# DBIA

## Ground Improvement Technologies for Stabilization and Releveling

HAYWARD BAKER
Geotechnical Construction
KELLER

www.HaywardBaker.com

# Before We Get Too Far today lets take a SAFETY Moment


## Think Safe, Work Safe, Go Home Safe

# CDOT mourners note job's dangers

By Tom McGhee
*The Denver Post*

POSTED: 04/09/2008 01:00:00 AM MDT



Paul Forster and Eladio Lopez should have returned to their families after a day on the job behind a string of orange safety cones four years ago. Instead, a drunken student going the wrong way on Interstate 25 mowed them down, cutting short their lives as they worked to make the highway safer.

Orange carnations are placed Tuesday at the memorial for Colorado Department of Transportation workers killed in the line of duty. The white marble monument, with workers' names, sits in front of CDOT headquarters in Denver. (Kathryn Scott Osler, The Denver Post)

They were "out there making a living fixing the roads for the people of Colorado," said Joyce Bunkers, a friend of Forster's who spoke at a ceremony Tuesday honoring Colorado Department of Transportation workers killed on the job.

Since 1929, 57 CDOT employees have died in the line of duty.


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# Treating the Symptoms - roadway

- Void Filling
- Slabjacking
- Remove and replace
- Overlay
- Monitor

# Slabjacking / Void fill

- Process by which a mobile material is injected between the soil subgrade and the underside of the slab to restore intimate contact and to fill voids. Slabs and sleepers can be releveled to fine tolerances with this process
  - Cement Slurry – not used as often anymore
  - Polyurethane / foam  - used most frequently

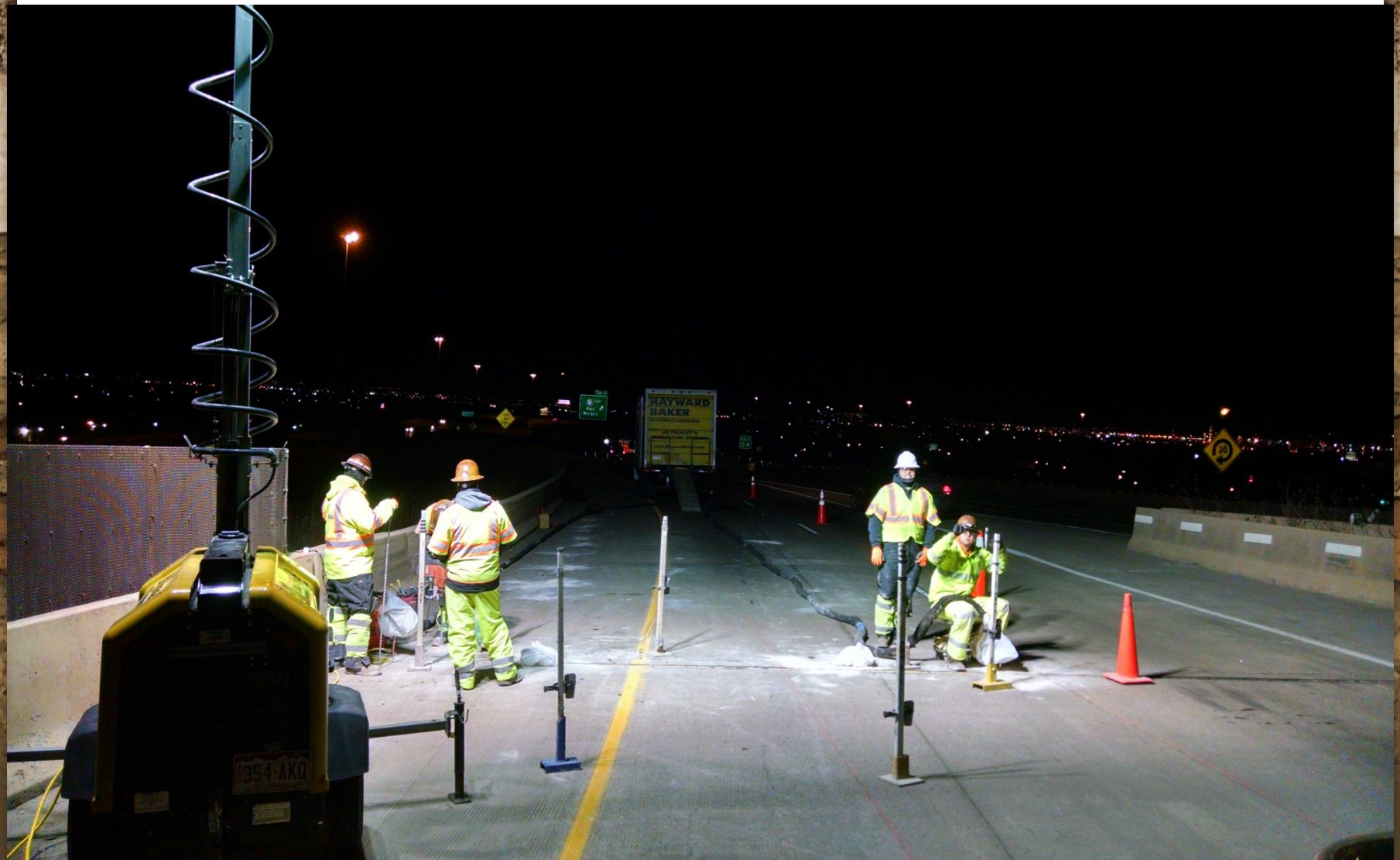

EXIT 108
17th


WEST
LEFT LANE
76
EAST

THINK SAFE

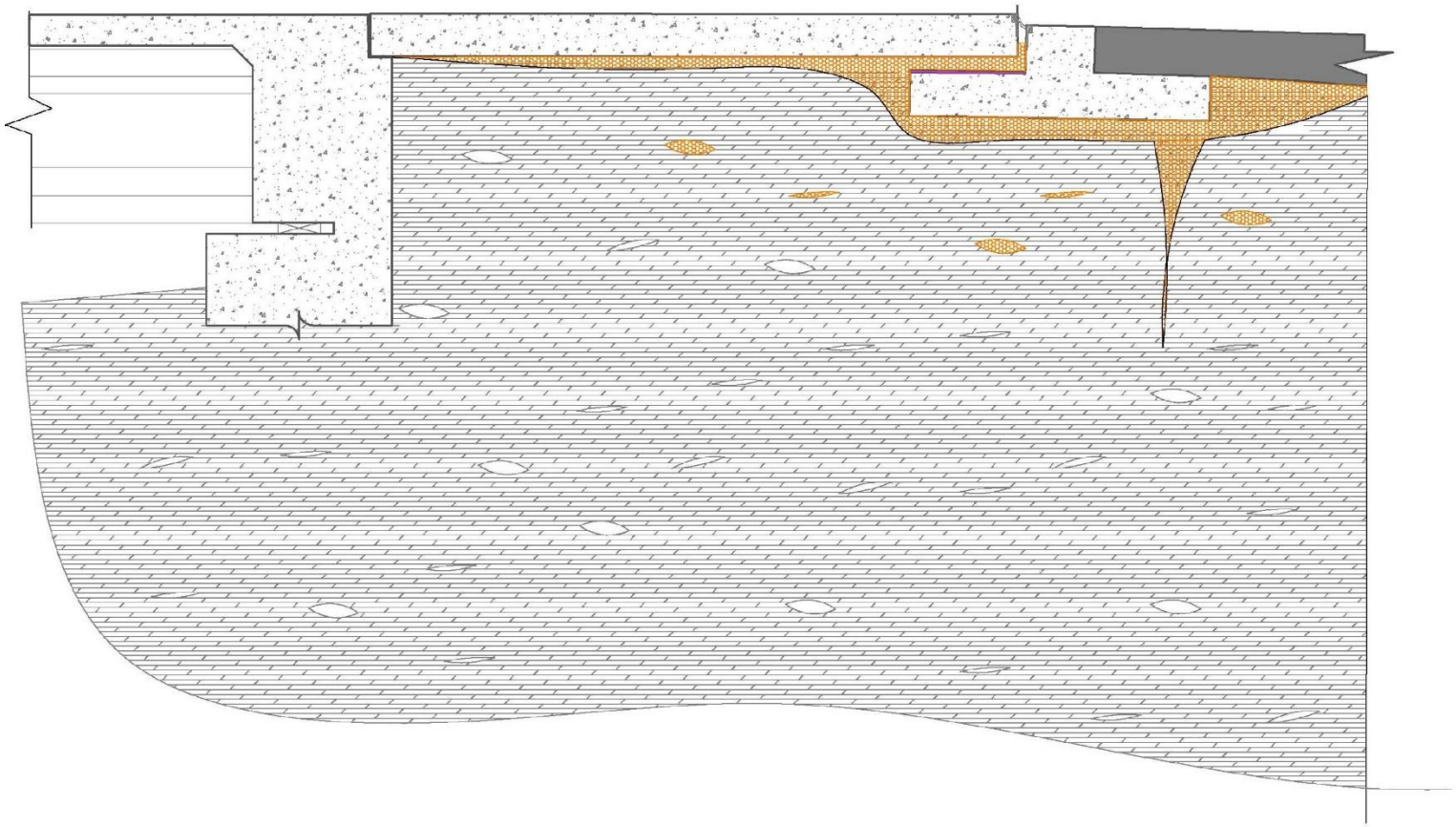
# Sleeper slabs can be jacked – with caution

# Sleeper and approach releveling



# View… Settlement

# If using mobile grouts ( cement or poly) care must be taken to assure product doesn't get between the slab and sleeper

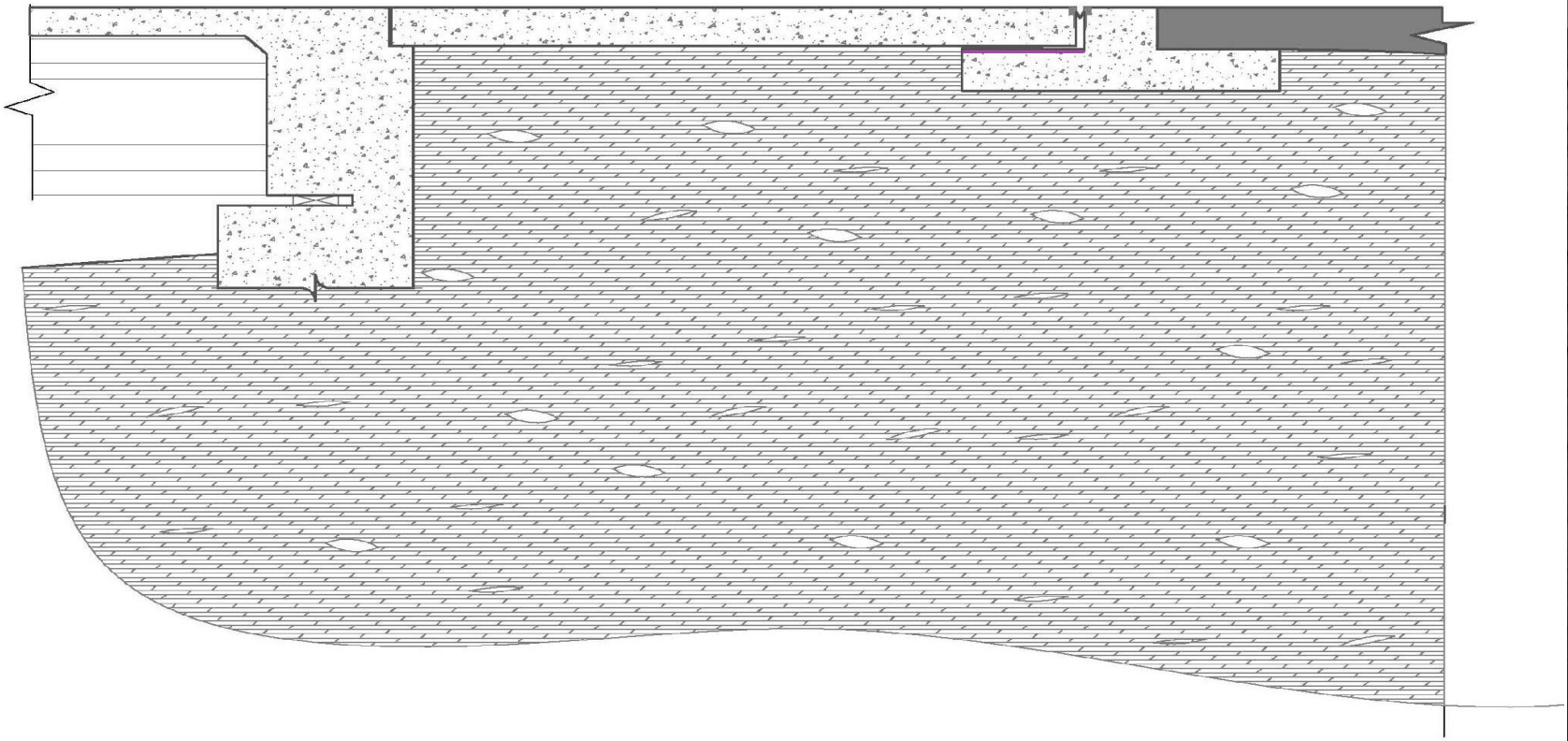


# Jacking Sleepers

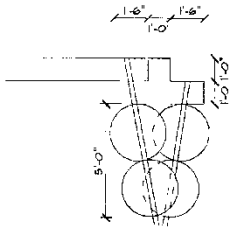
- Injected in liquid form so can travel some before setting. When trying to lift sleepers, numerous contractors have gotten foam between sleeper and slab and lifted slab off the sleeper.
  - Big profile dip is often eliminated, but sharp bump at sleeper is there forever if slabs are picked up off of sleeper.
  - Reports of sleepers being twisted
  - It is a chemical reaction and things can go awry

# Things to consider

If the consolidation or settlement problem is deep and ongoing, settlement will likely continue regardless of which material is injected at the shallow depths.



# How can one reduce risk of poly ( or slurry) infiltration in between sleeper and slab while assuring controlled lift?




## SLEEPER RELEVELING PROCESS

STEP 1 - OWNER OR G.C. PROVIDES TARGET ELEVATIONS ON SLAB.

STEP 2 - HBI DRILLS NOMINAL 3" HOLES THROUGH SLEEPER ON APPROX. 5' CENTERS.

STEP 3 - HBI INSTALLS GROUT CASING TO DEPTH OF APPROX. 3'-5'.

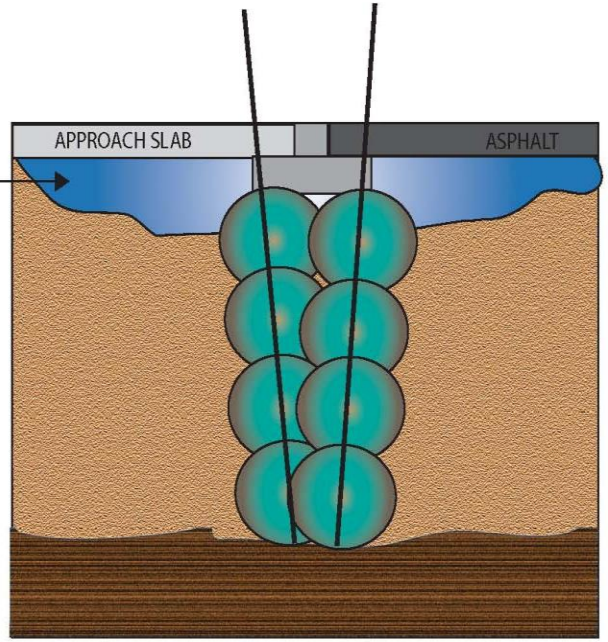
STEP 4 - A LOW MOBILITY GROUT IS INJECTED TO DENSIFY, STRENGTHEN AND COMPACT SHALLOW ZONE BELOW SLEEPER. MULTIPLE POINTS ARE INJECTED CONCURRENTLY WHILE RELEVELING SLEEPER TO DESIRED ELEVATION.

STEP 5 - UPON COMPLETION OF SLEEPER RELEVELING, SMALL DIAMETER HOLES SHALL BE DRILLED AS NEEDED THROUGH THE ADJACENT SLABS TO FILL VOIDS AND RELEVEL SLABS.

STEP 6 - UPON COMPLETION OF ALL GROUTING, ALL HOLES SHALL BE PATCHED WITH A NONSHRINK GROUT.

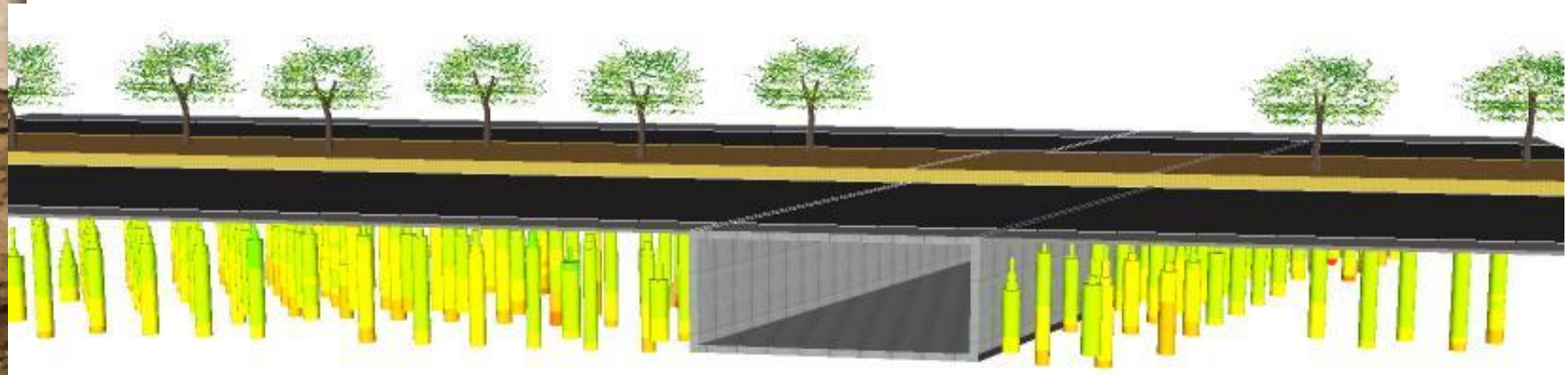
## LMG / HB Polylift

POLYURETHANE FOAM INJECTION TO FILL VOIDS



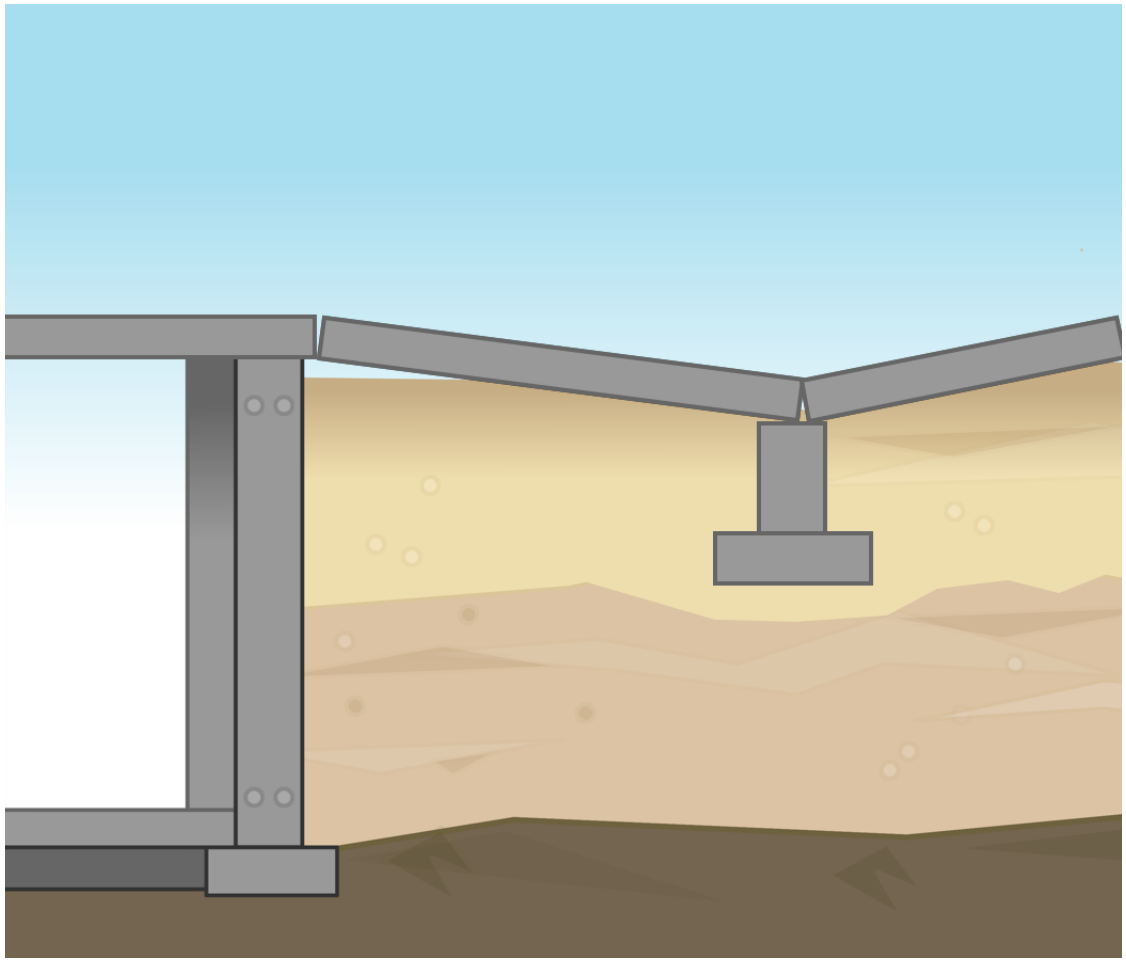
# Introduction--- What is Compaction Grouting or LMG

Compaction Grouting uses displacement to improve ground conditions. A very viscous (low-mobility), aggregate grout is pumped in stages, forming grout bulbs, which displace and densify the surrounding soils. Is also a very controlled means of releveling



# Bridge Approach Remediation:

## LMG controlled grouting and stabilization



# Low Mobility Grouting / Poly Combo Bridge Approach Remediation

*Can be used to treat both the "symptom and the cause" or as a shallow to moderate depth controlled lifting process--- LMG Grouting is not outdated, a bad thing, nor is it going away.*

Click to begin demonstration!

