DeepEX
Shoring Design
Software

DEEP EXCAVATION
GEOTECHNICAL SOFTWARE & SOLUTIONS

Design of Deep Excavations

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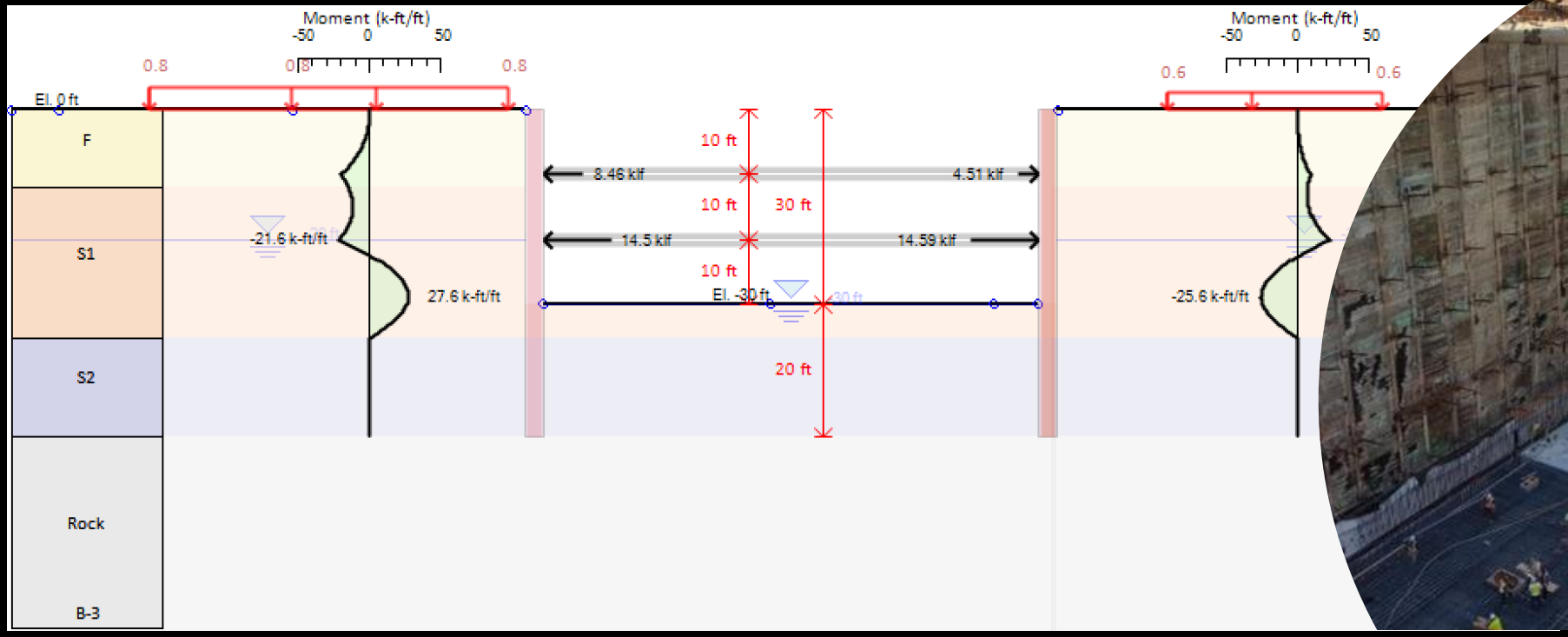
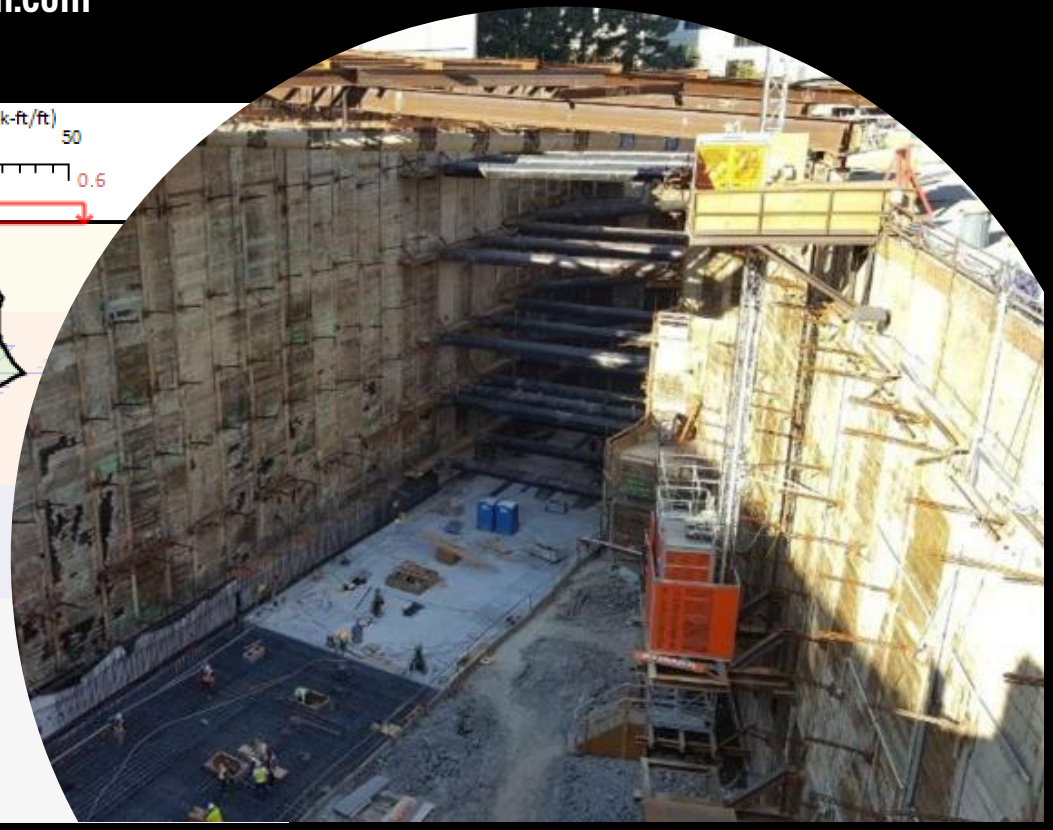




Introduction

How we got started in deep excavations!

Exhibit 2: Excavation at World Trade Center Liberty & Greenwich, 1968

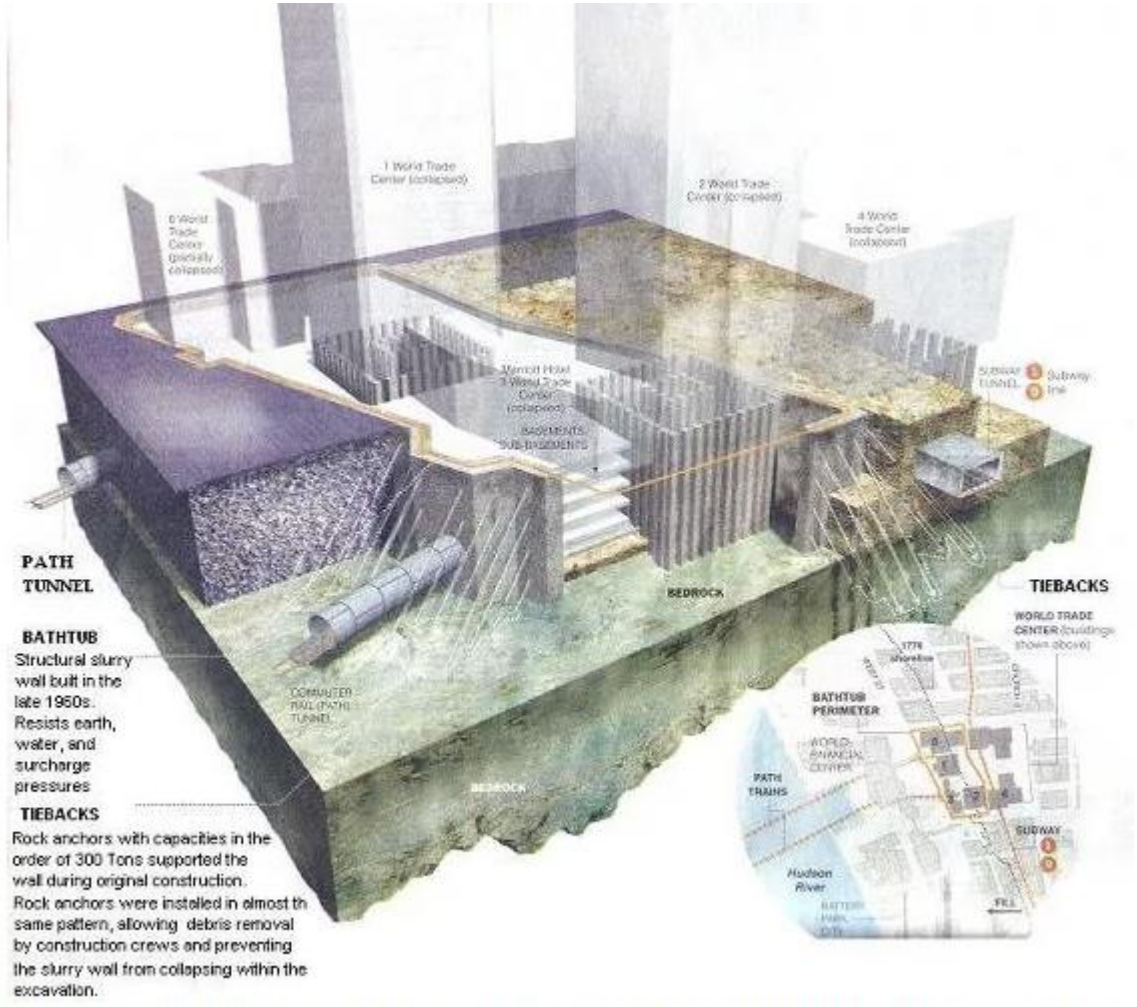
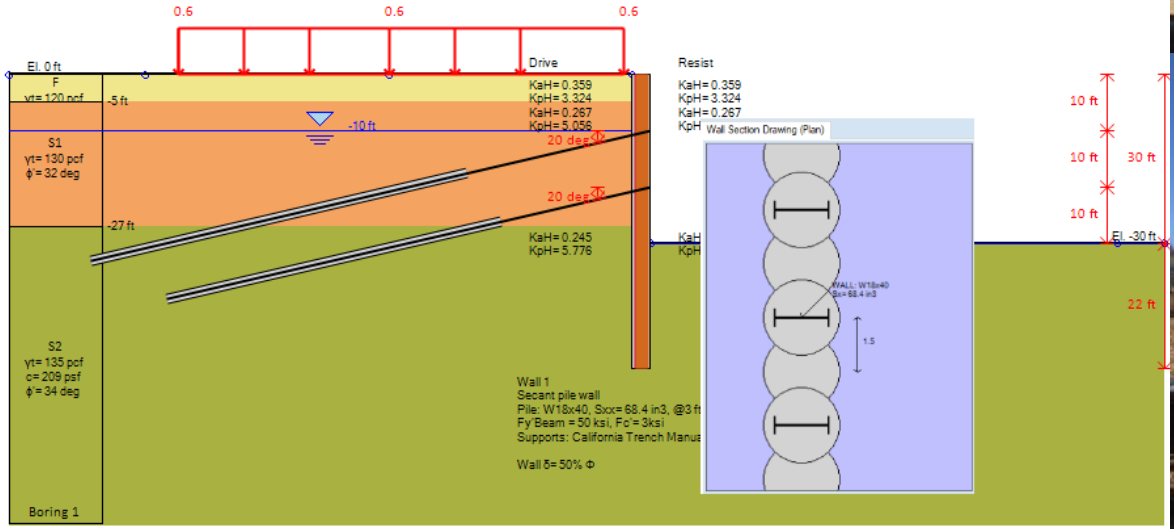


Exhibit 1: World Trade Center Bathtub and Original Conditions (adapted from NY Times 9/18/01)

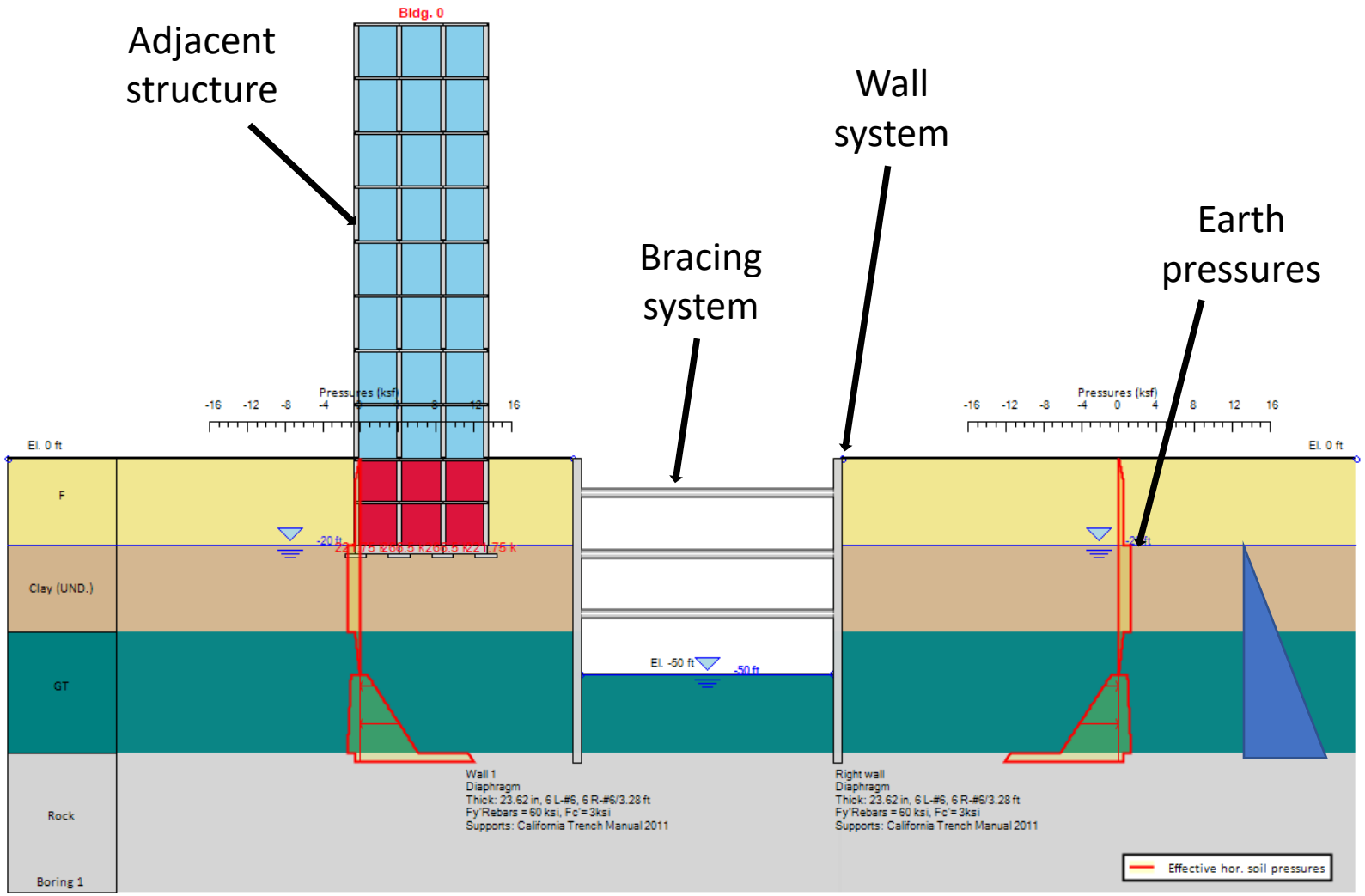
What in the word

Deep Excavation: Excavation deeper than 10 ft, 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



