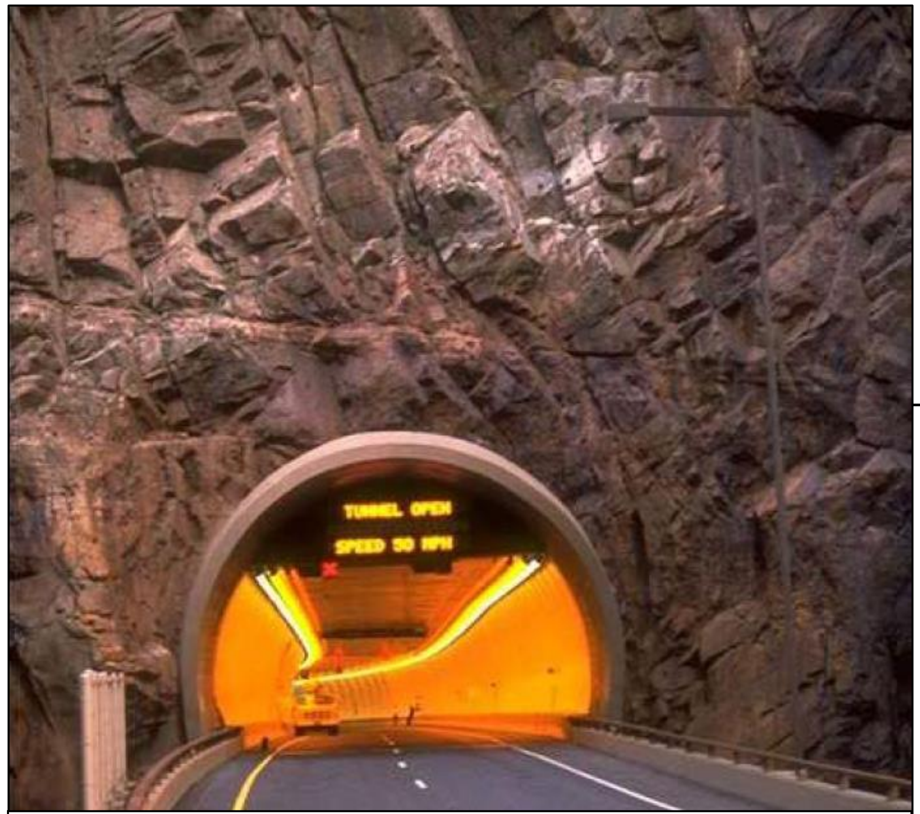
- Inelastic behavior prior to yielding
- Pressure dependent nonlinear stiffness
- Detailed unloading reloading behavior



