Geo³T²
April 4-5, 2013

Emergency Sinkhole Mitigation & Void Investigation of Abandoned Railroad Tunnel along US HWY 24 Tennessee Pass, CO – Case Study

Kanaan Hanna, Steve Hodges, John Nolte, ZAPATA
Joseph Elsen, Rex Goodrich, Matthew Figgs, David Thomas, CDOT
Tom Szynakiewicz, Hayward Baker
Mark Vessely, Shannon and Wilson

- ❑ Critical Project Issues
- ❑ Sinkhole Development Mechanism
  - ❑ Probability of sinkhole
- ❑ Preliminary CDOT Borings
- ❑ Hayward Baker Grouting
  - ❑ Flow-fill grouting
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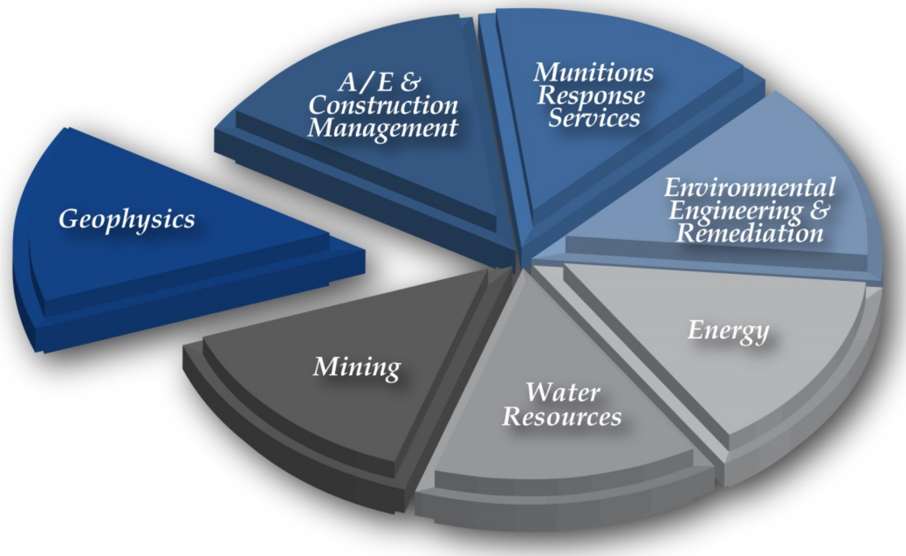
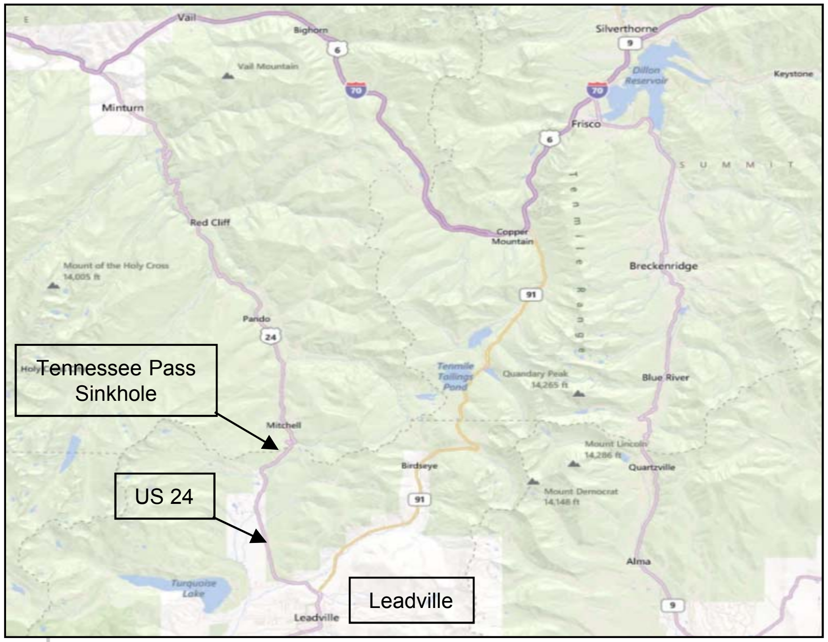
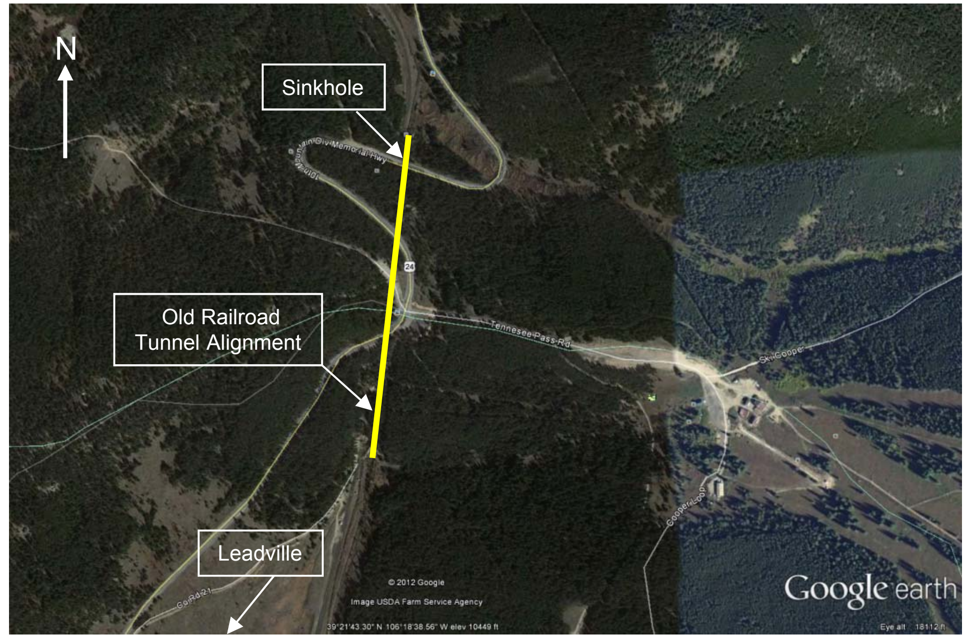
- ❑ ZAPATA Tunnel Void Investigation
  - ❑ 2D/3D Laser tunnel void scanning
  - ❑ Video imaging
- ❑ Tunnel Mitigation Strategy
- ❑ Summary

