Geotechnical Engineering Failures and Lessons Learned

JAMES W. NIEHOFF, PE

SENIOR GEOTECHNICAL ENGINEER

NOVA

Outline

- What is a failure?
- What factors lead to failures?
- Case Histories
- Questions

What is a failure?

- Constructed work does not meet legal requirements (i.e. building codes, location restrictions, standard of care)
- Does not serve intended purpose or meet client criteria
- Is not cost-effective
- Does not reach design life

What factors lead to failures?

- Limited Budgets
- Technical errors
- Lack of sufficient information
- Poor communication
- Lack of adequate supervision or testing during construction
- Unanticipated conditions encountered during construction
- Politics
- Poor maintenance
- Court settlements promote confidentiality, so mistakes are often repeated rather than learned from

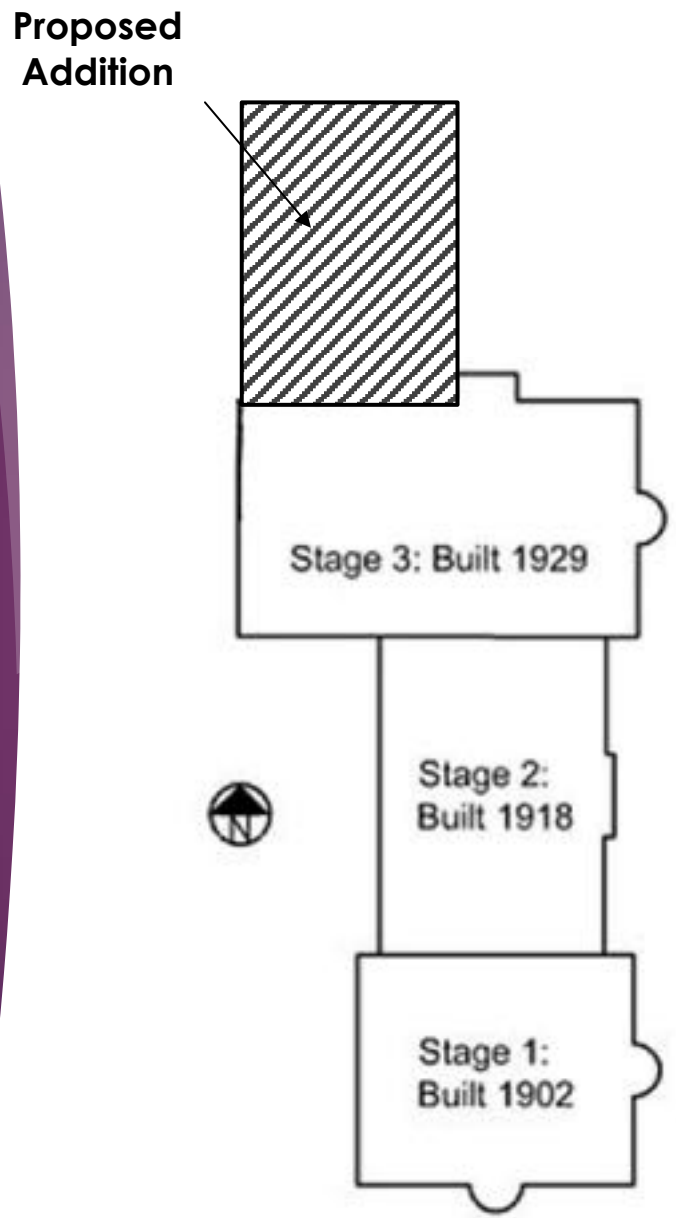
Engineering Failures – Case Histories

Menard Hall
Fargo, ND

December 2009

Building Addition

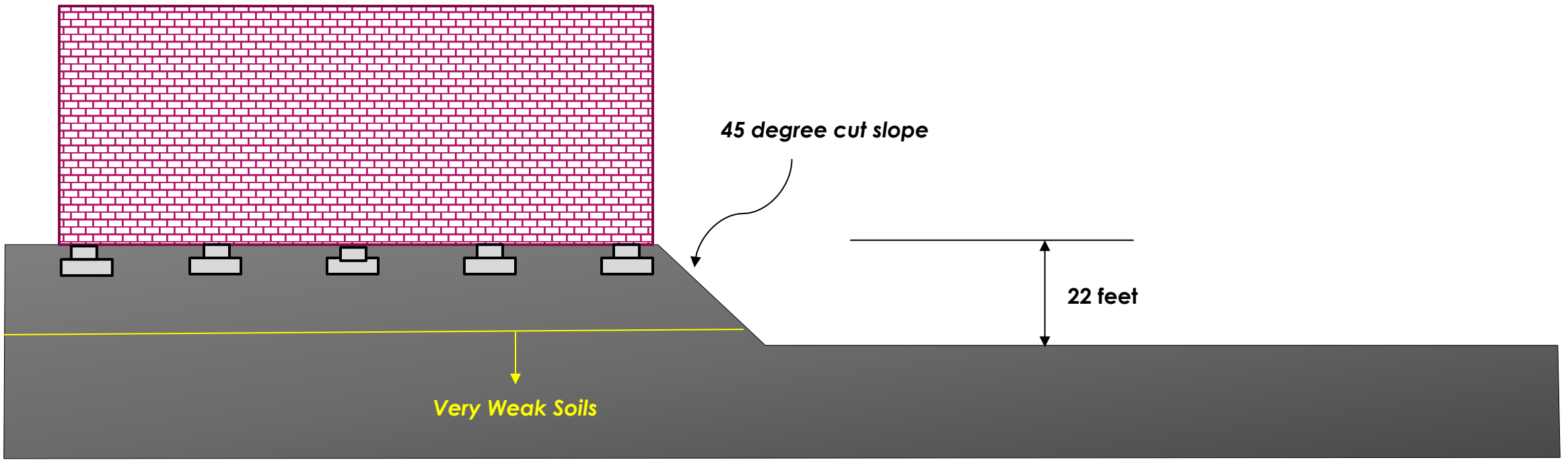
- Three levels above grade, two levels below grade
- Existing structure on shallow spread footing foundations close to ground surface
- Subsurface materials – Lake Agassiz clay



Building Collapse

- Collapse of 1929 section of building shortly after midnight on December 27, 2009.
- No one injured.