Subgrade Model

- Elastic behavior
- Defined by a $K_{subgrade}$ modulus

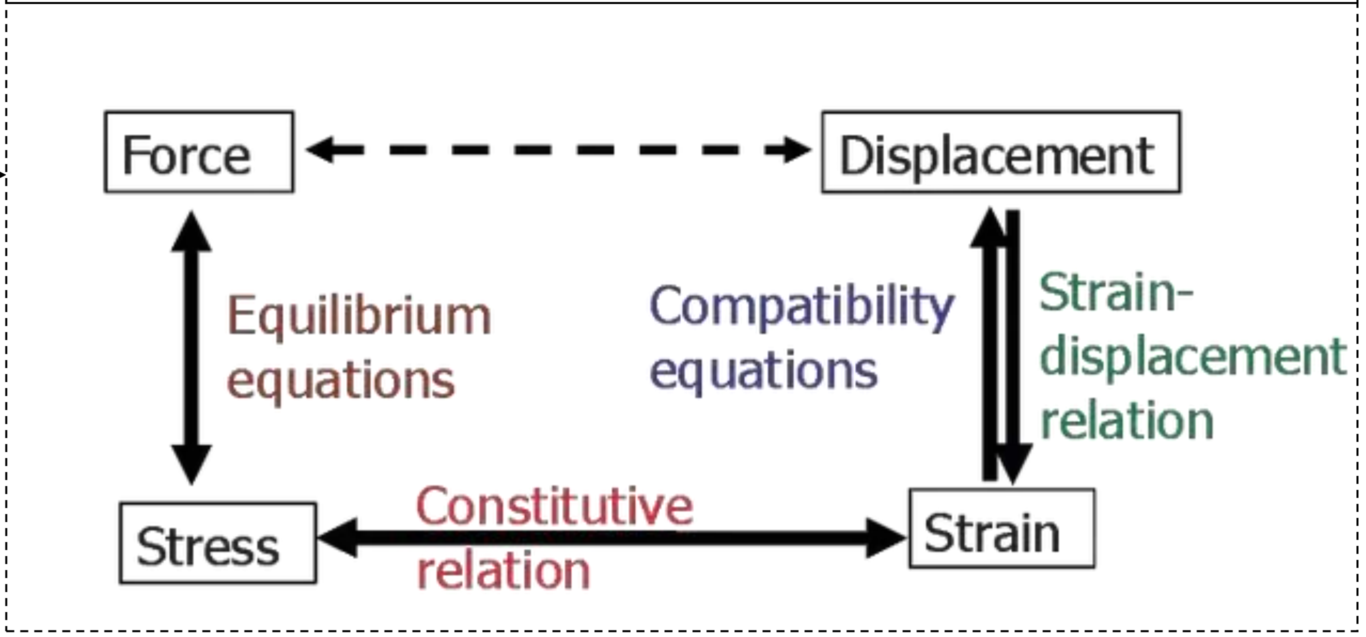
Finite Element Method (FEM)