Lessons Learned



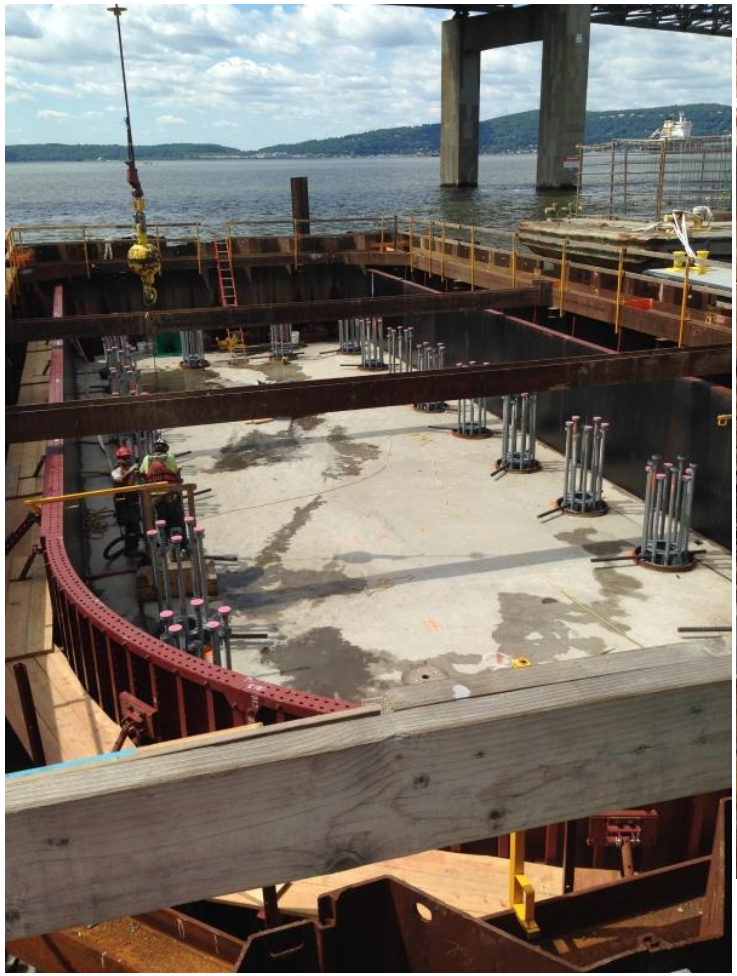
Things go wrong

Retaining wall collapse on May 12, 2005

Soldier pile walls

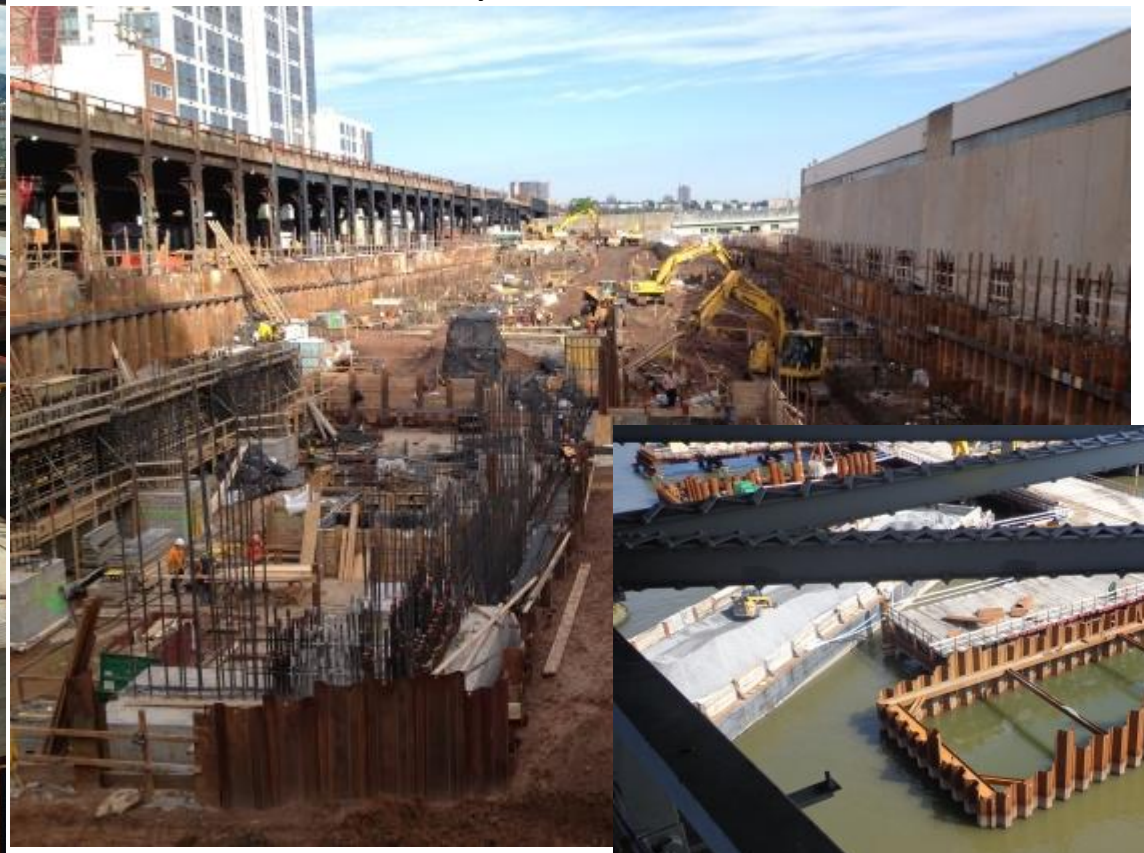
Internal bracing - Subway Station

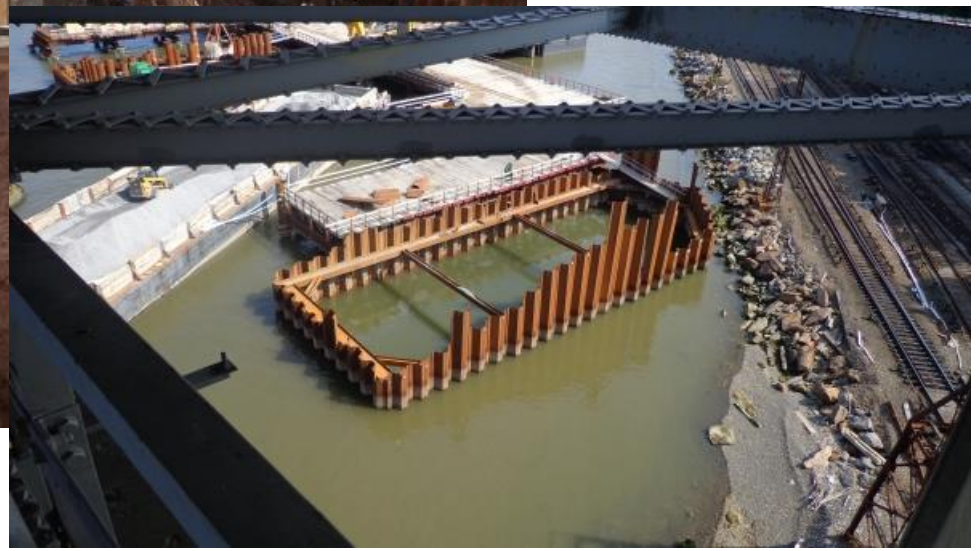
Cofferdams - sheet piles



Courtesy: Siefert Associates

Courtesy: FNA Associates





Courtesy: Siefert Associates

Secant pile walls - circular shafts

Courtesy: Hayward Baker

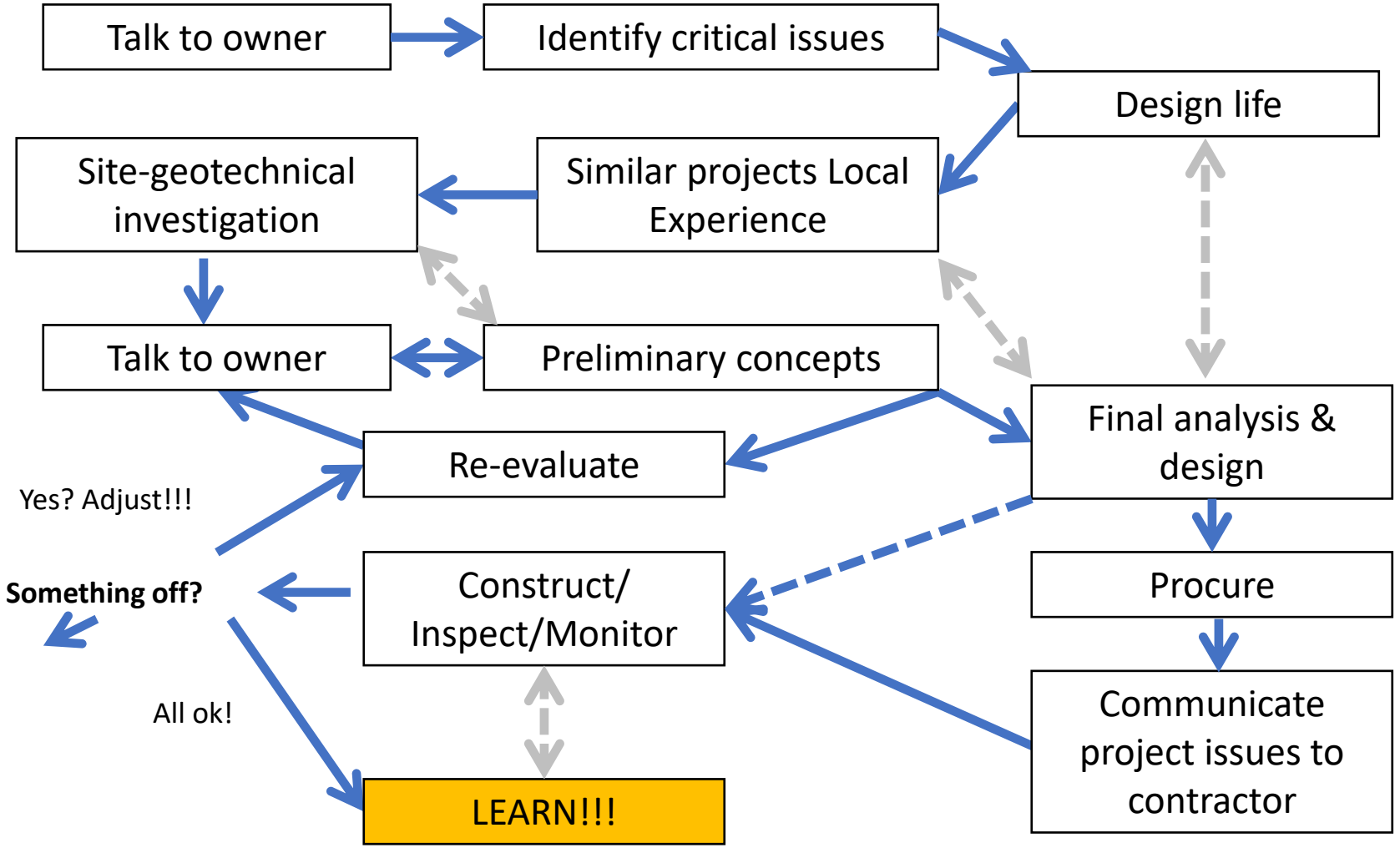
Diaphragm walls

Where do we start

Soil, rock, water, and what's in place

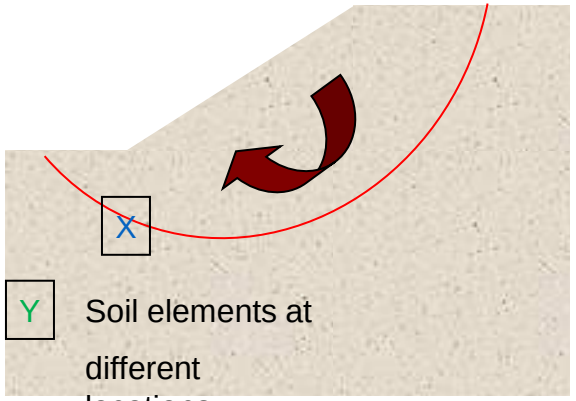
- Soil variability
- Soil strength, drained-undrained
- Water conditions
- Thin-layers
- Collapsible soils
- In-situ vs. laboratory tests
- Consolidation settlements
- Obstructions
- Unforeseen conditions
- Fake geotechnical reports
- Overly conservative data
- Living on the edge?
- Water flow
- Groundwater drop down
- Contamination
- Utilities
- Existing structures

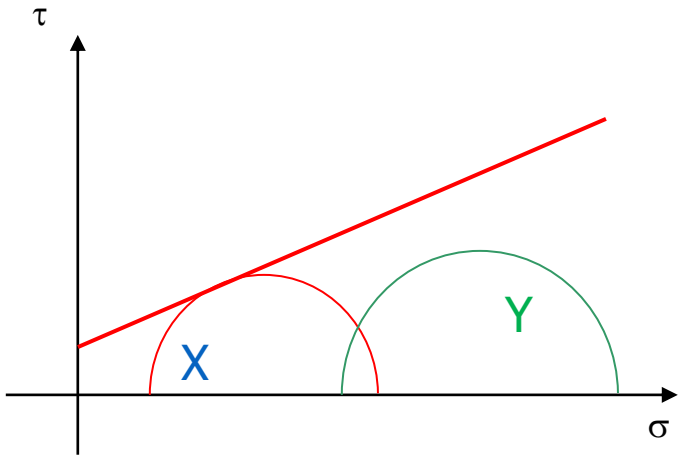
Deep excavation process



Soil strength

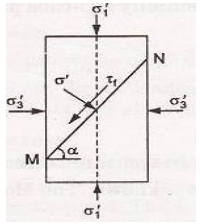
- Sands, silts, rocks, IGM
  - Use c’ and ϕ’
- Clays in general:
  - Drained : c’ and ϕ
  - Undrained: Su
  - Look at default response

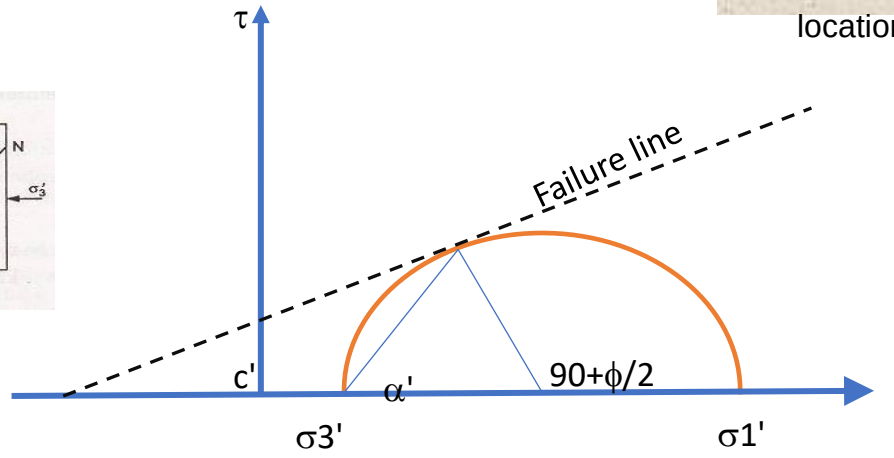




X ~ failure

Y ~ stable

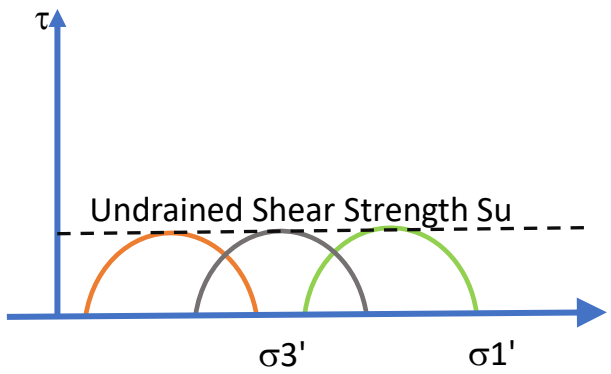


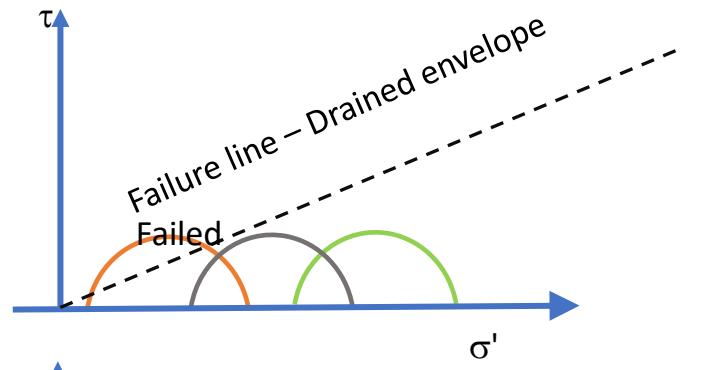


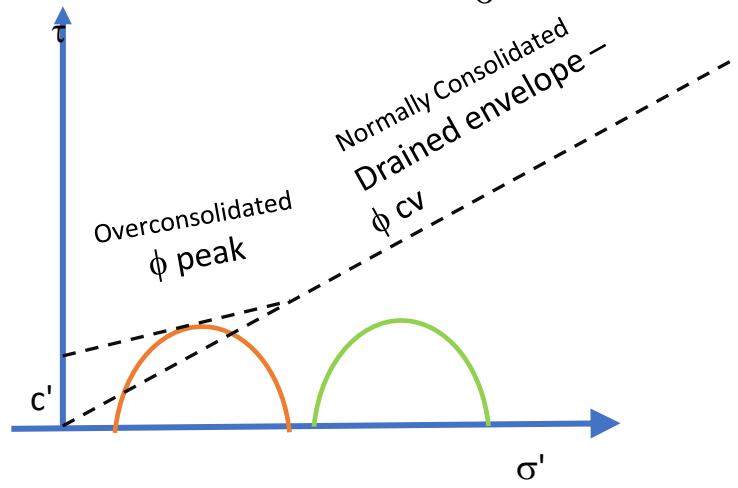
$\tau = c' + \sigma' \tan(\phi)$

Clay strength

- Clays undrained response
  - "Quick" stress change
  - Must be close to full saturation
  - Excess pore pressures

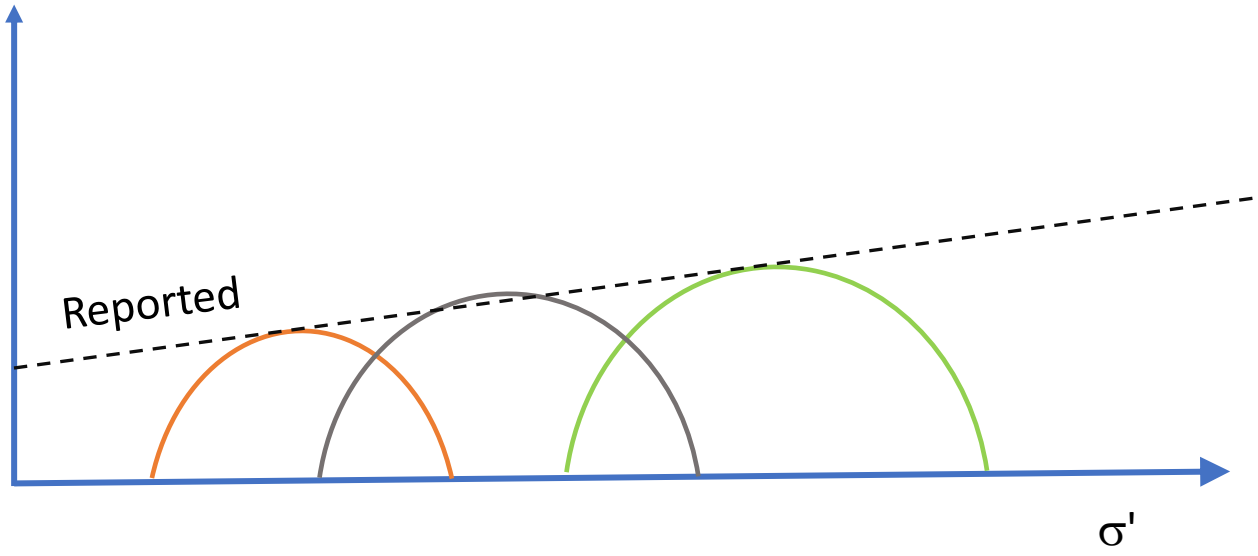






Clay Example

- Three clay samples are taken from the same depth. They were tested in the lab and the following strengths were reported:
  - c' = 800 psf, ϕ = 10 degrees