THINK SAFE

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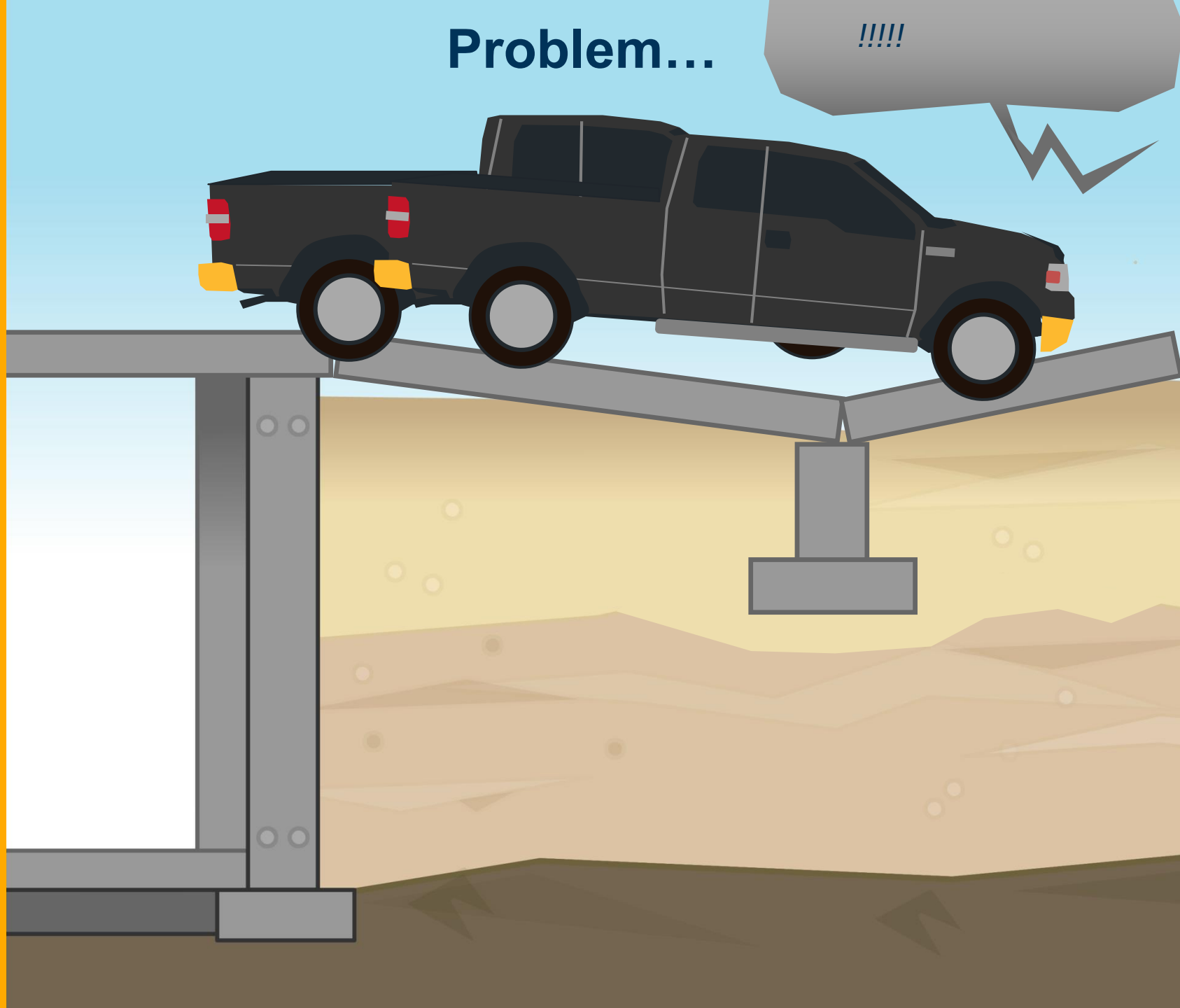
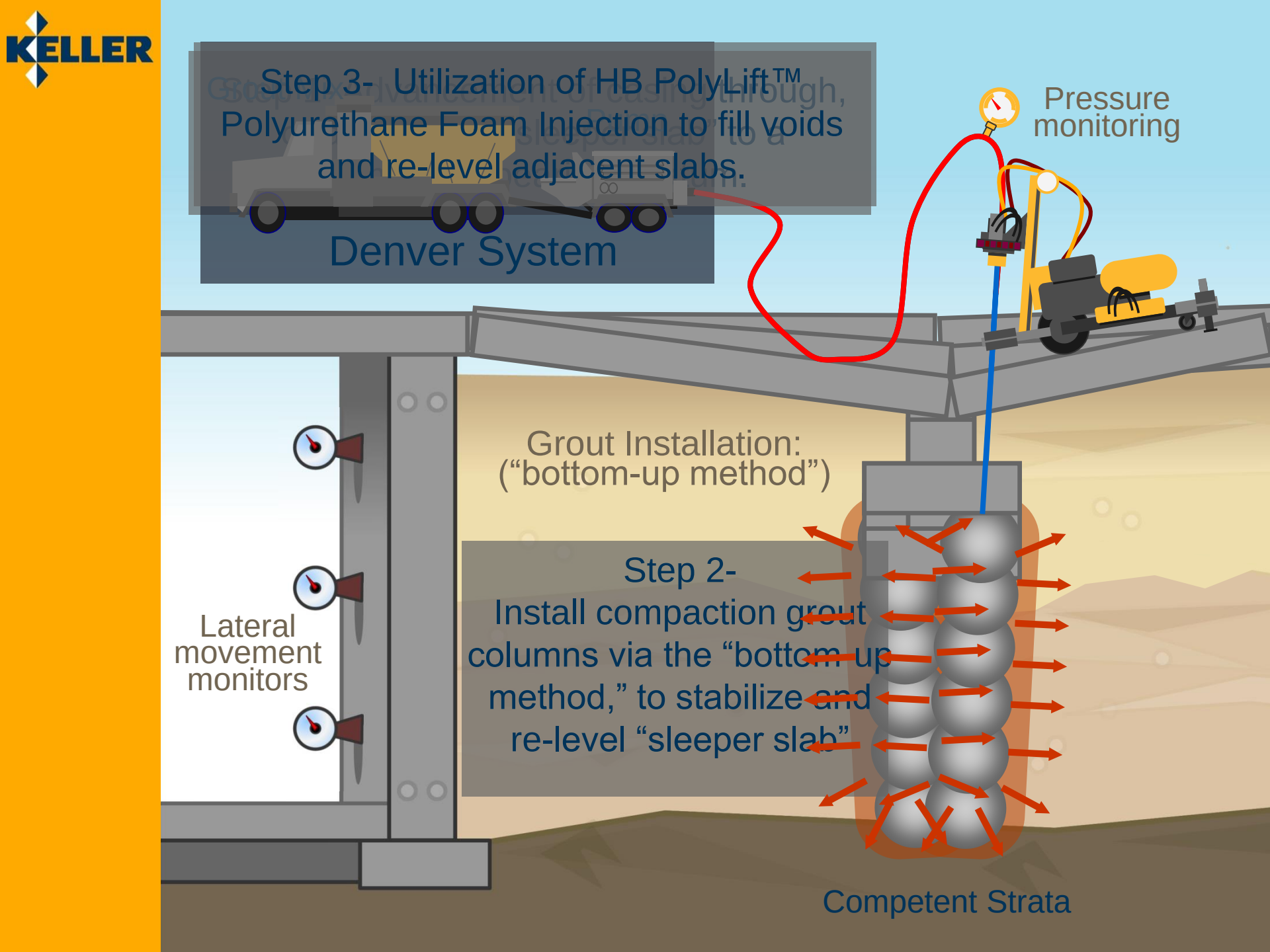
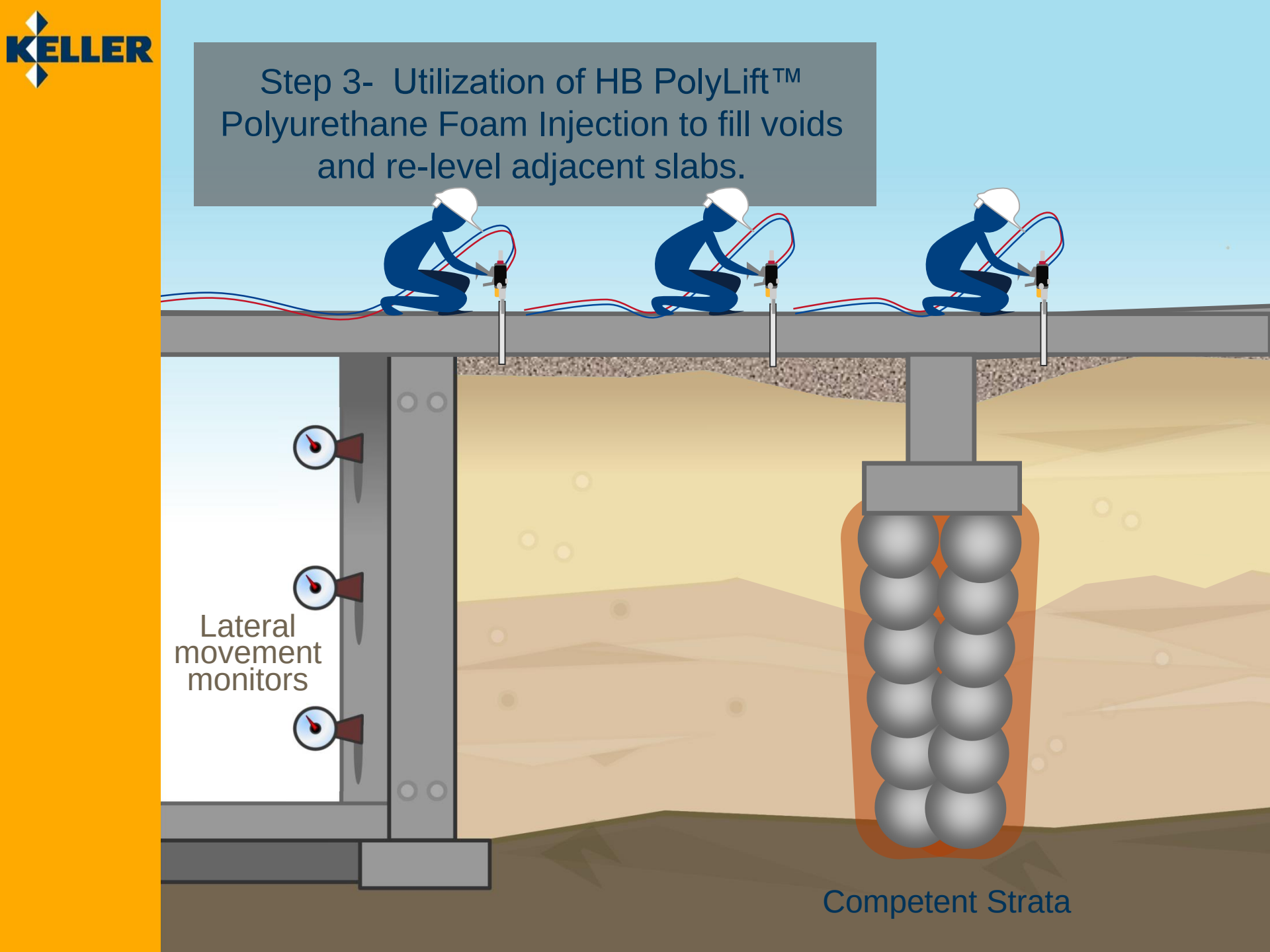
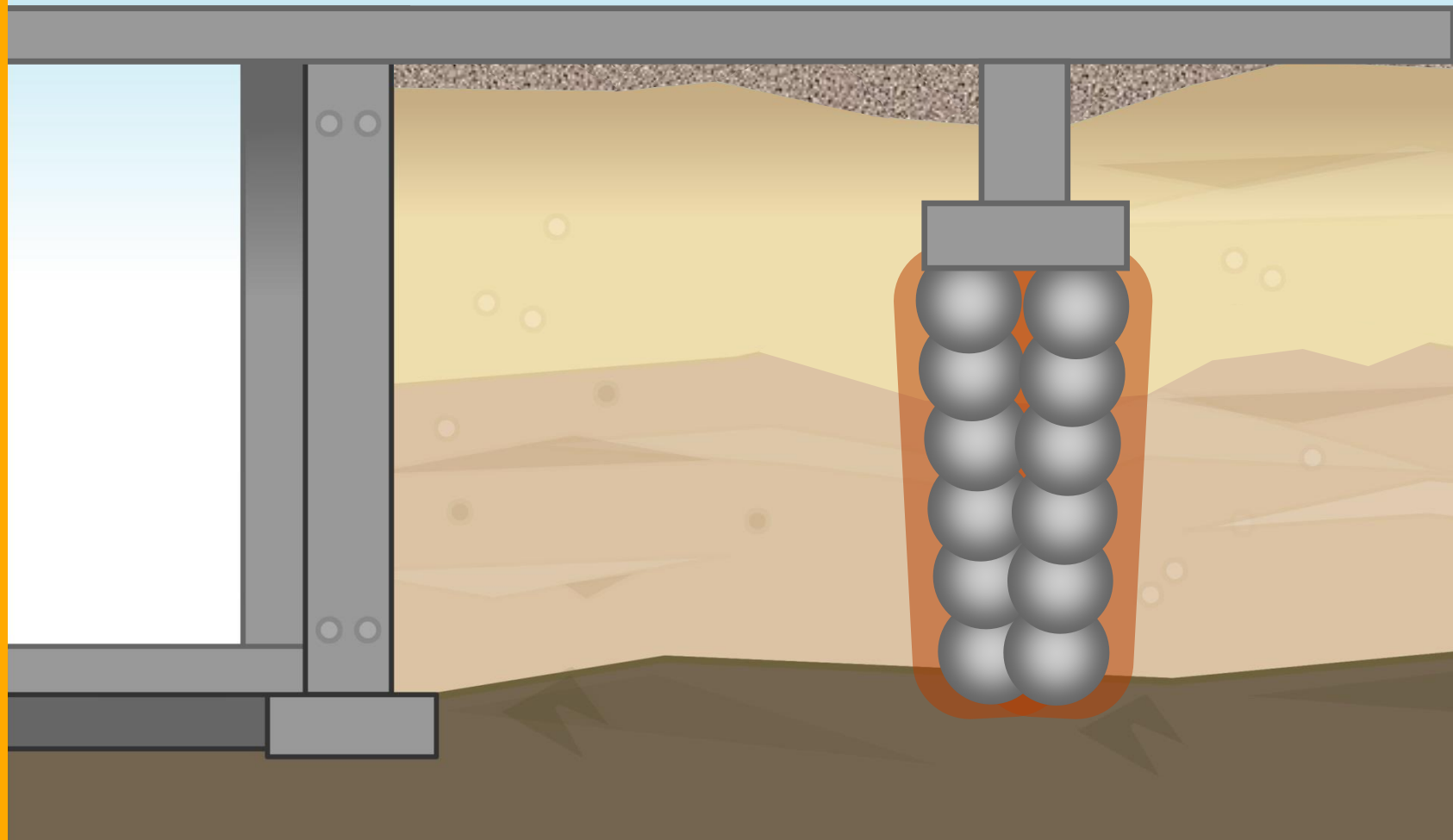
# Problem…

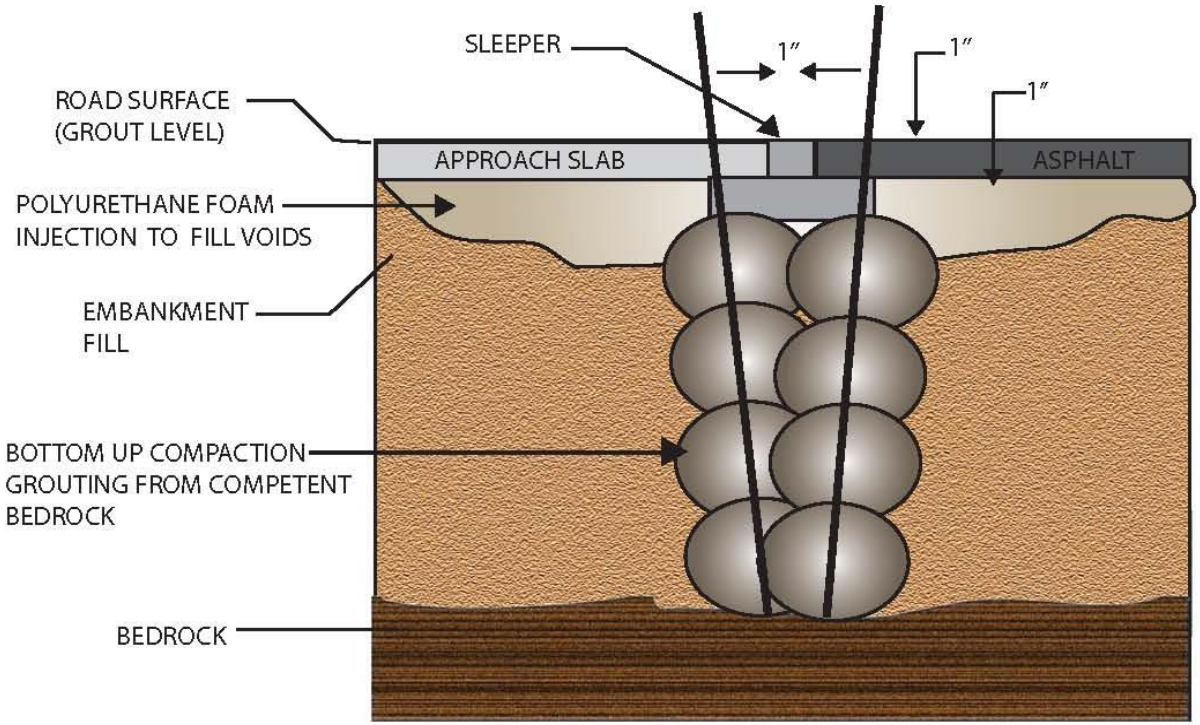



Step 3- Utilization of HB PolyLift™ Polyurethane Foam Injection to fill voids and re-level adjacent slabs.
Denver System
Pressure monitoring
Grout Installation: ("bottom-up method")
Step 2- Install compaction grout columns via the "bottom up method," to stabilize and re-level "sleeper slab"
Lateral movement monitors
Competent Strata

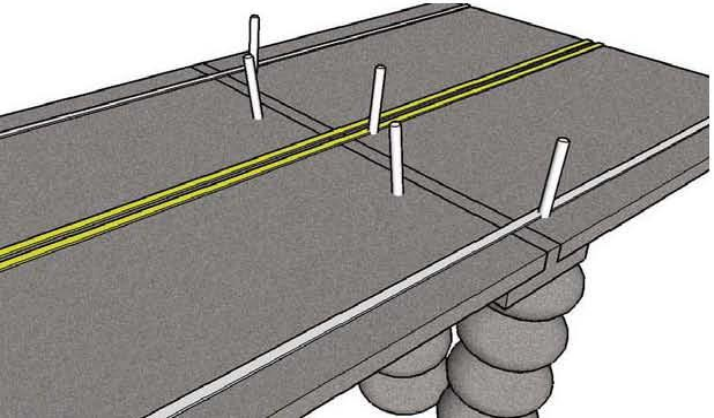

Step 3- Utilization of HB PolyLift™ Polyurethane Foam Injection to fill voids and re-level adjacent slabs.
Lateral movement monitors
Competent Strata

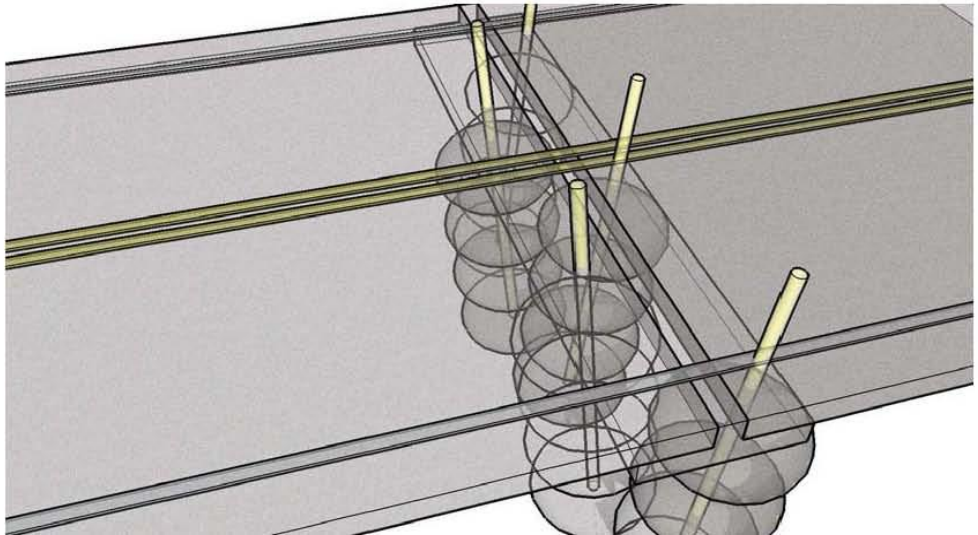
# End






SECTION VIEW
1/4″ = 1′0″





# T-Rex Bridge Approach stabilization and re-leveling

# Bridge Sleeper / approach

# So why utilize the low mobility and Poly lift systems in conjunctions with each other?

1) Utilize the time tested, cost effective, predictable efficient low mobility grout to lift load bearing elements such as a sleeper.

2) Utilize low mobility grout to densify the subgrade to a competent bearing stratum if desired for long term stability.

3) Utilize lightweight poly foam to fill voids and to lift adjacent slabs in conjunction with the low mobility grout

   * we don't ask the "foam" to do too much. Anytime you can use foam under the least amount of pressure, you get a "better bang for your buck".

4) Overall cost – This combination process is much more cost effective

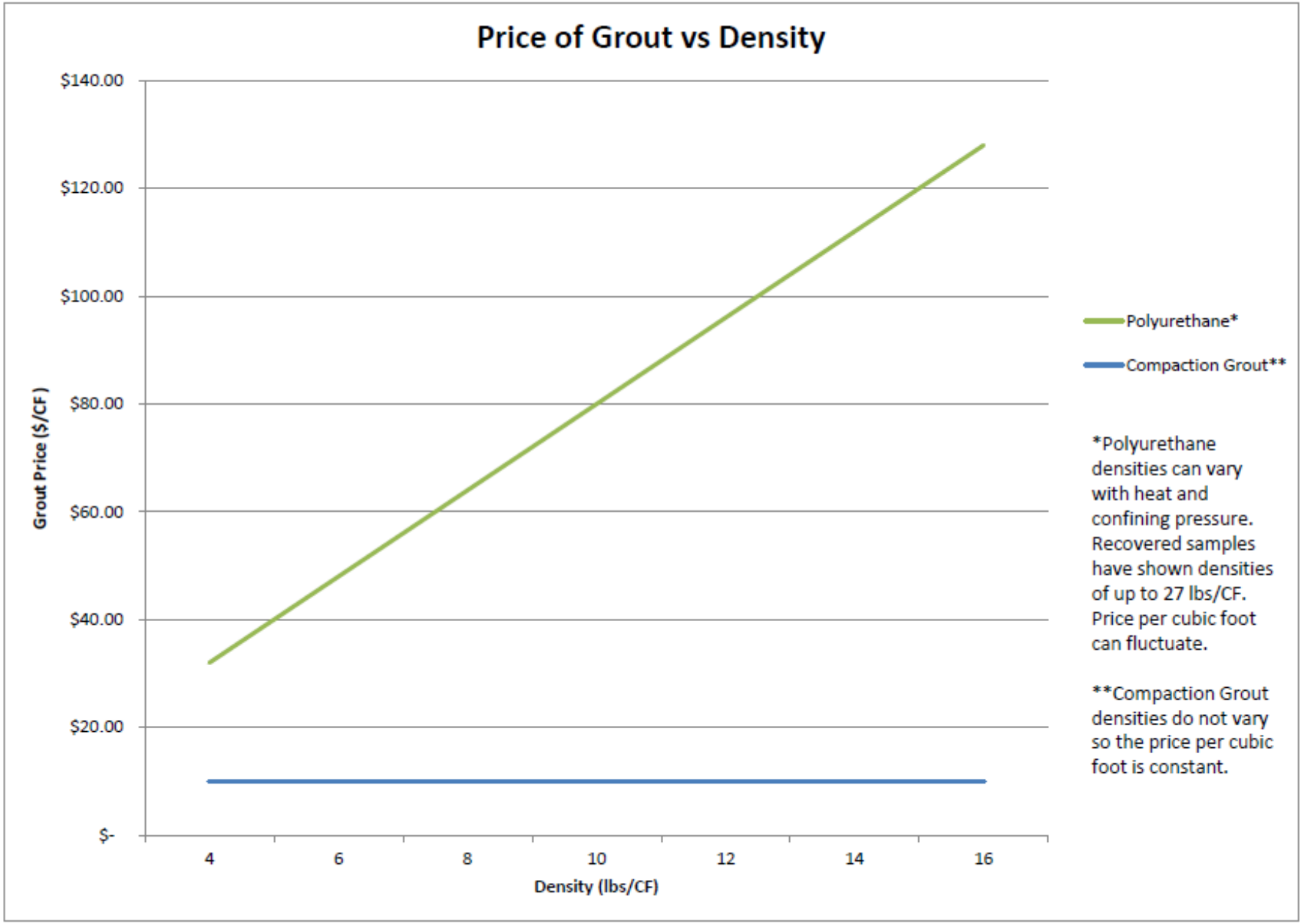
5) Long term stability – Combination of the processes provides a nice balance of cost and durability

6) Predictable results

7) Risk reduction in getting foam between sleeper and slab

# Potential Advantages of Compaction or LMG in roadway or bridge work

- Cost – still very economical – (density doesn't change when injected so you get exactly what you think you are paying for)
- Readily available
- Time tested and proven
- Very controlled and predictable process for re-leveling sleepers
- Pin point accuracy
- Assured and warranted long term solution if full treatment depth is performed


Price of Grout vs Density
$140.00
$120.00
$100.00
$80.00
$60.00
$40.00
$20.00
$-
Grout Price ($/CF )
4
6
8
10
12
14
16
Density (lbs/CF)
Polyurethane*
Compaction Grout**
*Polyurethane densities can vary with heat and confining pressure. Recovered samples have shown densities of up to 27 lbs/CF. Price per cubic foot can fluctuate.
**Compaction Grout densities do not vary so the price per cubic foot is constant.