ZAPATA Services



Project Site Location – Critical Issues



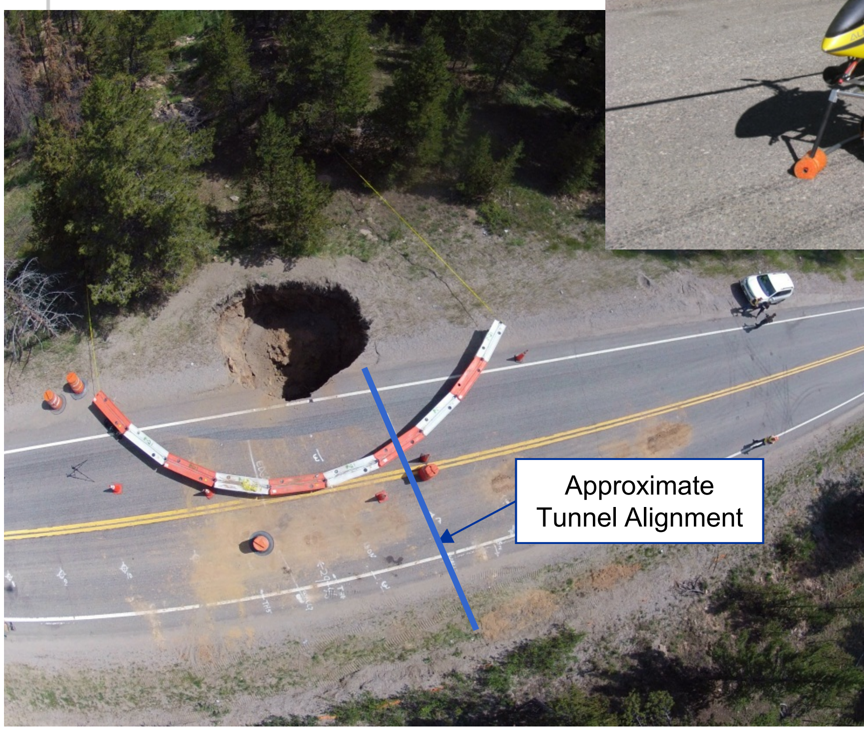


Critical Project Issues

- Safely opening the road as quick as possible.
- Prime tourist season in mountains, accommodating bike rides / races.
- Permanent mitigation of collapse and settlement hazard within CDOT easement.
- Excessive grout loss.
- Avoid damage to the existing tunnel.
- Project delivery ~ Less < 25 days to copmlete, bonus to re-open at least one lane earlier than 20 days from start date.