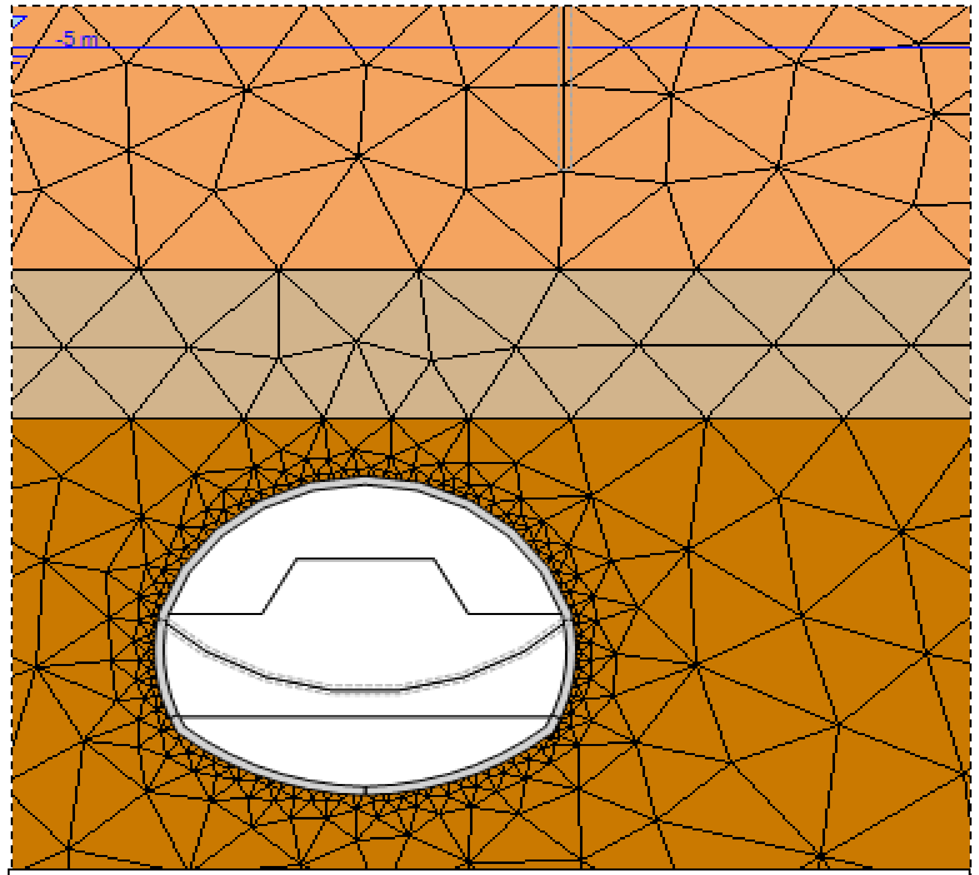
Physical structure

Modelling assumptions

Mathematical formulation



Discretization

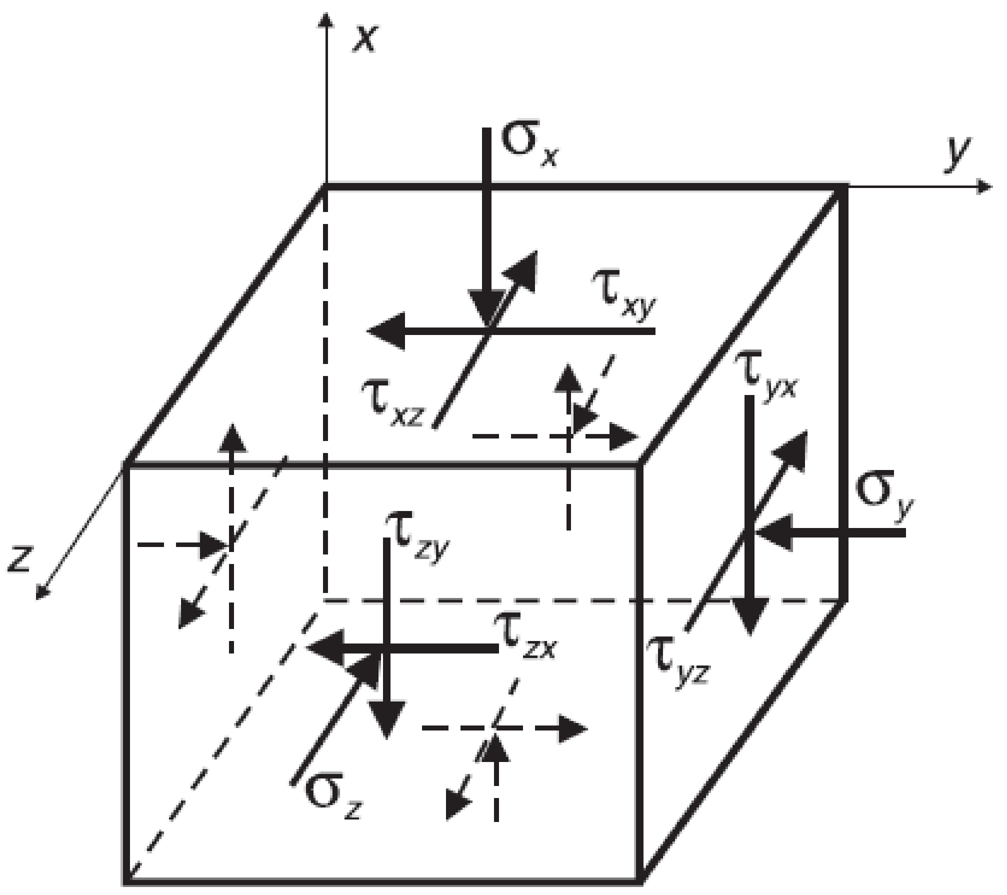


FEM numerical model

Finite Element Method (FEM)