# Things to consider

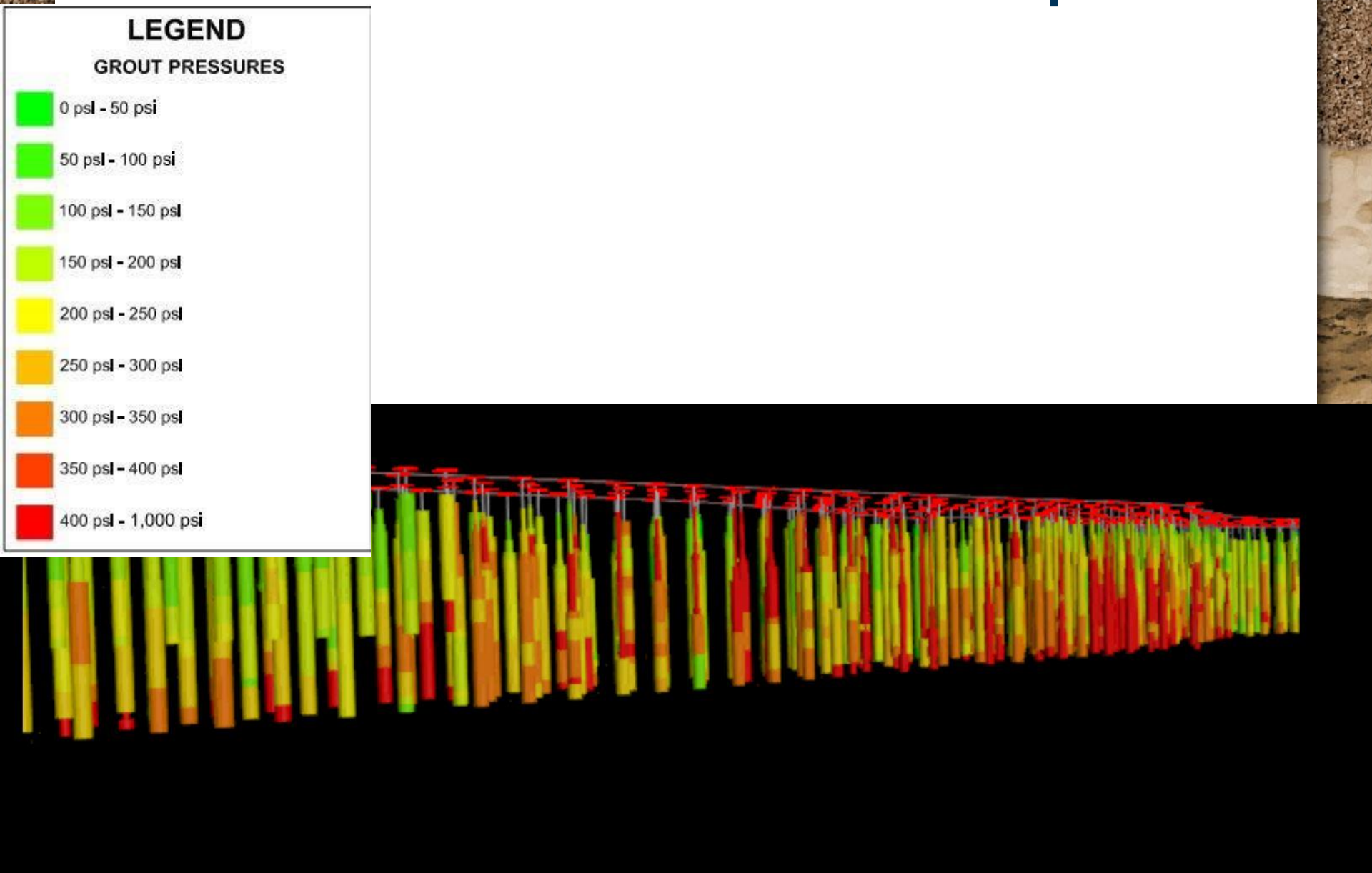
- When grouting directly adjacent to MSE walls, embankments or abutments, one must monitor and grout with caution as the densification process compacts soils for some distance from the point of injection as determined by grout placement quantity
  - ( Sequencing is very important)
  - ( admittedly, it may not always be the right in-situ remedial technique)

# Other uses of Compaction or Low Mobility Grouts

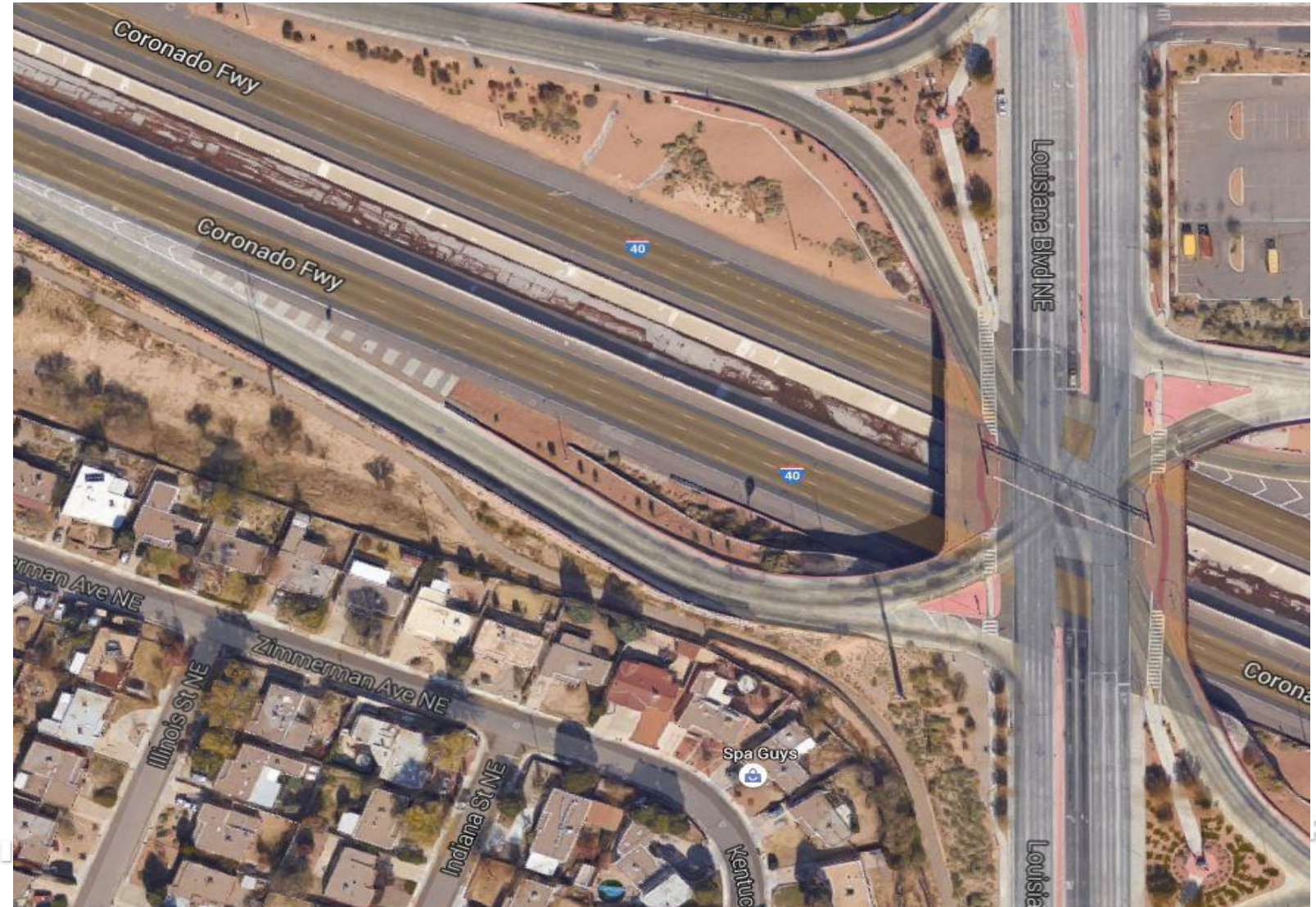
- Embankment Fill rehab
- MSE Wall stabilization
- Wall Backfill rehab
- Trench Backfill rehab
- Compensation / Emergency grouting ( tunneling gone awry, utility break)

# Man Placed Fill around box culvert rehab

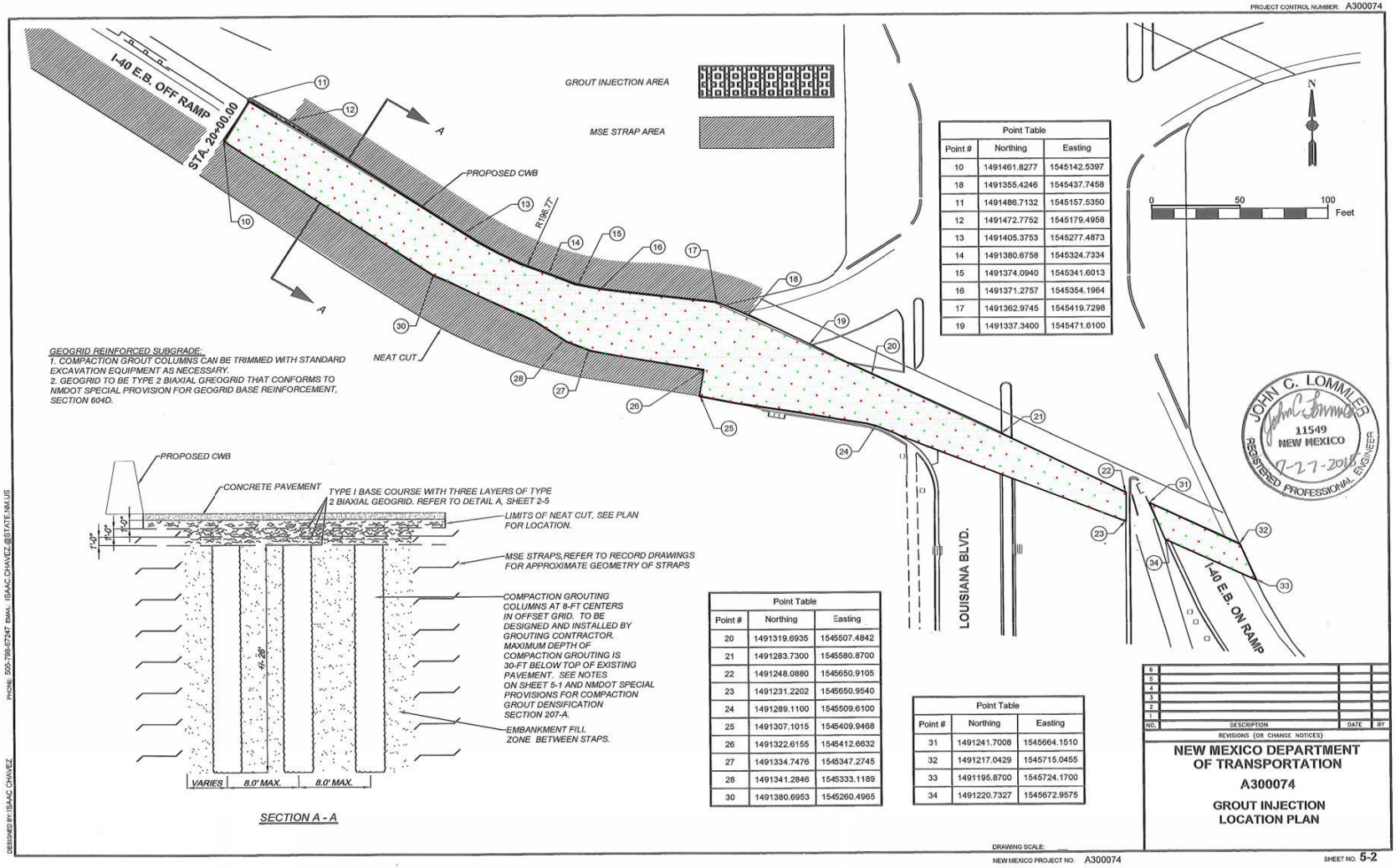
# 3D As Builts are now commonplace



# Embankment Fill rehab between MSE Walls

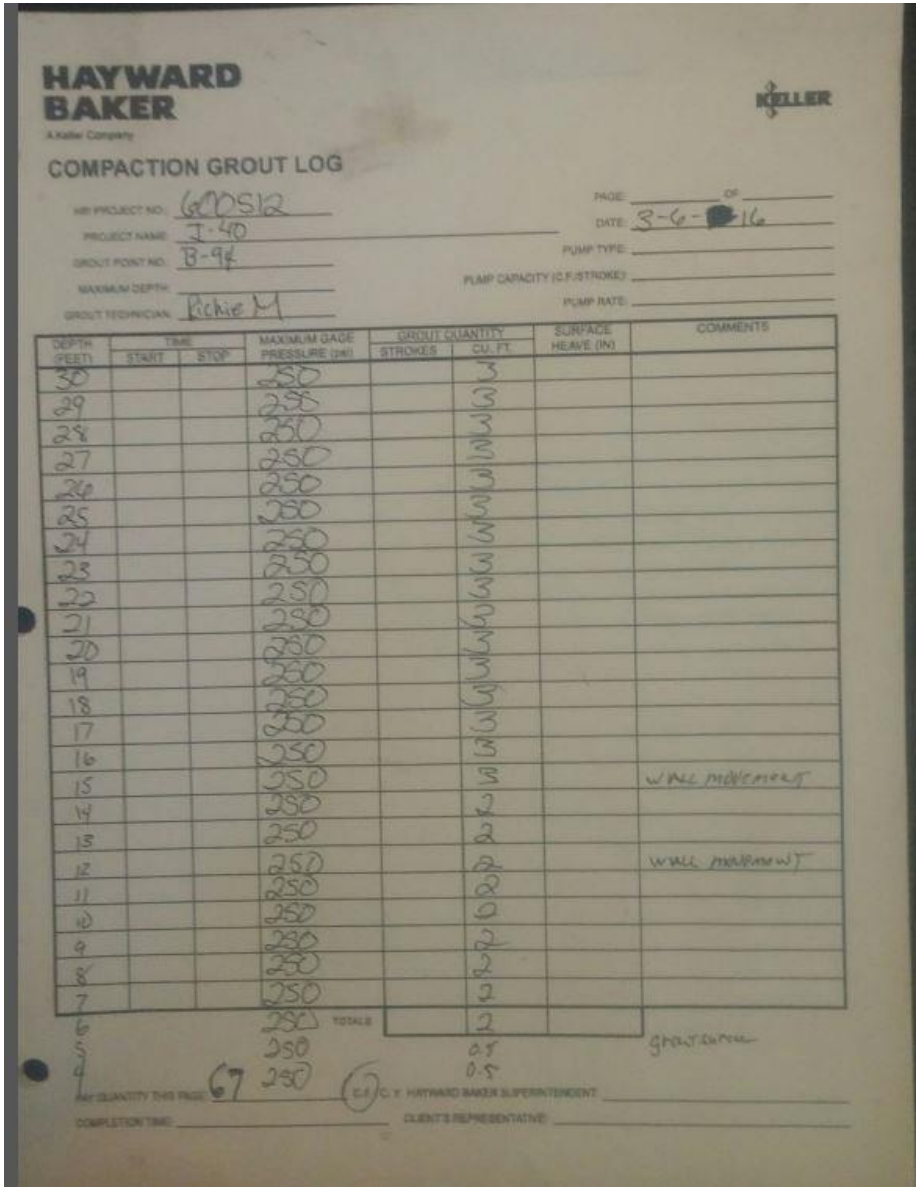


# Grouting Plan



# Grouting Operation

# Actual Field Log



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A Keller Company

KELLER

COMPACTION GROUT LOG

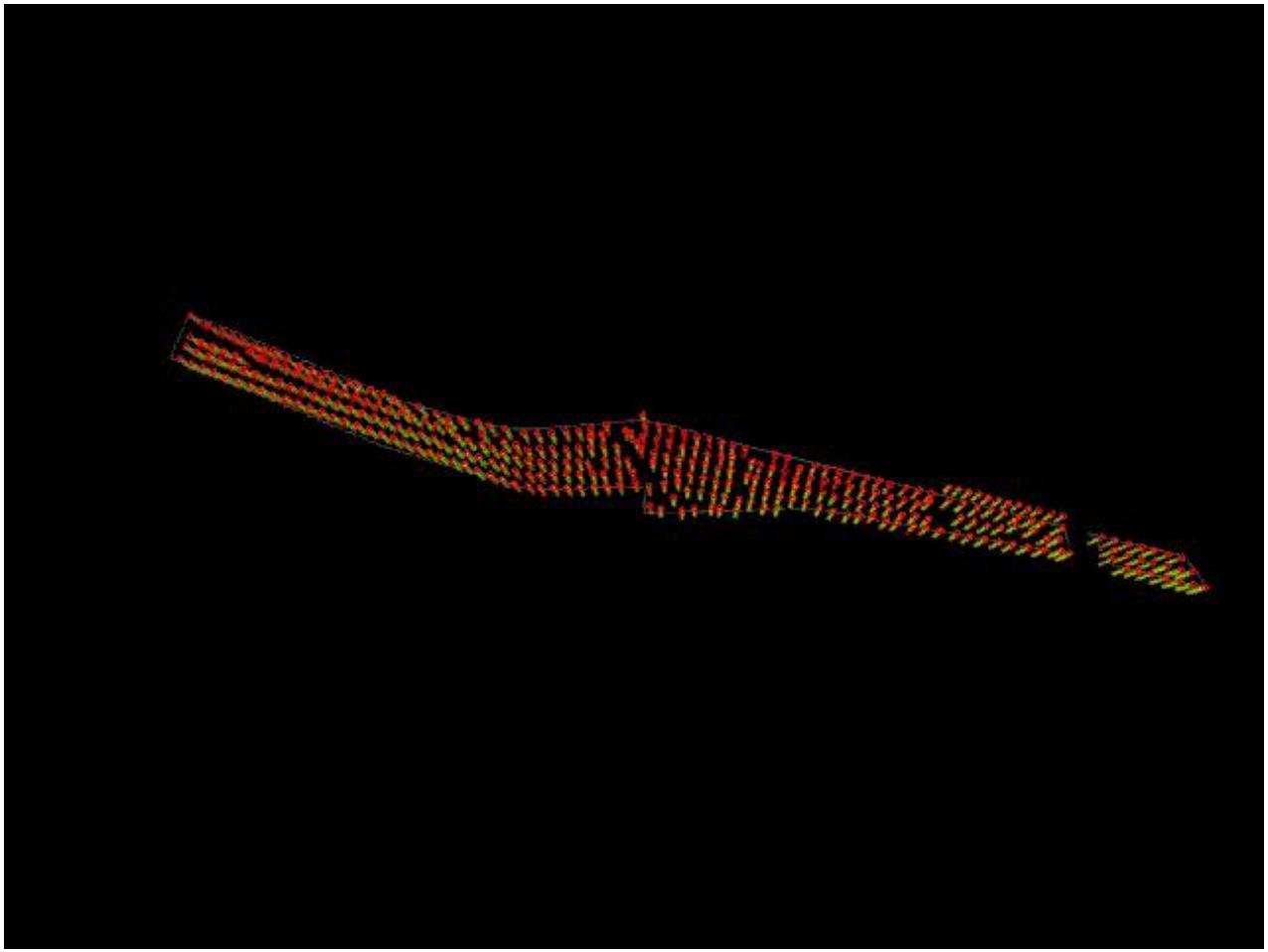
HB PROJECT NO.: 600512
PROJECT NAME: I-40
GROUT POINT NO.: B-9f
MAXIMUM DEPTH:
GROUT TECHNICIAN: Richie M

PAGE: ___ OF ___
DATE: 3-6-16
PUMP TYPE:
PUMP CAPACITY (C.F./STROKE):
PUMP RATE:

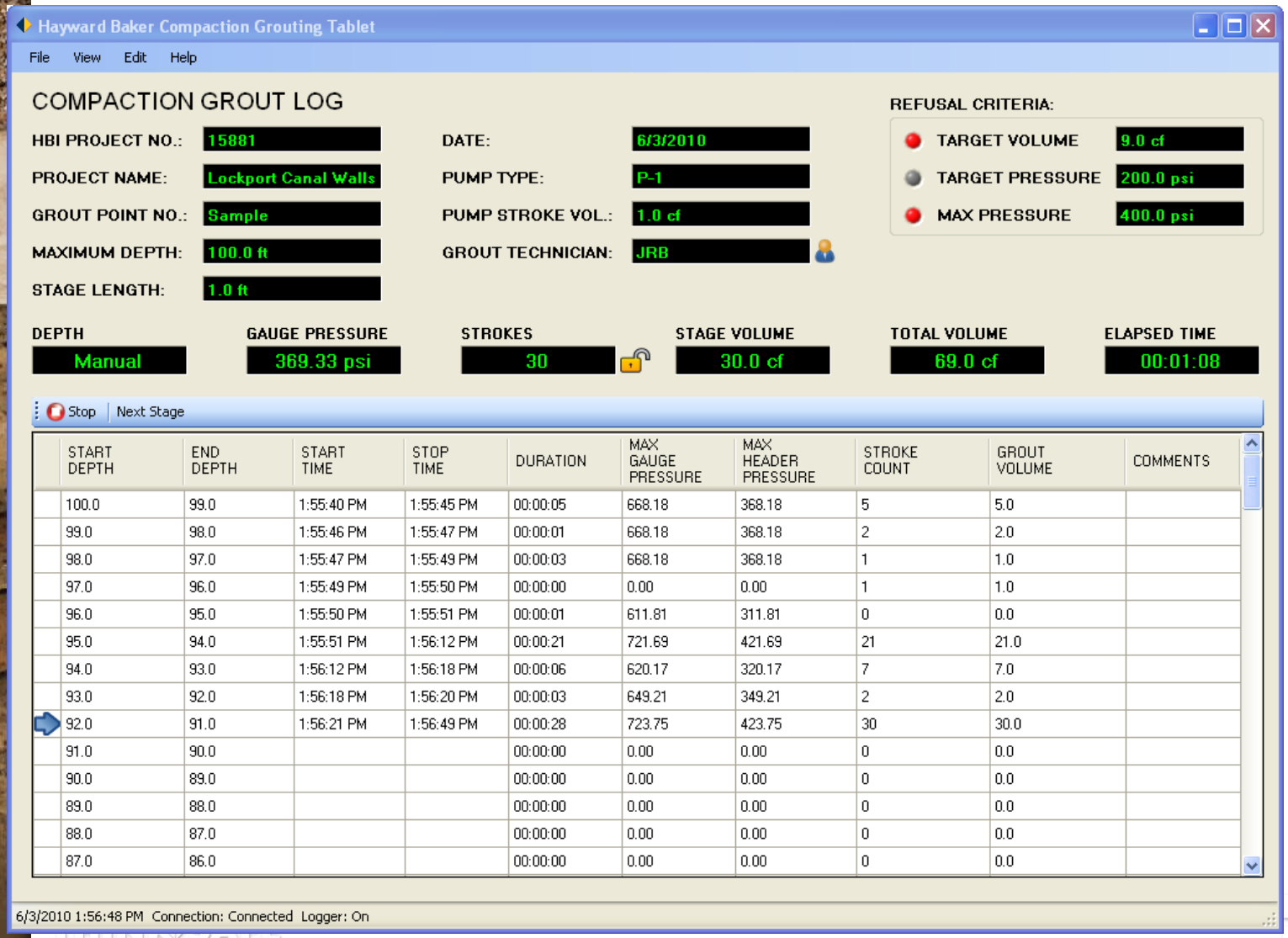
| DEPTH (FEET) | TIME START | TIME STOP | MAXIMUM GAGE PRESSURE (psi) | GROUT QUANTITY STROKES | GROUT QUANTITY CU. FT. | SURFACE HEAVE (IN) | COMMENTS |
|---|---|---|---|---|---|---|---|
| 30 | | | 250 | | 3 | | |
| 29 | | | 250 | | 3 | | |
| 28 | | | 250 | | 3 | | |
| 27 | | | 250 | | 3 | | |
| 26 | | | 250 | | 3 | | |
| 25 | | | 250 | | 3 | | |
| 24 | | | 250 | | 3 | | |
| 23 | | | 250 | | 3 | | |
| 22 | | | 250 | | 3 | | |
| 21 | | | 250 | | 3 | | |
| 20 | | | 250 | | 3 | | |
| 19 | | | 250 | | 3 | | |
| 18 | | | 250 | | 3 | | |
| 17 | | | 250 | | 3 | | |
| 16 | | | 250 | | 3 | | |
| 15 | | | 250 | | 3 | | WALL MOVEMENT |
| 14 | | | 250 | | 2.5 | | |
| 13 | | | 250 | | 2.5 | | |
| 12 | | | 250 | | 2.5 | | WALL MOVEMENT |
| 11 | | | 250 | | 2.5 | | |
| 10 | | | 250 | | 2.5 | | |
| 9 | | | 250 | | 2.5 | | |
| 8 | | | 250 | | 2.5 | | |
| 7 | | | 250 | | 2.5 | | |
| 6 | | | 250 | TOTALS | 2 | | |
| 5 | | | 250 | | 0.5 | | grout curtain |
| 4 | | | 250 | | 0.5 | | |

67 (C.Y.)

C.Y. HAYWARD BAKER SUPERINTENDENT:
COMPLETION TIME:
CLIENT'S REPRESENTATIVE:

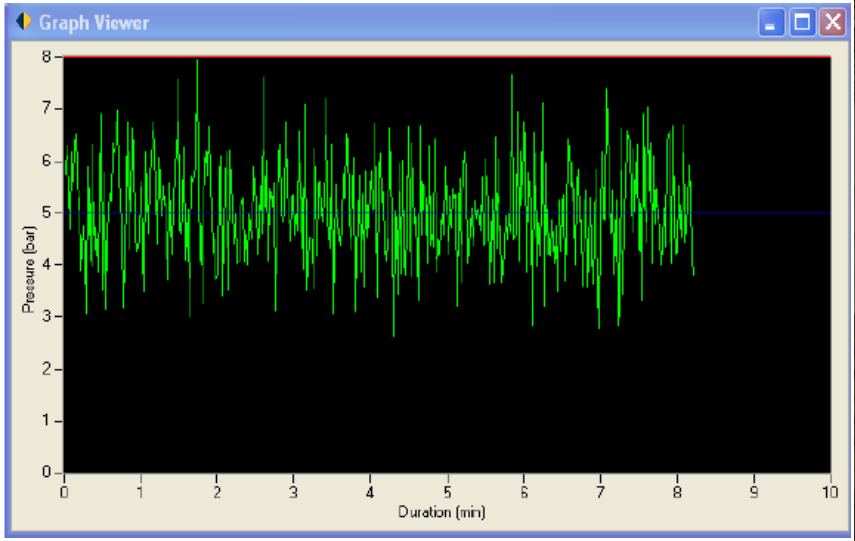


# Tablet Compaction Software



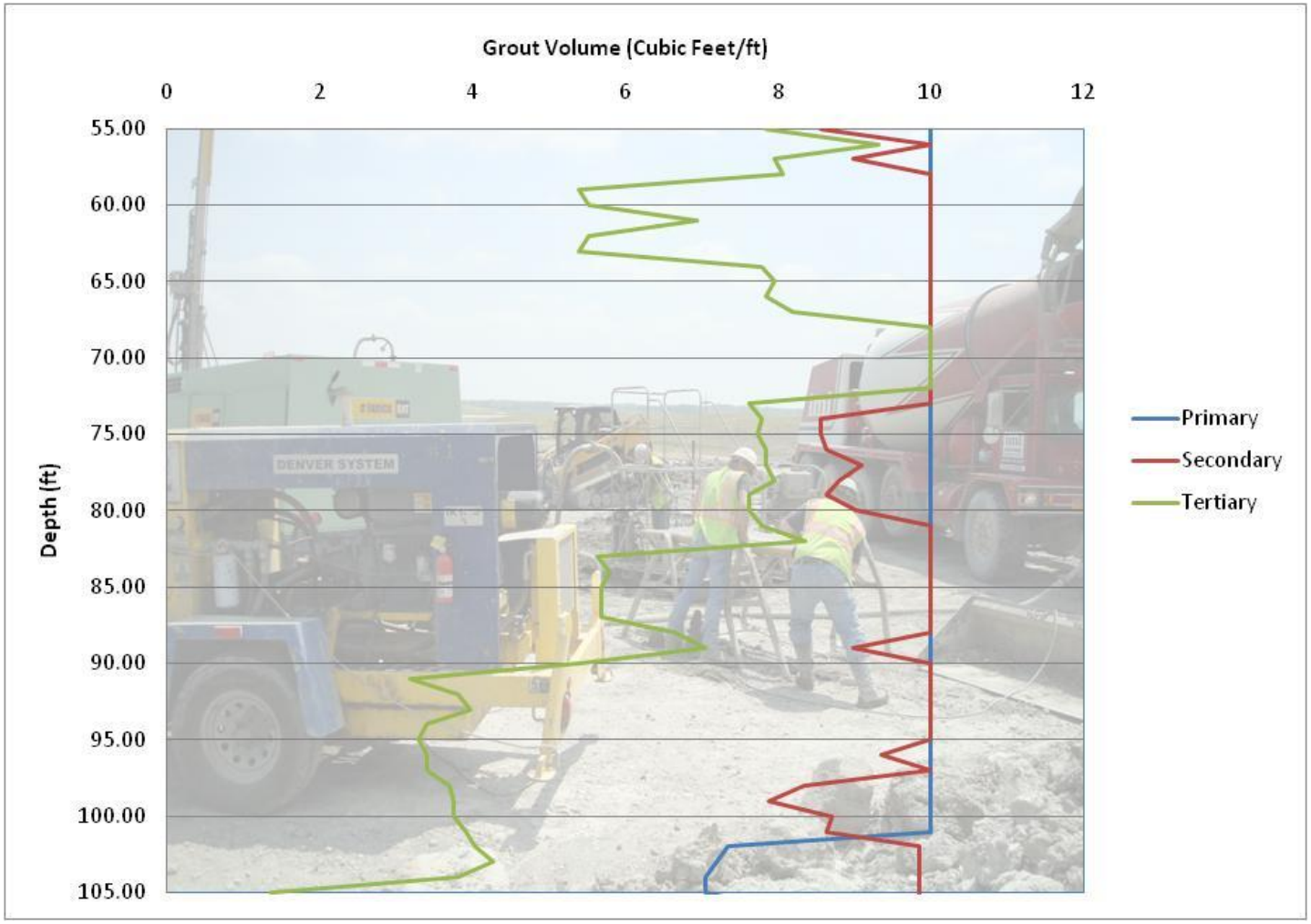
# Tablet Compaction Features

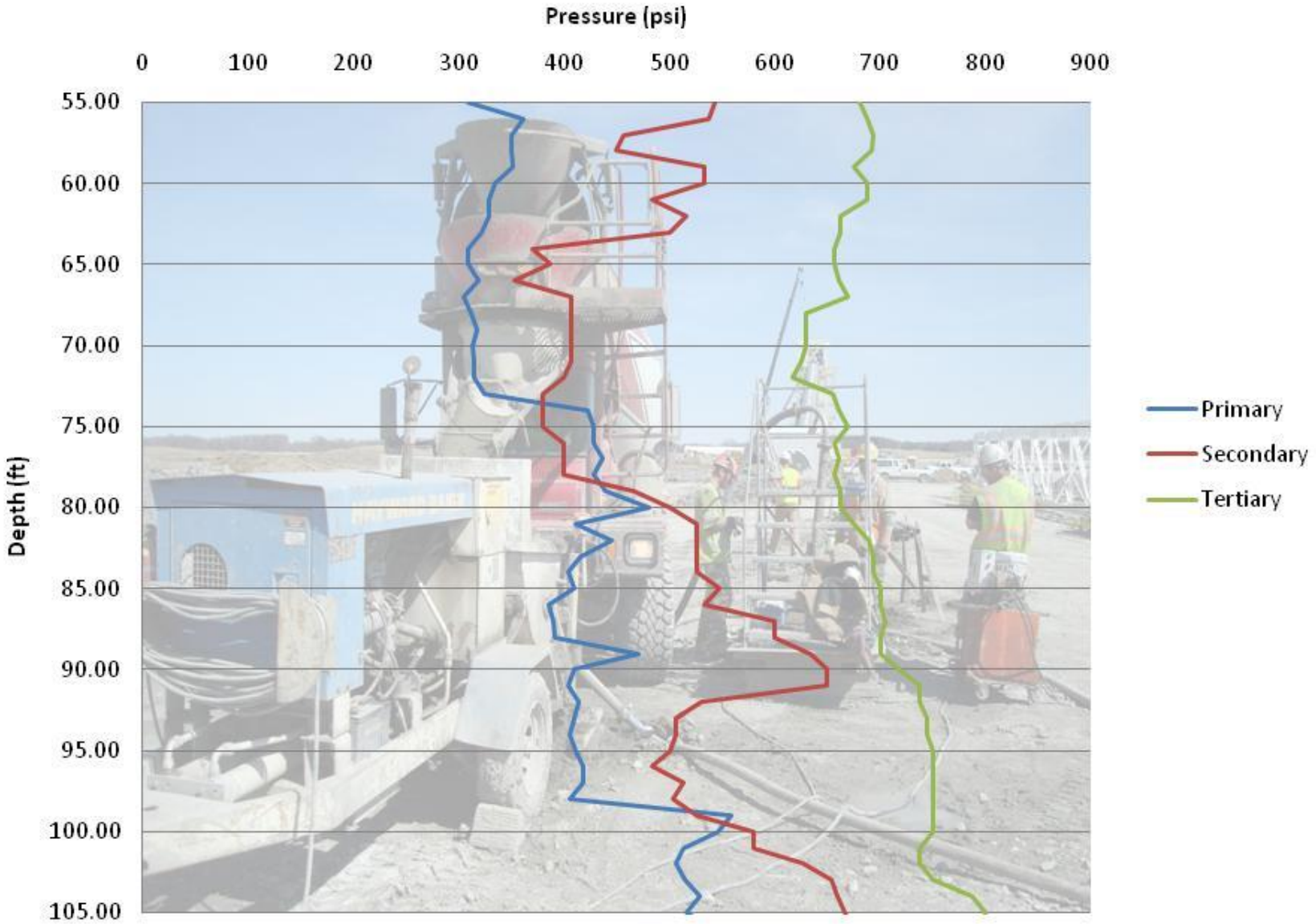
- Stores data in SQL database on local machine.
- Syncs data directly to DAQ server database
- Finished Excel logs are automatically output at the end of each operation



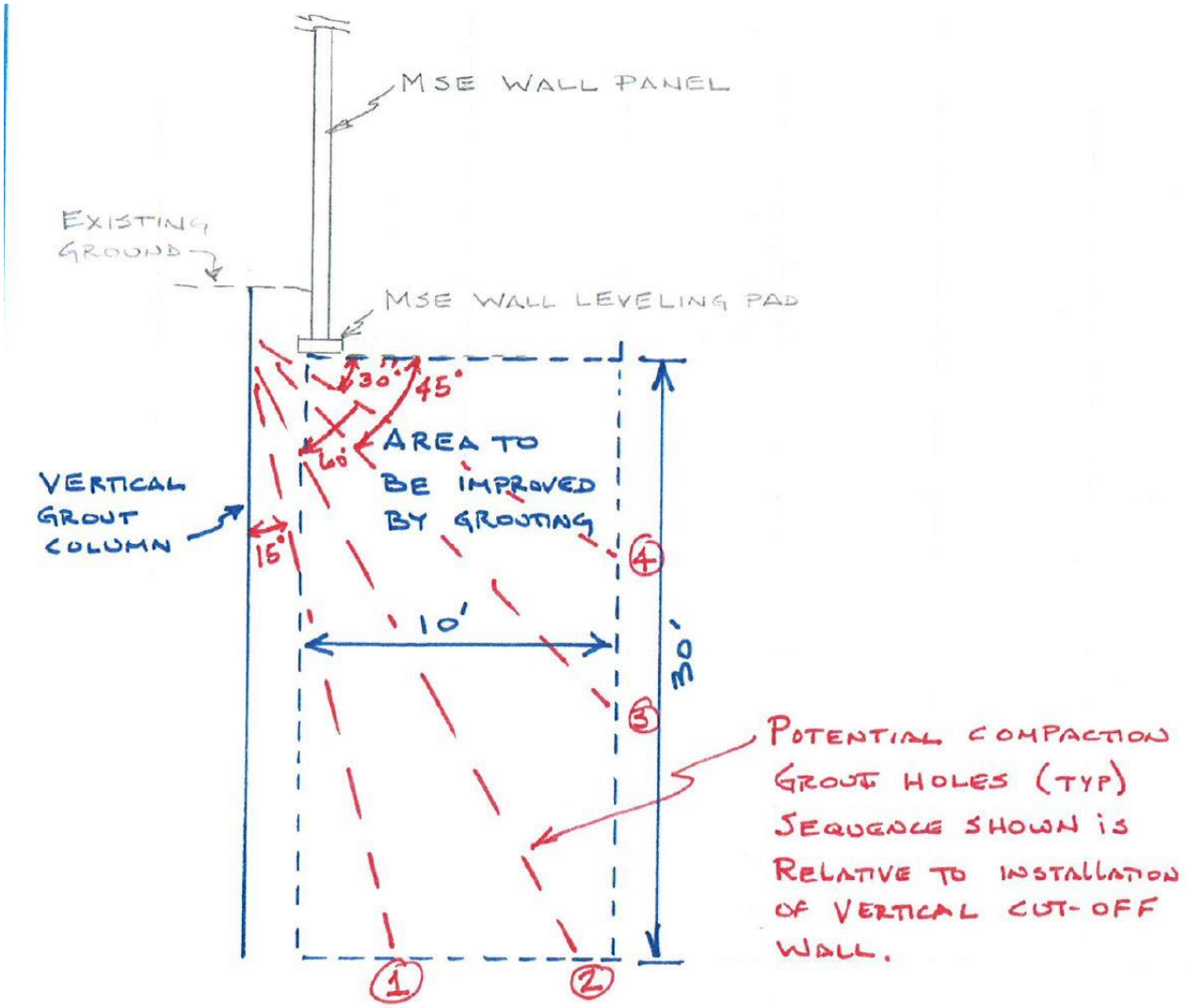

- **Real-time graphs of pressure, stroke count, volume**
- **Add comments for each stage**