Sinkhole Development

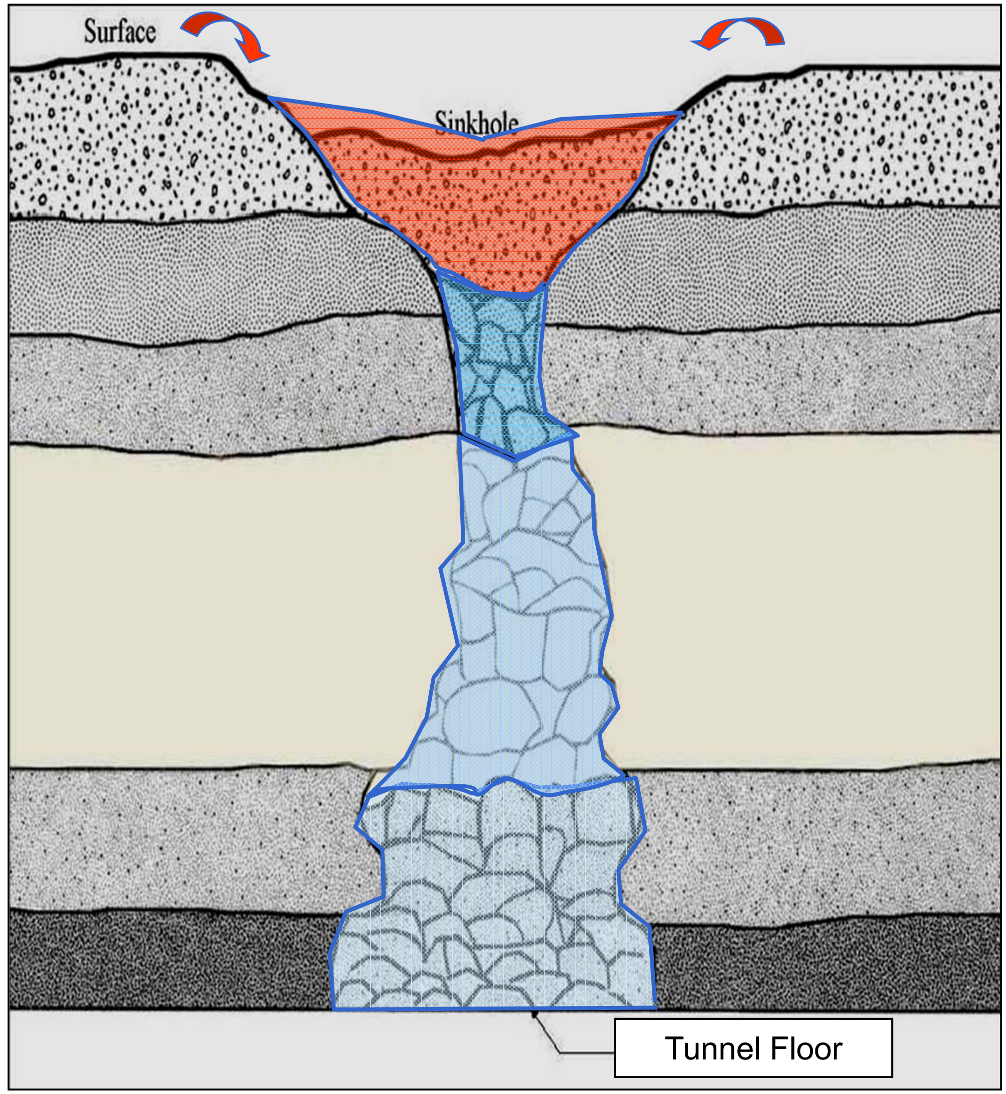
- Sinkhole above an old railroad tunnel (build in 1880)
- Sinkhole developed on July 9, 2012 on the southbound shoulder
- Approximately: 35 ft x 35 ft x 60 ft deep
- Original estimated volume was approximately 1000 CY
- Sinkhole propagated directly underneath the highway and continued to erode material
- CDOT elected to close a 4 mile stretch for safety, accept for few local resident allowed to park cars on either side of closure.

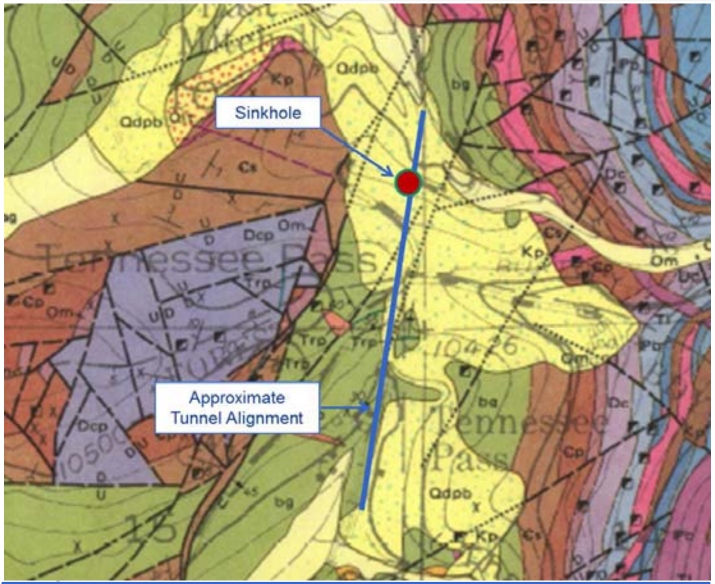


Sinkhole Development Mechanism

Sinkhole development
above the railroad tunnel

- Sinkhole size: ~ 35' x 35' x 60' deep
- Tunnel depth at the site ~ 158' to 175'
- Tunnel size: ~ 17' W x 20' H
- Tunnel invert: ~ 180' to 192'