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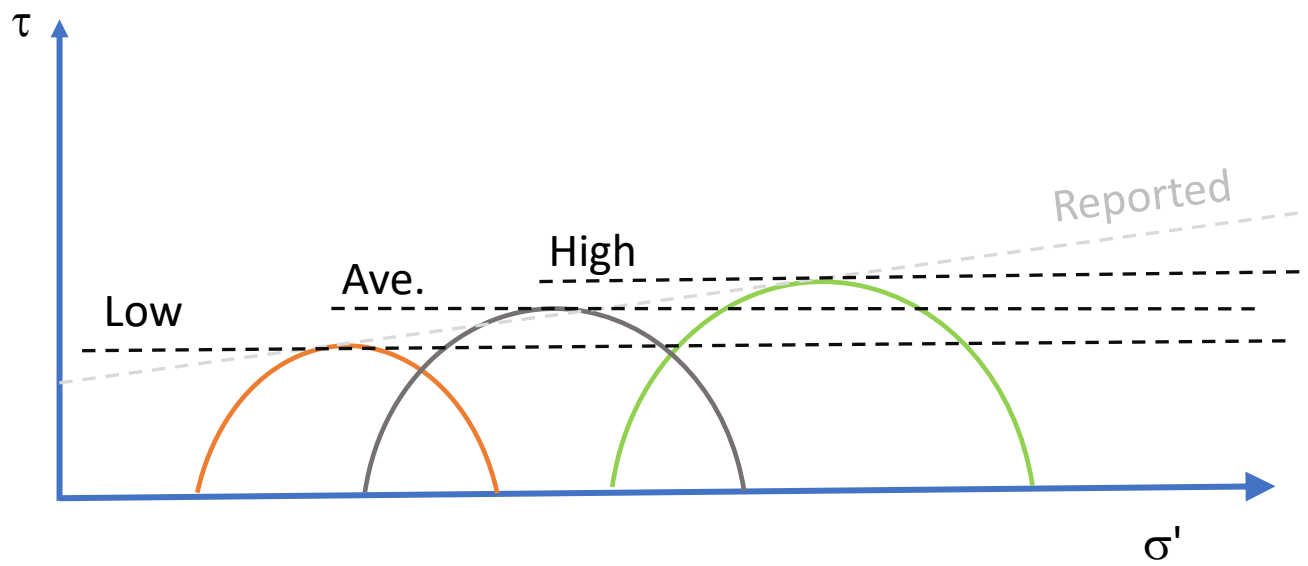
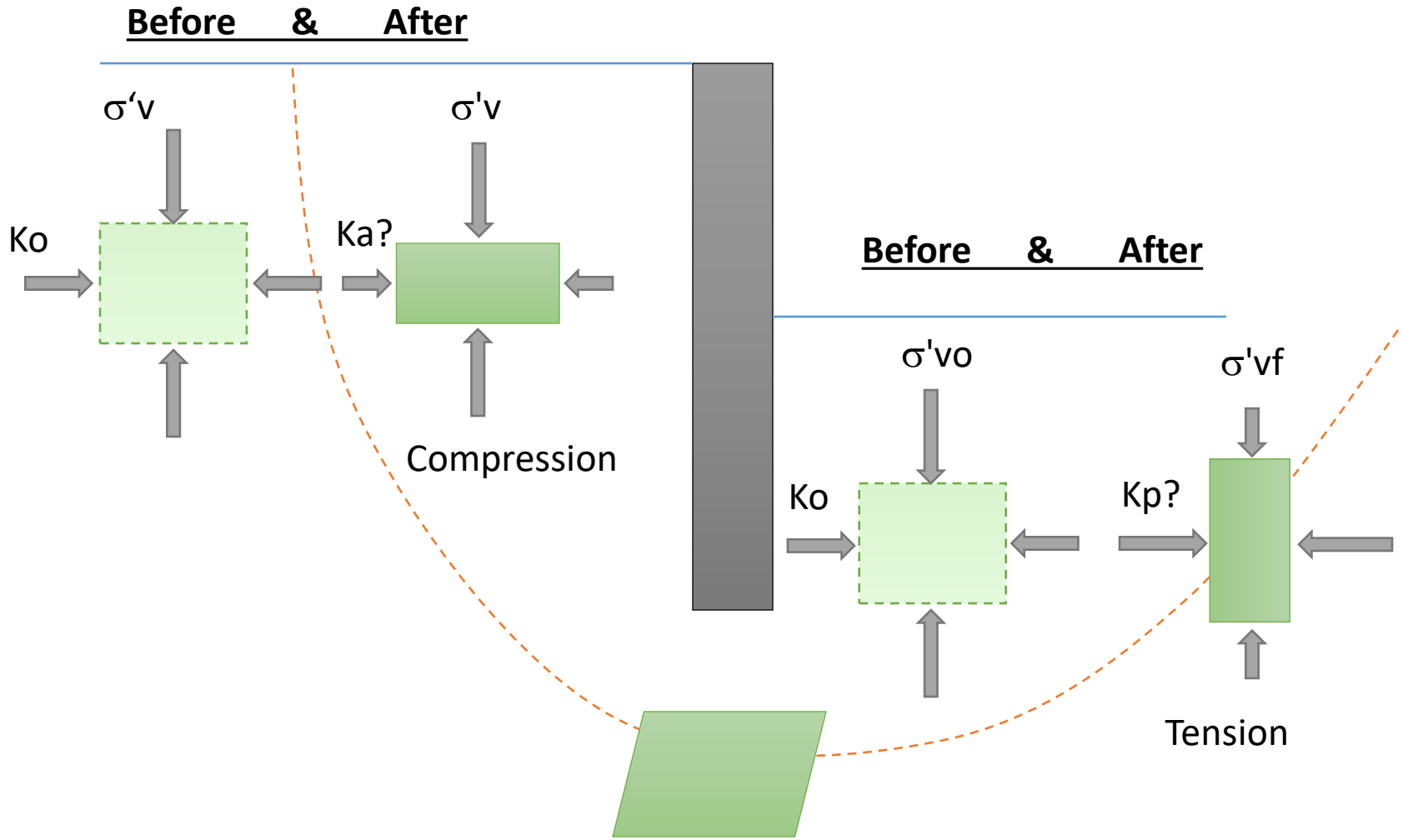
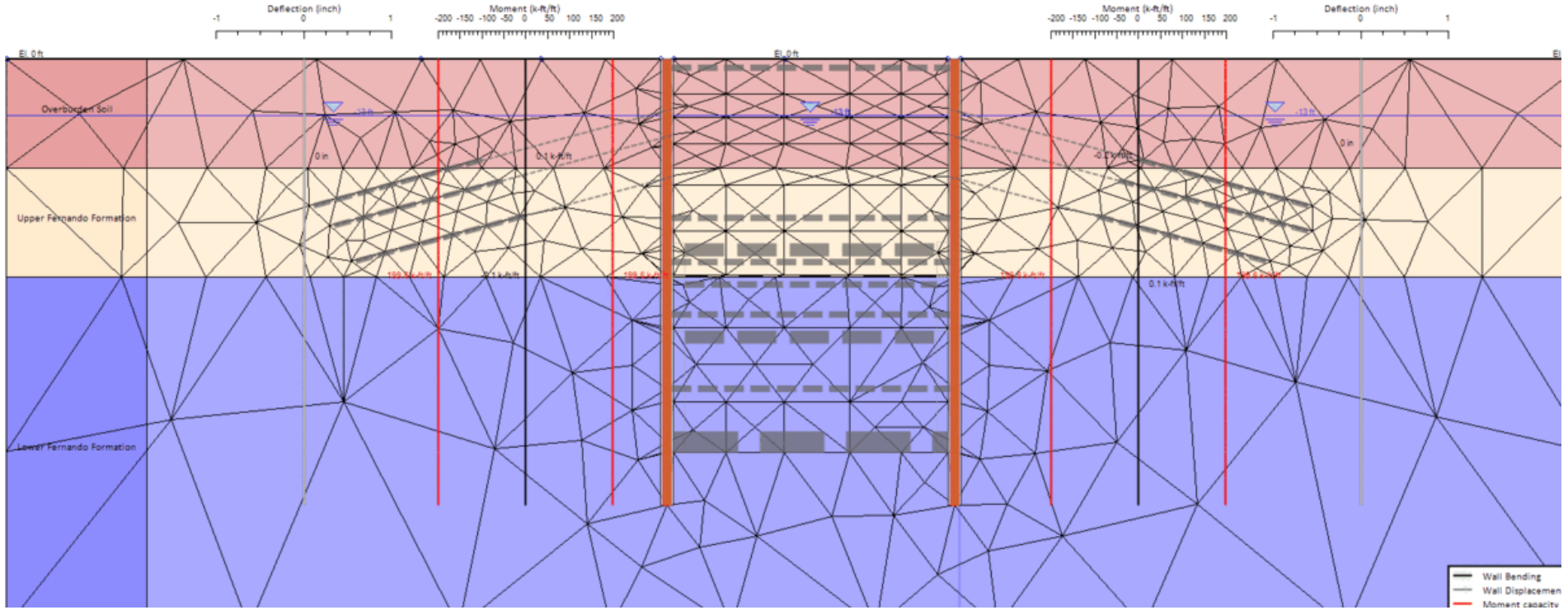


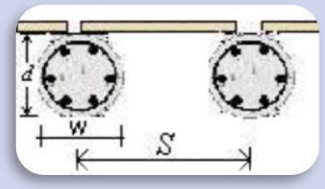
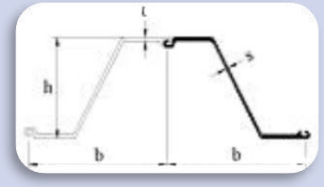
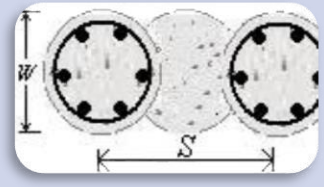
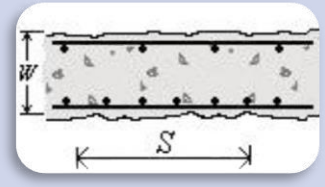
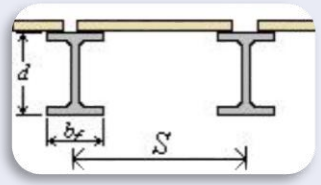
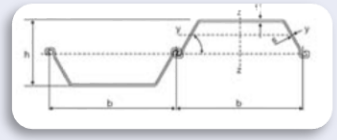
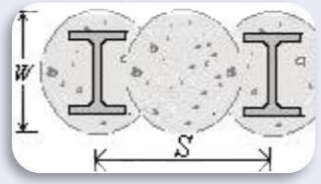
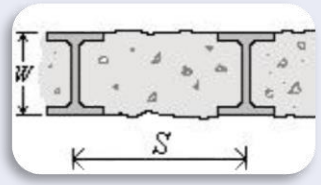
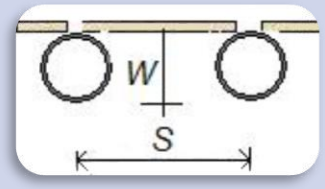
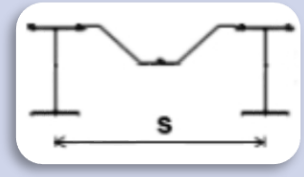
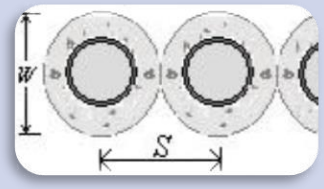
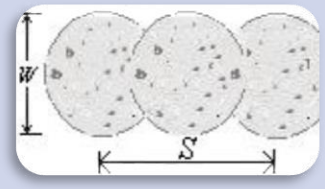
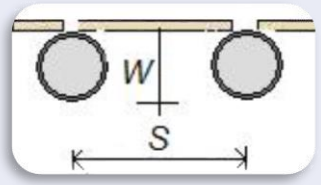
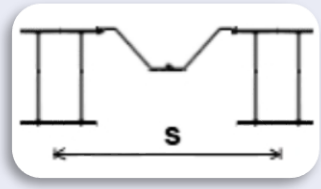
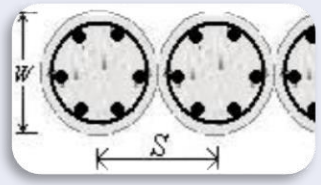
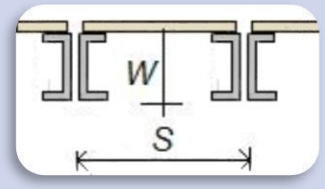
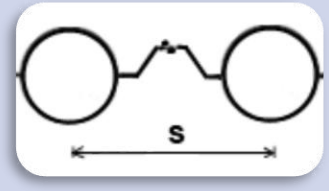
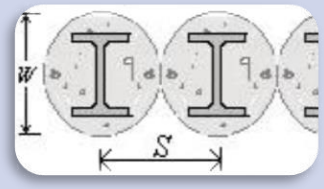
Soil response in deep excavations



Staged Construction

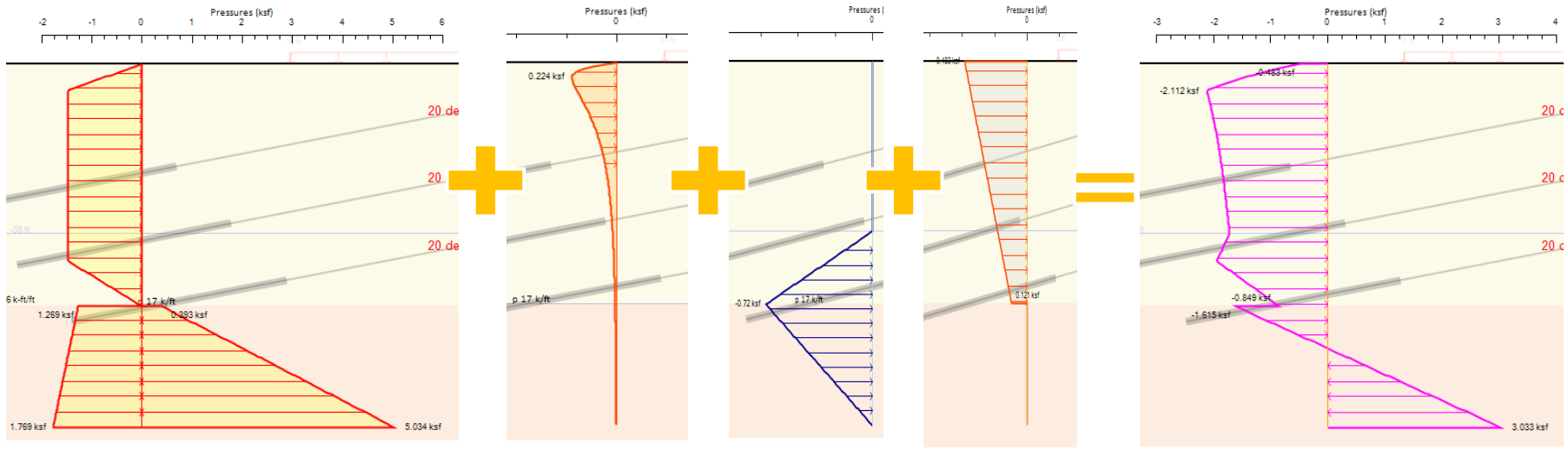
- Deep excavations always require staged construction.
- Even wall construction can affect performance.
- Start from at-rest conditions (or before)



Soldier pile walls	Sheet piles / Combined walls	Secant/Tangent piles	Slurry walls SPTC, Soil Mix, etc
			
			
			