# USING HOLE SEQUENCING FOR VERIFICATION

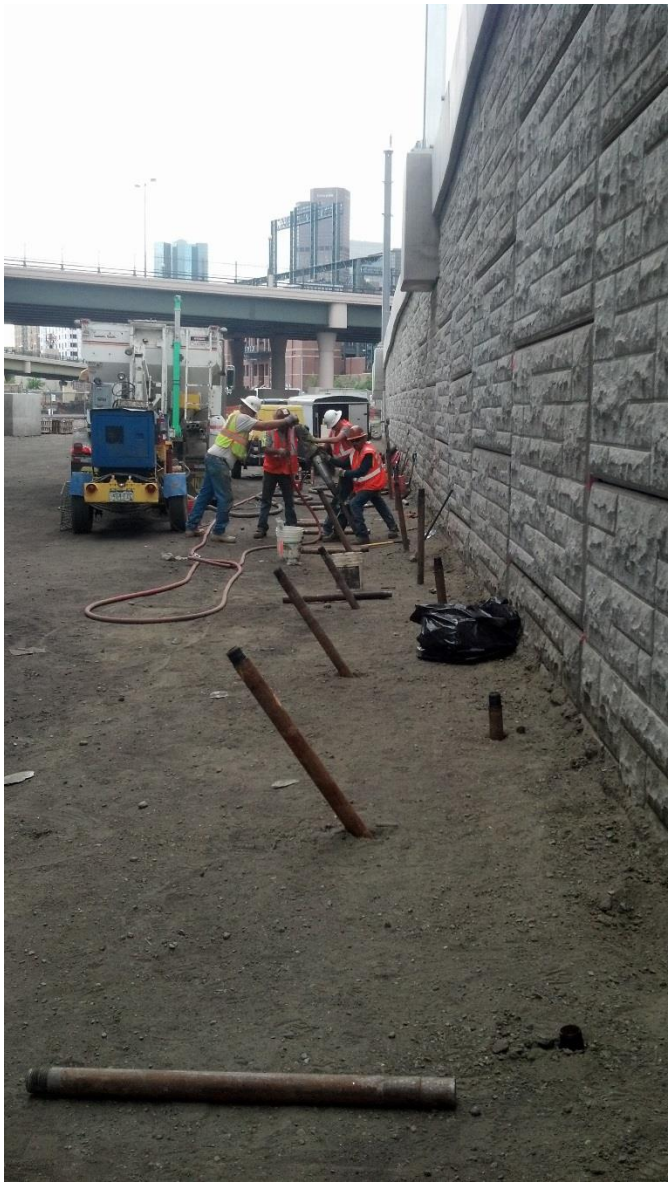


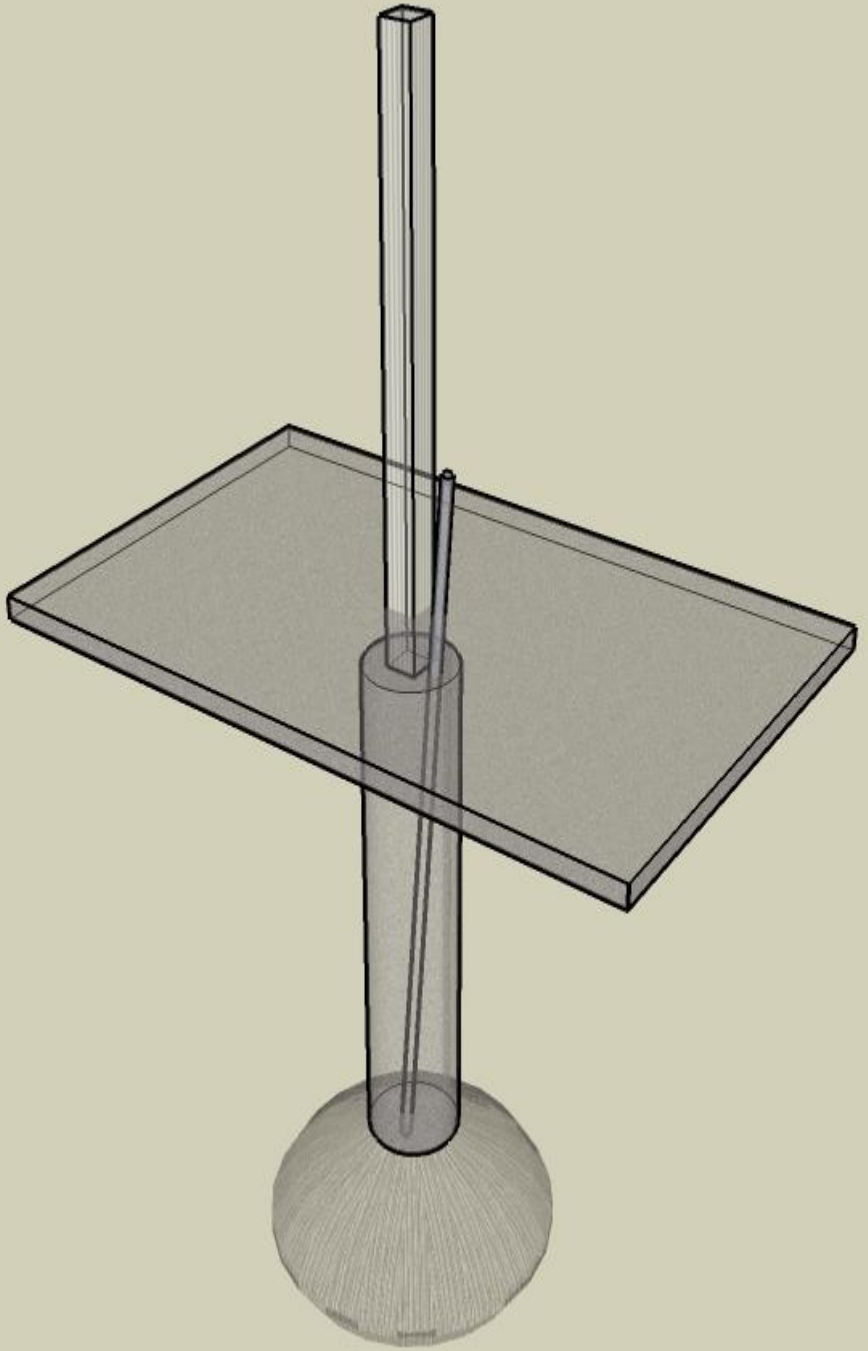


# MSE Wall and footing stabilization



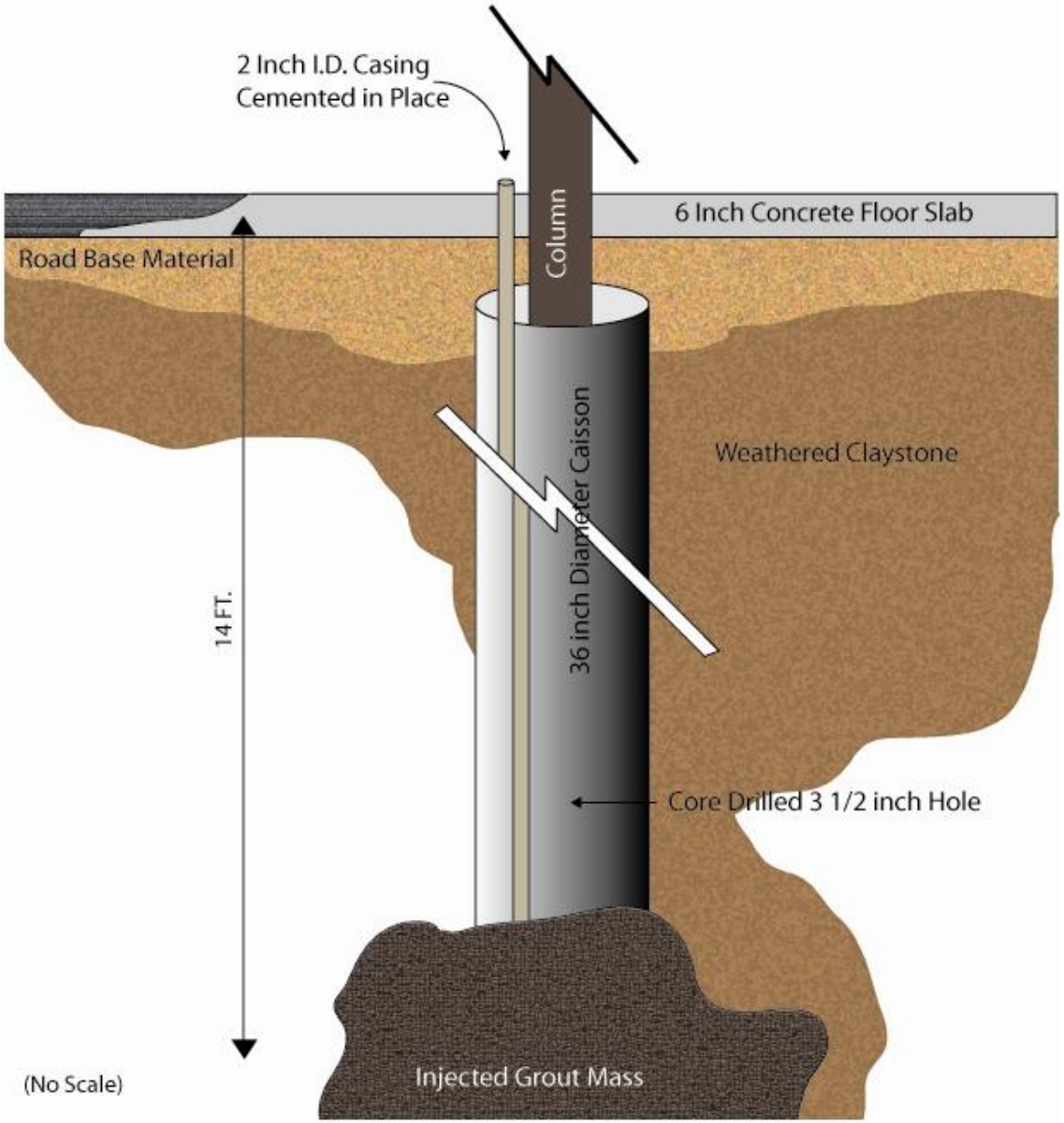
# MSE / Retaining walls re-leveled





IBM Village Center
Dallas, Texas

Caisson Stabilization Plan
Using "Compaction Grouting"



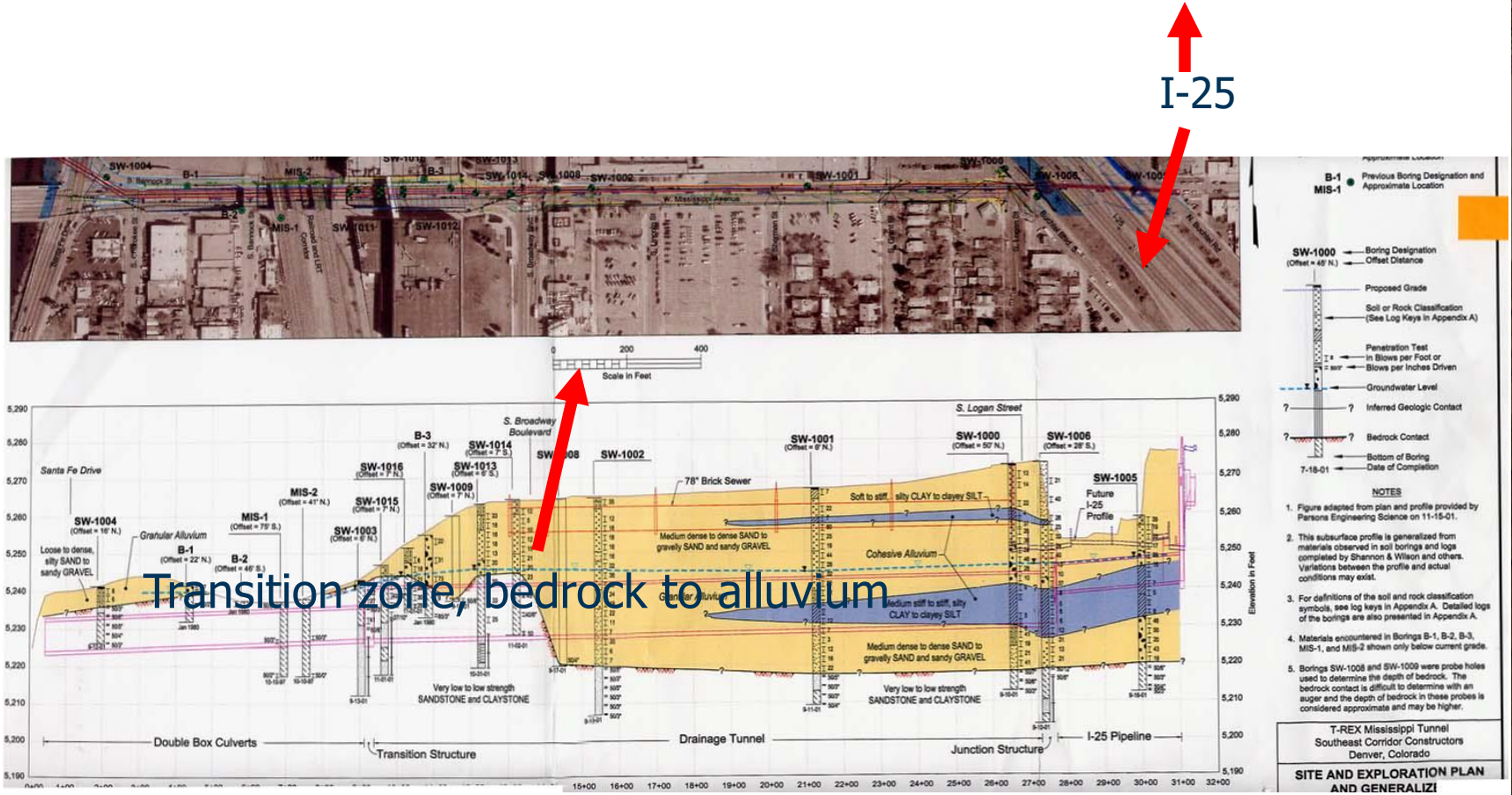
# Compensation Grouting– Tunneling

# Mississippi Ave. outfall Tunnel Project
# Denver, CO

- Problem Description:
- Fifteen-foot diameter TBM cutting in claystone, transitioning into saturated granular alluvium only 25’ below city streets and buildings. High potential for subsidence in mixed-face transition zone

- Solution:
- HBI worked with the tunneling contractor to develop a Compaction Grouting Program to compensate for settlement over the TBM, to allow tunneling to progress through this zone without surface disturbance.

# Mississippi Ave. Outfall Geologic Profile



# Earth-pressure-balance TBM Portal

# Grouting Holes

- Flush-joint 2-5/8" grout casing advanced to point 10' above tunnel crown on 10' centers, ahead TBM advance.
- Low slump compaction grout injected as tail shield passes by to compensate for soil loosening.

# Compensation Grouting Plan

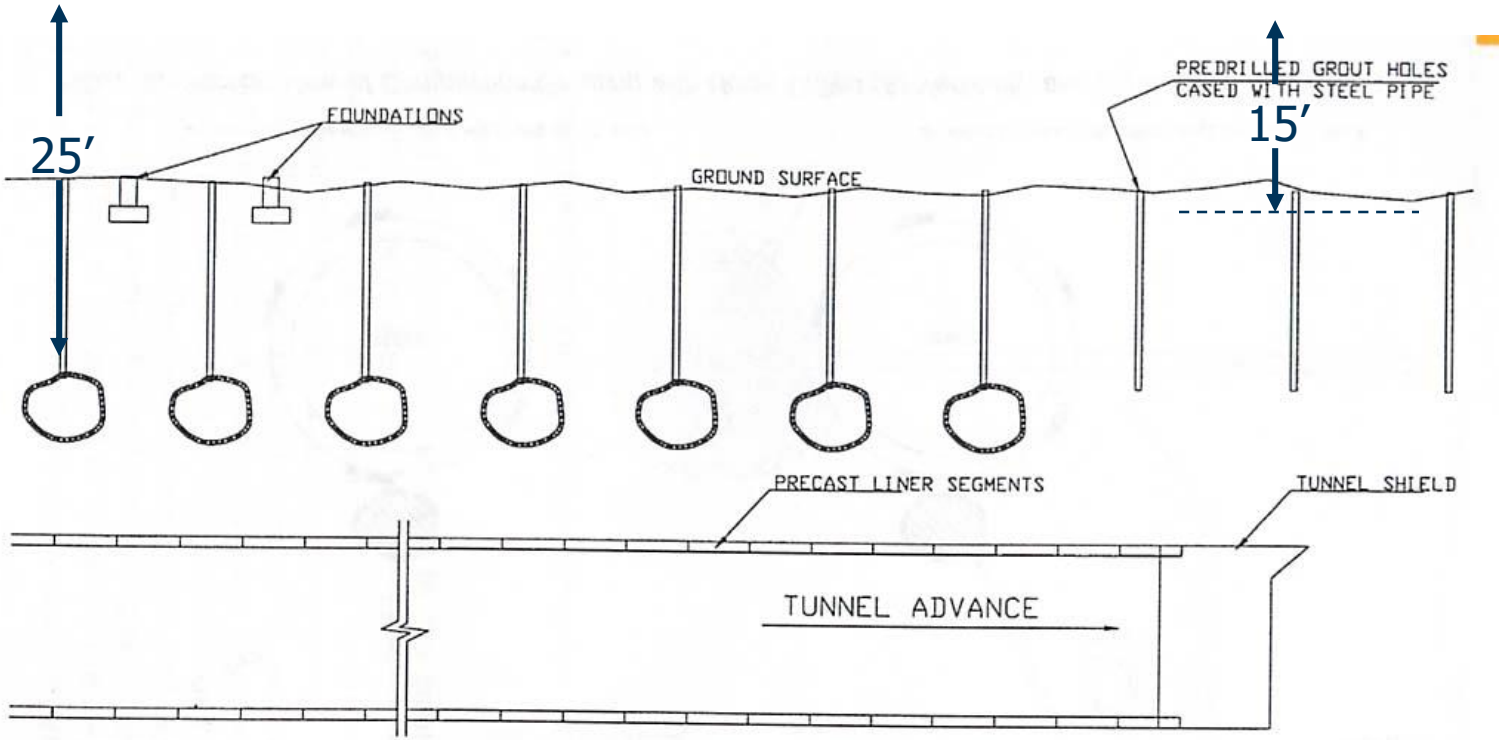



FIG. 2-7 Longitudinal View of Compensation Grouting Used to Control Settlement in Conjunction with Excavation of Soft-Ground Tunnel

Figure from Hehn, *Grouting Underground Structures*, used with permission

# Drilling and setting grout casing ahead of advancing TBM on tunnel centerline. Angled hole to avoid high pressure gas line.

# Compensation Grouting at Transition Zone

- Extensometers and tell-tails showed when and where settlement occurred
- Compaction grouting commenced immediately to compensate for soil loosening above tunnel
- 6 cubic yards injected into three holes in transition zone at low pressures during tunneling
- Second phase of compaction grouting conducted later to tighten up ground in the transition area; higher pressures, lower takes

# Sinkholes above crown of TBM

# Drilling above tunnel to compaction grout voids

# Grouting Holes in Sinkhole area

- grout casing advanced to point 5’ above tunnel crown into center of each sinkhole, and at all stations where TBM parked between shifts. Voids logged and casing set for grouting
- Low slump compaction grout injected to fill and compact voids.
- Up to 5cu.yd placed in base of sinkhole areas at 150-200psi.
- Sinkhole filled and stabilized from bottom to surface under street.
- 78 in. brick-lined storm sewer also stabilized

# Project: Trench Backfill Rehab

## Infrastructure Developed in 2005 – 2006

- The Issue
  - Significant pavement distress & settlement in roadways starting in 2007 – 2008
  - Settlement on the order of 3 – 6 inches with multiple areas exhibiting settlement as much as 12 to 24 inches
  - CTL | Thompson determined that settlement was due to poor placement and compaction of sanitary and storm sewer trench backfill
  - About 7600 lineal feet of sanitary and storm sewer trench and associated manhole backfill was at risk or exhibiting settlement
  - Backfill depth ranged between 13 to 19 feet for sanitary sewer trench
  - Storm sewer pipe diameter ranged from 24 to 78 inches. Backfill depth ranged between 9 to 22 feet with isolated areas of 25 to 30 feet depth.
-

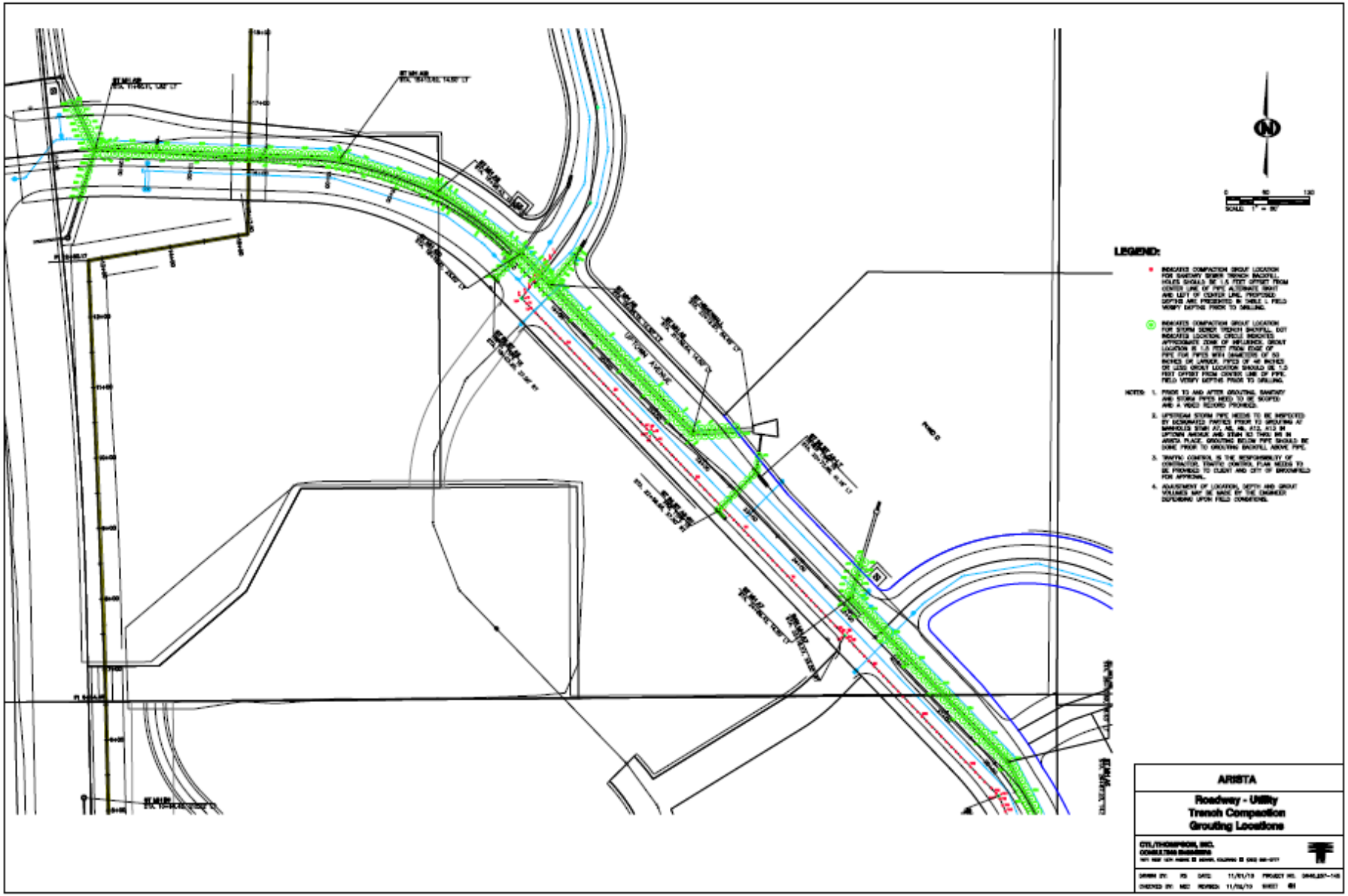

LEGEND:
NOTES:
ARISTA
Roadway - Utility
Trench Compaction
Grouting Locations

**Photo 1**
**June 4, 2009**
**Project No. DN 43,846-145**

**Photo 2**
**June 4, 2009**
**Project No. DN 43,846-145**


Photo 355
June 8, 2009
Project No. DN 43,846-145

**Photo 356**
**June 8, 2009**
**Project No. DN 43,846-145**

Photo 358
June 8, 2009
Project No. DN 43,846-145

**Photo 63**
**June 5, 2009**
**Project No. DN 43,846-145**

Photo 64
June 5, 2009
Project No. DN 43,846-145


**Photo 66**
**June 5, 2009**
**Project No. DN 43,846-145**

**Photo 81**
**June 5, 2009**
**Project No. DN 43,846-145**

# Remediation Alternatives

- Mechanical Remove, Rework or Replace of Existing Fill
- Densify the Existing Fill in Place using Low Mobility Compaction Grouting Techniques

# Considerations for Remediation

- Mechanical Methods
  - Total Trench Remediation 7600 lineal ft
  - Top of trench may need to be on the order of 12 to 18 feet to address backfill zone
  - Depth of trench may range between 6 to 22 feet
  - Shoring and/or bracing of trench sides to protect existing improvements
  - Underpinning & support of shallow utility crossings
  - Difficult to address fill beneath pipe at gradient/ manhole changes
  - Portions of existing fill too wet to remove & replacement may need to dry or export/import
  - Prolonged lane and road closures

# Considerations for Remediation

- Mechanical Methods (cont'd)
  - Weather could impact progress
  - Significant cut & removal of existing pavement system and associated, curb-gutter & landscape islands
  - Schedule/duration
  - Cost estimate varied from $2.5 to 3.5 million
  - If done newly placed & compacted backfill may experience consolidation & settlement

# Considerations for Remediation

- Compaction Grouting Techniques
  - Method uses a 3 inch diameter core for access through pavement
  - No need to remove & replace pavement
  - Weather typically does not impact contractor's operations
  - Increasing density in place – Alternating patterns allows verification of previously grouted areas
  - Can potentially lift & correct grade
    - Concrete Elements
    - Asphalt Elements
  - Void fill beneath concrete elements with either grout of polyuerethane
  - Existing utility avoidance

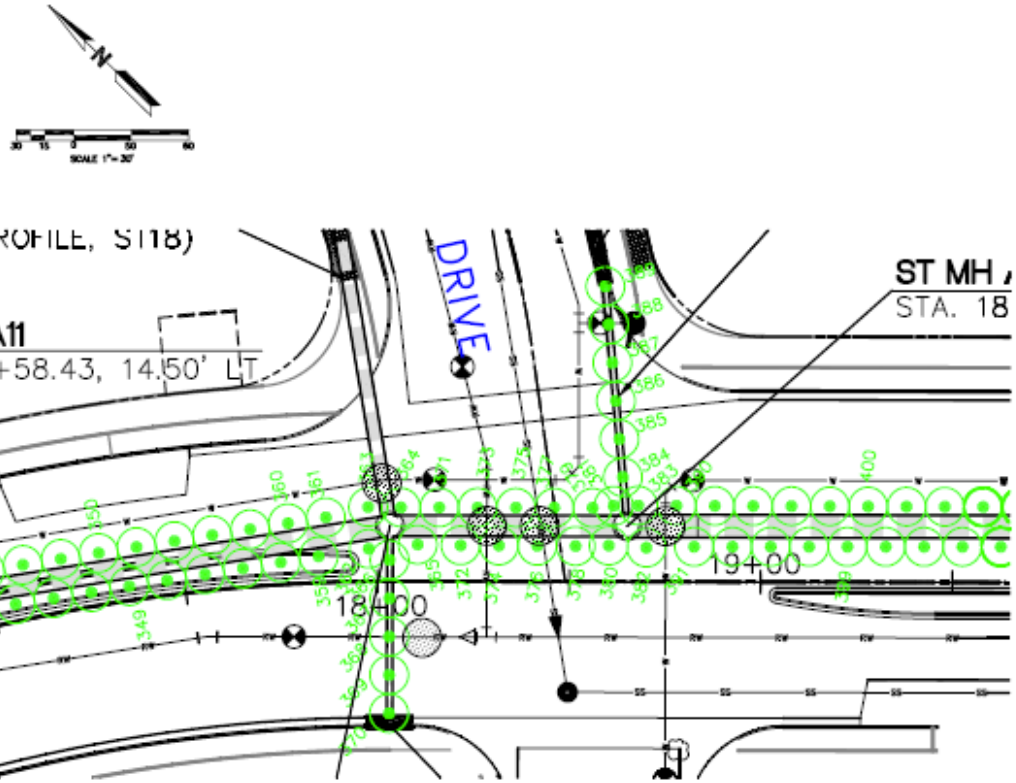
# Considerations for Remediation

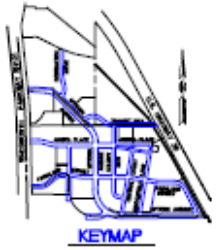
- Compaction Grouting Techniques (cont'd)
  - Minimal disruption to traffic flow
  - Traffic lanes re-open each night & on weekends
  - Design/build approach allows field adjustment as conditions warrant
  - Address fill beneath pipe and gradient drops
  - Rotomill & repave as needed – no complete removal necessary except at previously damages areas


TBANK
CENTER
General Parking
VIP Permits & ADA Parking
2011.8.2 10:05 AM


2011.8.3 11:51 AM


DESTINATION
2011.8.3 12:42 PM




CTL | THOMPSON
ENGINEERING
1971 W. 12th AVENUE, DENVER, CO 80204
PHONE (303) 825-6777
www.ctlthompson.com