Building Addition

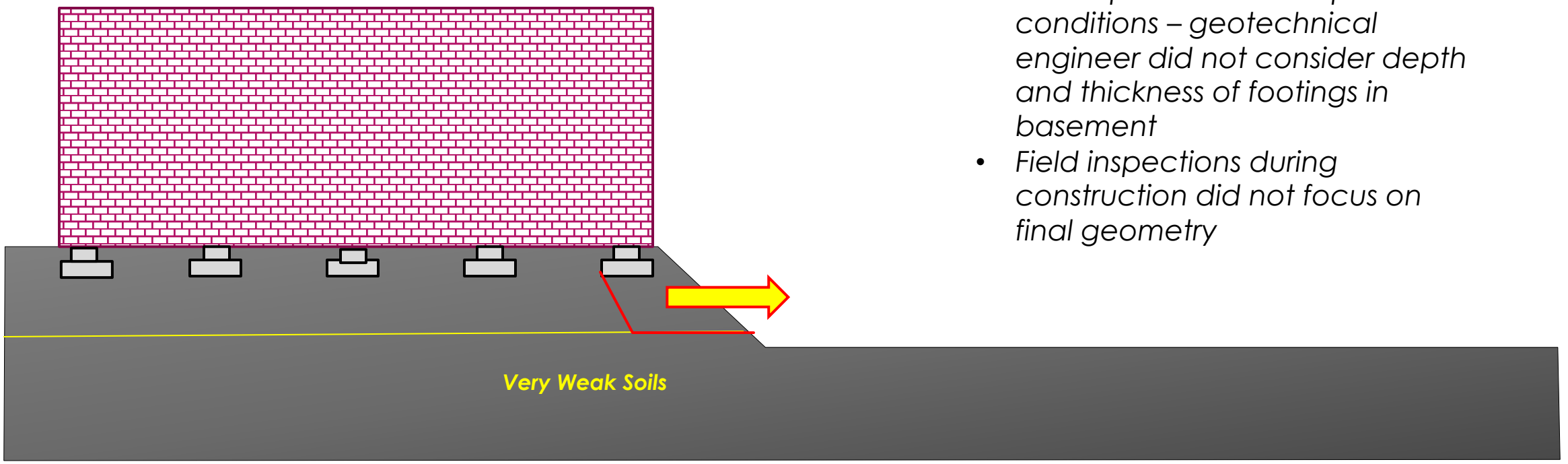


Investigation

Displacement of Foundation Wall – Predominantly Lateral

Failure Surface in Clay Below Footing

Conclusions



- *Cut slope was too steep for conditions – geotechnical engineer did not consider depth and thickness of footings in basement*
- *Field inspections during construction did not focus on final geometry*

Demolition and Reconstruction

Lessons Learned

- Consider final configuration of cut slopes
- Be conservative in selection of material properties – use lower bound strengths, when consequences of failure are high
- Use excavation bracing systems to protect critical structures – this is not the best place to save on construction costs
- Install monitoring devices and take readings frequently during construction

Marriott Courtyard Hotel 14th Street Atlanta, Georgia

June 1993

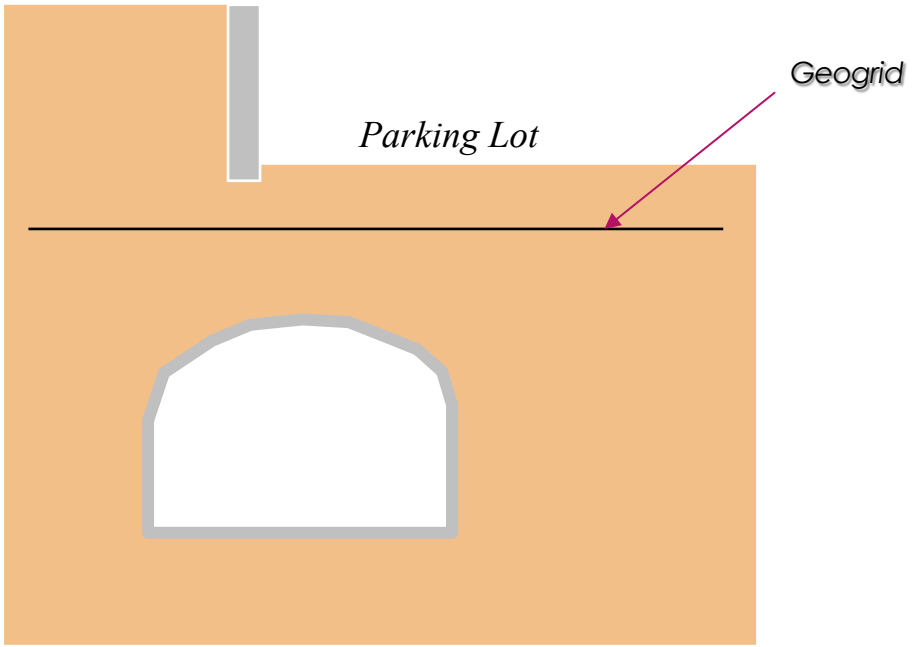
Marriot Courtyard

- A depression was noted in the parking lot near a storm sewer manhole in mid-June 1993
- Small area roped off to protect public
- Studies of the cause of the depression were planned and scheduled

Marriot Courtyard

- The next day on June 14th, Atlanta experienced a 50-year storm event
- The depression in the parking lot widened and a large puddle formed causing a car to stall when entering parking lot
- The car's driver entered the hotel and requested assistance from an employee.
- Upon reaching the car, a sinkhole nearly 200 feet in diameter dropped out, swallowing both individuals and three cars.

Site History



Sewer Line Configuration

Lessons Learned

- Communication failed at several points:
  - Developer did not inform operator of the presence of geogrid or its purpose
  - Inspector did not communicate extent or urgency of the problem to the hotel operator
- In some instances, mitigation techniques can mask a problem and increase the consequences of failure

Ritz Carlton Kapalua Hawaii

1993

Hotel Configuration

Ritz Carlton

- Within 2 months of opening, slab on grade floors sagged and sounded hollow in public areas of the hotel
- Voids up to 12 inches in height found under slab “on grade” floors