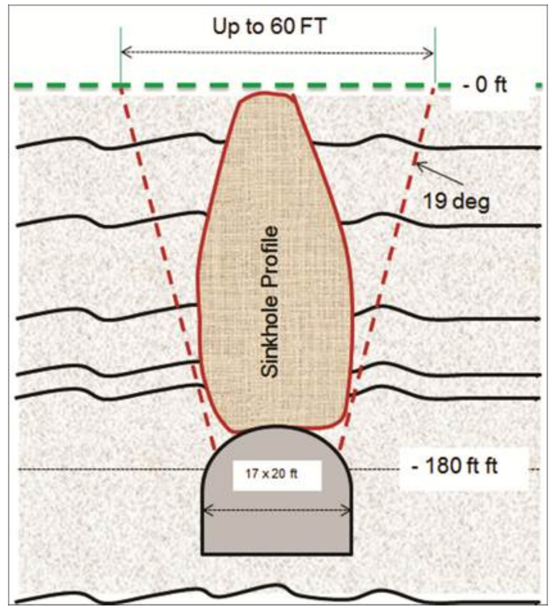




Qdpb:

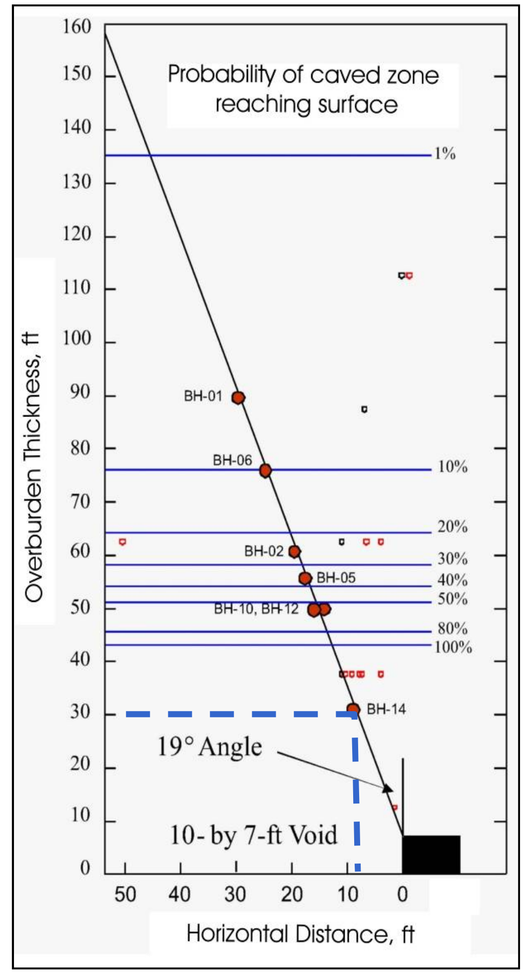
- The area is highly faulted.
- Sheet-like drift from two glaciations.
- Glacial deposits at the site were found to range from 24 to > 50' in depth overlaying weathered gneiss.
- Clayey sand/boulder/gravel with thickness ≥175' at the sinkhole.

Sinkhole Limit and
Sinkhole Profile Line
(Not t0 Scale)