			Jet grout
			Ground freezing

Traditional Design Approach

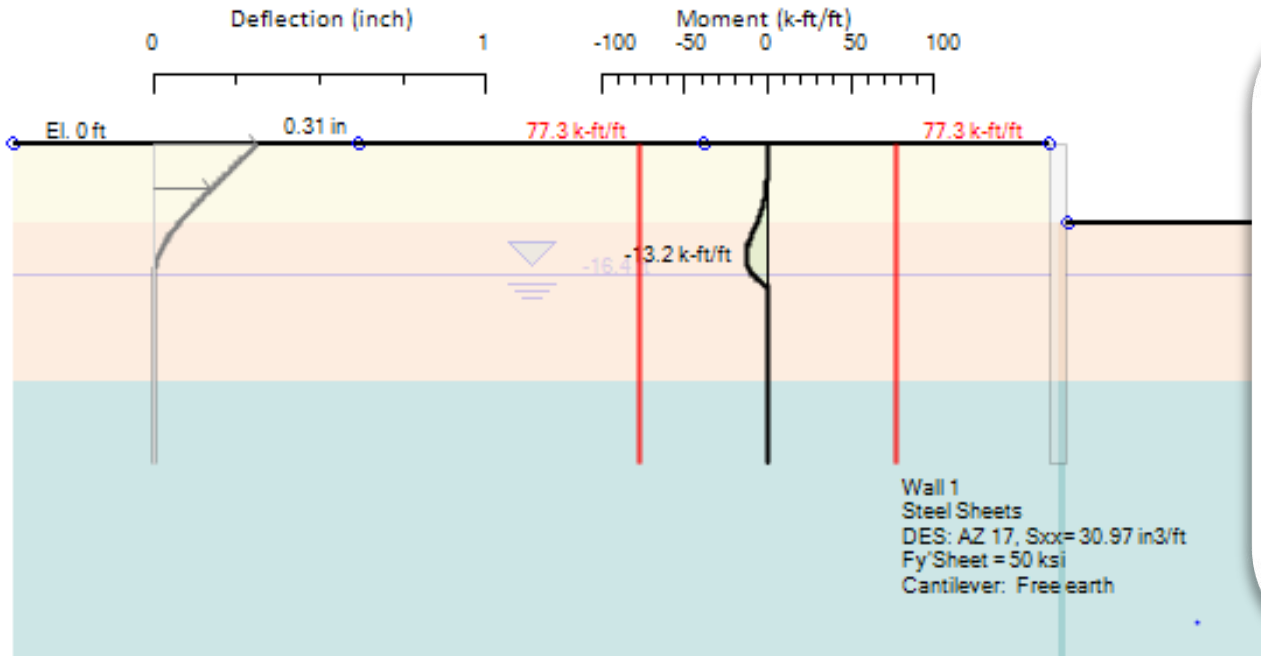
Determine net loading diagram on wall

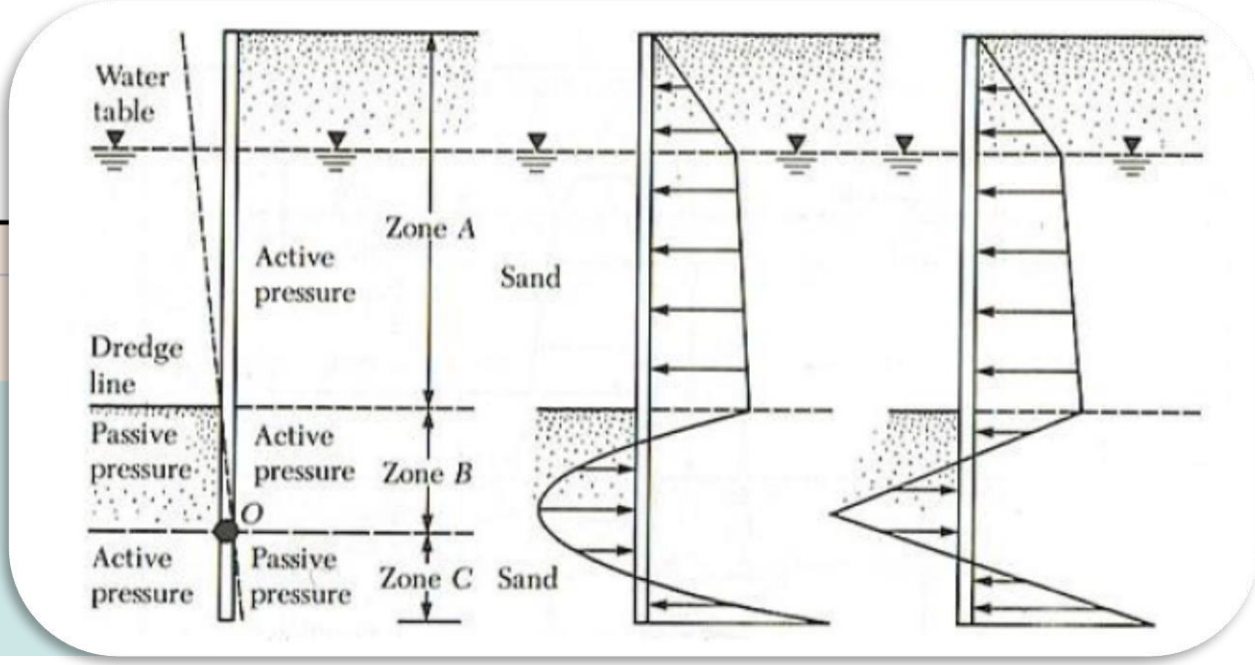


Soil pressures **Surcharge** **Water** **Seismic** **Net loading**

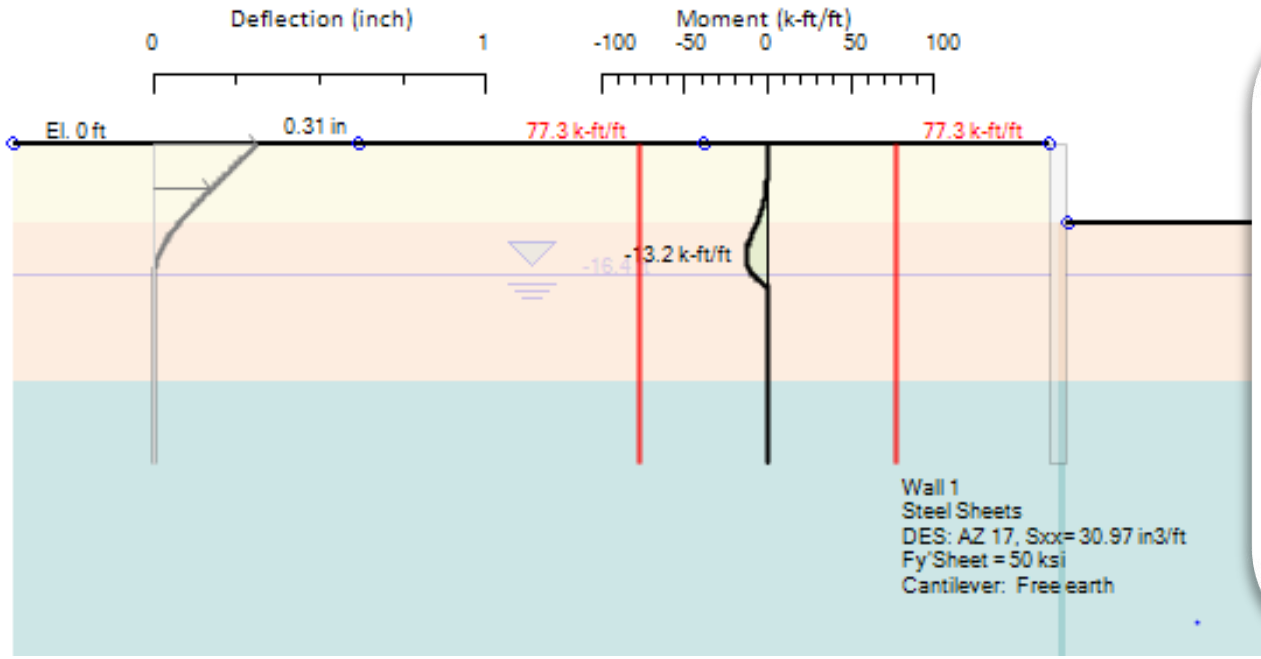
Soldier pile walls (berlin type), 3D effects
Pile spacing above excavation,
Active and passive effective widths, Water width

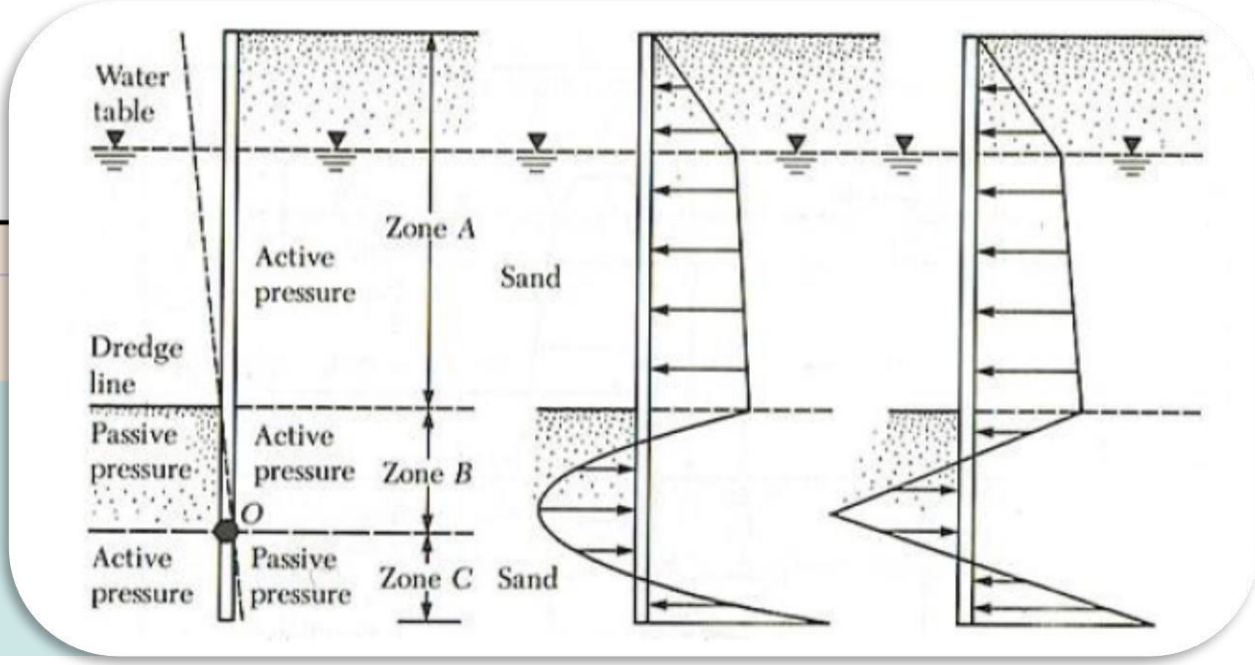
Cantilever excavation





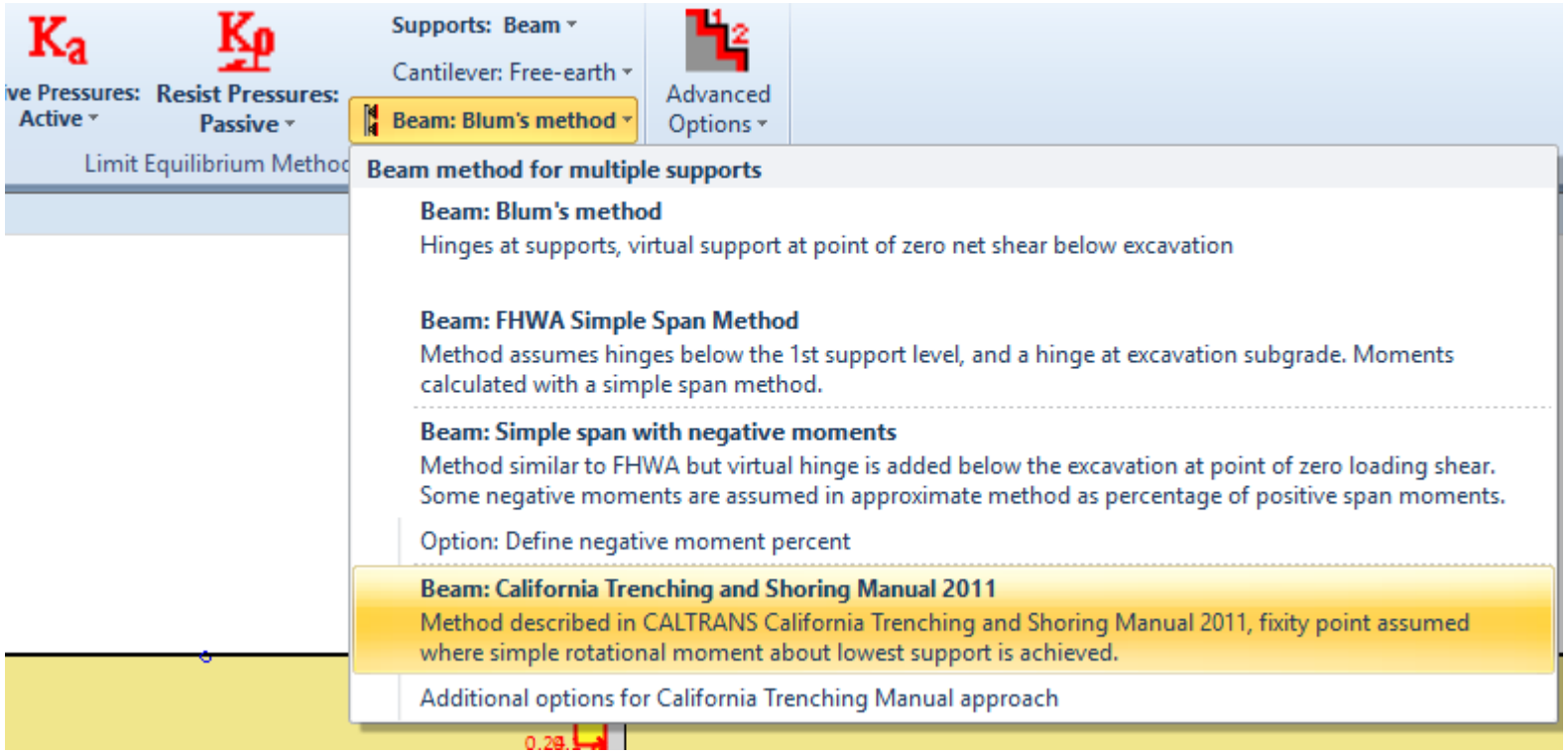
Cantilever excavation





CALTRANS METHODS

- Use CALTRANS approach for more reasonable cantilever displacements



SURCHARGE METHODS

12.6.4 Due to Strip Load (No Yielding Wall)

Similarly, Boussinesq's solution due to a strip load (Figure 12.30) is doubled to get lateral stress on a non-yielding wall as:

$$\sigma_h = \frac{2q}{\pi}\,[\beta - \sin\beta\,\cos(2\theta)] \qquad (12.45)$$

where angles β and θ are defined in Figure 12.30.

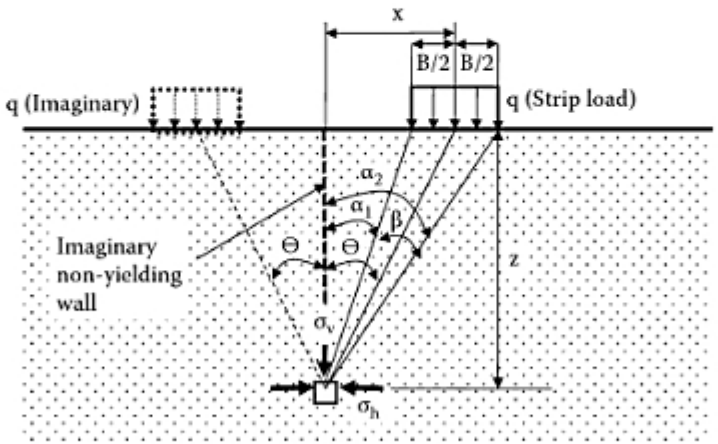
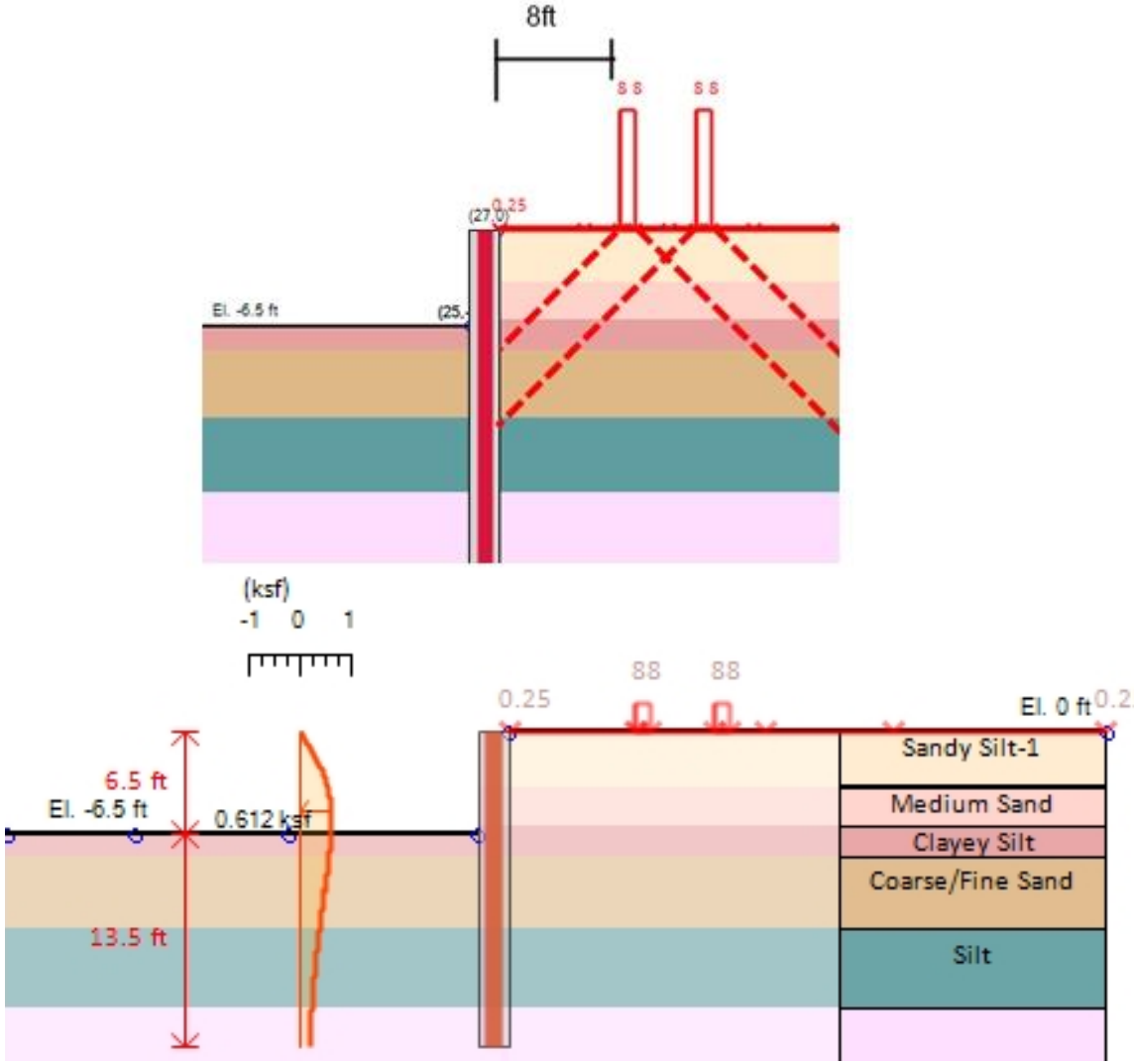


FIGURE 12.30 Boussinesq's lateral stress against nonyielding wall due to strip load.