Arista

Roadway Utility Trench
Compaction Grouping
Locations

CTL | T PROJECT NO.
DN:65,267x149
DATE
11/03/2010

ST-MA


SLOW
2011.9.1 10:36 AM


Mountain Lasers
2011.9.1 02:36 PM


W-E-O'NEIL
303-238-7900
TRANSIT
ONLY
ONLY
2011.9.23 09:06 AM


2011.9.7 10:04 AM


BROOMFIELD LN
2011.11.9 11:05 AM


SPEED
LIMIT
20
2011.9.23 02:06 PM


WE O'NEIL
2011.9.23 12:01 PM

# ARISTA
## Roadway Monitoring

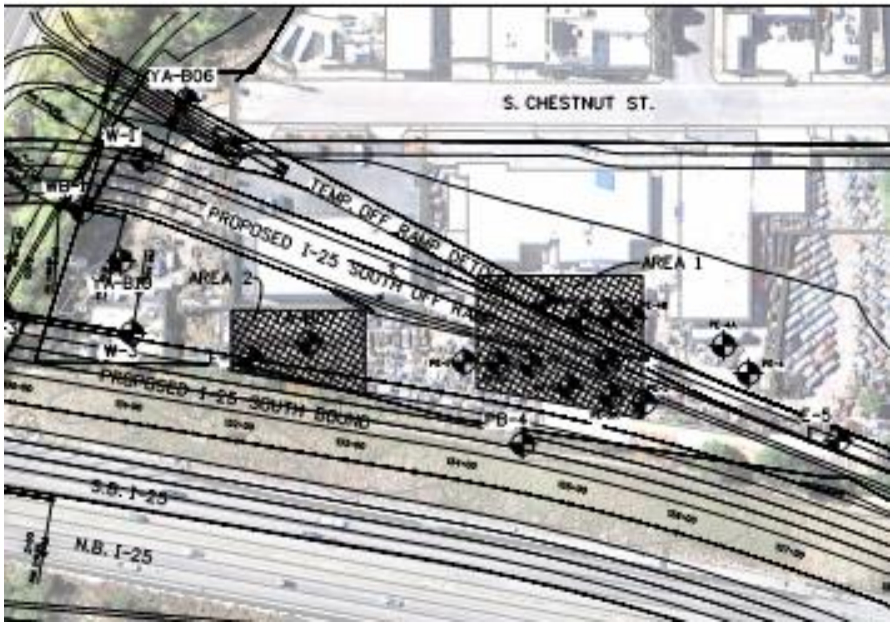
| | November 27, 2012 | | | | April 3, 2014 | | | |
|---|---|---|---|---|---|---|---|---|
| PT # | HI | Minus | Elevation | PT # | HI | Minus | Elevation | Diff. |
| 1 | 5483.859 | 3.865 | 5479.994 | 1 | 5483.747 | 3.760 | 5479.987 | -0.007 |
| 2 | 5483.859 | 4.295 | 5479.564 | 2 | 5483.747 | 4.193 | 5479.554 | -0.010 |
| 4 | 5473.687 | 4.305 | 5469.382 | 4 | 5472.130 | 2.752 | 5469.378 | -0.004 |
| 5 | 5473.687 | 5.875 | 5467.812 | 5 | 5472.130 | 4.323 | 5467.807 | -0.005 |
| 6 | 5473.687 | 12.300 | 5461.387 | 6 | 5466.319 | 4.922 | 5461.397 | 0.010 |
| 11 | 5447.040 | 7.840 | 5439.200 | 11 | 5445.661 | 6.452 | 5439.209 | 0.009 |
| 12 | 5447.040 | 8.825 | 5438.215 | 12 | 5440.233 | 2.018 | 5438.215 | 0.000 |
| 30 | 5446.642 | 3.393 | 5443.249 | 30 | 5447.752 | 4.498 | 5443.254 | 0.005 |
| 31 | 5446.642 | 3.198 | 5443.444 | 31 | 5447.752 | 4.303 | 5443.449 | 0.005 |
| 32 | 5446.642 | 2.862 | 5443.780 | 32 | 5447.752 | 3.978 | 5443.774 | -0.006 |
| 39 | 5483.859 | 2.210 | 5481.649 | 39 | 5483.747 | 2.110 | 5481.637 | -0.012 |
| 40 | 5483.859 | 2.720 | 5481.139 | 40 | 5483.747 | 2.618 | 5481.129 | -0.010 |
| 41 | 5483.859 | 3.968 | 5479.891 | 41 | 5483.747 | 3.860 | 5479.887 | -0.004 |
| 42 | 5483.859 | 4.657 | 5479.202 | 42 | 5483.747 | 4.540 | 5479.207 | 0.005 |
| 86 | 5446.642 | 2.640 | 5444.002 | 86 | 5447.752 | 3.748 | 5444.004 | 0.002 |
| 87 | 5446.642 | 1.795 | 5444.847 | 87 | 5447.752 | 2.905 | 5444.847 | 0.000 |

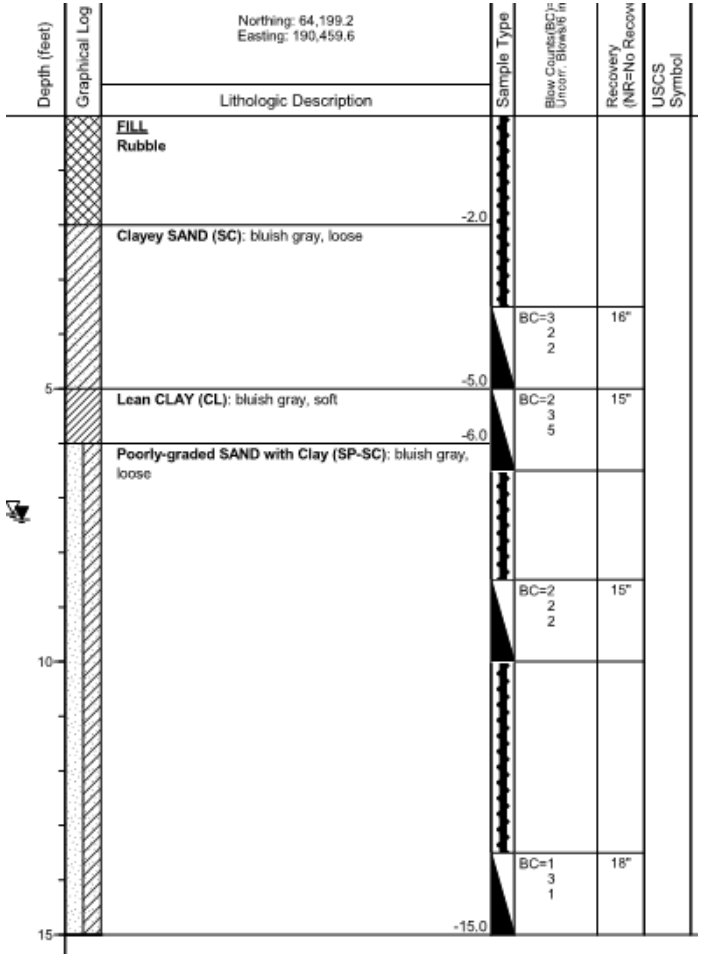
# Compaction Grouting Project Summary

- A total of 1800 grout locations
- Total grout volume:
  - 508 cu yds sanitary sewer
  - 1214 cu yds storm sewer
- Estimated volume replacement ranged between 8 to 12 percent
  - Translates to increase density in that same range
- Cost at budget due to the design build approach adjustments allowed additional areas to be treated which were not part of the original scope
- Minimal impact to the public
- Essentially no additional trench/pavement settlement

# Ground Modification Techniques: Increase Bearing Capacity / Reduce Settlement

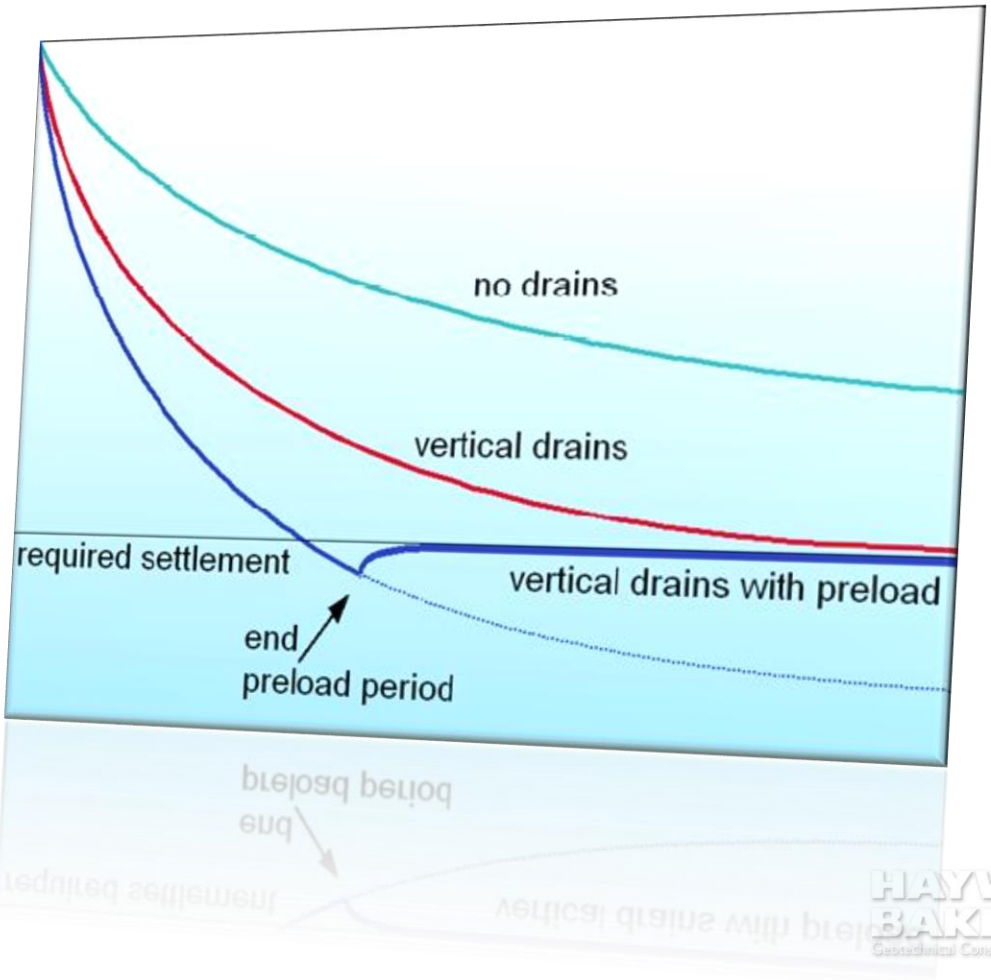
# Soft Soils Under Proposed Exit Ramp



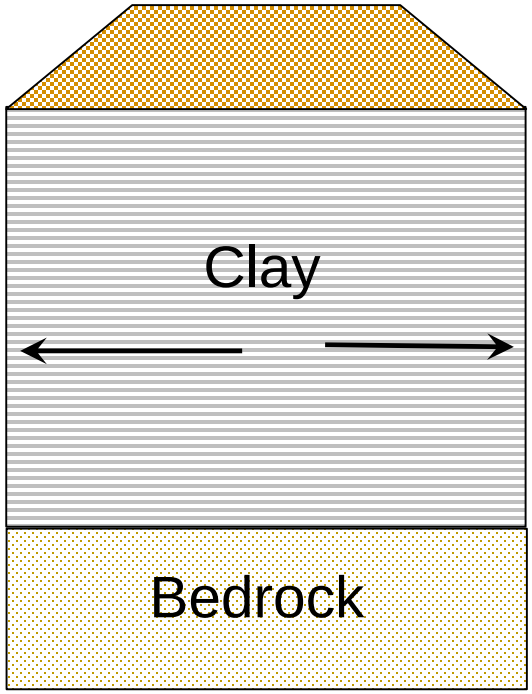



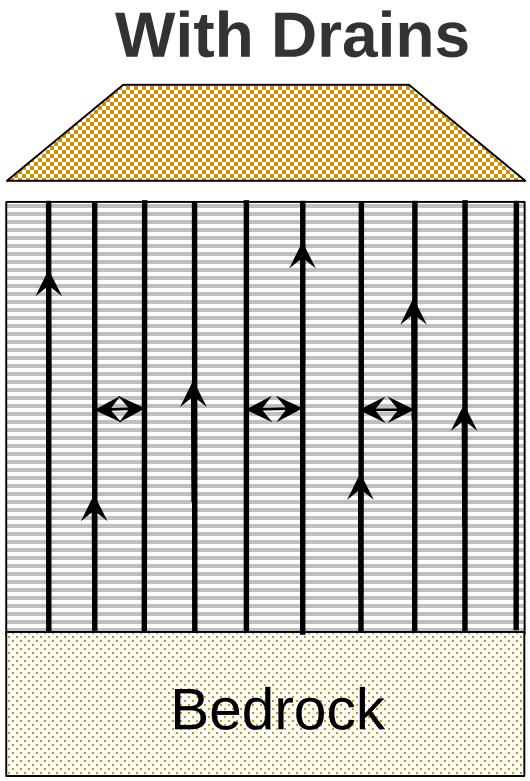
# Wick Drains: Decrease Settlement

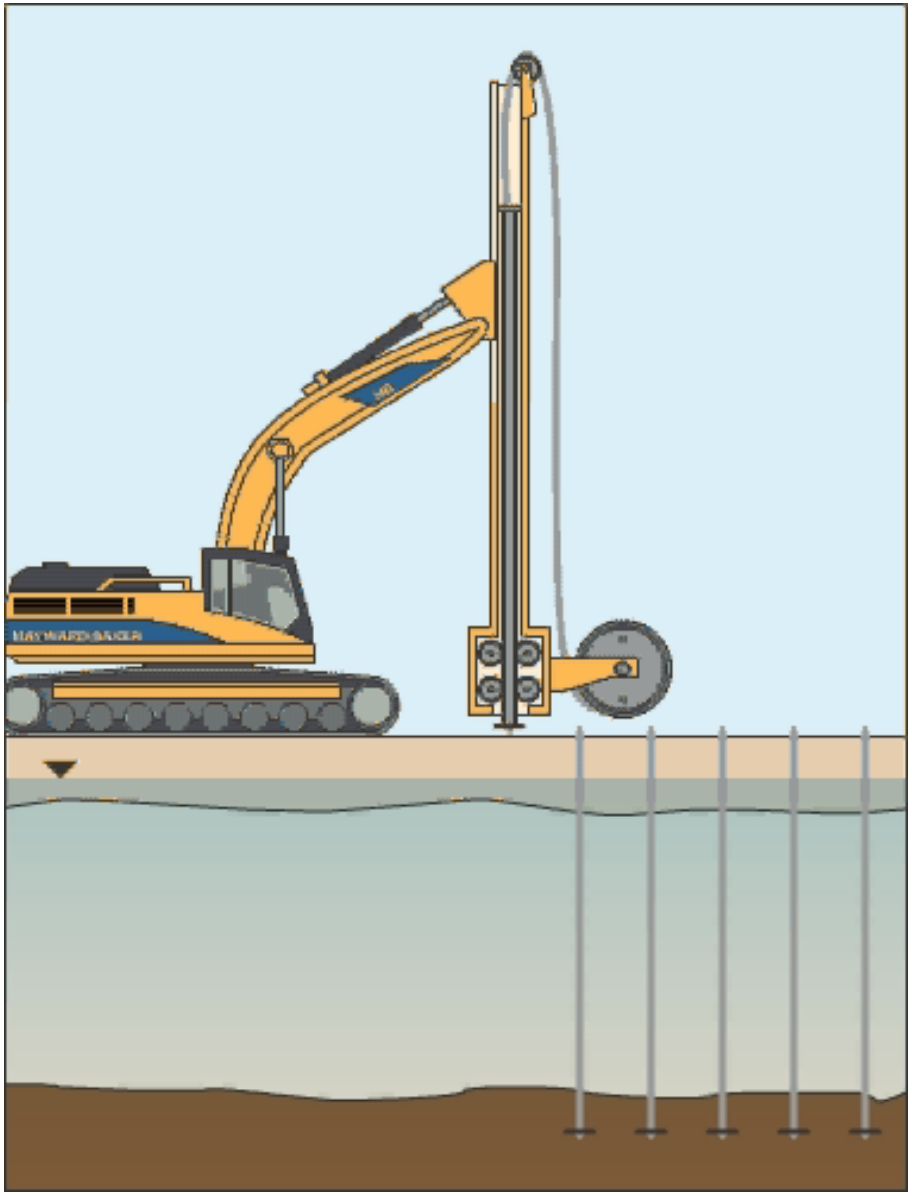
- Prefabricated Vertical Drains (PV drains, PVD's)
- Wick Drains
- Synthetic drains
- Band Drains
- Strip Drains