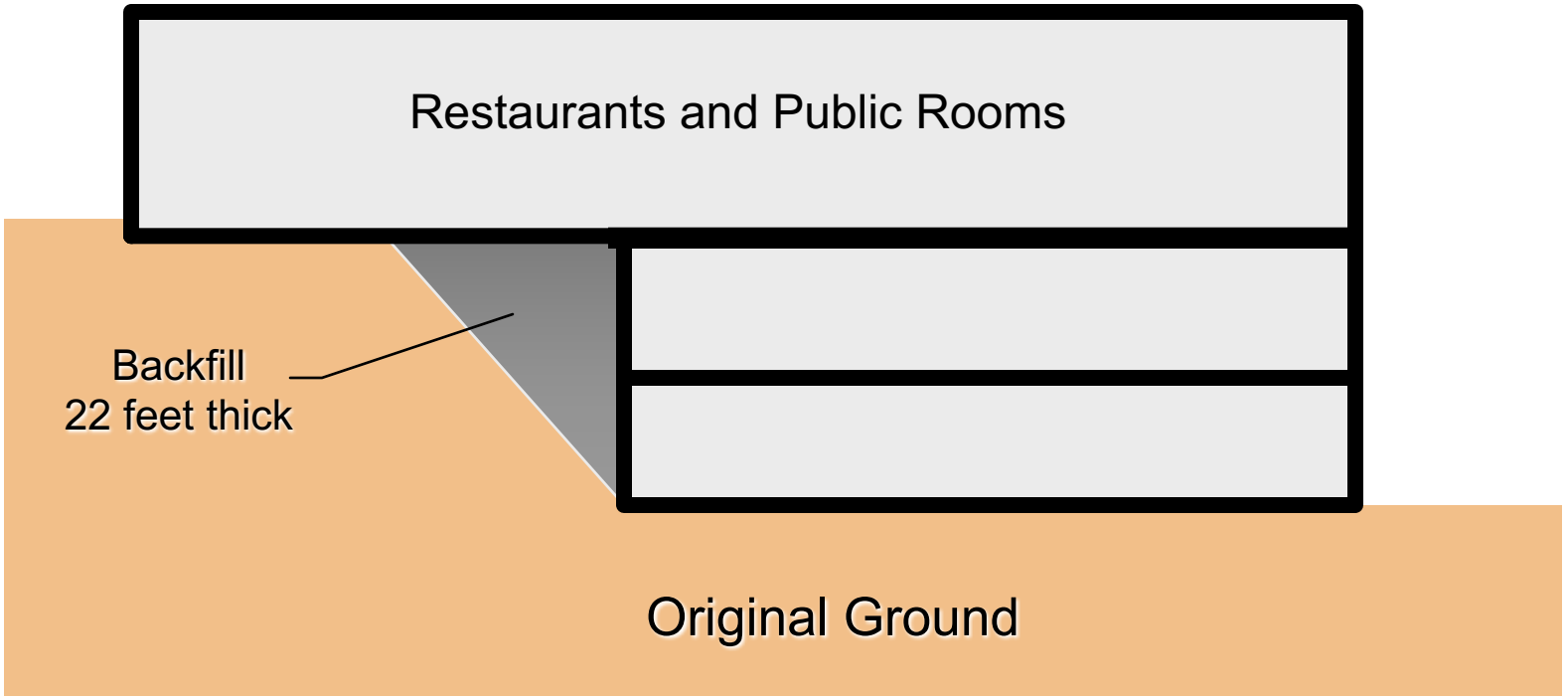
Investigation

- Review history of construction
- Testing of subgrade soils
- GPR testing of floor slabs

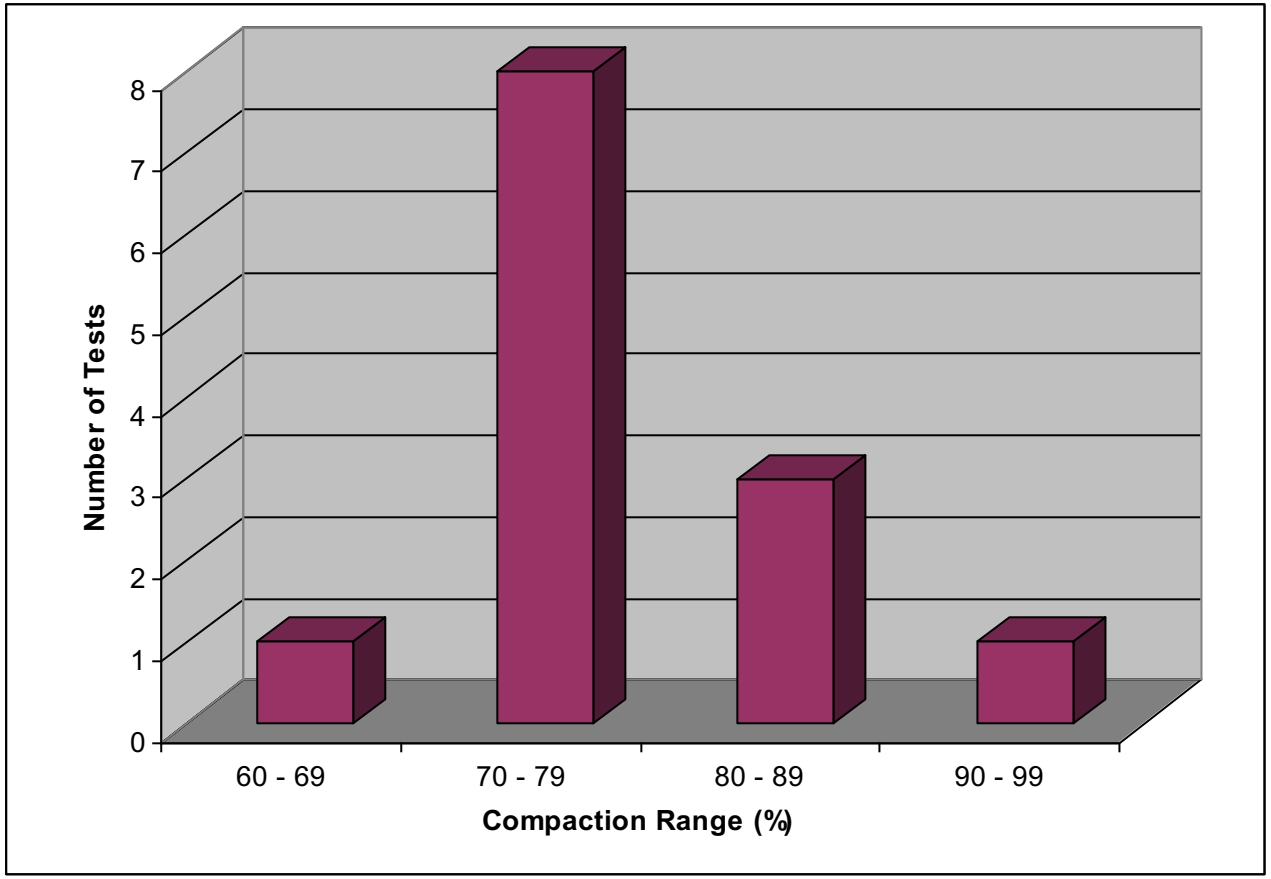
Construction

- Initial hotel construction encountered ancient burial ground
- Hotel site was moved upslope
- Developer cut testing budget to offset cost over-runs

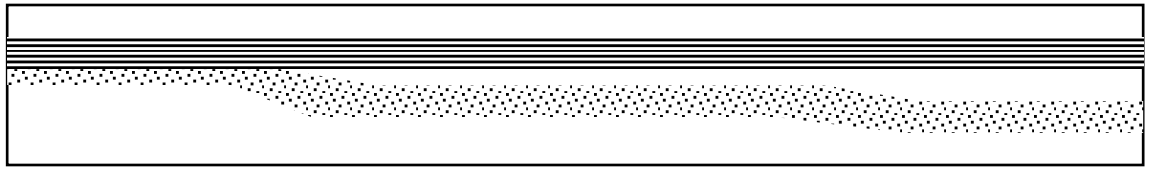
Cross-section through Hotel



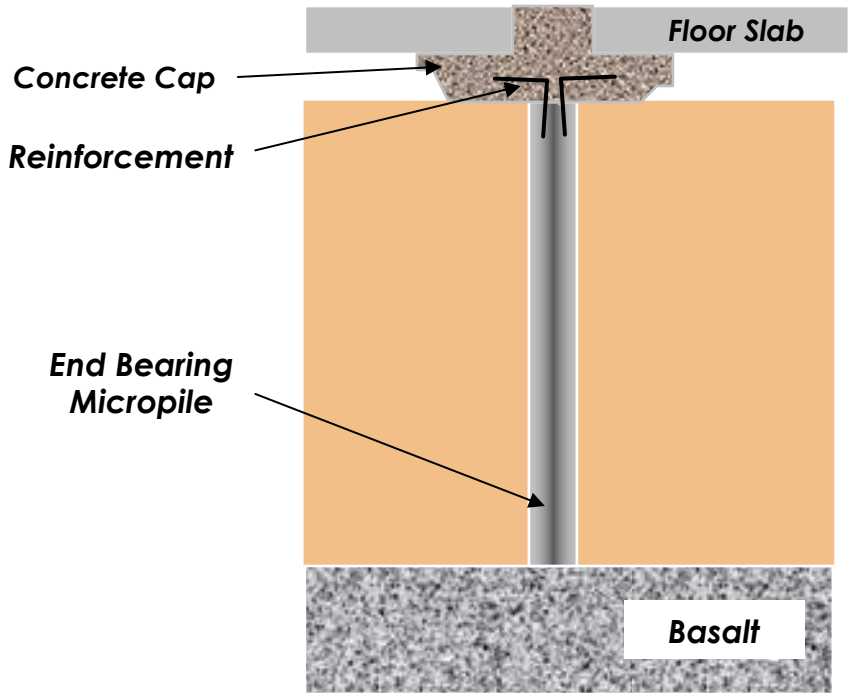
Results of Compaction Tests - Backfill



GPR Test Results



Remediation – Over 1000 Micropiles



Outcome

- Over $7 million in direct remediation costs
- Hotel restaurants and meeting rooms shut down for several months
- The hotel is now notorious for having experienced settlement – loss of reputation

Lessons Learned

- Construction testing and inspection should not be cut to compensate for budget over-runs
- Construction testing is relatively inexpensive when compared with consequences of poor workmanship
- Cost of repairs are only a fraction of the total cost of failures.