(a) Equilibrium equations

Stresses within the soil medium
must satisfy equilibrium



Mathematical form: Cauchy momentum equation

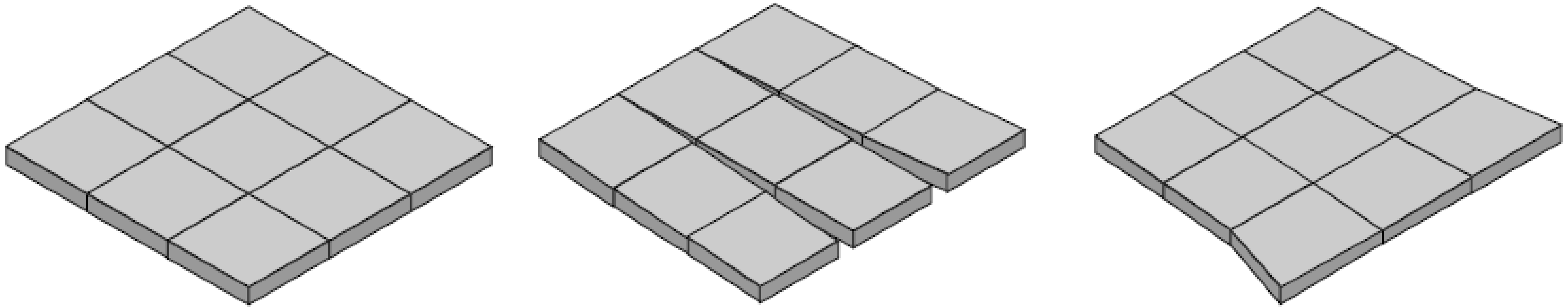
External body forces

$$\underbrace{div_{\boldsymbol{x}}\boldsymbol{\sigma}}_{\text{Divergence of stress tensor}} + \overbrace{\boldsymbol{b}}^{\text{External body forces}} = \underbrace{\rho\ddot{\boldsymbol{u}}}_{\text{Acceleration (equal to zero for static analysis)}}$$

Divergence of stress tensor

Acceleration (equal to zero for static analysis)

(b) Compatibility equations



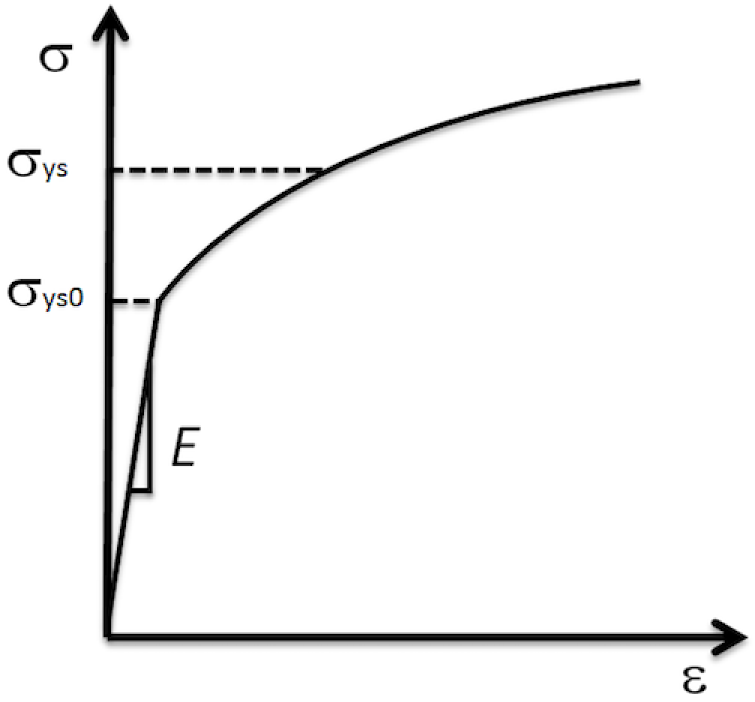
(a) Original (b) Non-compatible (c) Compatible

Strain to displacement relationship:

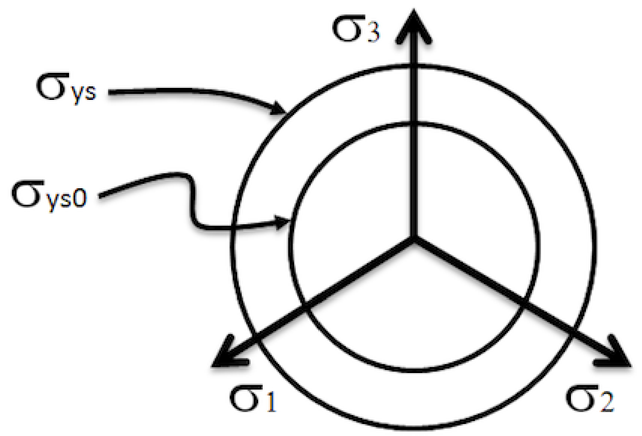
$$\varepsilon_x = -\frac{\partial u}{\partial x}; \quad \varepsilon_y = -\frac{\partial v}{\partial y}; \quad \varepsilon_z = -\frac{\partial w}{\partial z}$$