Figure 1: Excerpt from "Soil Mechanics Fundamentals"



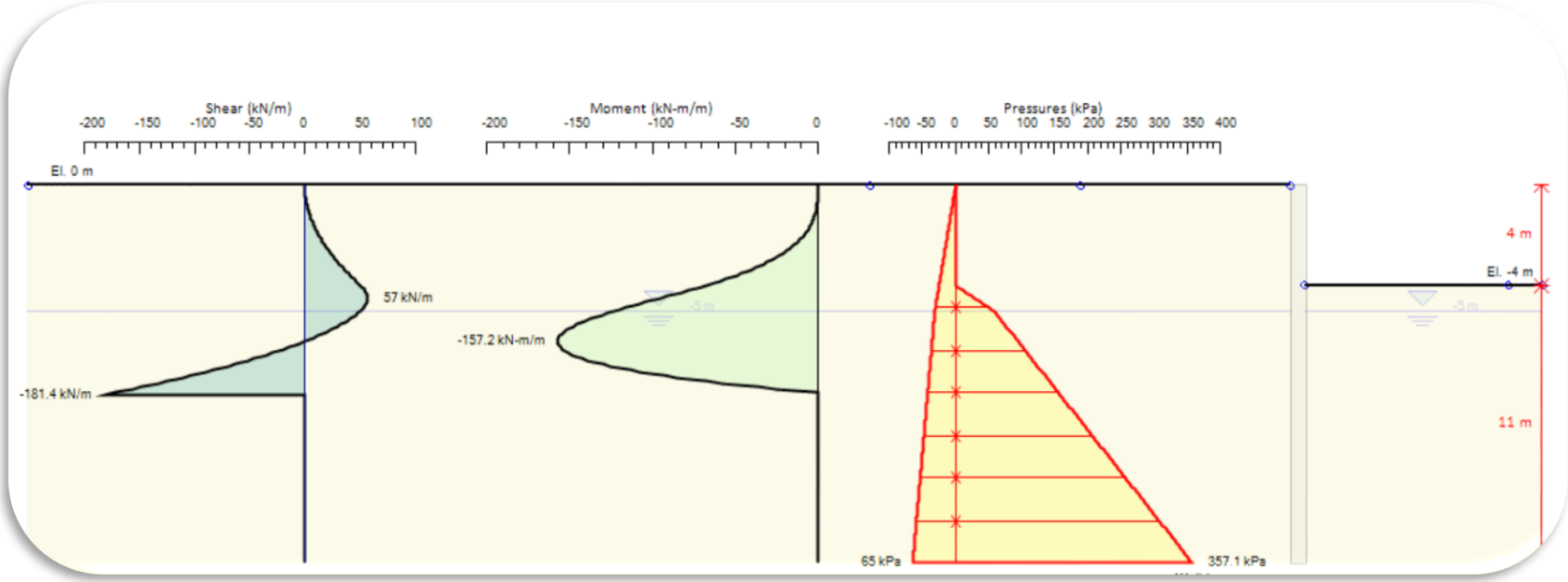
CALTRANS METHODS

Balances out moment

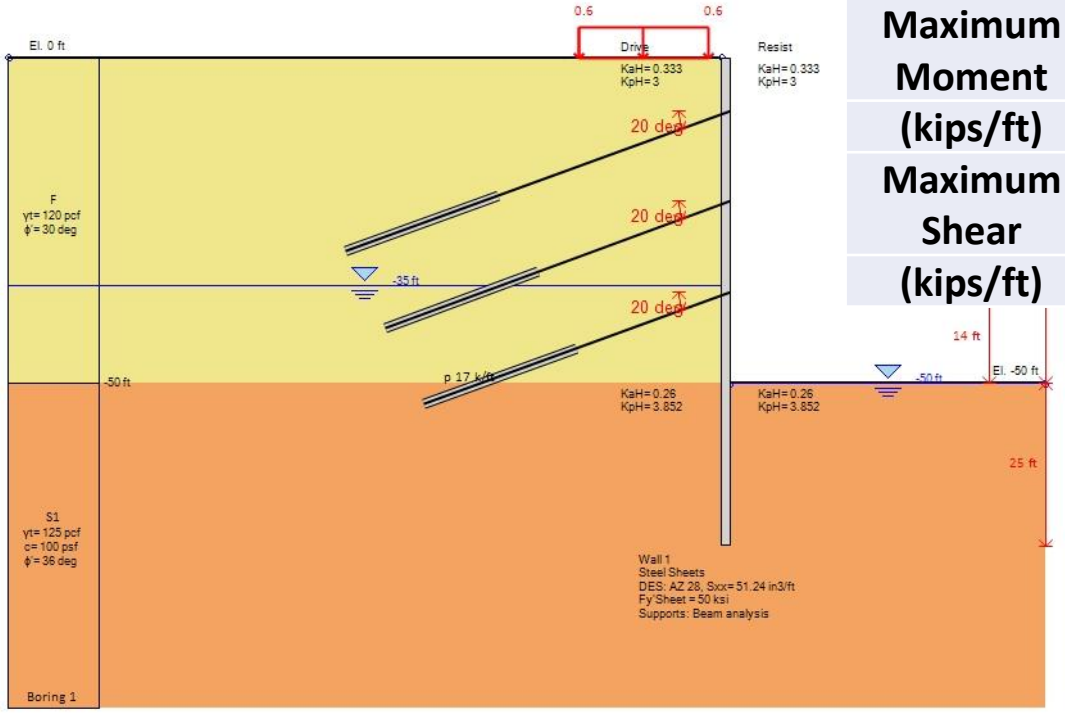
Shear not balanced

Increase length by 1.2 to get FS 1.0

Then apply additional safety factors



LEM Methods

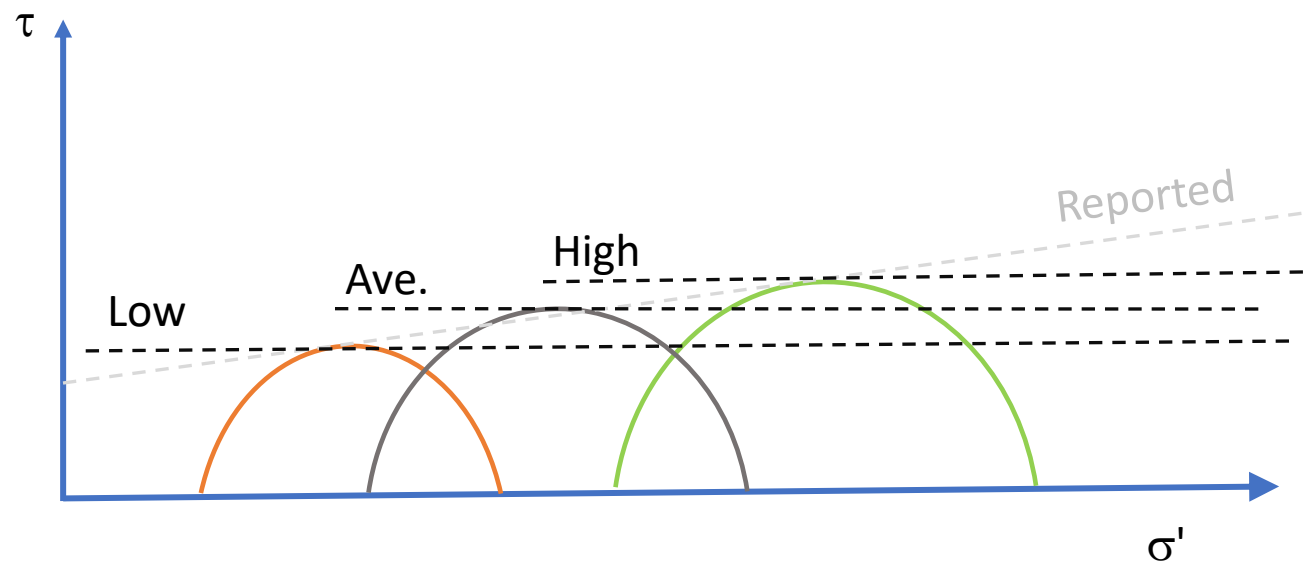


Static loading final excavation (50 ft exc.)

	Blums's method	FHWA Simple span	FHWA Mixed Blum	CALTRANS Method	CALTRANS - negative	Nonlinear analysis*
Maximum support reaction (kips/ft)	33.68	23.91	27.66	30.08	30.08	30 – 31.8
Maximum Moment (kips/ft)	58.25	36.78	74.29	99.41	87.45	65 – 86
Maximum Shear (kips/ft)	18.13	13.14	15.49	17.77	17.77	17.4 - 20

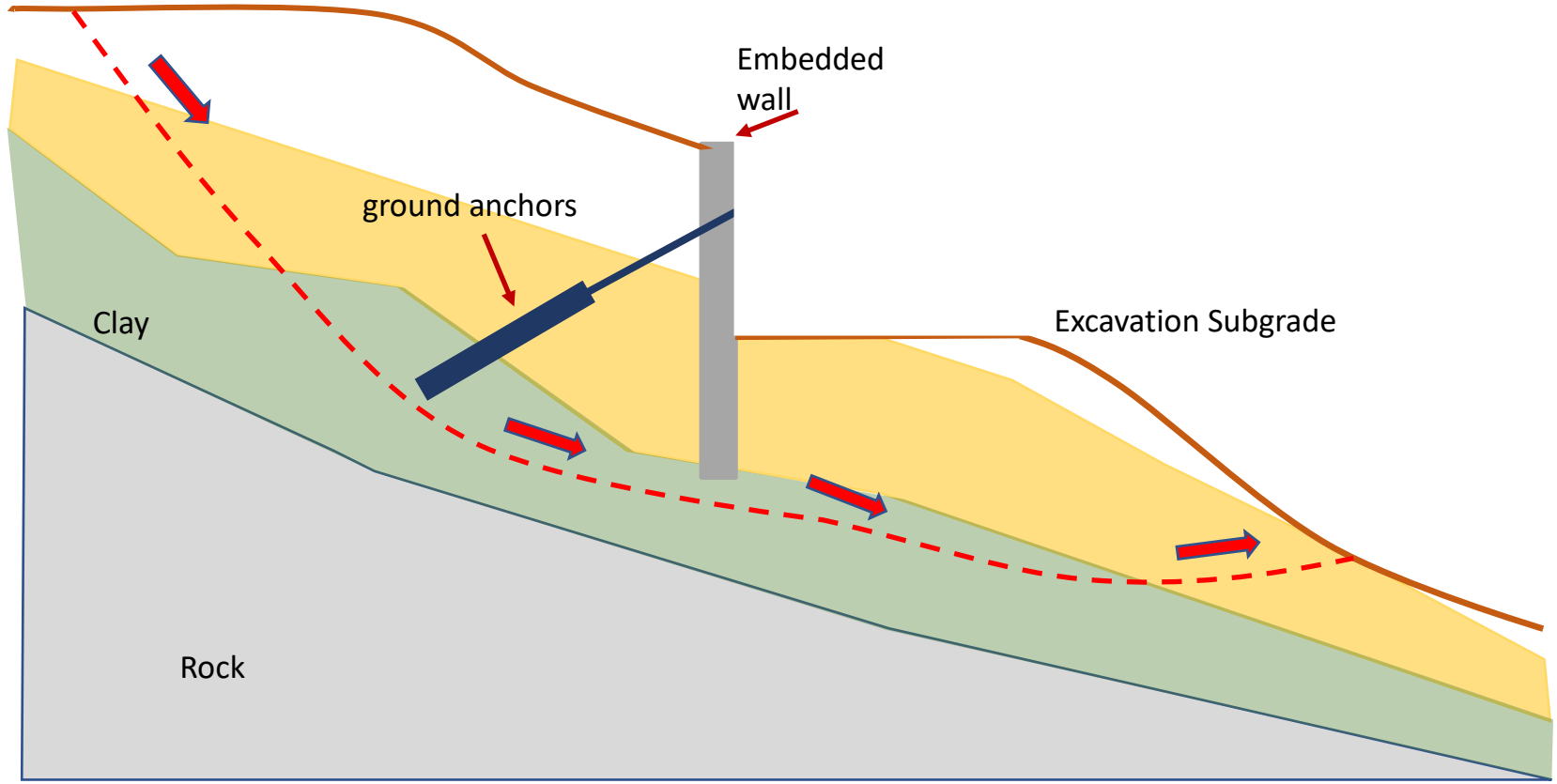
Clay Example

- Three clay samples are taken from the same depth. They were tested in the lab and the following strengths were reported:
  - c’ = 800 psf, ϕ = 10 degrees

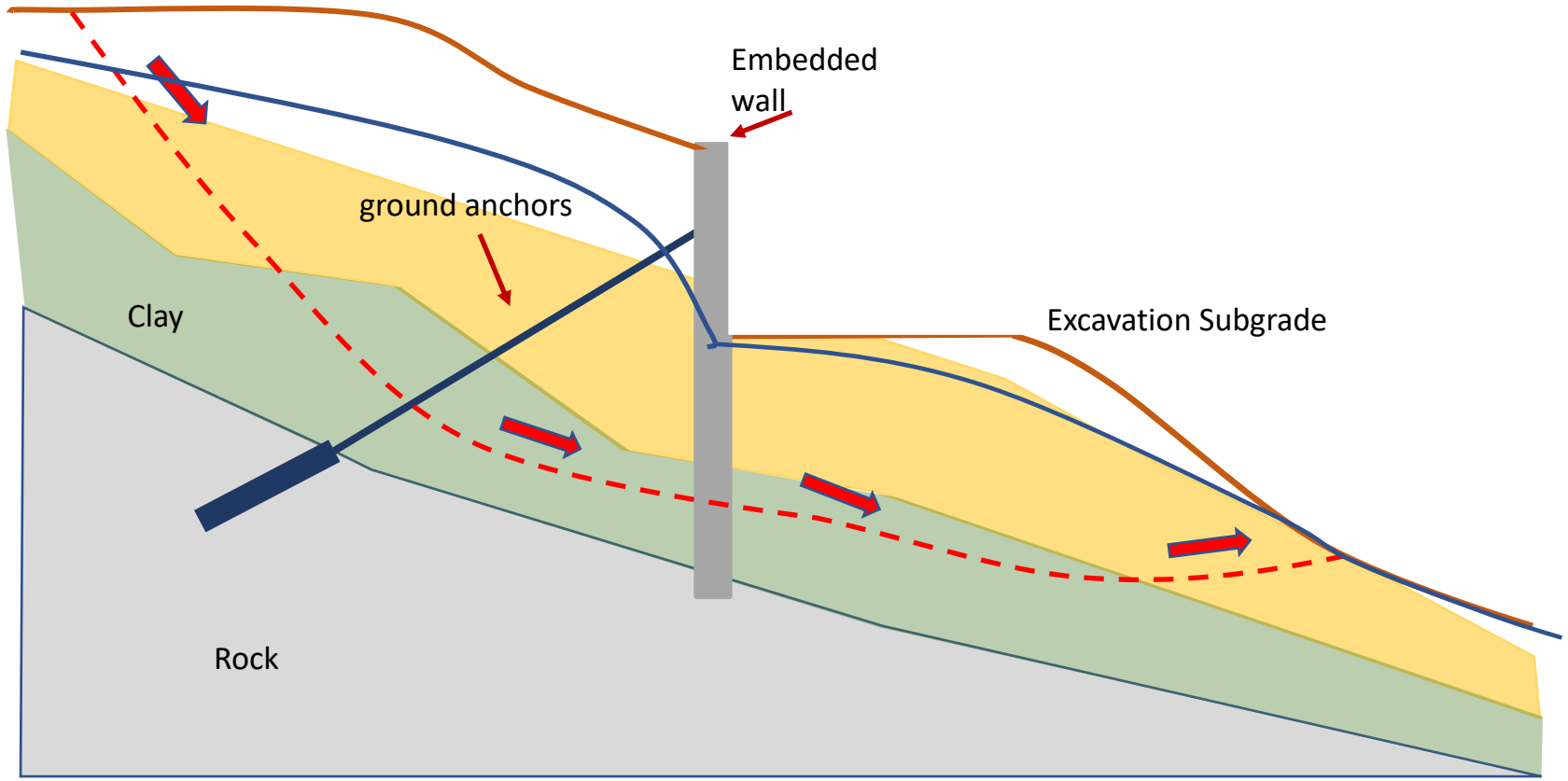


COMPLEX SLOPES

- Traditional active and passive pressures are based on active and passive wedges.
- In slopes, many times, sliding mass is far beyond a simple wedge