Overlook Village Shopping Center Asheville, NC

1978

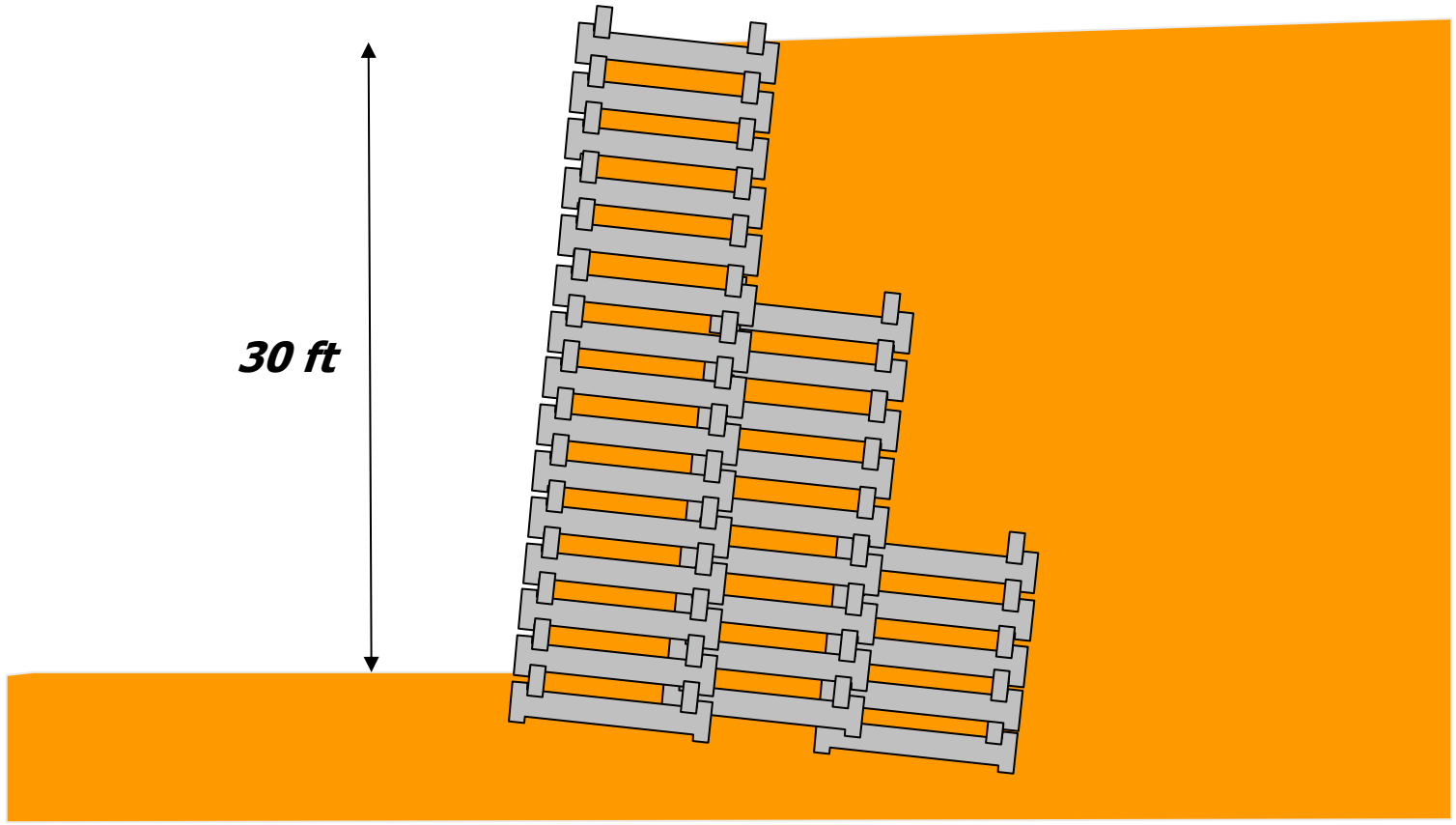
Site Configuration

- Significant cuts and fills dictated use of retaining walls near property boundaries
- Crib wall selected due to low relative cost