$$\gamma_{xy} = -\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}; \quad \gamma_{yz} = -\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}; \quad \gamma_{xz} = -\frac{\partial w}{\partial x} - \frac{\partial u}{\partial z}$$

(c) Constitutive law



Uniaxial stress-strain curve



Yield surface in principal stress-space

Constitutive law

$$\boldsymbol{\Delta\sigma} = f_m(\boldsymbol{\Delta\varepsilon})$$

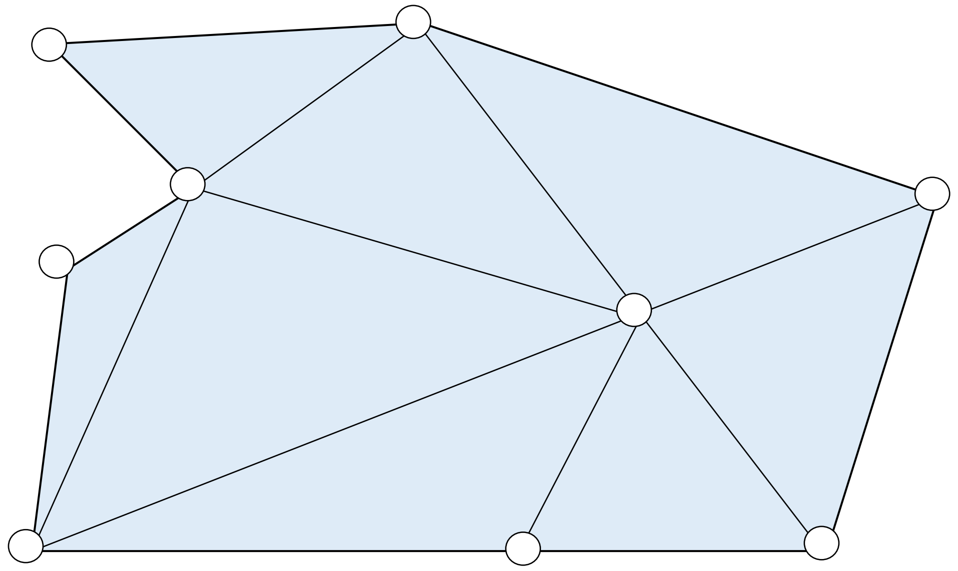
$$\begin{Bmatrix} \Delta\sigma_x \\ \Delta\sigma_y \\ \Delta\sigma_z \\ \Delta\tau_{xy} \\ \Delta\tau_{xz} \\ \Delta\tau_{zy} \end{Bmatrix} \qquad \begin{Bmatrix} \Delta\varepsilon_x \\ \Delta\varepsilon_y \\ \Delta\varepsilon_z \\ \Delta\gamma_{xy} \\ \Delta\gamma_{xz} \\ \Delta\gamma_{zy} \end{Bmatrix}$$