# Wick Drains



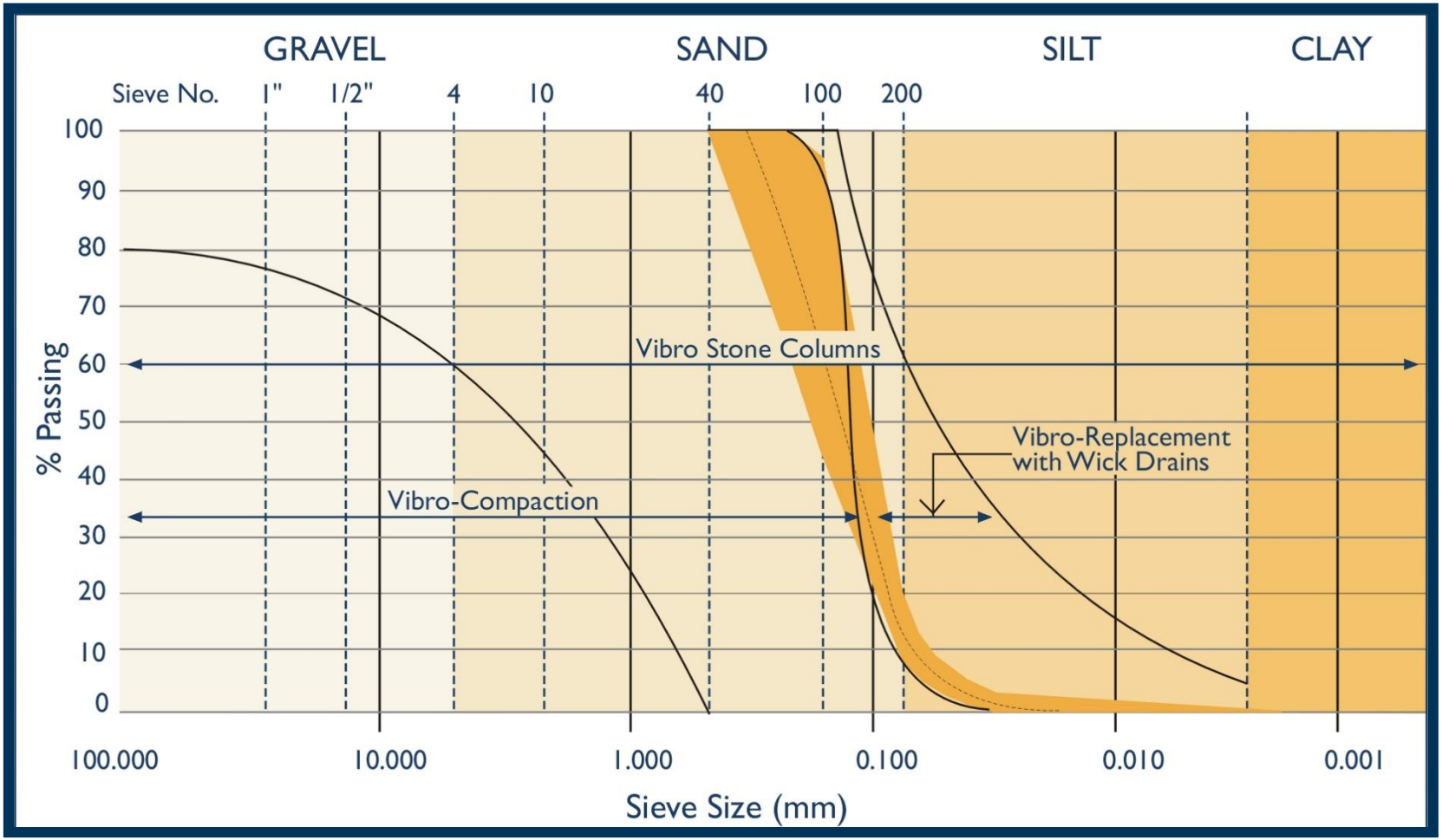





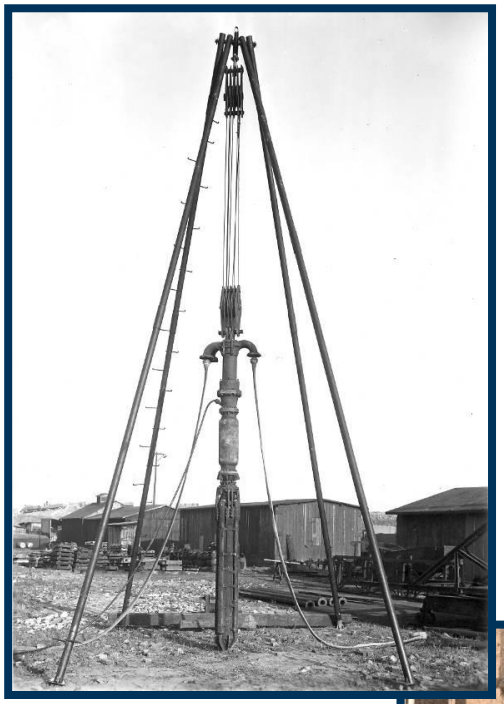
THINK SAFE

HAYWARD BAKER
Geotechnical Construction

# No Time for Settlement: Vibro Techniques



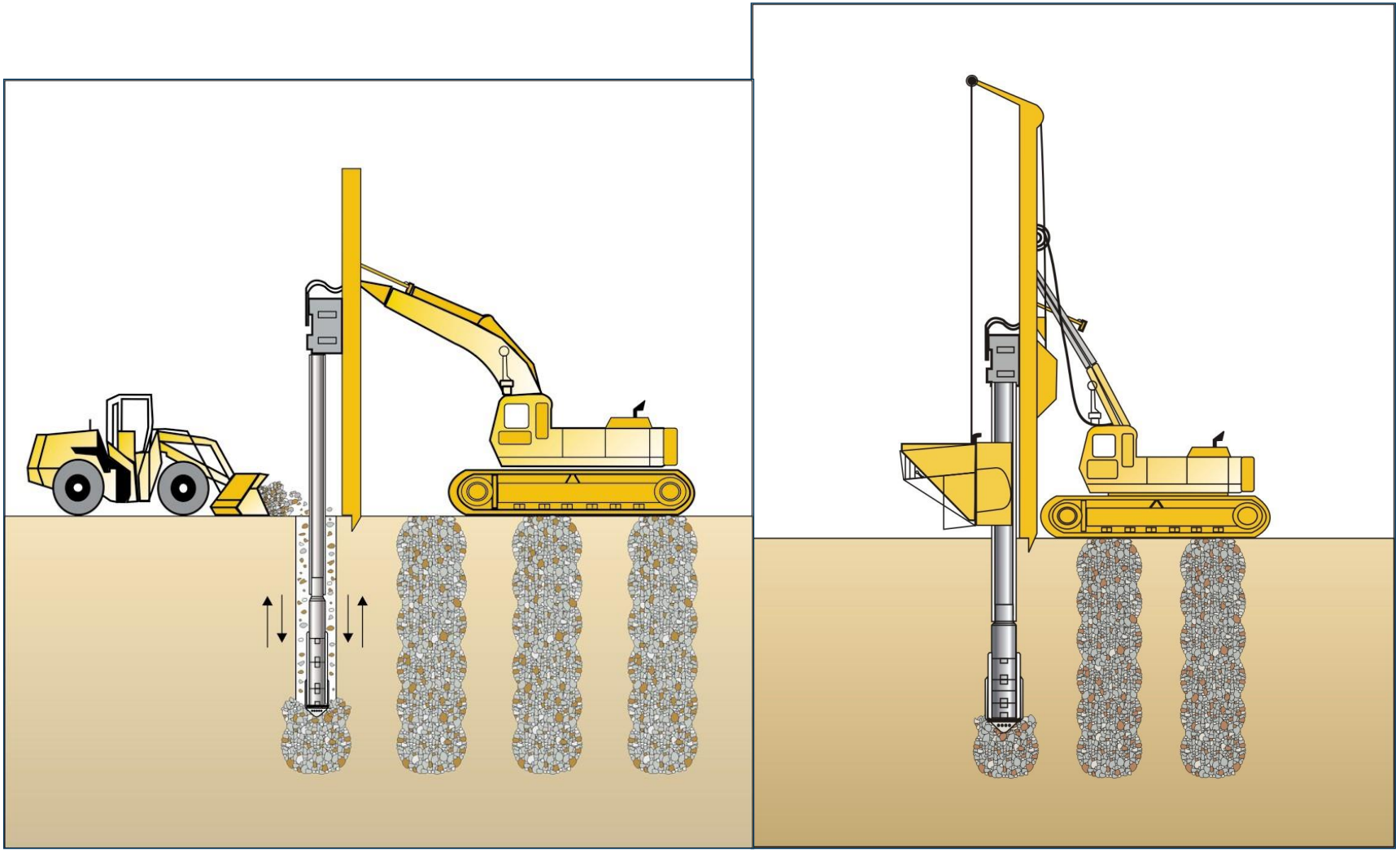
# Vibro Piers – Time Tested Technique



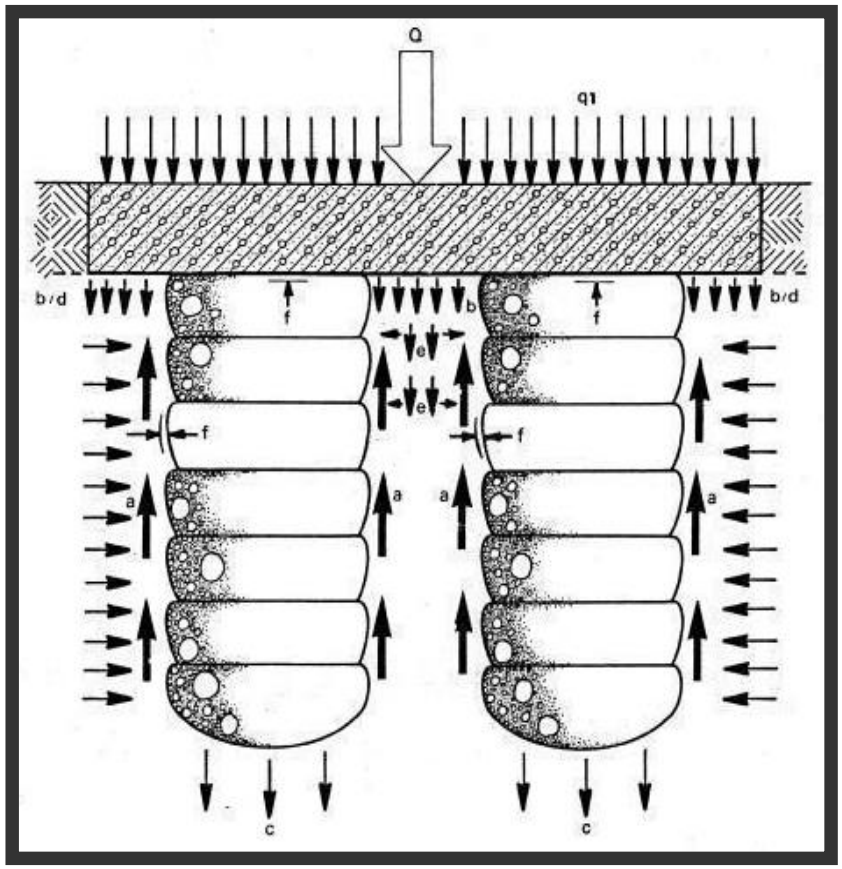
Keller rigs, circa 1932

Keller rig crews, at 1910
50th anniversary

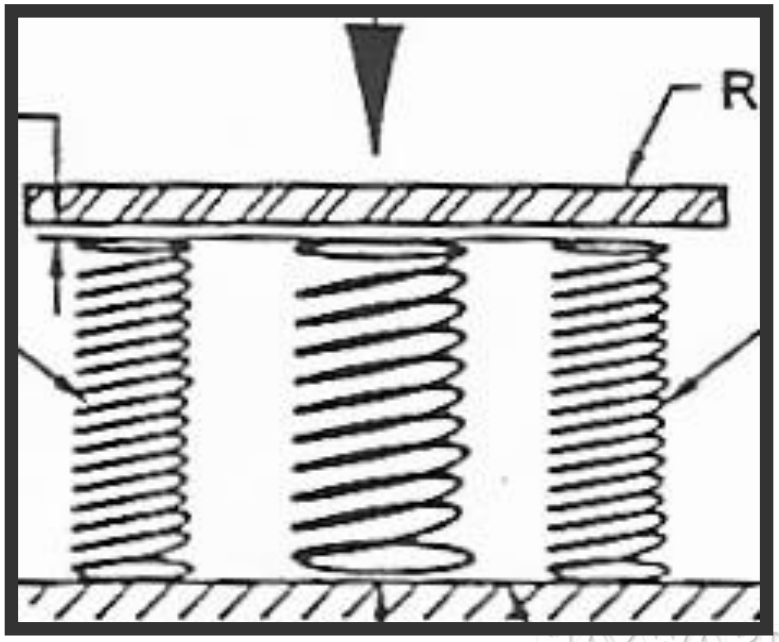
# Installed using top or bottom feed methods (Above or Below Water Table)



# Stone Columns/Aggregate Pier Design Methodology



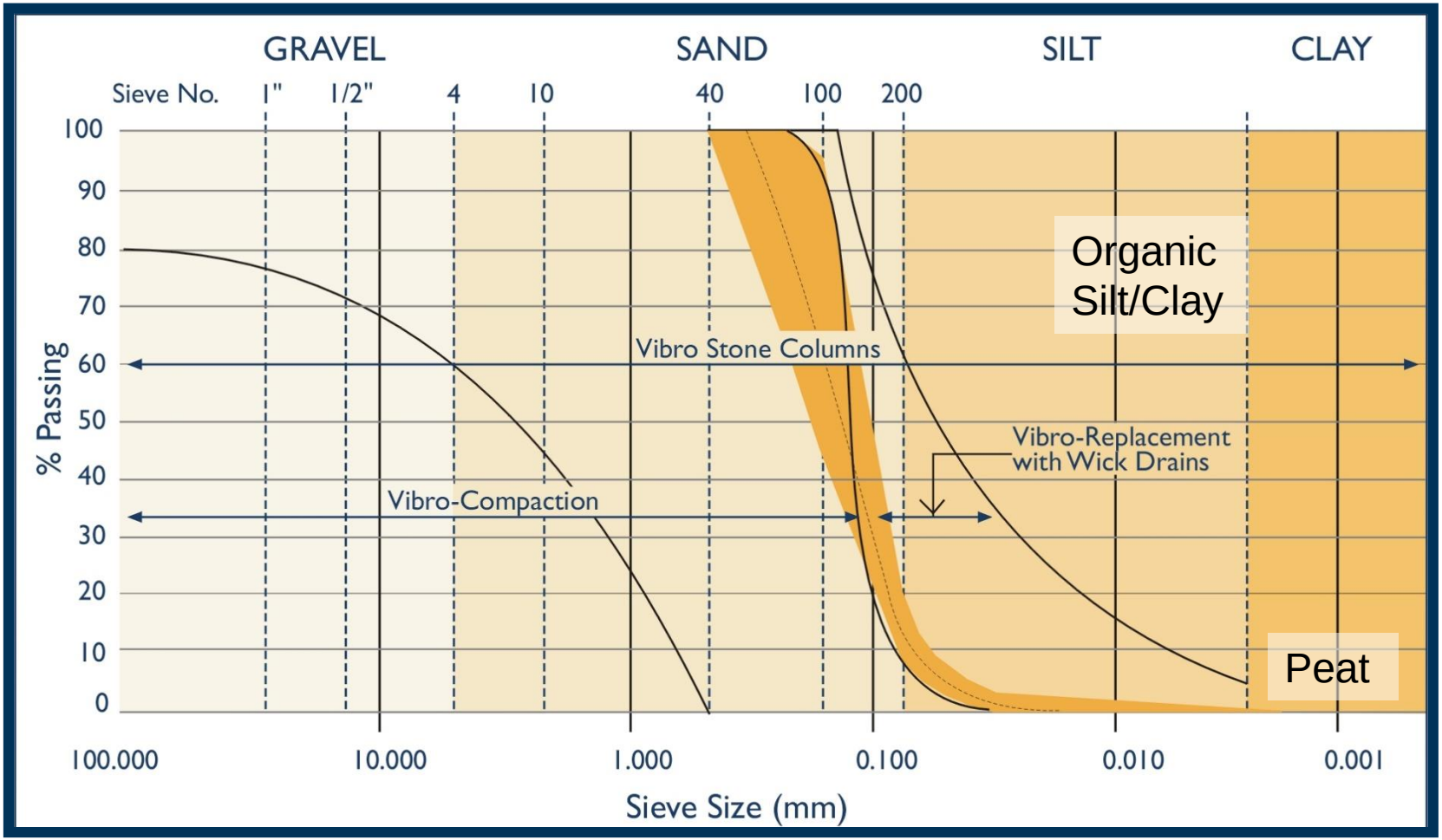

Reinforcement
Mechanism / Model



# Vibro Piers for MSE Wall Support

# Vibro Piers:
# Bottom Feed Unit

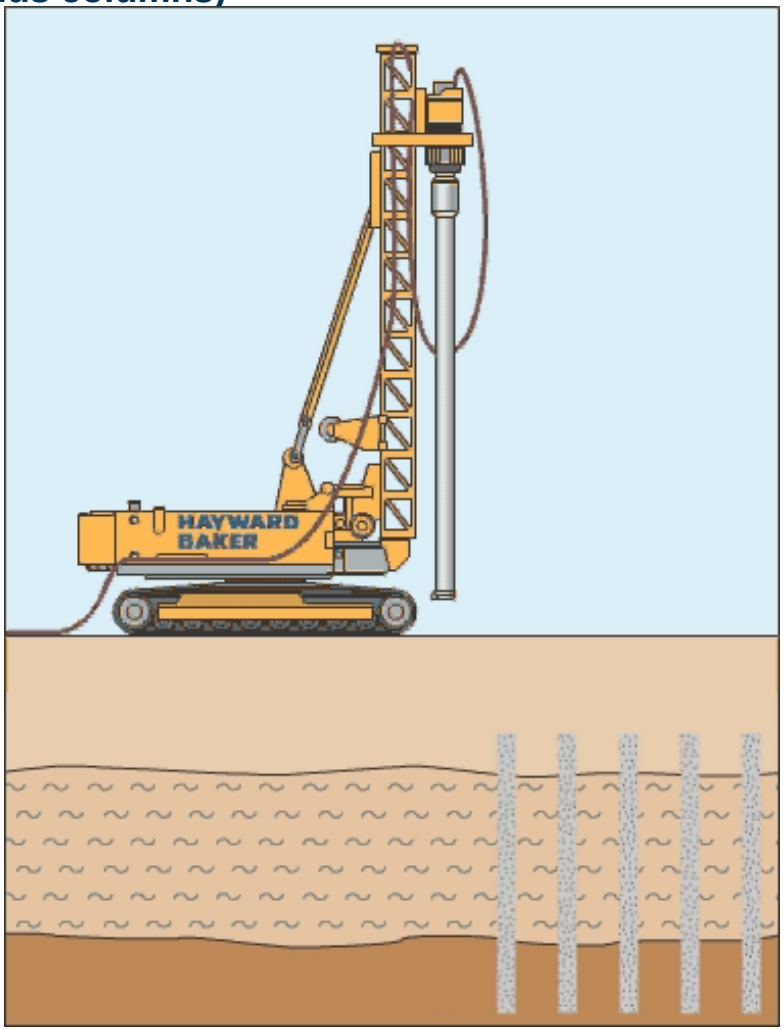
# What if the Ground is Very Soft!



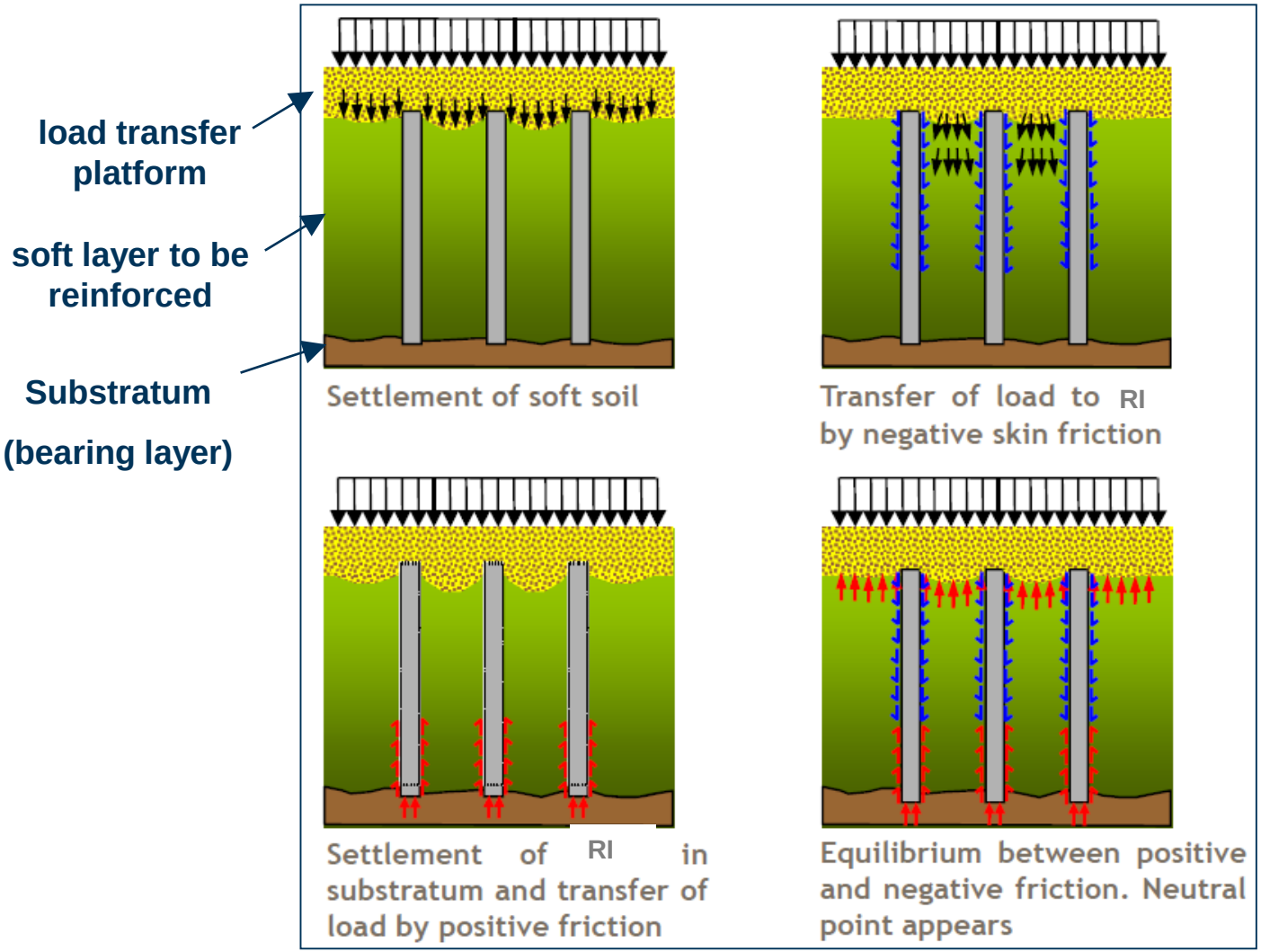
# Rigid Inclusions

**(controlled modulus columns)**

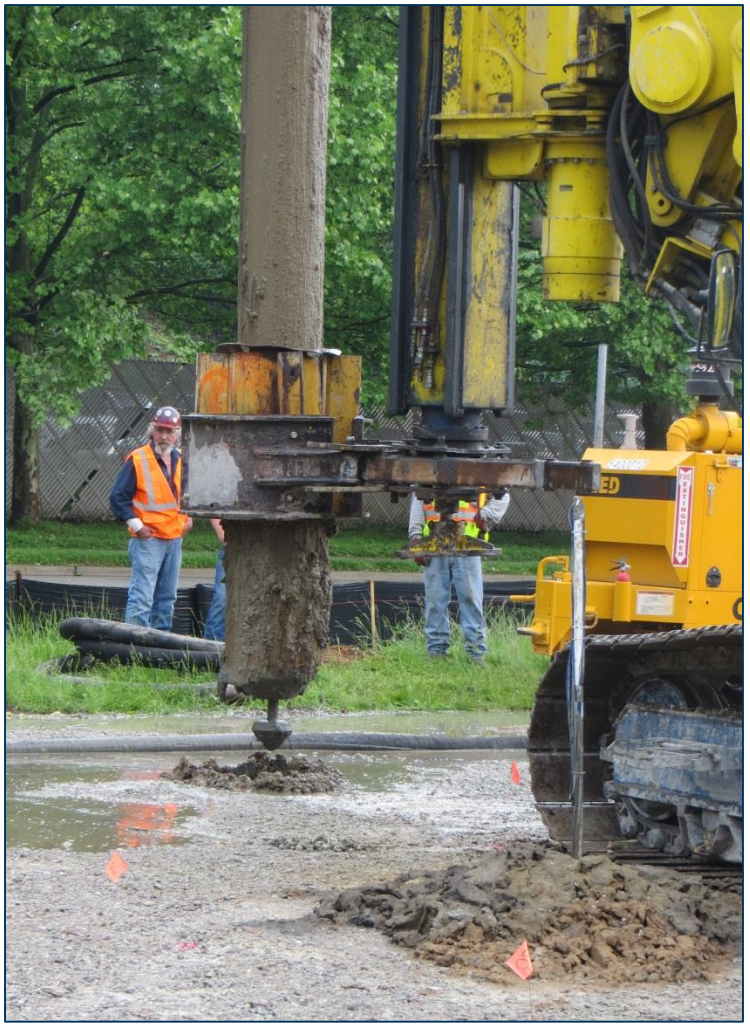
- High modulus columns constructed through compressible soils
- Not in direct contact with foundations
- Used to reinforce soft, compressible soils
- Load transfer platform