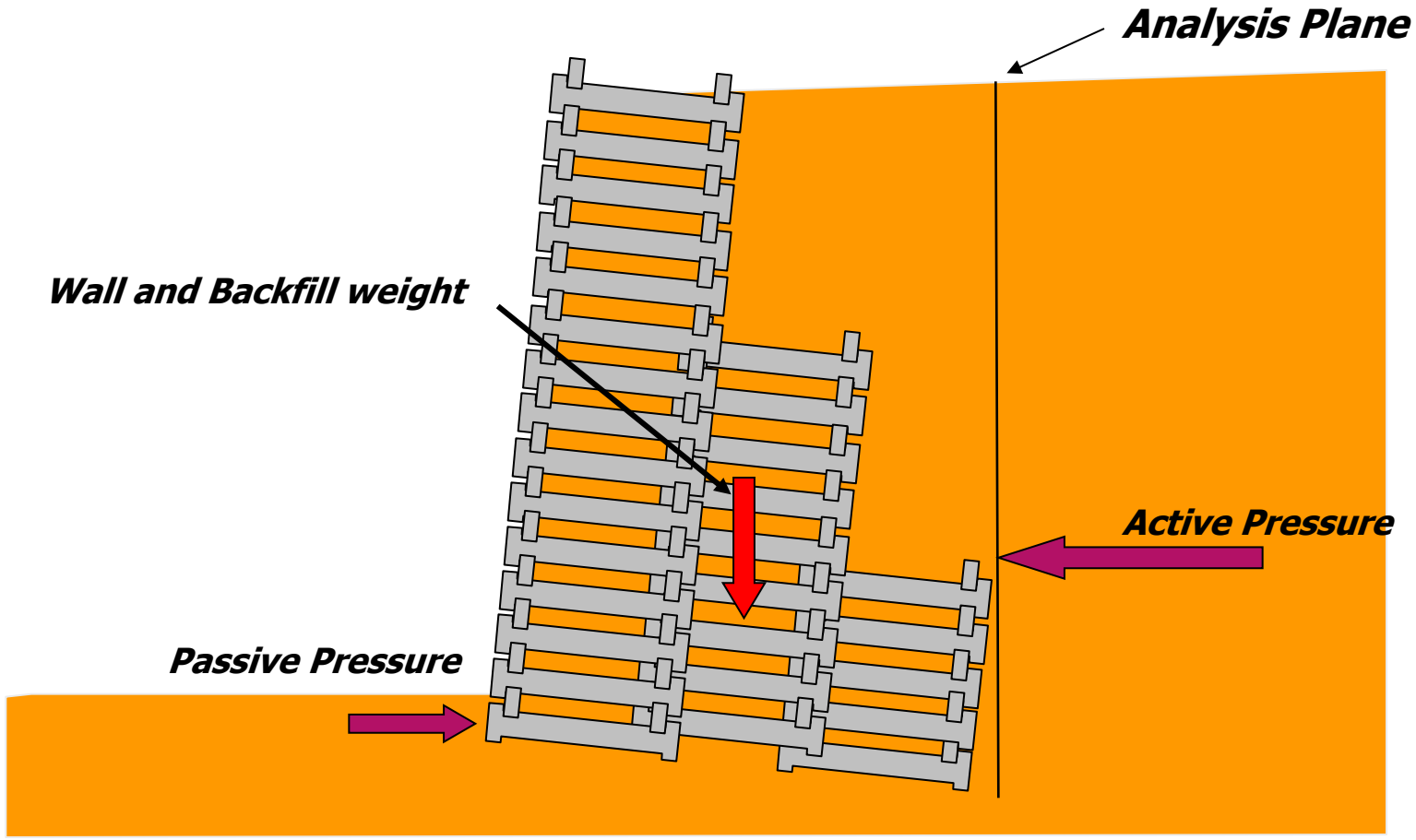
Crib Wall Failure

- Within 6 months of construction, crib wall failed
- Threatened parking lot of adjacent shopping center