Stress increment

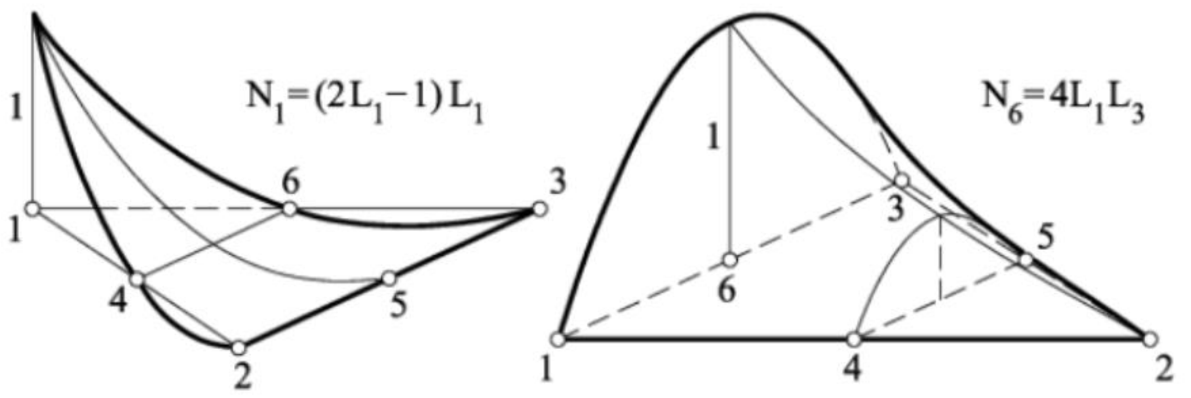
Strain Increment

Finite Element Method (FEM)

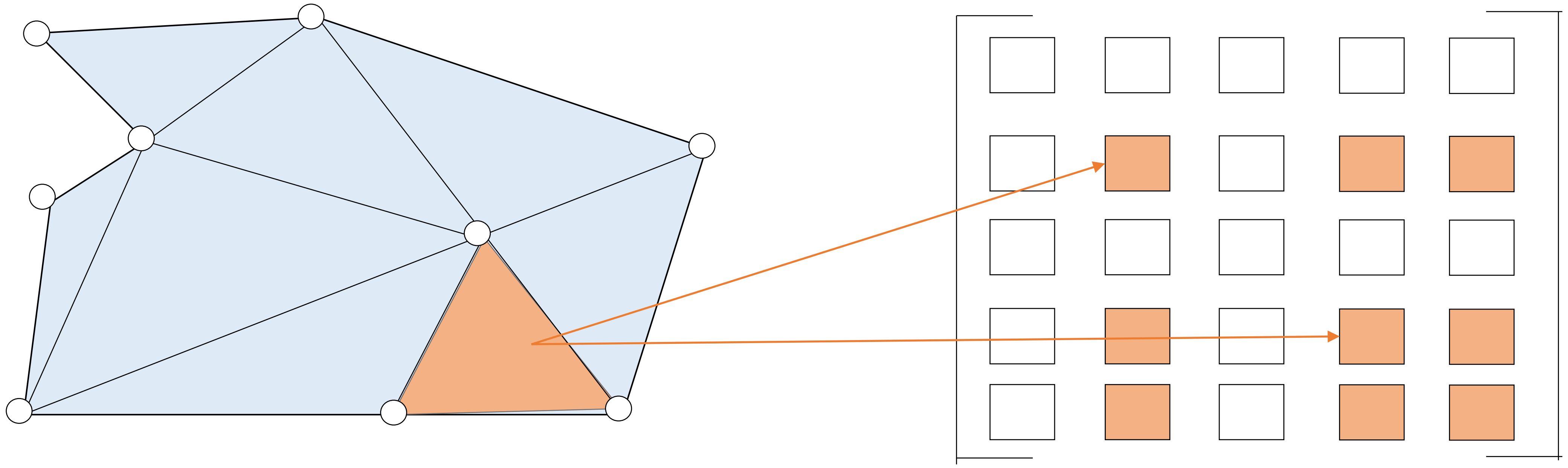
Reformulating the PDE system to an easily solvable system of algebraic equations!!