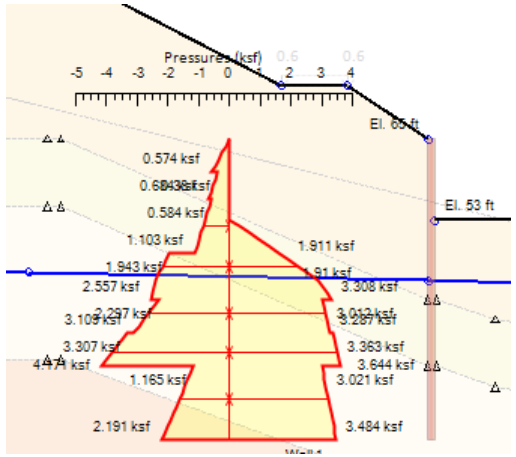
SLOPE STABILIZATION

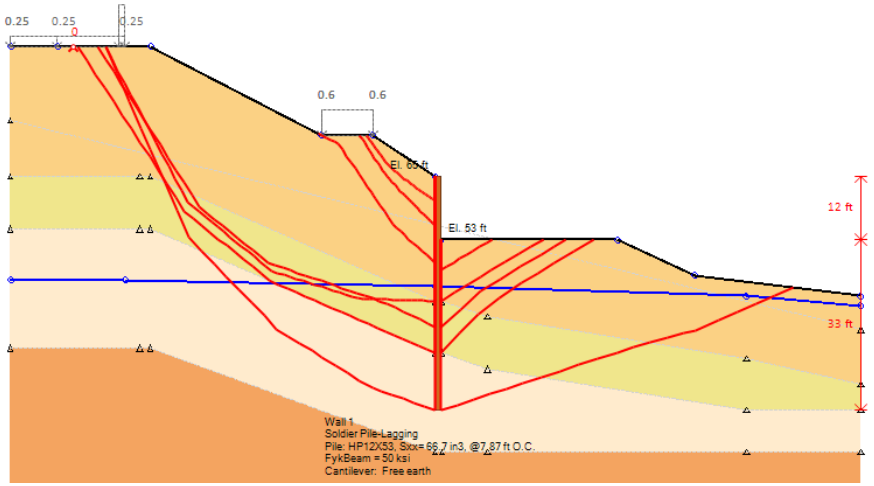


Wedge vs. Non-linear slip surfaces

Wedge active search: Active thrust = 54.5 k/ft of wall

Automatic search in clays, Active thrust: 77.1 k/ft of wall



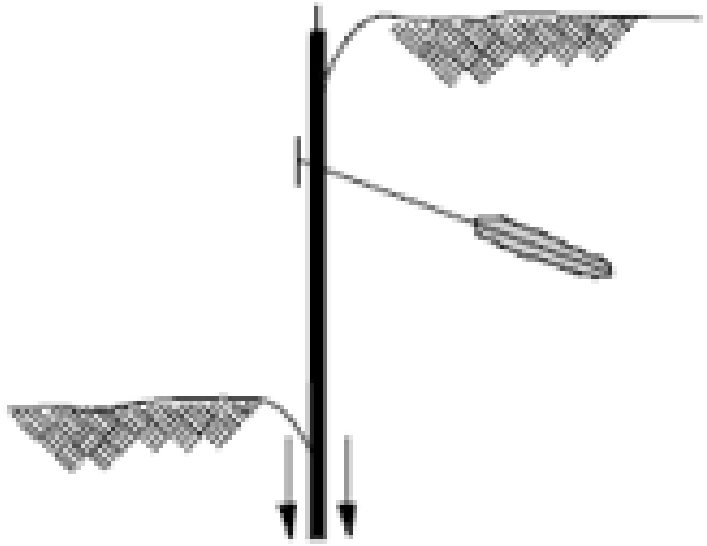


AXIAL WALL FORCES

Ignoring axial forces on wall

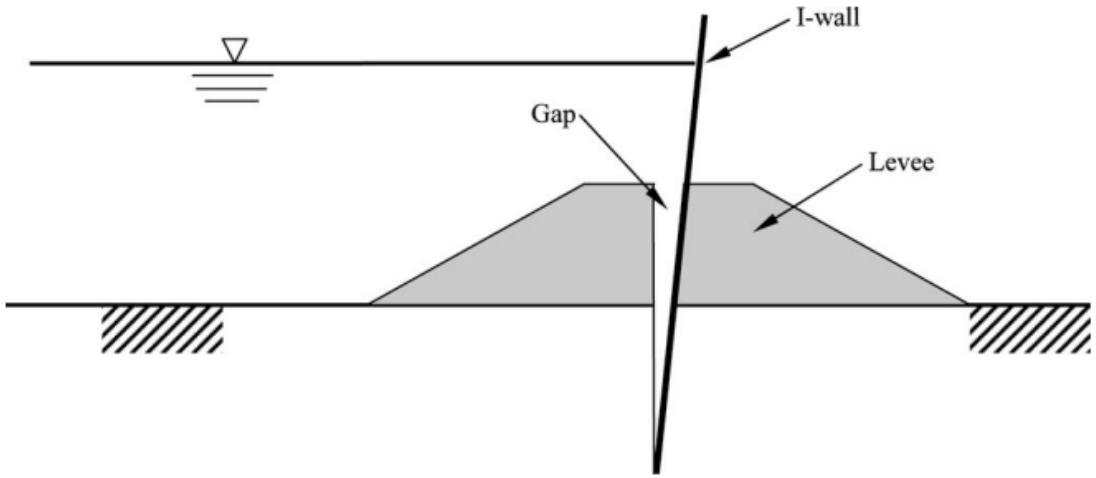
Imposed by steeply inclined tiebacks

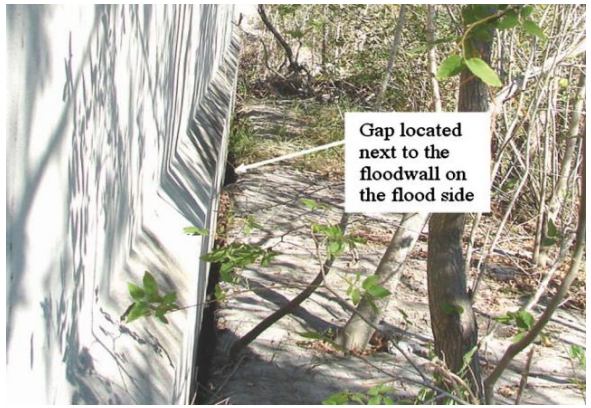
Wall does not have sufficient geotechnical pile resistance below excavation

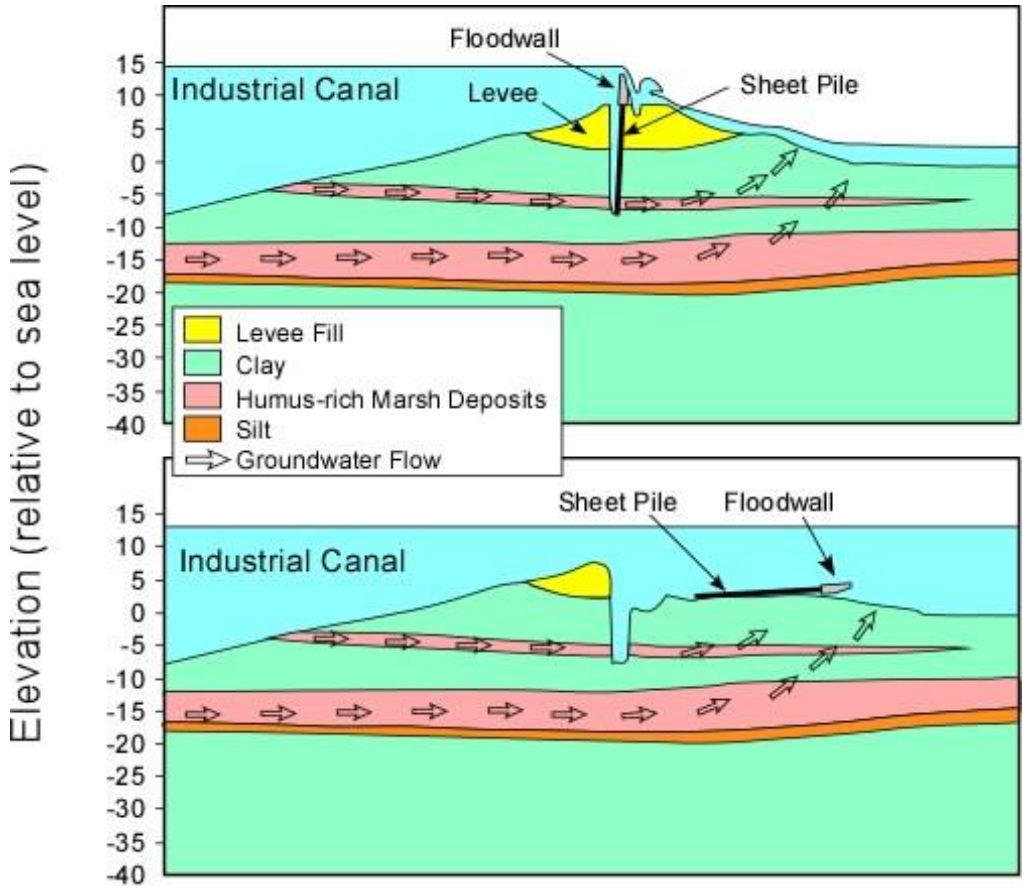


NEW ORLEANS FLOODING

17th Street Canal Breach Area



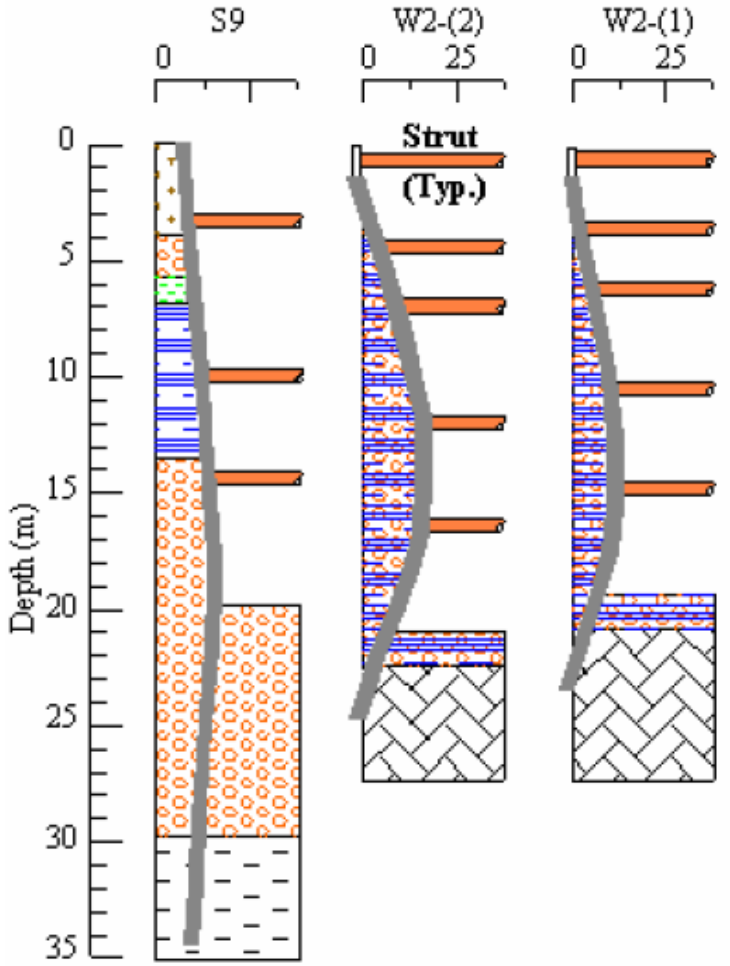




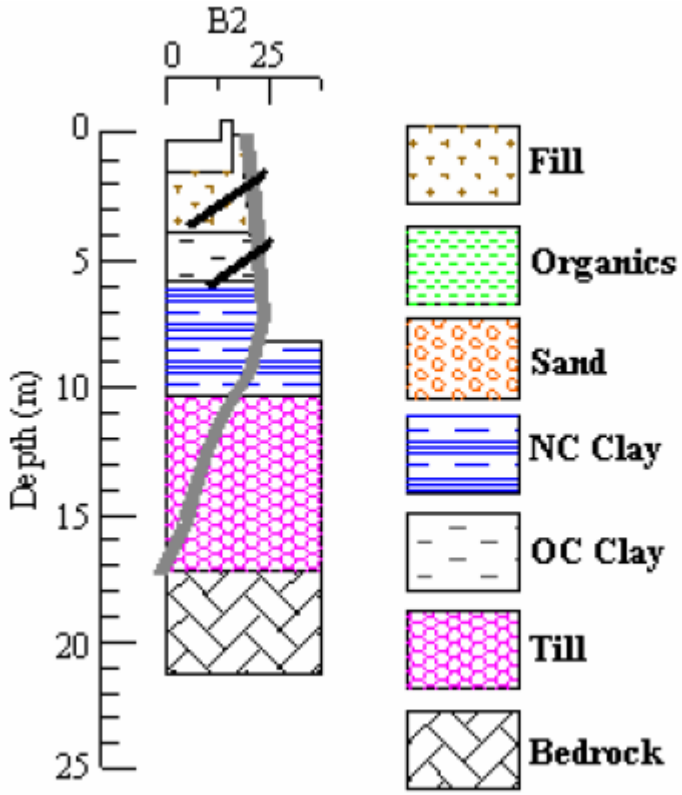
Reference: Prof. Stephen A. Nelson, Tulane University

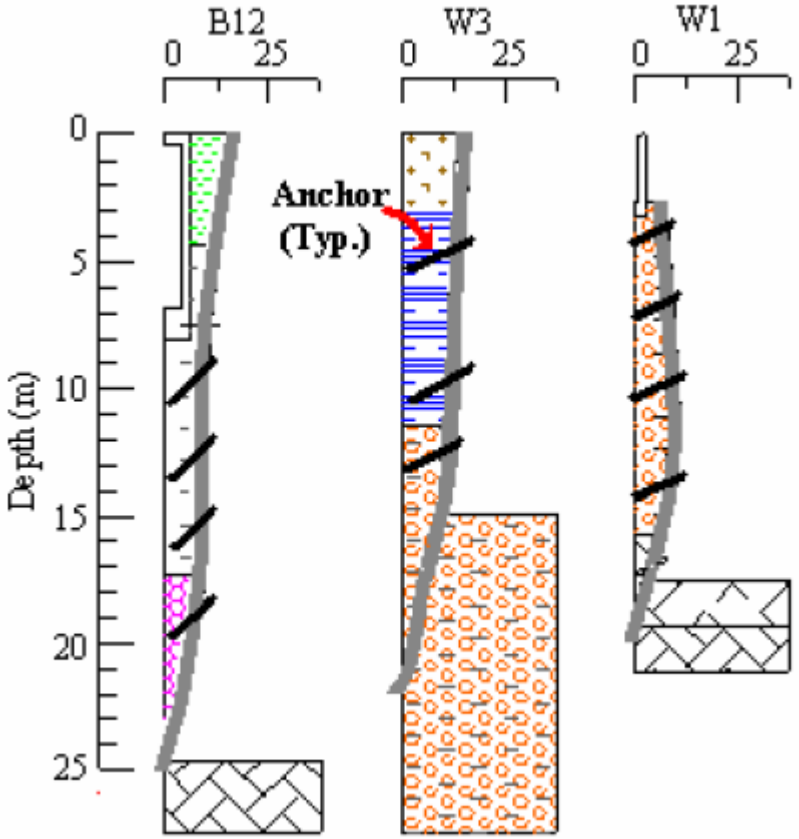
STRUTTED EXCAVATIONS

- Struts transfer forces, but usually not prestressed
- Displacements accumulate on every stage
- Embedment into stiff stratum (rock makes a difference)



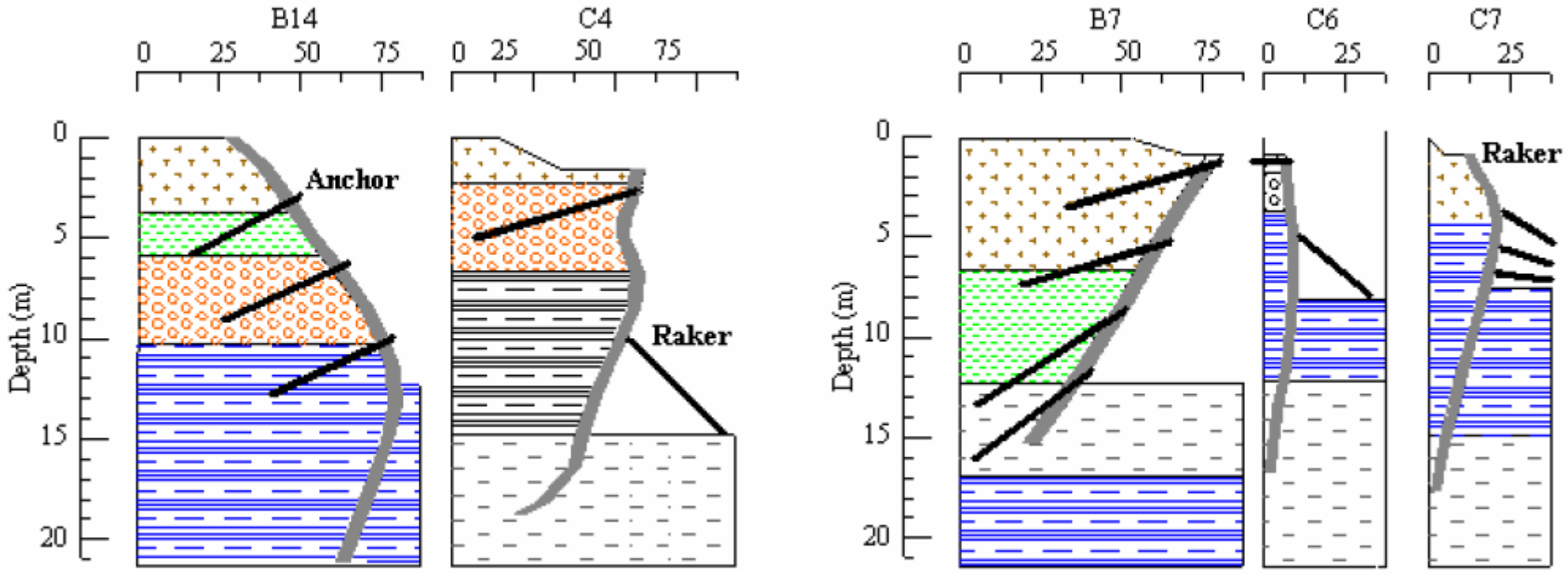
- Wall base does not move



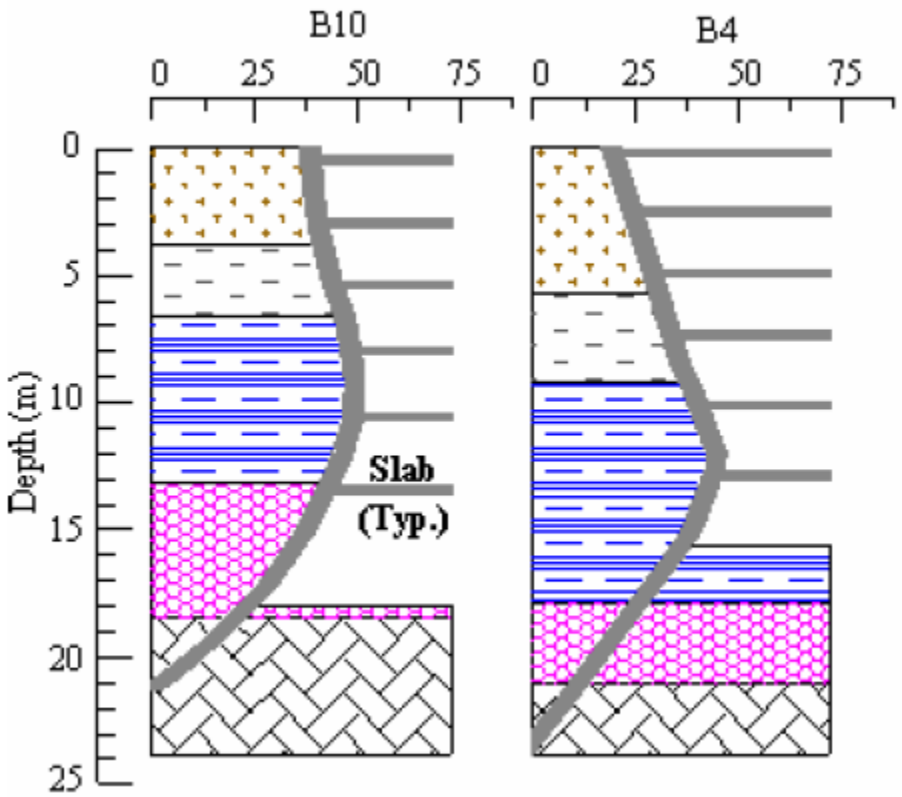


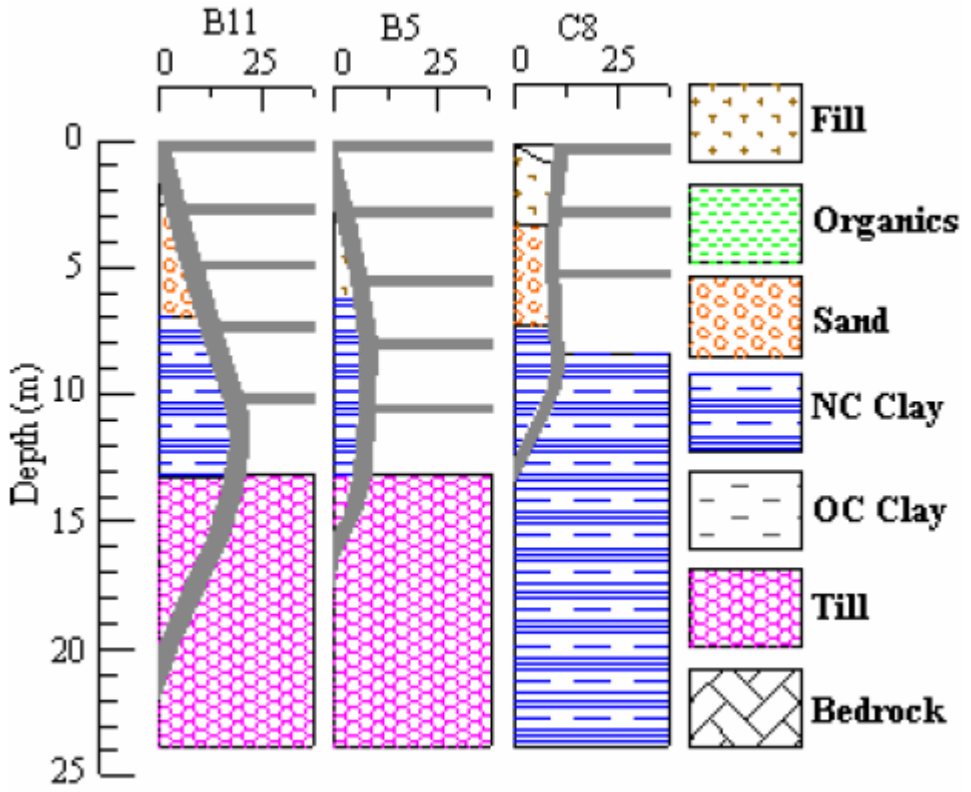
ANCHORED WALL "FLOATING"