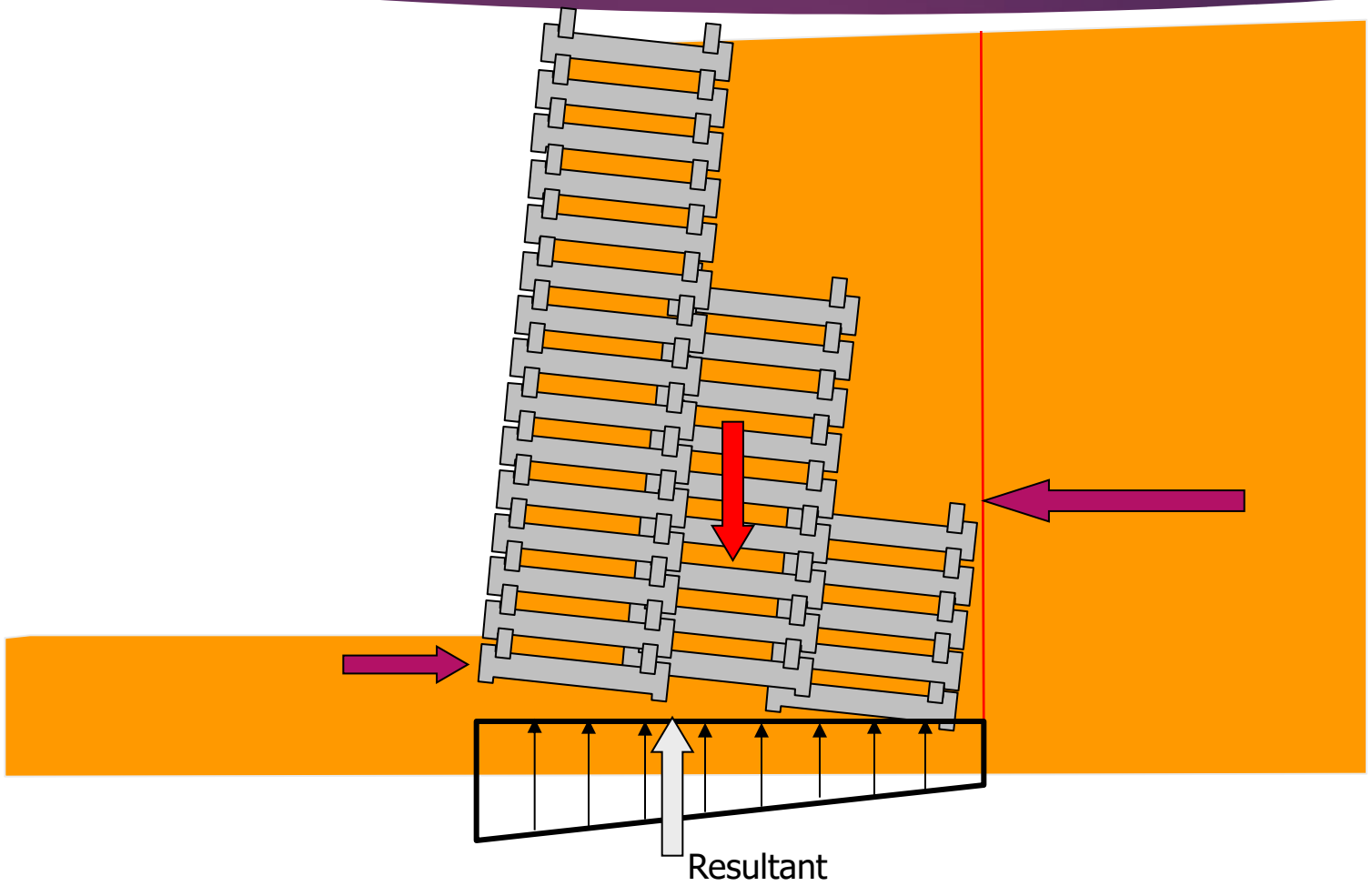
Wall Configuration



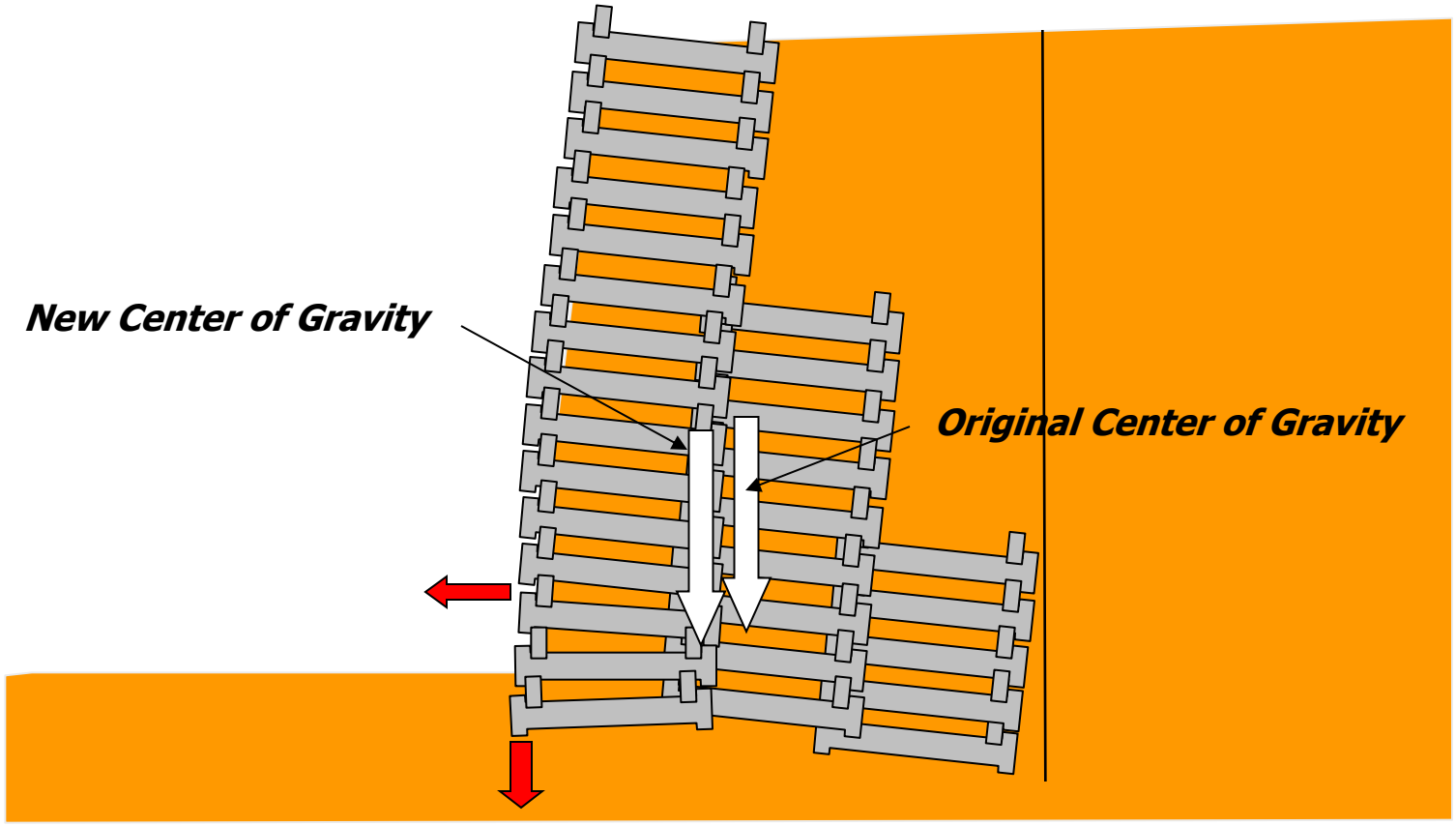
Stability Analysis



Gravity Wall Analysis Results



Crib Walls are not Rigid!



Analysis

- Walls over 25 feet in height were found to settle differentially leading to a progressive failure over time.
- More massive walls were required to shift the resultant of pressures to the center of the wall base to avoid differential settlement.

Reconstructed Wall As It Looks Today

Lesson Learned

- Computer programs are only as useful and accurate as the assumptions made and data inputs used

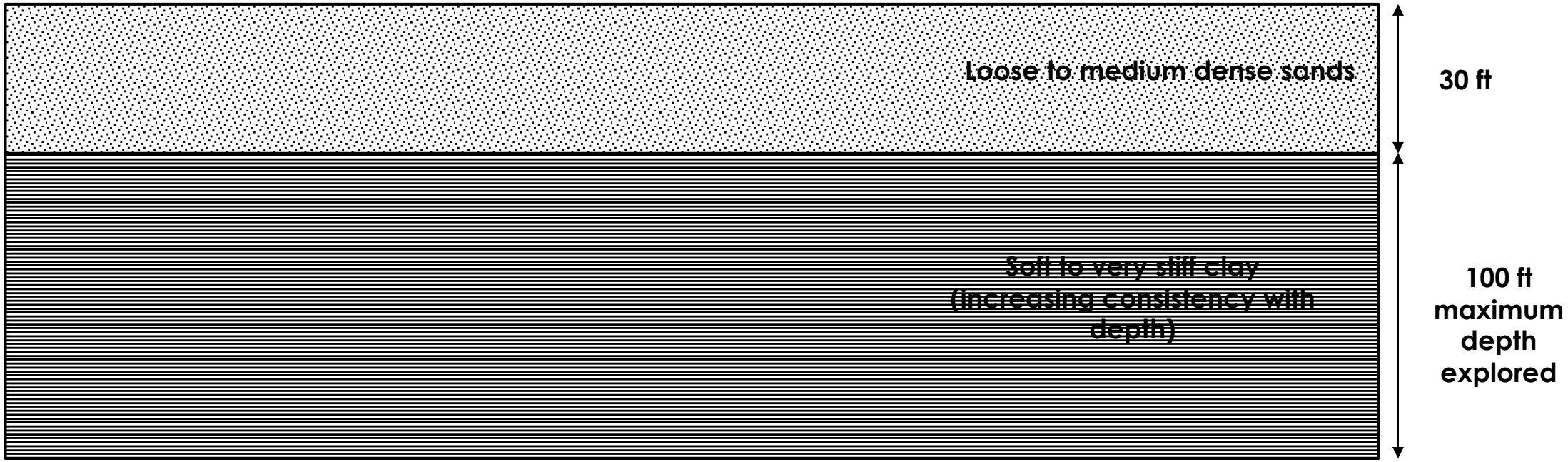
Confidential Building – Texas Gulf Coast

2008

Confidential Building

- 31 story condominium
- Began to settle significantly when it reached floor 17
- Over 16 inches of differential settlement caused massive damage to columns and structural frame, particularly at the interface between the high and low-rise sections

Subsurface Profile



Structural Configuration

- Mat foundation supported by 100 foot long,16 inch diameter augercast piles (125-ton capacity) under tower
- Pile caps supported by 16 inch diameter augercast piles in parking deck
- Structure post-tensioned

Analysis

- Blow counts in the test borings were not corrected for depth. What appeared to be 24 blow per foot material was closer to 10 blows per foot after correction.
- Design did not consider the group effects of 500 piles under the tower.
- The low and high-rise sections were structurally connected and experienced 16 inches of differential movement over 1 bay.
- While tower settled relatively uniformly, and was structurally sound, it could not be separated from the parking deck due to the post-tensioning cables.

Final Outcome

Lessons Learned

- Pile groups do not perform the same as individual piles – consider group effects
- Isolate high rise from low rise sections of buildings as they will experience different magnitudes of settlement

Black Thunder Mine - Wyoming

2009

Conveyor System Required to Transport Coal to Railway

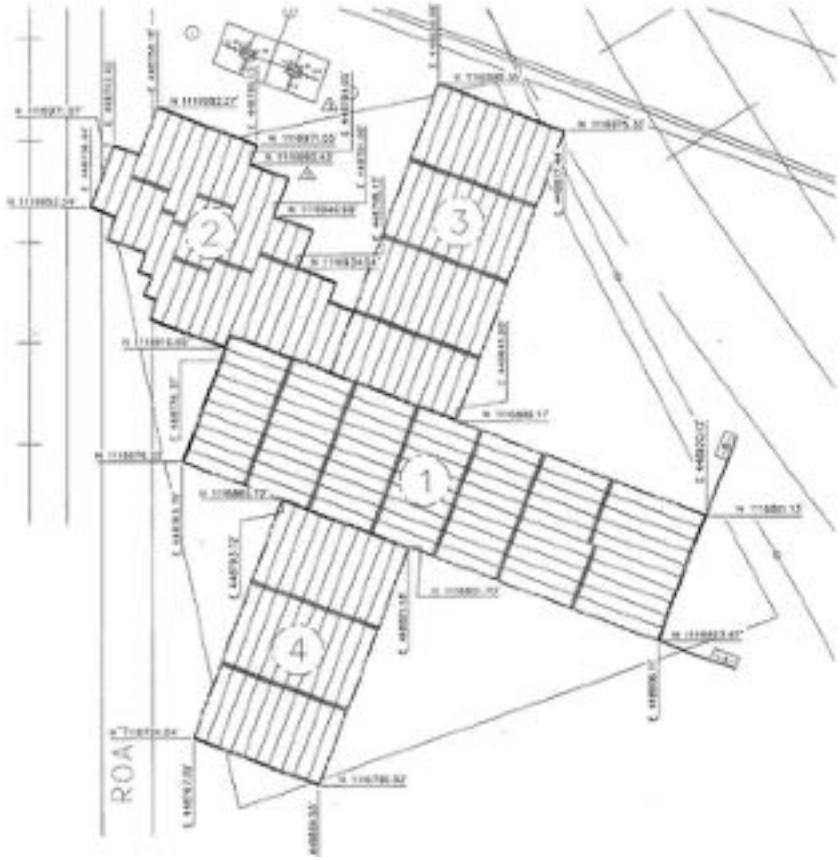
- Required use of massive crane (over 300 feet in height)
- Crane supported by timber mats bearing on subgrade soils
- Very low tolerance to out of level operation