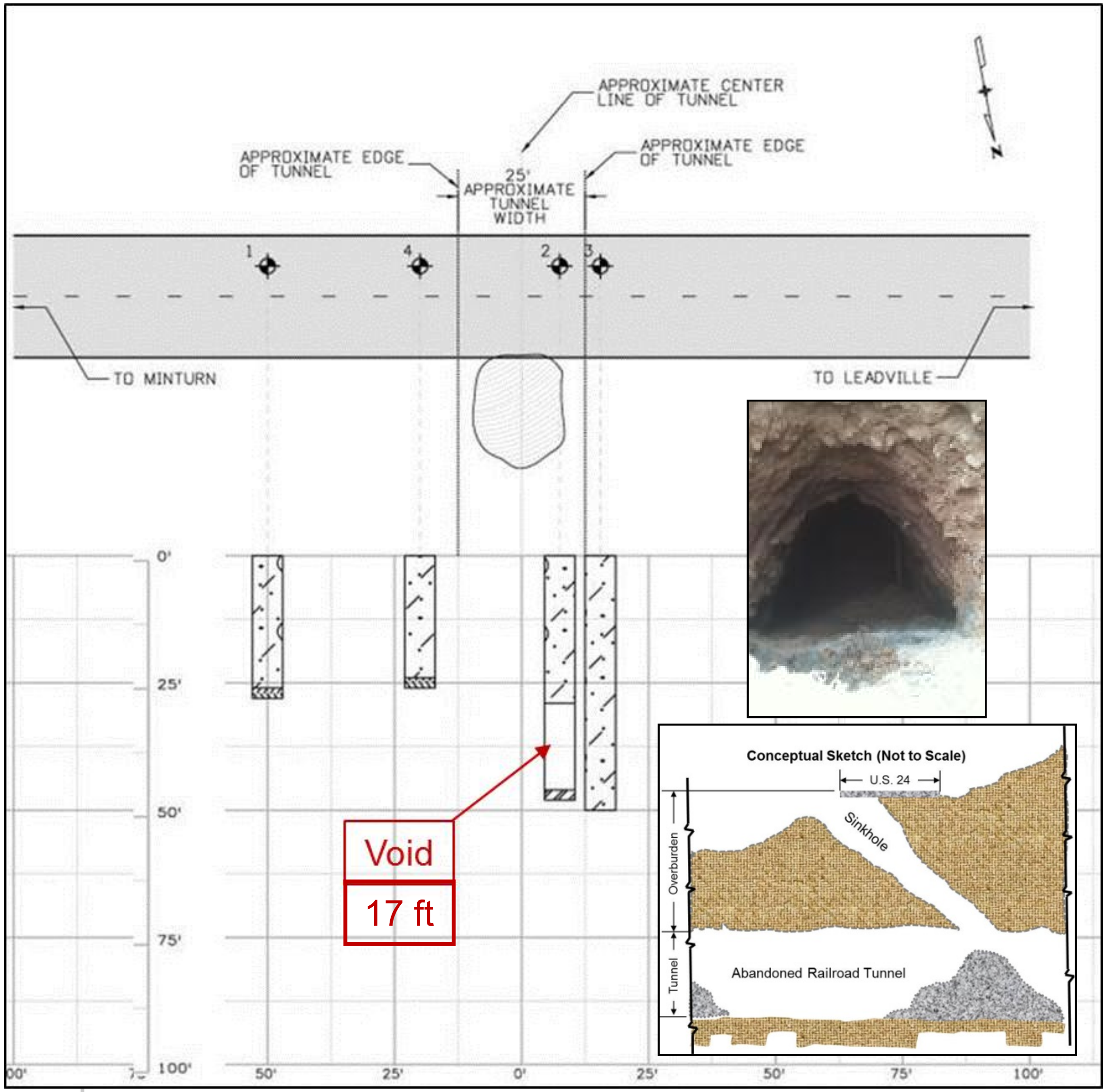


Sinkhole will develop if the overburden lithology consists of weak materials

Probability of Sinkhole (Caved Zone)
Reaching Surface
As a Function of Overburden Thickness