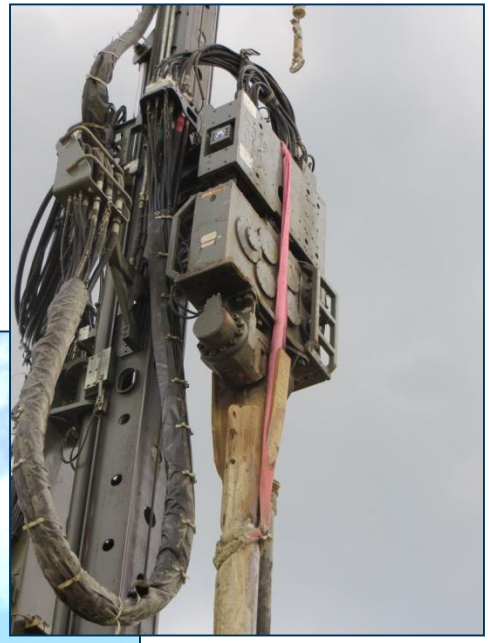


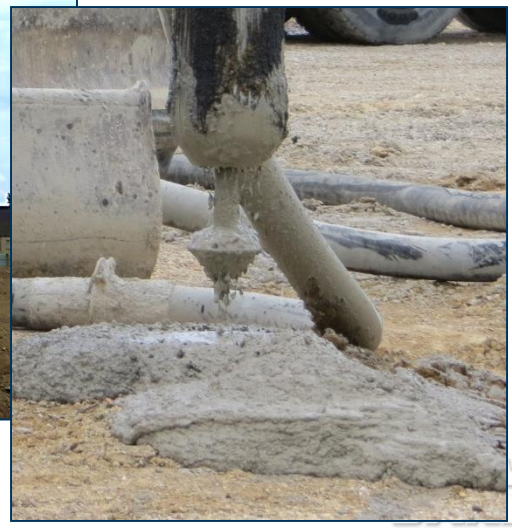
# Subsurface Load Transfer



# Rigid Inclusion Construction Methods



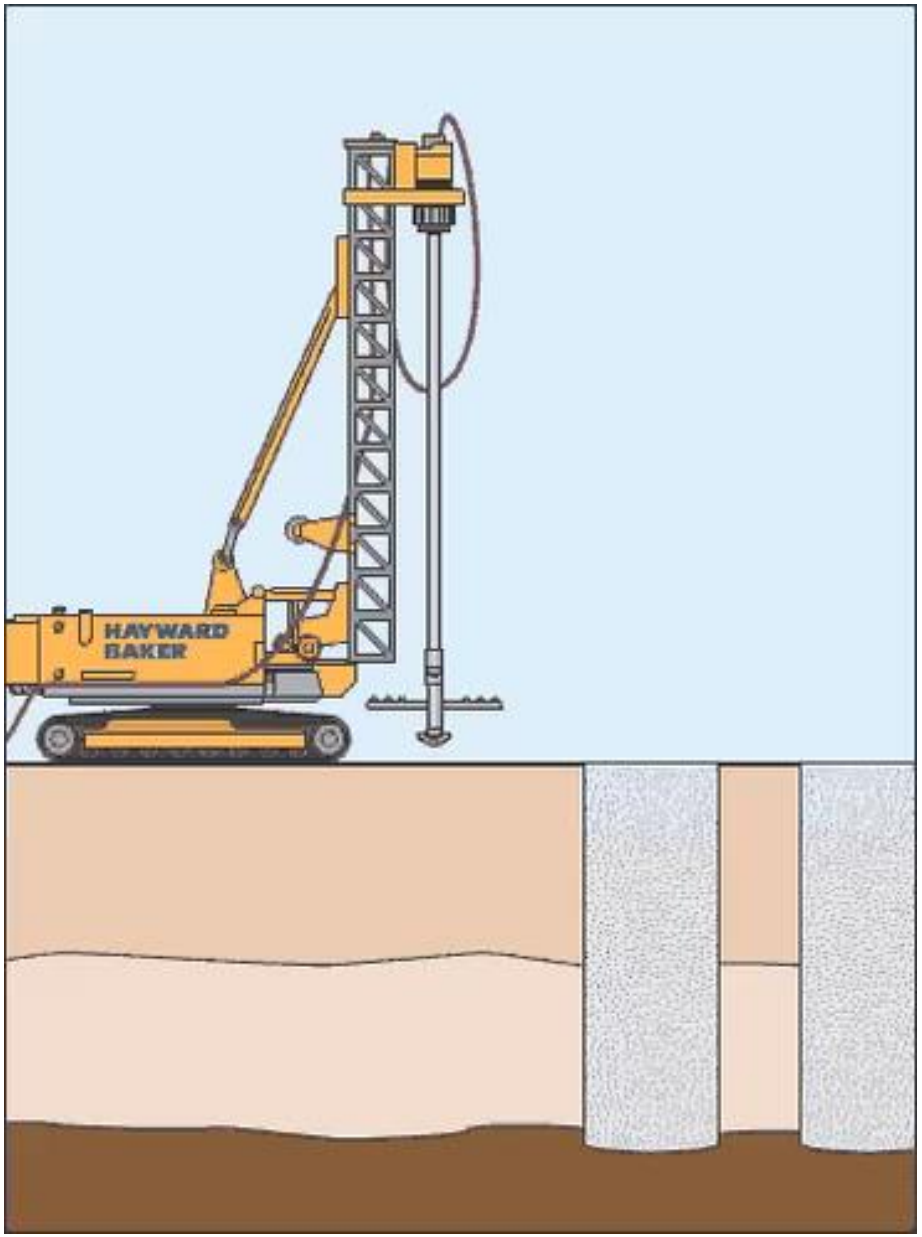



# Still too much calculated settlement? Soil Mixing

# Soil Mixing

- 50psi to 500psi soilcrete
- Dry or Wet Mixed
- Data Acquisition Available

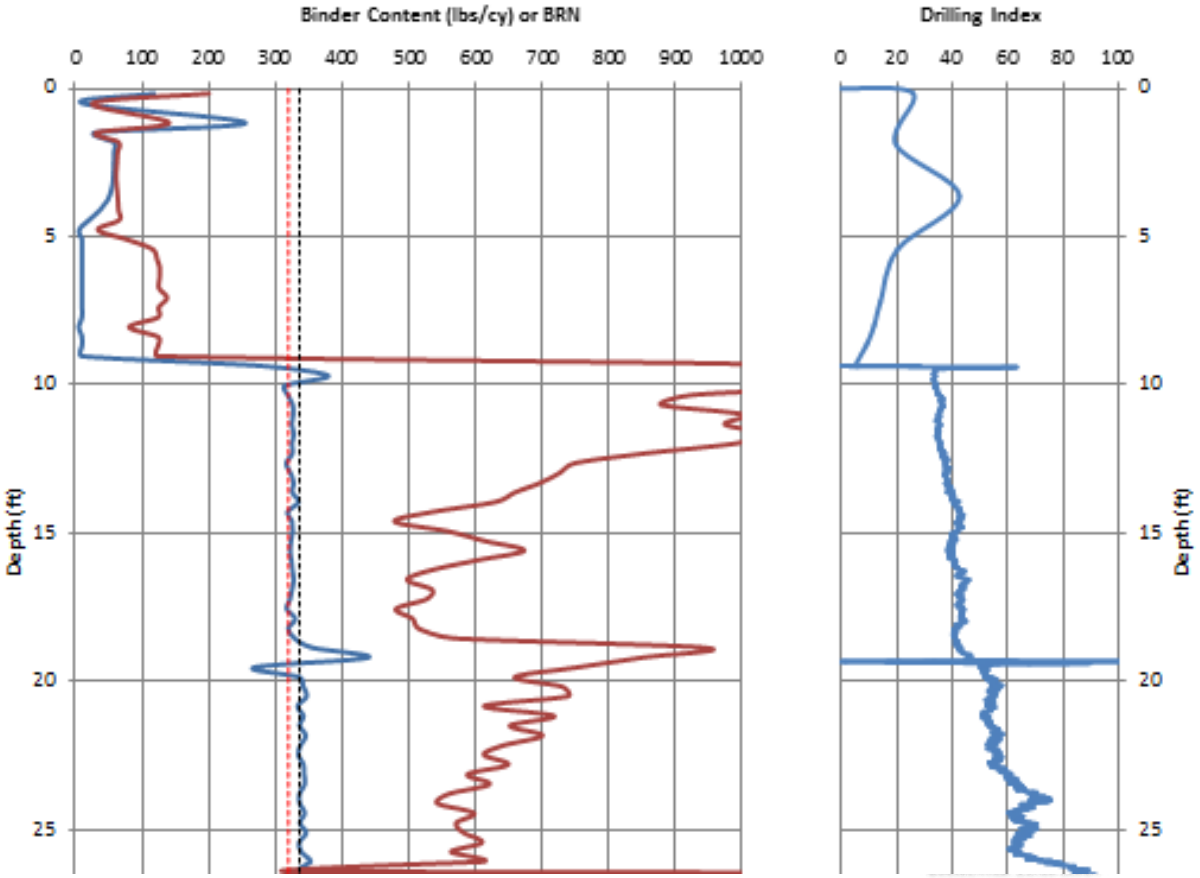


# Data Acquisition for Soil Mixing (HBIDAQ)

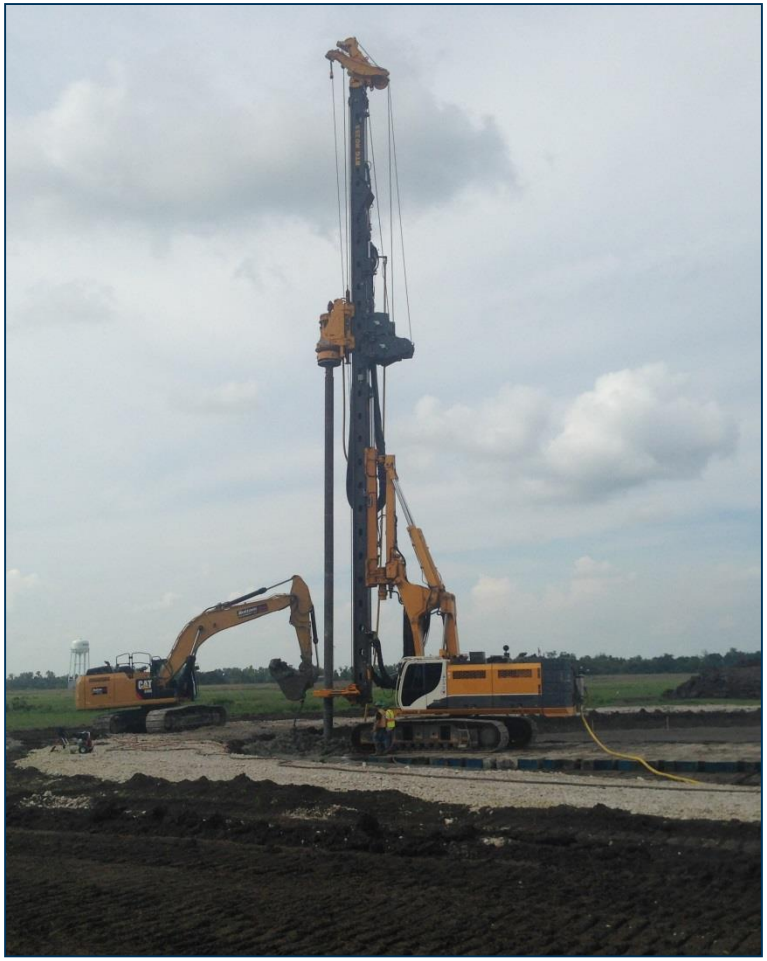
HAYWARD BAKER
Geotechnical Construction
KELLER

West Dowling Phase 2
Wet Soil Mixing Installation Log
Column 1-184

| | | | | | |
|---|---|---|---|---|---|
| **Column Diameter:** | 8.0 ft | **Penetration Avg. Injection Rat** | 155.06 gpm | **Date:** | 7/14/2014 |
| **Column Length:** | 26.58 ft | **Withdrawal Avg. Injection Rate** | 39.50 gpm | **Start Time:** | 2:54 PM |
| **Top of Column Dep** | 9.34 ft | **Avg. Penetration Rate:** | 0.99 ft/min | **End Time:** | 3:18 PM |
| **Average Grout SG:** | 1.44 | **Avg. Withdrawal Rate:** | 9.03 ft/min | **Penetration:** | 00:20:04 |
| **Total Grout Volume** | 3048 gal | **Inclination (X):** | -0.58° | **Withdrawal:** | 00:03:42 |
| **Total Binder Weight** | 16399 lbs | **Inclination (Y):** | 0.43° | **Total Time:** | 00:23:46 |
| **Avg. Binder Conten** | 347 lbs/cy | **Project X:** | 0.00 ftUS | **Rig:** | BG-28 |
| **Job Number:** | 860047-28 | **Project Y:** | 0.00 ftUS | **Project Z:** | 0.00 ft |

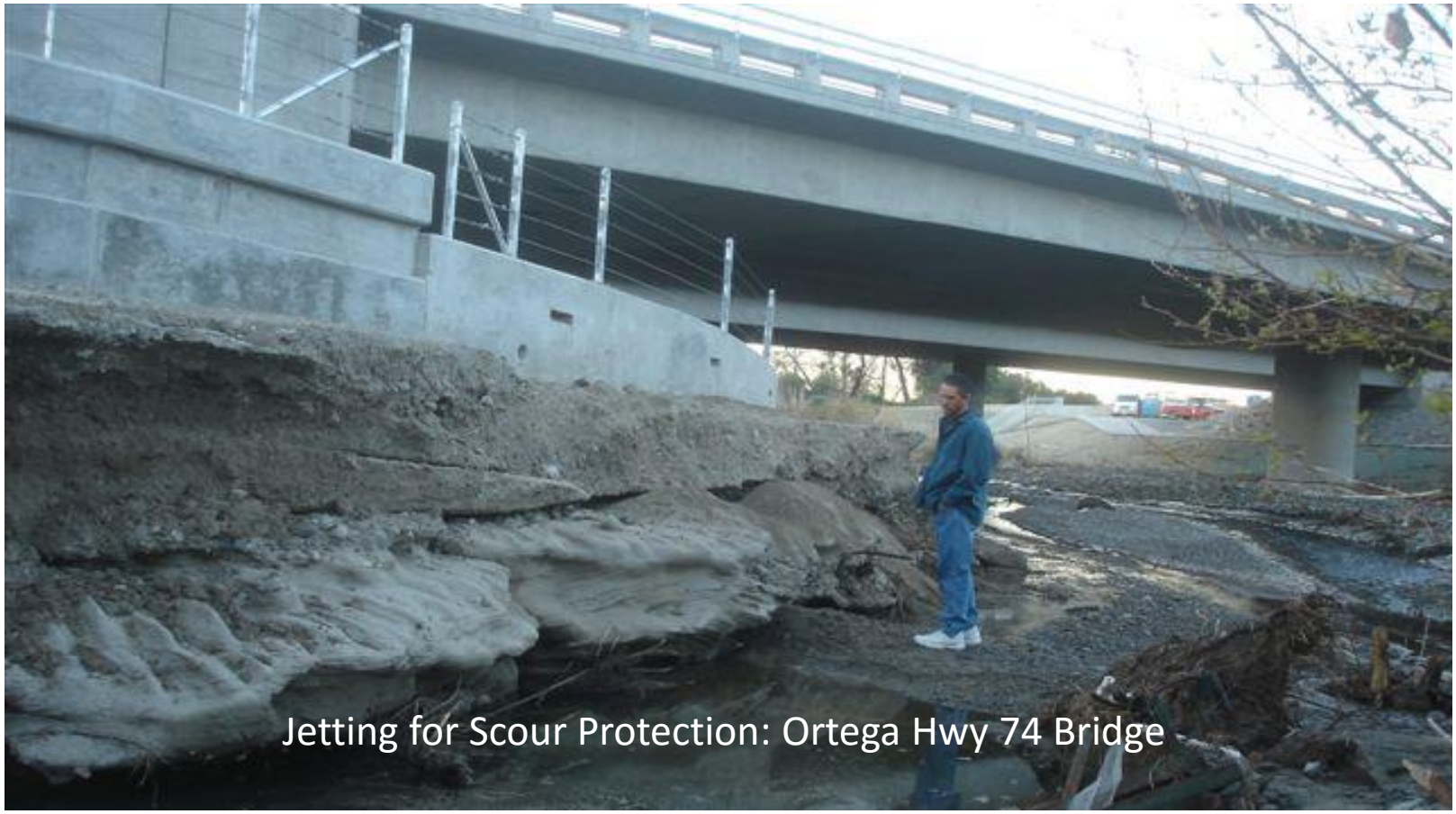


# Soil Mixing at Work



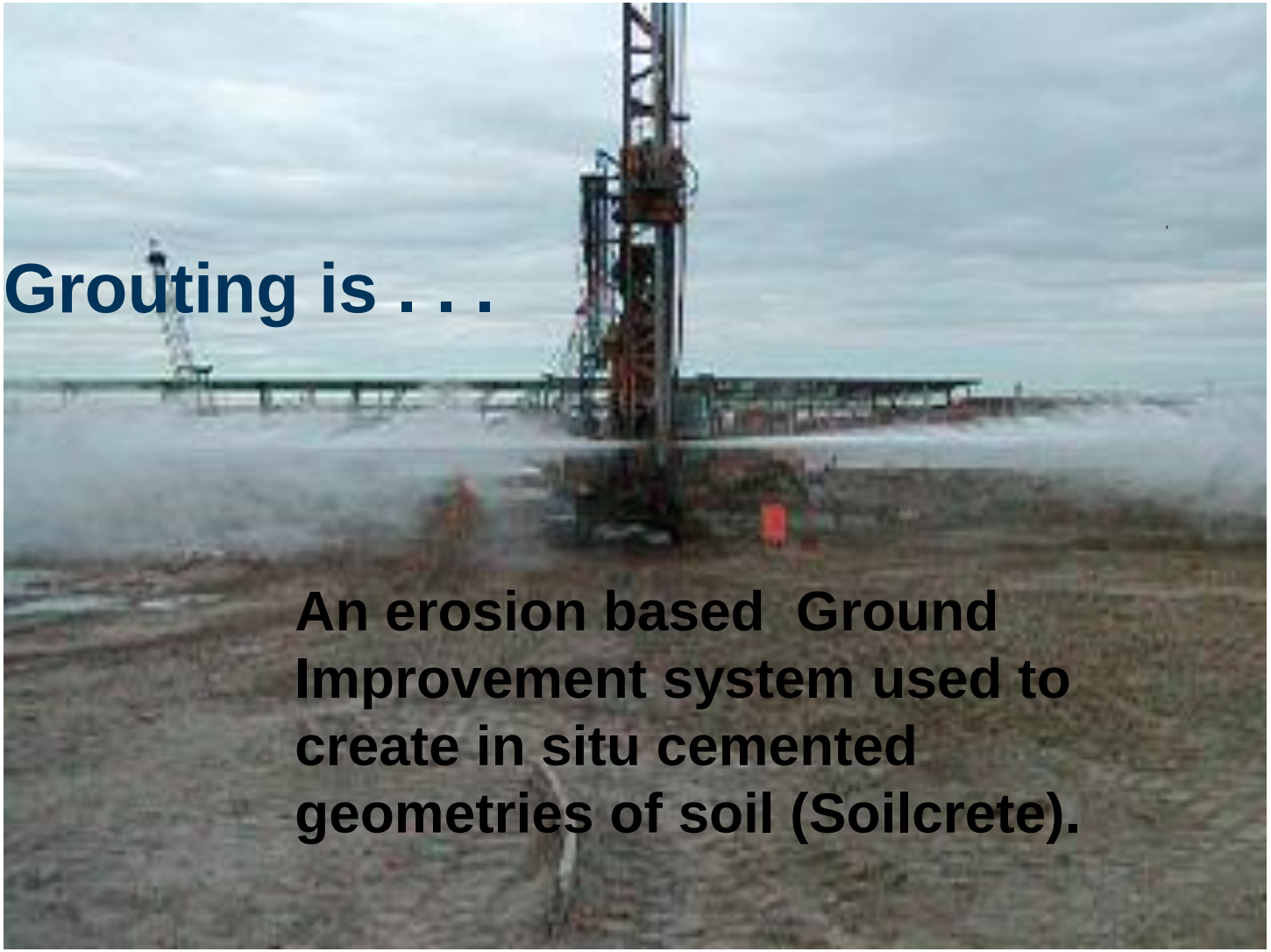
# Mass Soil Mixing

# What if access is a problem?
# Jet Grouting

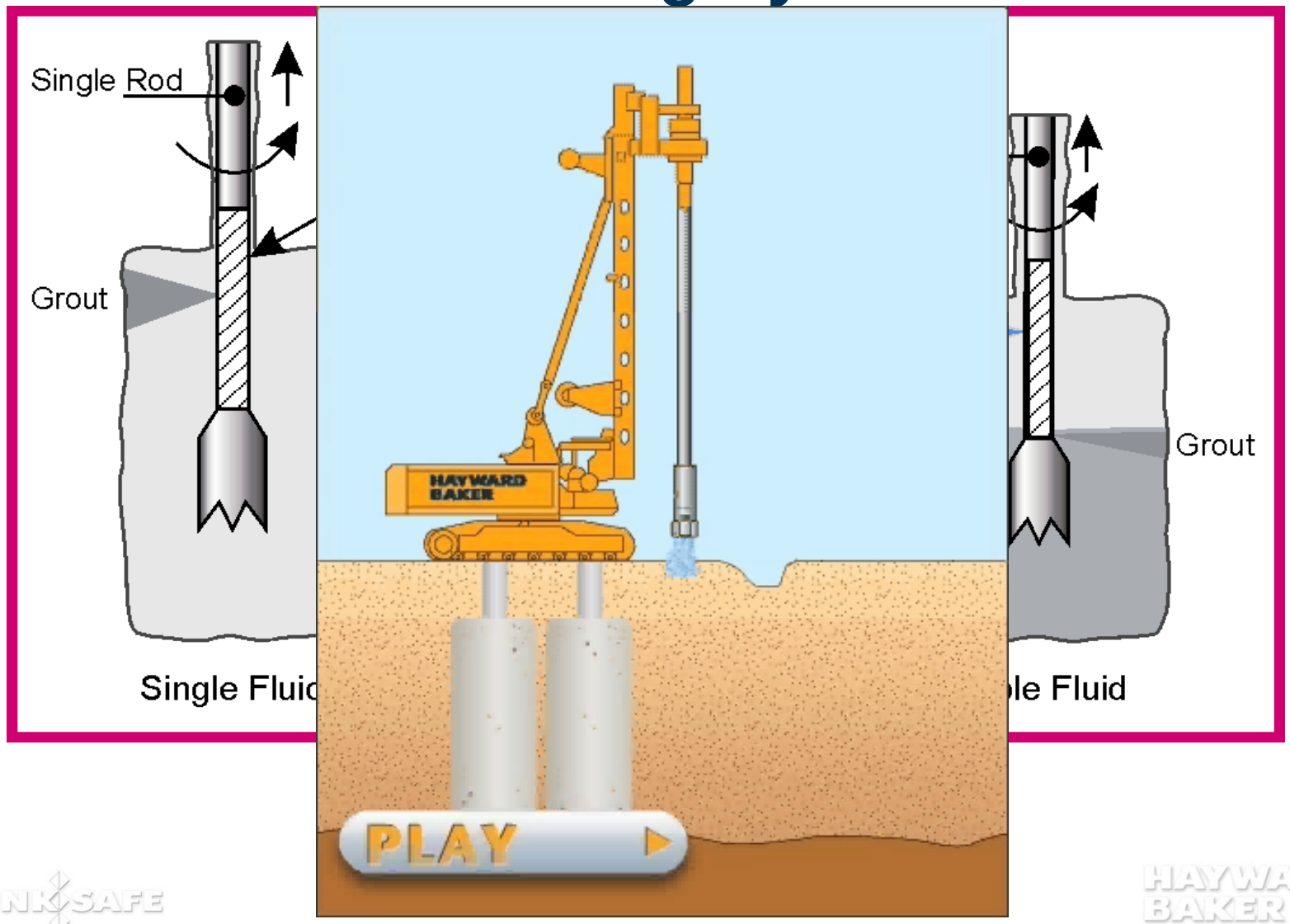


Jetting for Scour Protection: Ortega Hwy 74 Bridge

# Jet Grouting is . . .



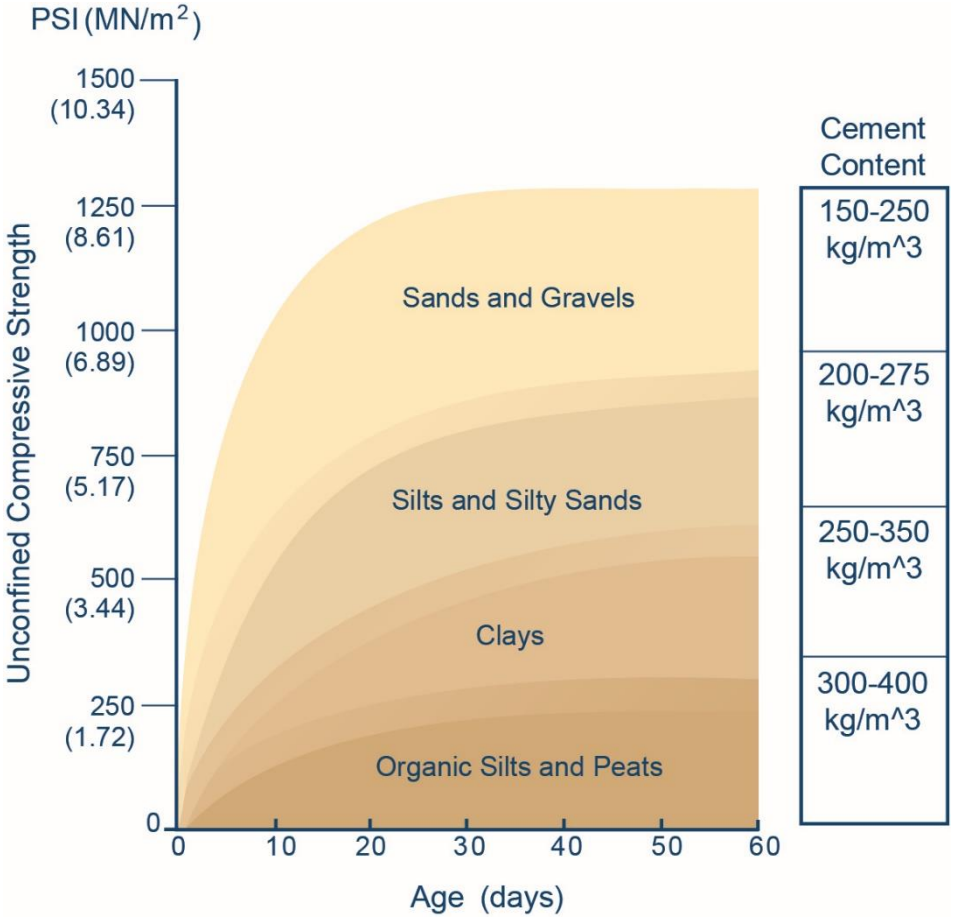
# Jet Grouting Systems



# Geometry is a function of:

- Dynamic pressures
  - Velocity of the fluid
  - Air shroud (reduces attenuation)
  - Nozzle focus and condition
  - Injection volume rate
- Erosion time
  - Rotation speed
  - Lift speed (step time and height)
- And most importantly: Soil strength and plasticity

# Typical Soilcrete Strengths



# Questions?