Crane Collapse

- Crane collapsed while installing a 1/2 million pound section of conveyor system
- Three workers injured
- Rail line blocked
- Total loss of $3 million crane

Timber Mat

- Mat placed on sandy silt soil – subgrade inspected by project geotechnical engineer and judged to be suitable
- Mat situated in low area between two sets of railroad tracks
- 4 inches of rain recorded in days leading up to failure – water ponded around timber matting



Timber Mat After Collapse

Timber Mat Settlement

Lessons Learned

- Engineers should consider support capacities of soil under all environmental conditions
- Contractors should react to obvious and observable changes in conditions and should seek support from qualified engineers

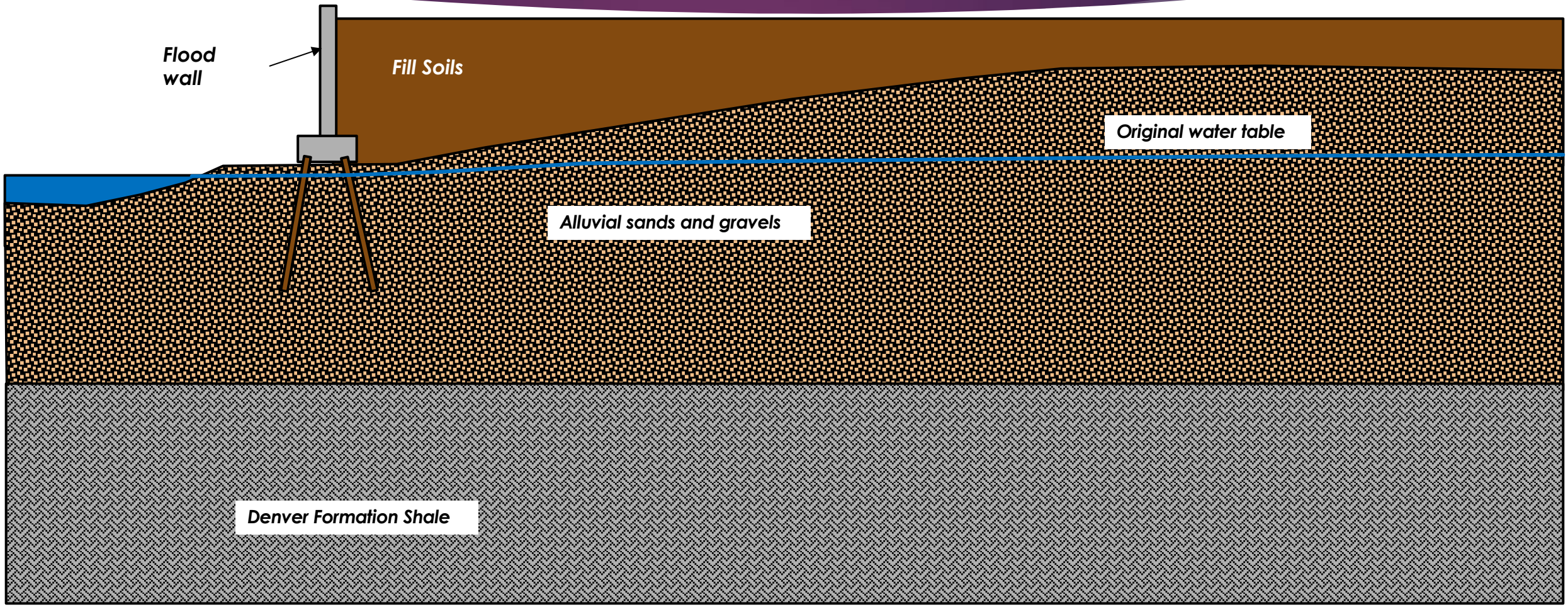
Confluence Tower Denver, Colorado

2016

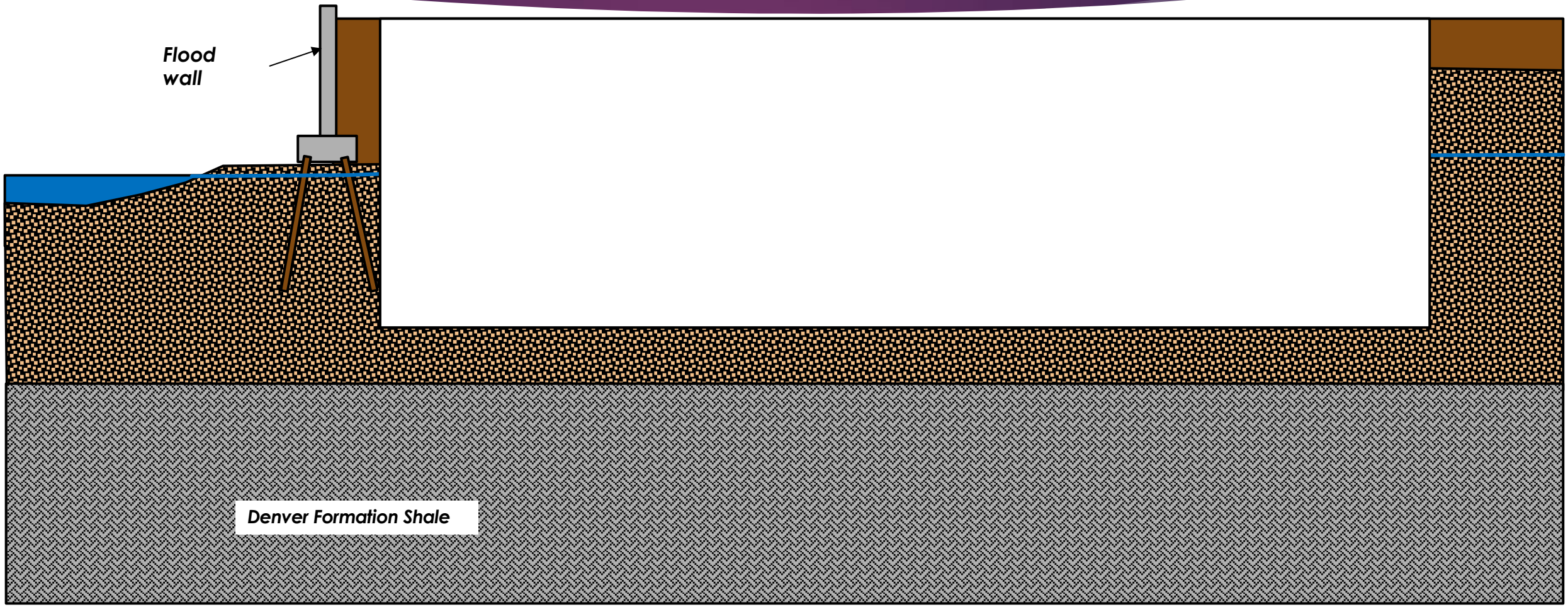
Confluence Tower

- 3 below grade levels adjacent to Cherry Creek creek and the South Platte River
- 40 feet of coarse sand over weak shale bedrock
- 34 above grade levels