- Basal movements add to wall displacing at bottom
- Ground anchors in zone of movements



- Concrete has tendency to shrink





GIGO

- GIGO (Garbage in – garbage out)
- Wall is wished in place
- It is good to know what to expect!
- Small strain stiffness vs. large strain
- Basal heave and cantilever displacements usually overestimated
- Surface settlements occasionally are out of touch (models without anisotropy)
- Nice colors can give a false sense of assurance

Case History

- 3ft diaphragm wall (0.9m)
- Up to 92 ft excavation
- Buildings on two sides

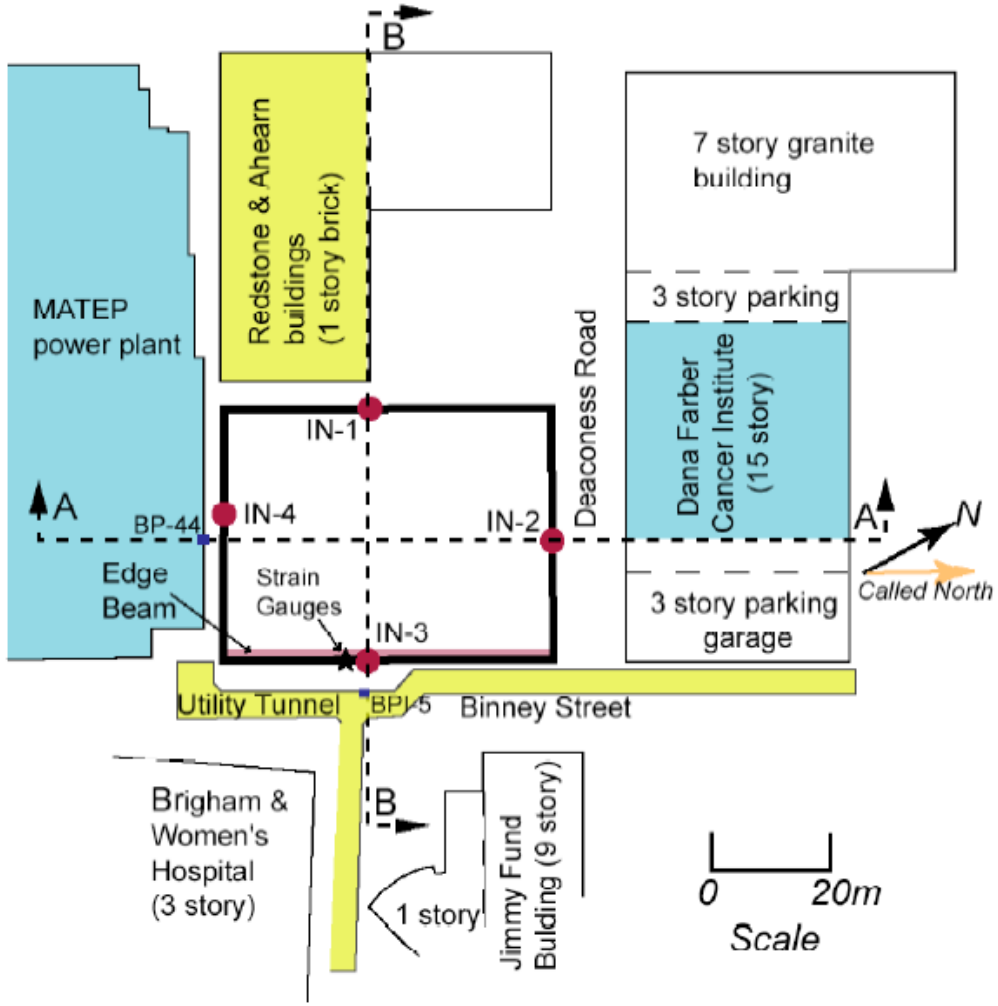
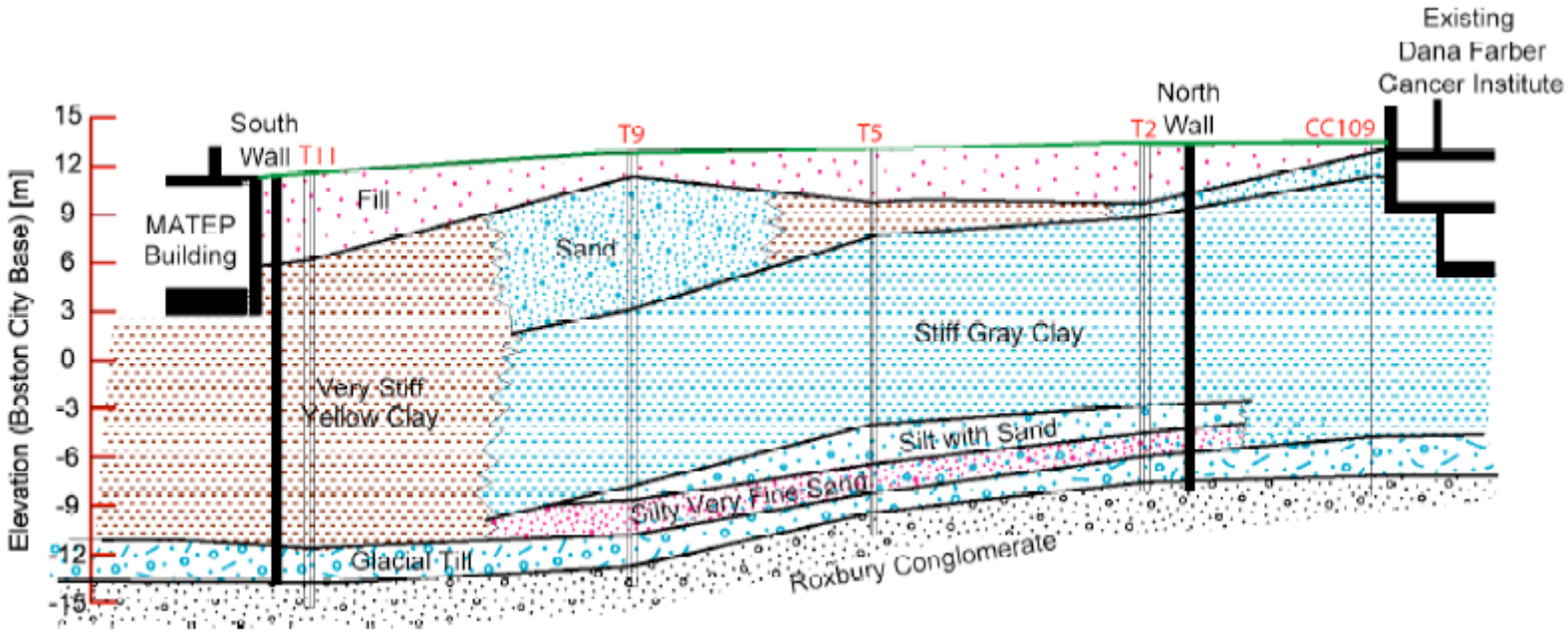


Fig. 1. Dana Farber research tower site plan

Cross Section

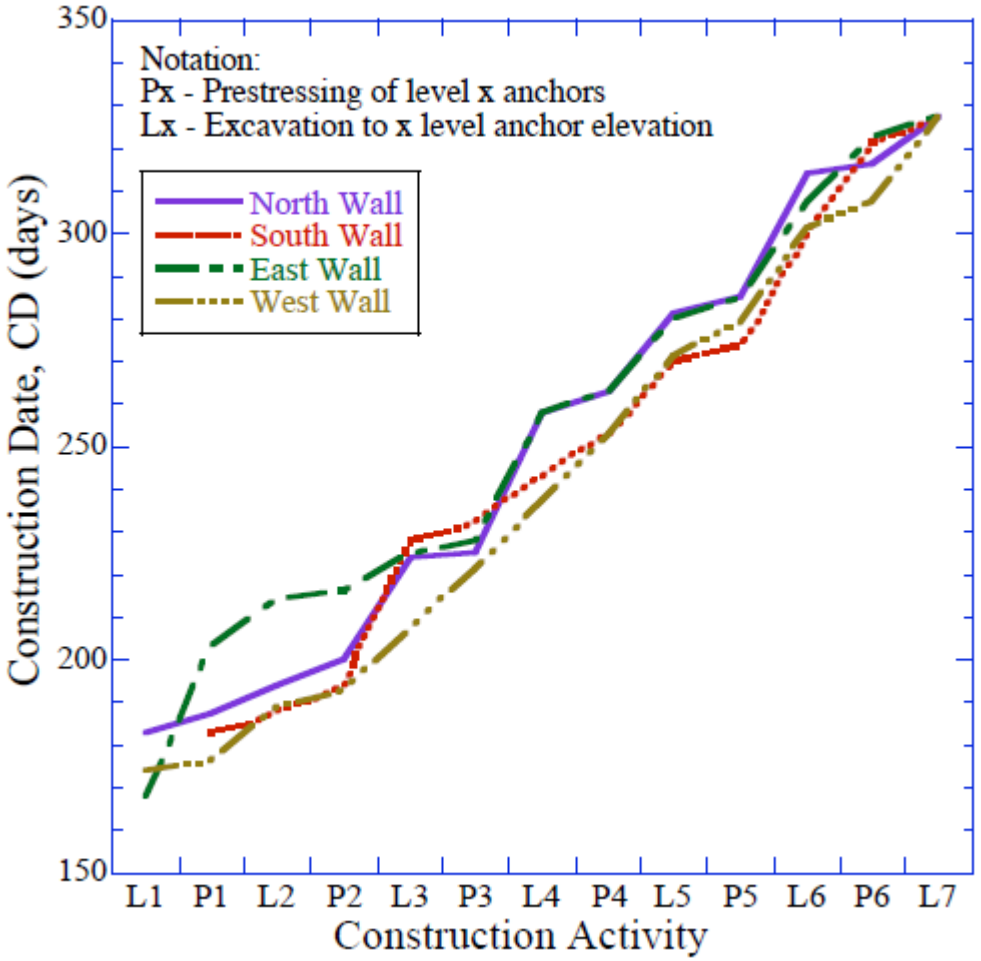


a) Cross-section A-A

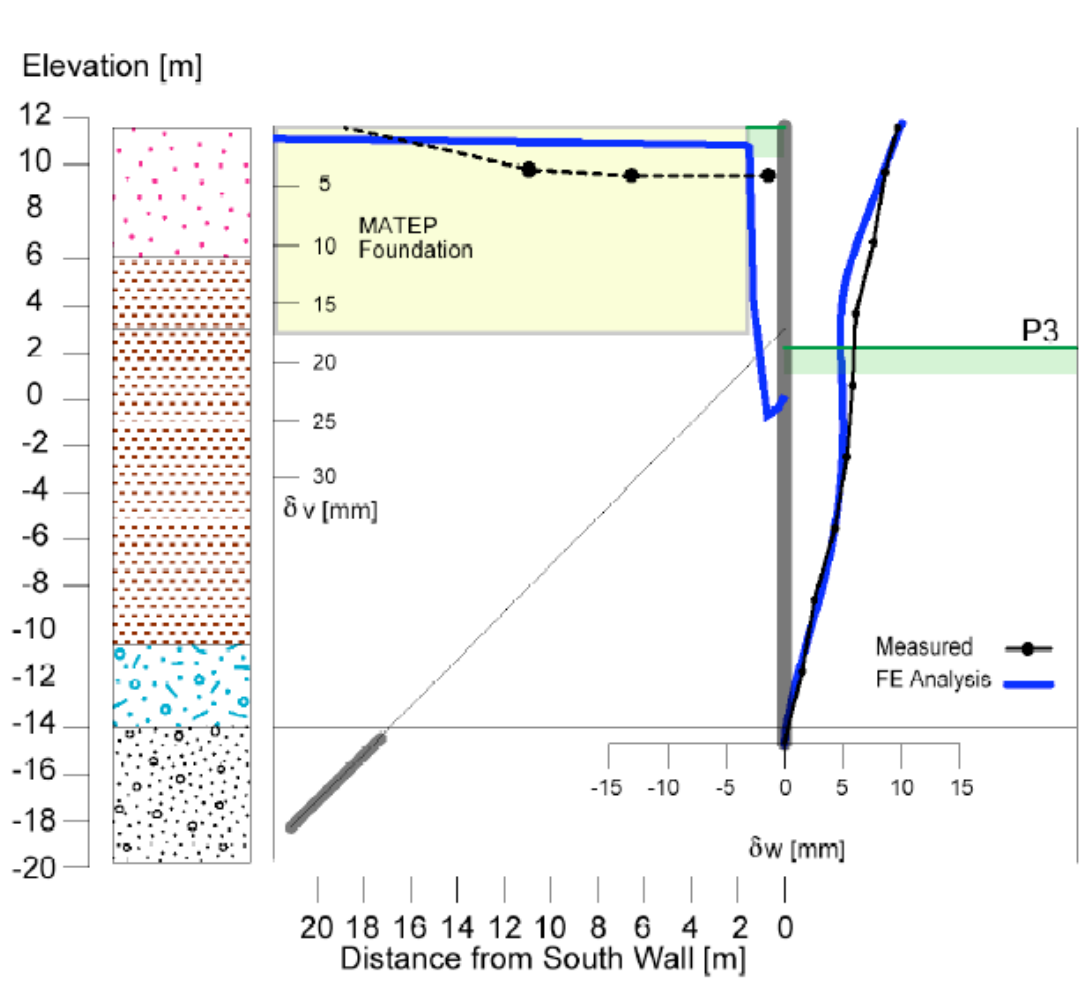
Construction Progress

Anchor	Parameter	North	South	East	West
P1	EA (x10^3 kN/m)	0.79	--	0.016[2]	0.79
El. 9.0m	L_f (m)	24.4	--	--	32.9
	F_L (kN/m)	385	--	250[2]	397
P2	EA (x10^{3}kN/m)	0.96	--	0.96	0.96
El. 5.9m	L_f (m)	20.1	--	25.0	28.0
	F_L (kN/m)	435	--	426	438
P3	EA (x10^{3}kN/m)	1.66	1.08	1.66	1.66
El. 2.9m	L_f (m)	15.9	24.4	20.7	23.8
	F_L (kN/m)	795	510	1349	829
P4	EA (x10^{3}kN/m)	2.04	1.45	2.04	2.84
El. –0.2m	L_f (m)	11.6	19.5	16.7	19.5
	F_L (kN/m)	965	695	1052	1486
P5	EA (x10^{3}kN/m)	1.14	1.95	1.14	2.30
El. –3.3m	L_f (m)	7.0	15.2	12.2	15.2
	F_L (kN/m)	550	905	820	1024
P6	EA (x10^{3}kN/m)	1.14	2.72	1.14	2.30
El. –6.3m	L_f (m)	4.6	11.0	7.9	9.1
	F_L (kN/m)	550	1135	867	1310

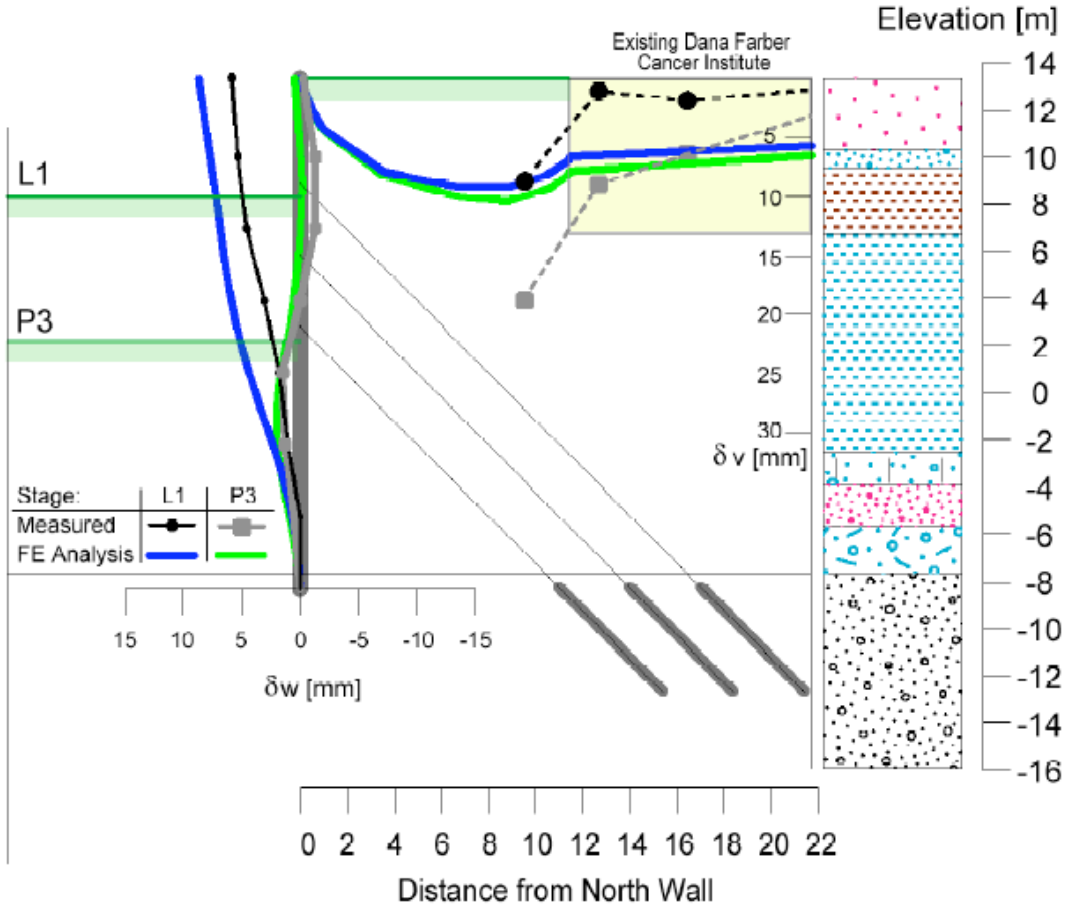
Notes: 1. F_L – lock-off load,
L_f – estimated free-length of anchor
2. Edge beam installed at ground surface (Fig. 1).