Preliminary CDOT Borings



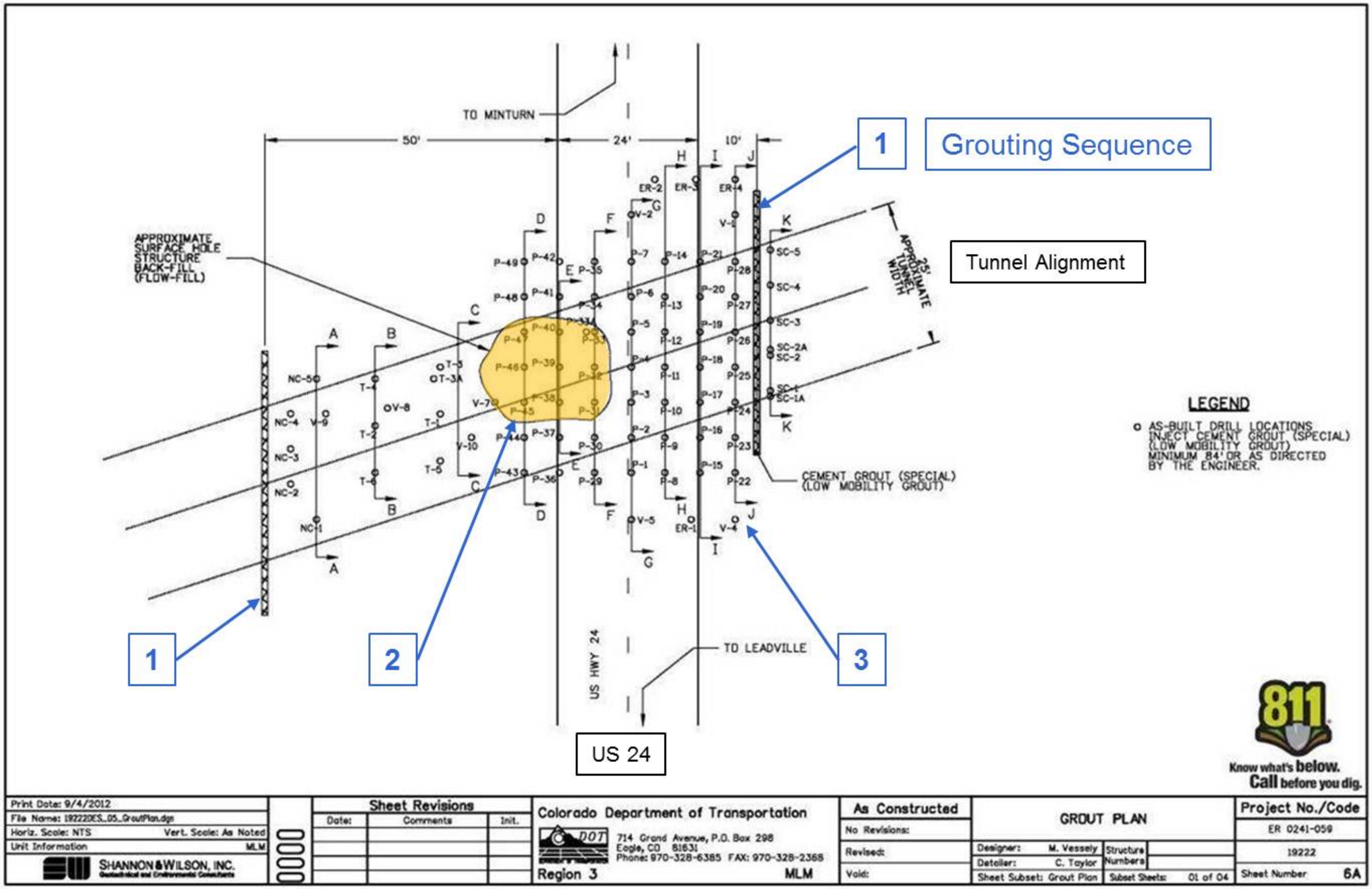
BORING 1:
0'-26' ASPHALT THEN INTERBEDDED SANDY CLAY WITH CLAYEY SAND LENSES AND OCCASIONAL COBBLES.
26' LIMIT OF DRILLING. WEATHERED GRANITE.

BORING 4:
0'-24' ASPHALT THEN SANDY CLAY WITH SAND LENSES AND OCCASIONAL COBBLES.
24' LIMIT OF DRILLING. WEATHERED GRANITE.

BORING 2:
0'-29' ASPHALT THEN CLAYEY SAND AND CLAY WITH SAND LENSES AND OCCASIONAL COBBLES.
29'-46' VOID
46' LIMIT OF DRILLING. APPARENT METAL.

BORING 3:
0'-50' ASPHALT THEN CLAY WITH SAND LENSES AND OCCASIONAL COBBLES.

Hayward Baker: Grout Plan – As Build



Sequence 1: Install North and South Cut-off Walls

"Inclined and vertical drilling and injection of low-mobility grout (LMG) into the throat of the sinkhole to provide a cut-off / plug for the sinkhole flow-fill"

Hayward Baker: Project Grouting Sequence(cont.)

Sequence 2: Sinkhole backfilling from surface with "Flow-fill" until hole is filled

Sequence 3: Compaction grouting on a "Grid Pattern" to tunnel elevation and outside of the tunnel alignment

Sequence 3 – Compaction Grouting

"Uses displacement to improve ground conditions"