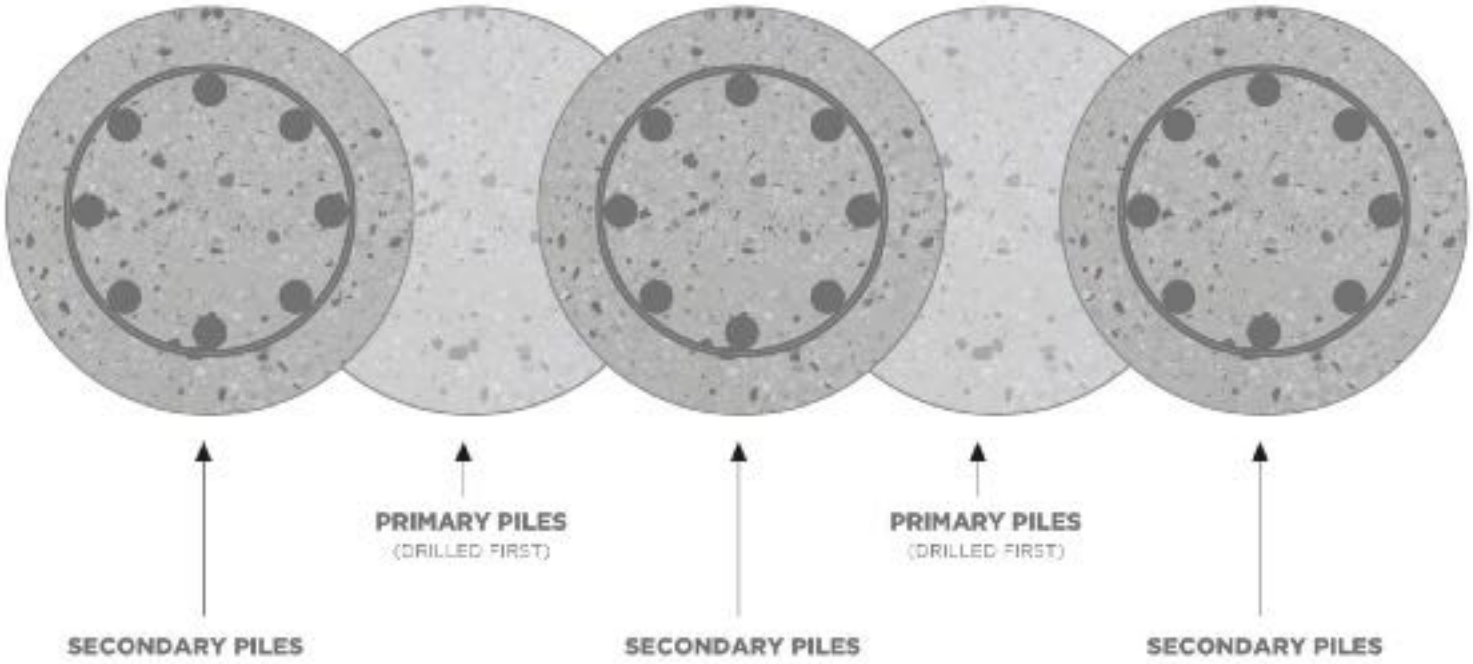
Profile Through Site



Profile Through Site - Construction



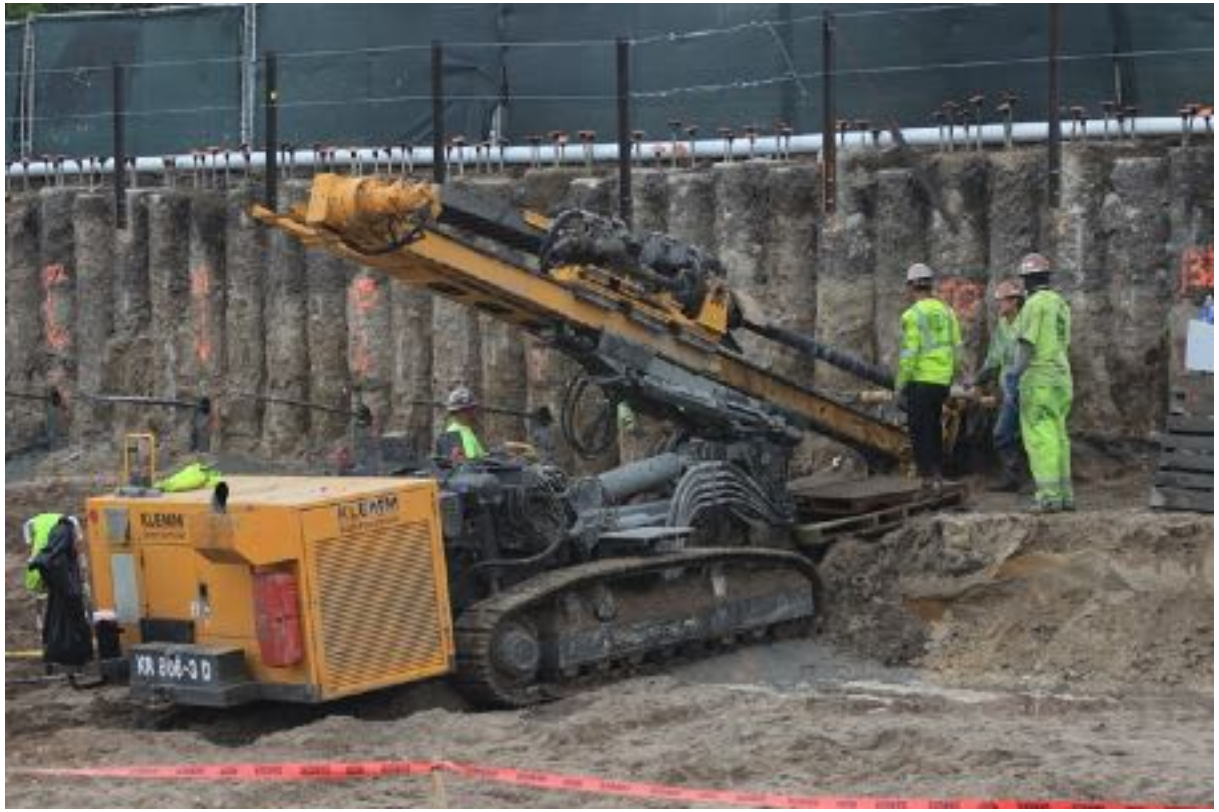
Secant Pile Wall



Secant Pile Walls

- Overlapping CFA piles 3 feet in diameter to create impervious barrier
- Socketed 5 feet into bedrock

Excavation



Misalignment

Misaligned Piles

Old Timber Piles

Resulting Problem

Sinkhole Exterior to the Excavation

Causes of Problems

- CFA Rig used multiple flights with non-rigid connections
- Instrumentation in cab only measured inclination of mast, not the auger during drilling

After the Seals…..

Tying Steel for the Shear Wall Mat

Topping Out December 2016

Lessons Learned

- Use proper equipment for conditions – cased piers would have been more appropriate for this project
- In top down construction, it is not always possible to detect problems, even with an experienced inspector

Questions

NOVA