Section A-A Early Results

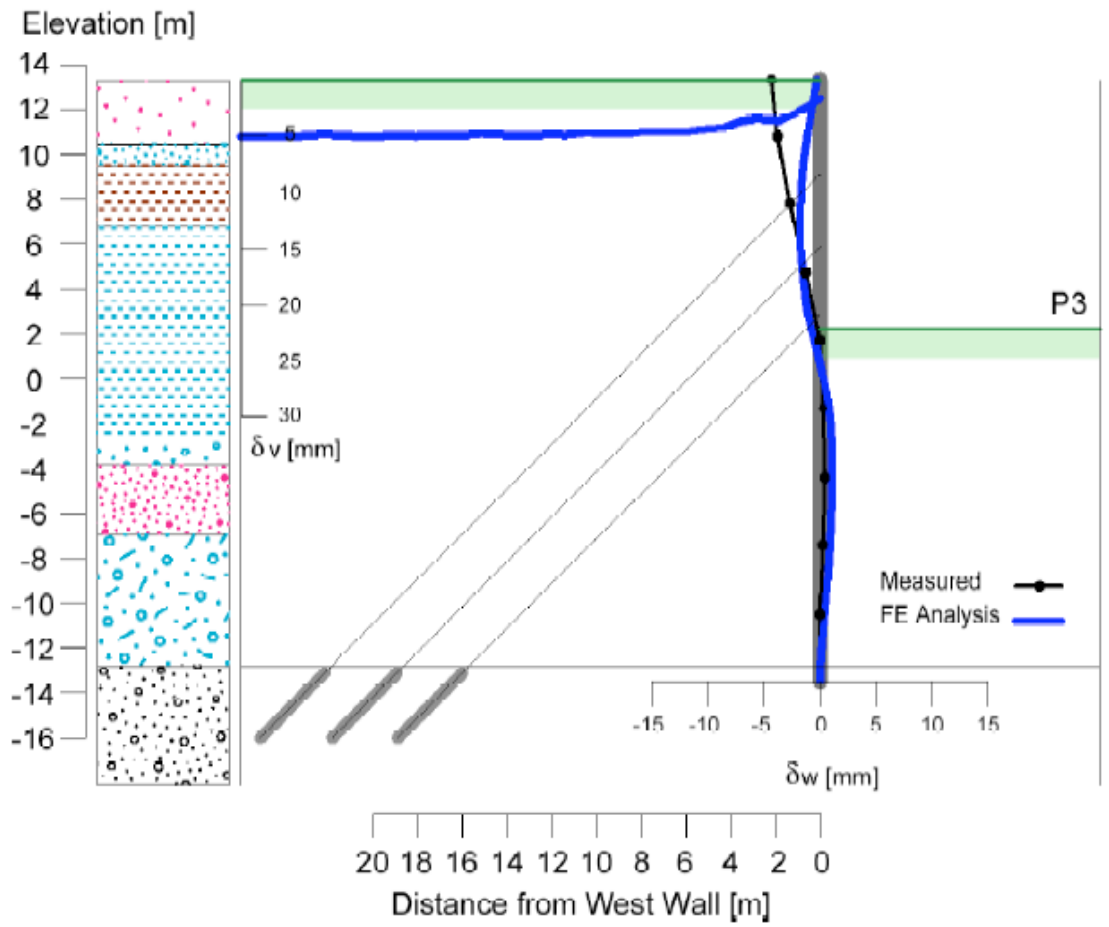


a) South Wall

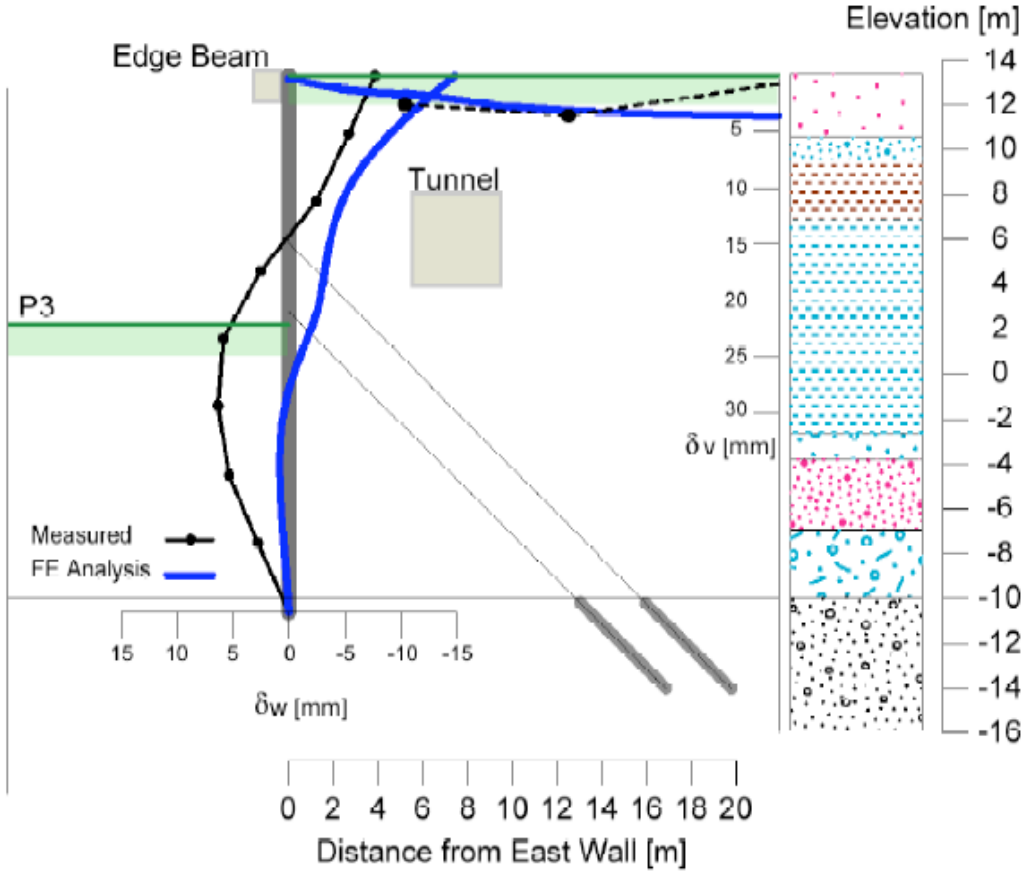


b) North Wall

Section B-B Early Stages

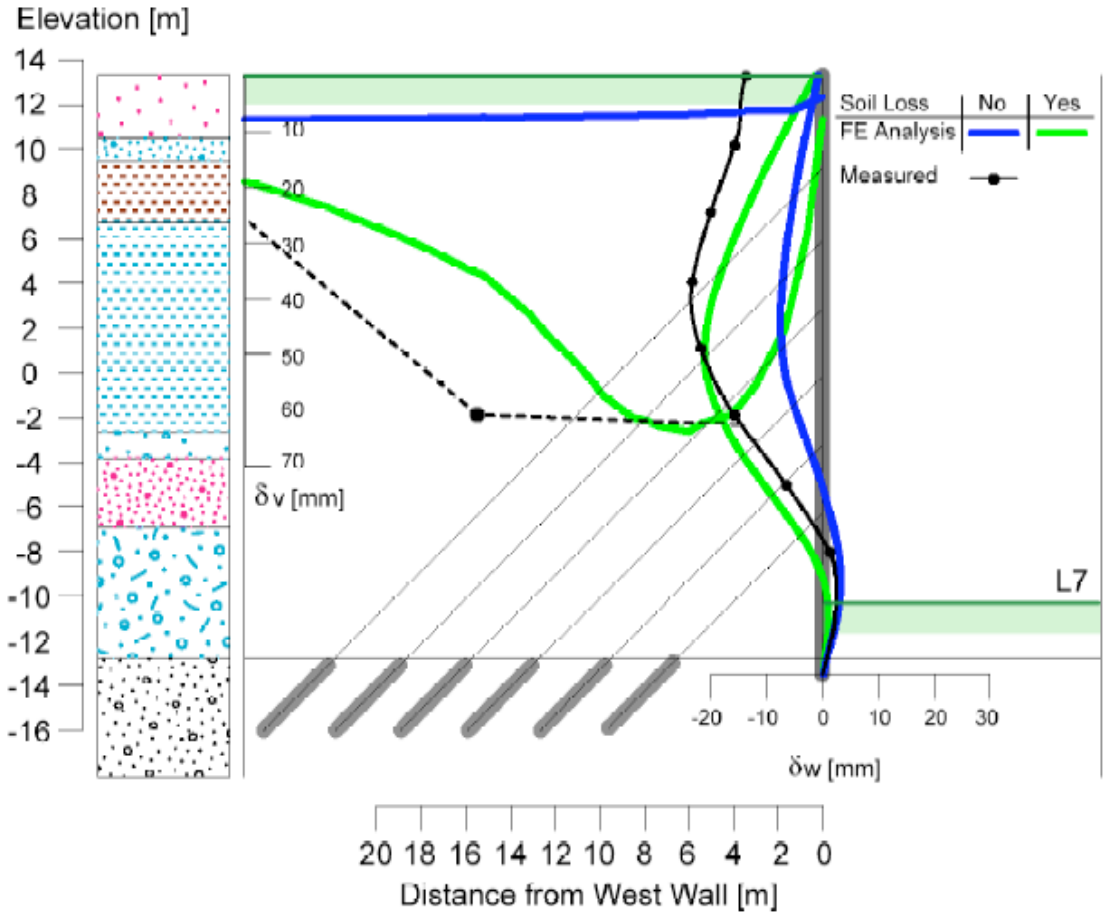


a) West Wall

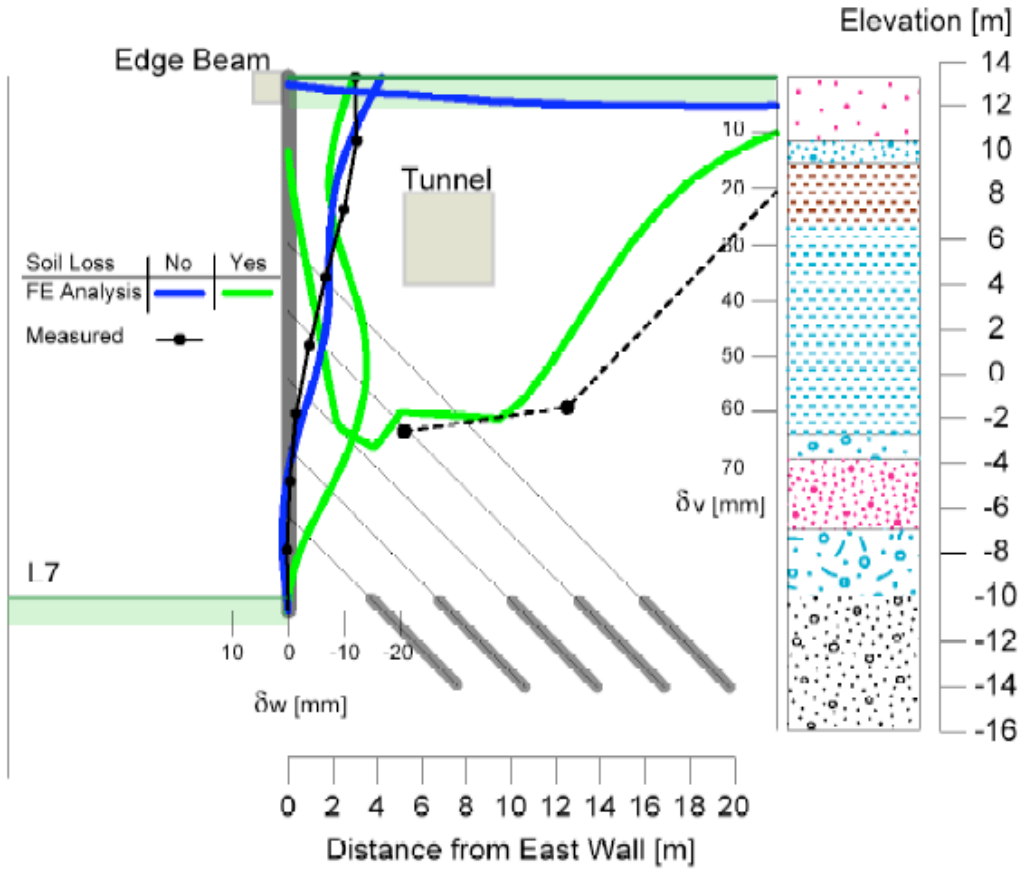


b) East Wall

Section B-B Final Stages



a) West Wall



b) East Wall

Bending moments vs. Strain Gages

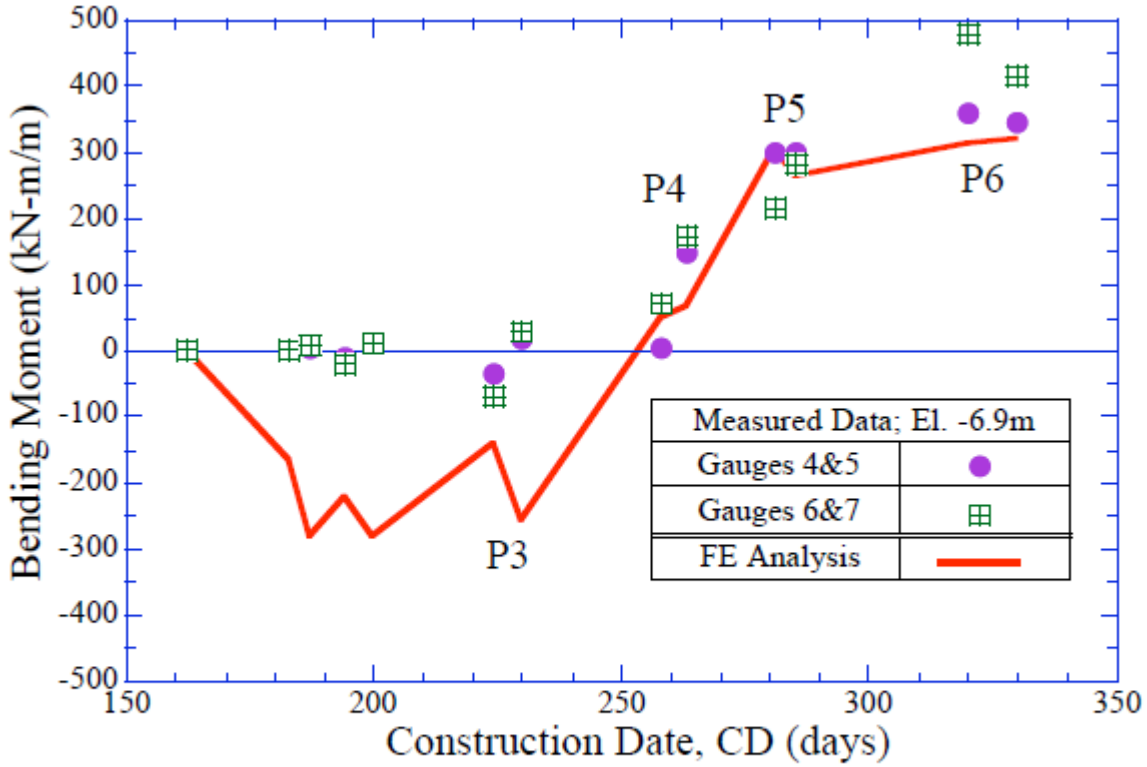


Fig. 9 Comparison of computed and measured bending moments in North wall

Lessons Learned

- Extremely difficult if not impossible to create perfect match
- Construction effects could not have been foreseen in regular design but played major role in actual performance
- Bending moments may be even more challenging to match
- Settlements were more difficult to match than horizontal displacements

How many things to check?

- Deep excavation design complexities
- **Numerous items that might have to be considered**
- DeepEX software gives a number of warnings and diagnostics, about 200 checks!
- Good engineering judgement still rules!