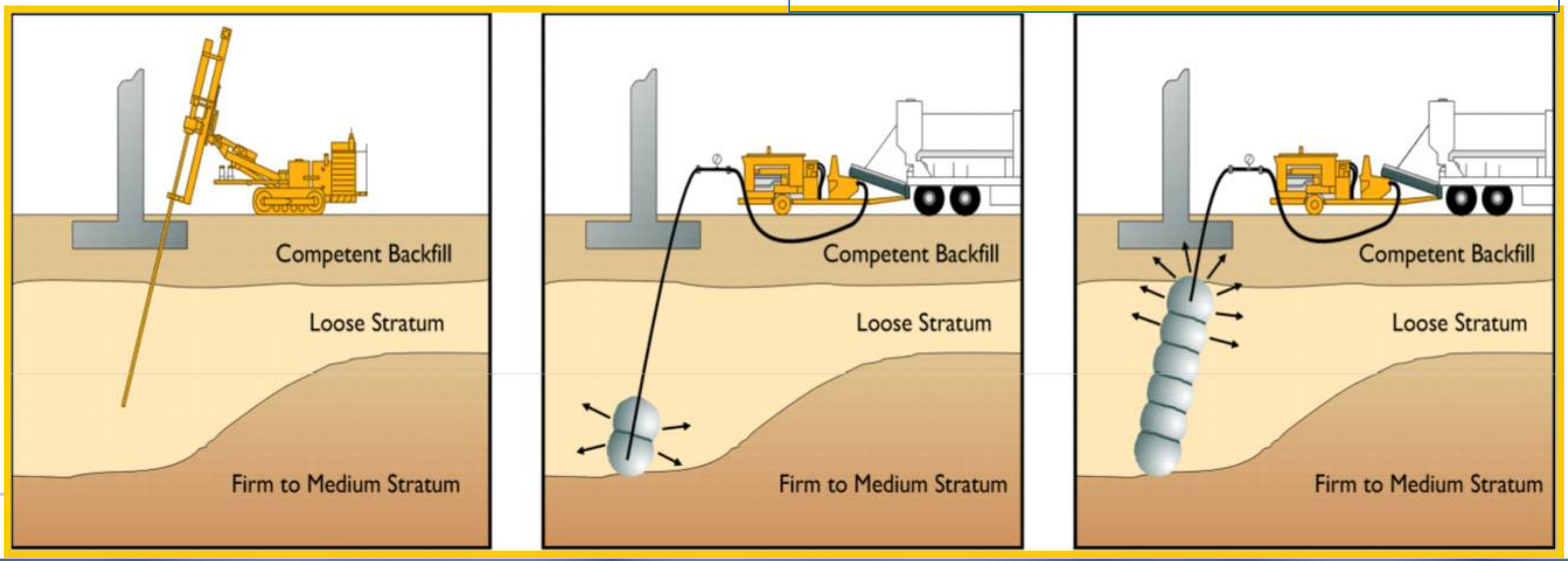
Grouting Process

Installation of Grout Pipe:

- Drill or drive casing
- Location very important
- Record ground information from casing

Initiation of Grouting:

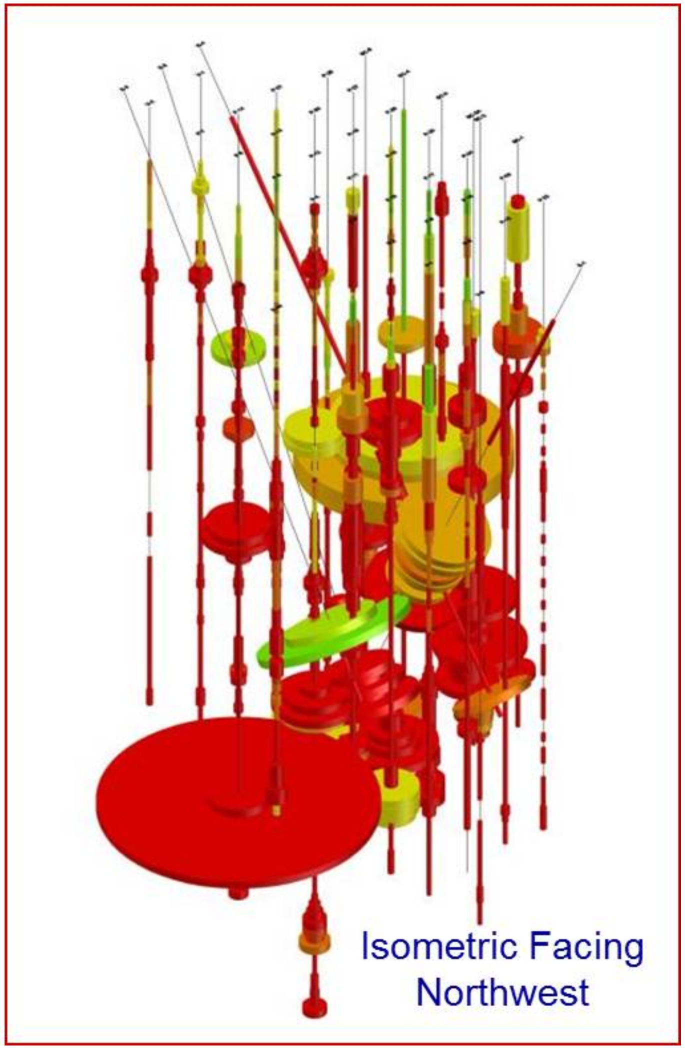
- Typical bottom up, but can also be top down
- Grout flow (rheology) important (low mobility, not necessary low slump)
- Usually pressure and / or volume of grout limited slow, uniform stage injection