Step 1: Discretize the continuum

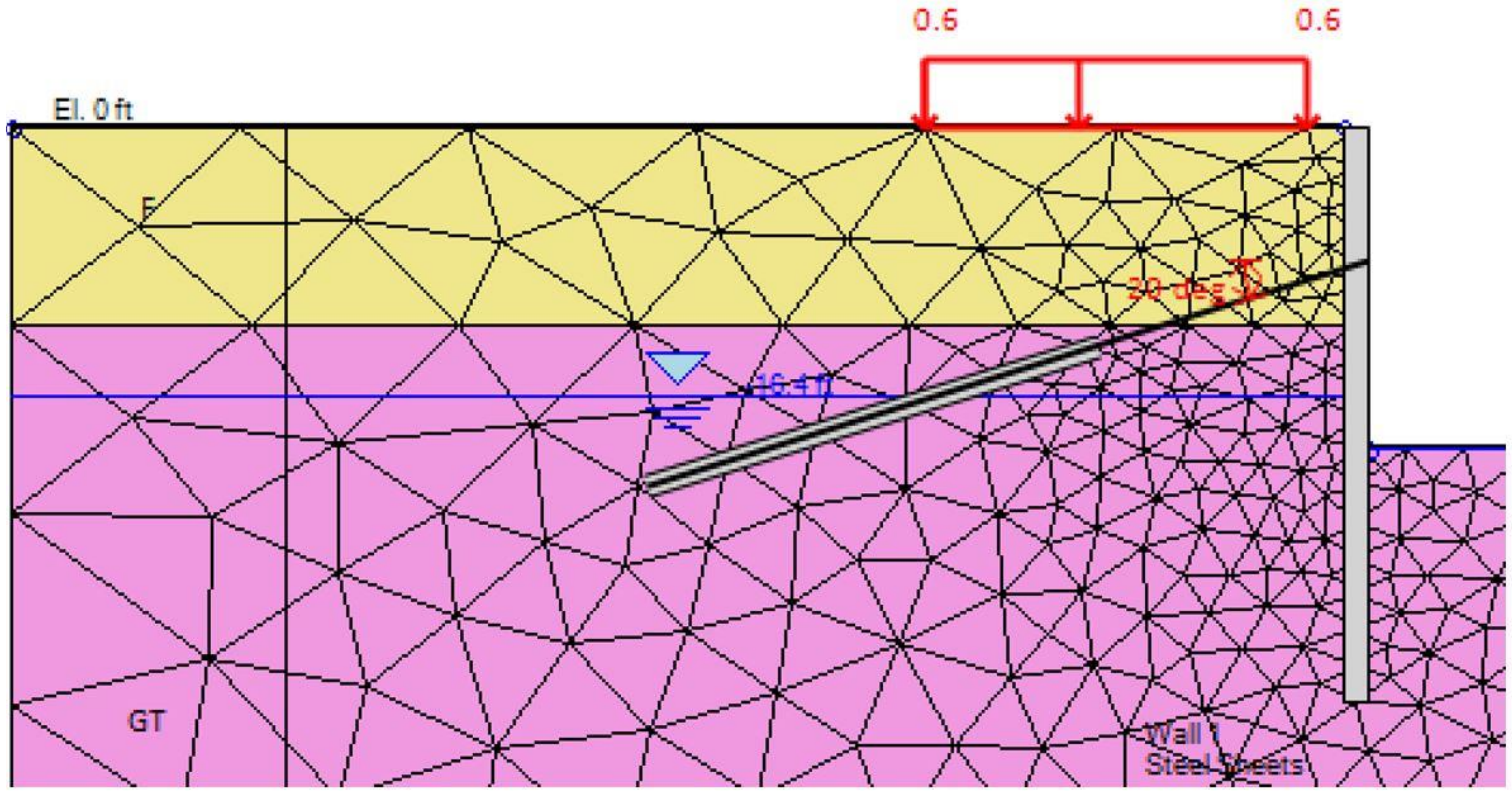


Step 2: Select interpolation functions



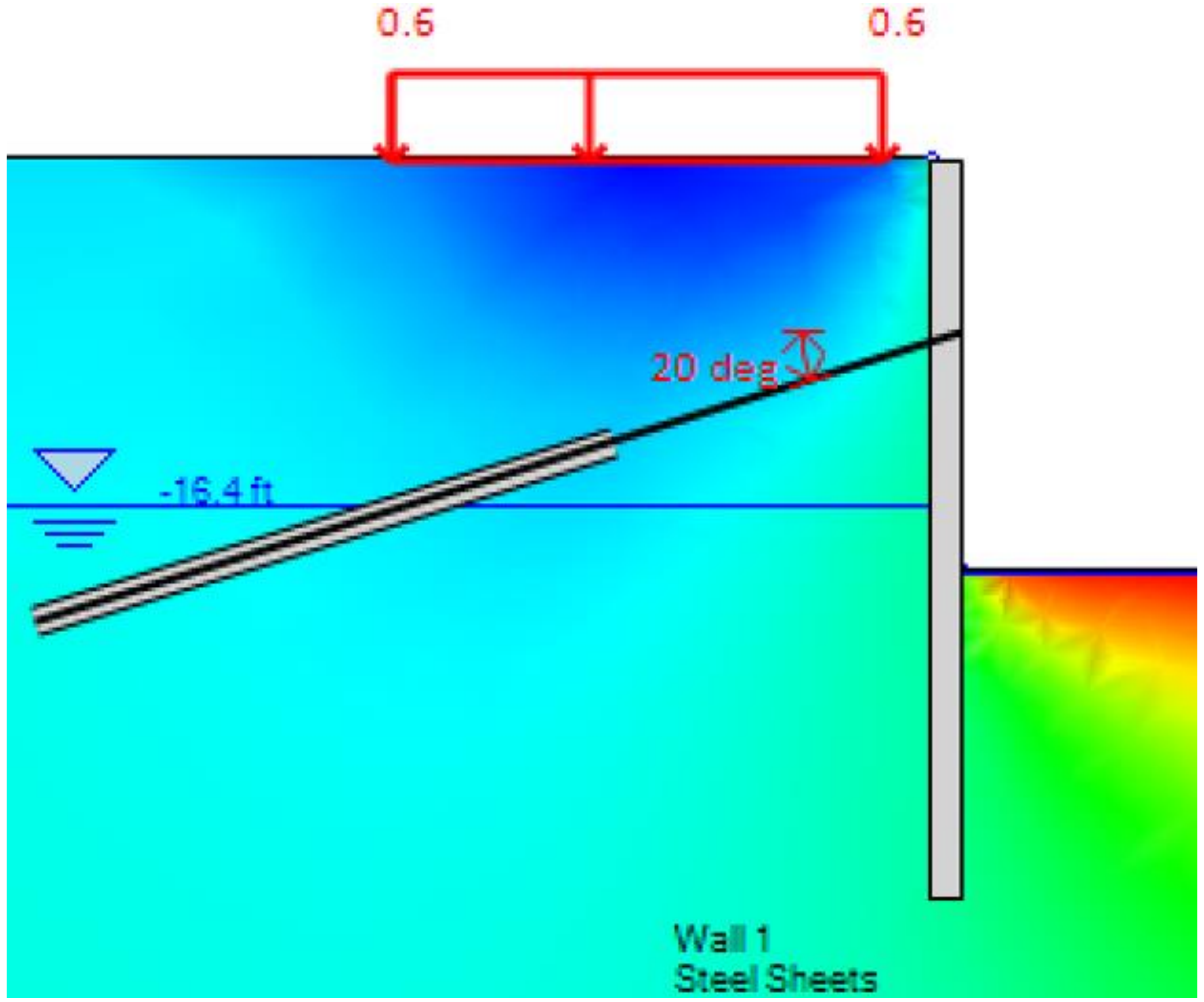
Step 3: Assemble the global equation system

Finite Element Analysis Concept (FEM)



Soil Models:

- ✓ Elastoplastic Model (Mohr - Coulomb)
- ✓ Exponential (Hyperbolic) Model (approximate solution)
- ✓ Exponential (Hyperbolic) Model (complete solution): Soil hardening model



- ✓ Moments and reactions calculated with Finite Elements
- ✓ Consider full soil-structure interaction
- ✓ Calculate surface settlements
- ✓ Design Tiedowns, Foundation Piles and Steel Columns

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Part 5

DeepEX Versions & Training Materials

- ✓ Customizable Packages
- ✓ Powerful Additional Modules
- ✓ Personal Technical Support
- ✓ Videos, Examples, Manuals

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