Ideal Grout Make-up

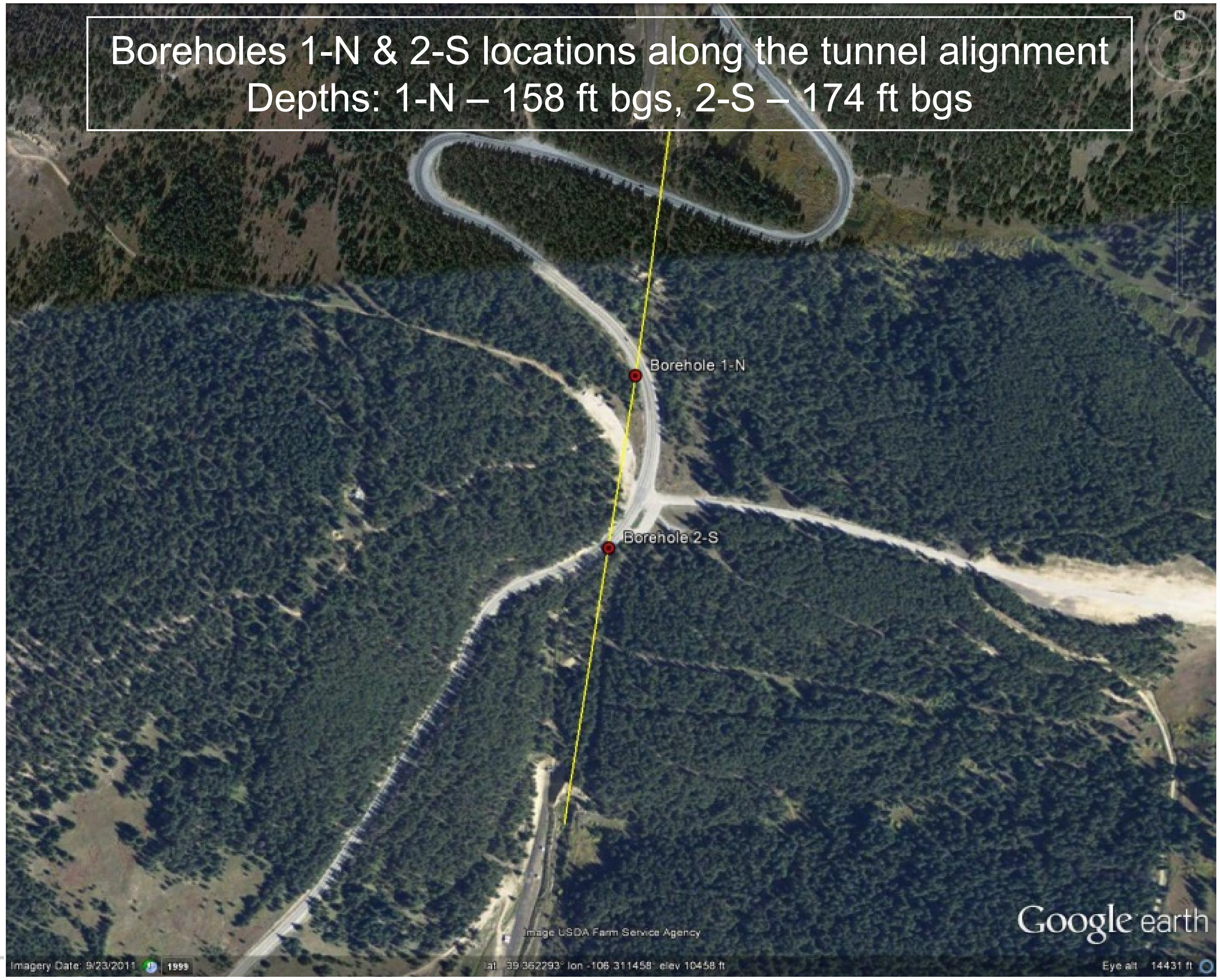
- 100% passing 3/8”
- 15-25% passing #200
- Rounded pea gravel helps
- 10-20% cement by volume
- Slump – Typically less than 2” for pre-treatment and around 1” for underpinning and piles

Grouting Intake 3 D Model



Once northbound lane is fully compaction grouted, open lane to traffic and repeat similar process on southbound

3D Laser and Video Camera Imaging of the Tunnel Geometry



Tethered Robotic Downhole Systems
Void Mapping & Imaging
"Real Time Visualization"

Downhole Sonar Void Scanning / Mapping (Water-filled void)

- Imagenex Digital Multi-frequency Profiling
- One-axis scanning: horizontal plane (360-degree scan)
- Scans: multiple 2-D plans create 3-D model
- Distance measurements: 300 ft
- Accuracy: ± 1 degree

Downhole Laser Void Scanning / Imaging (Air-filled void)

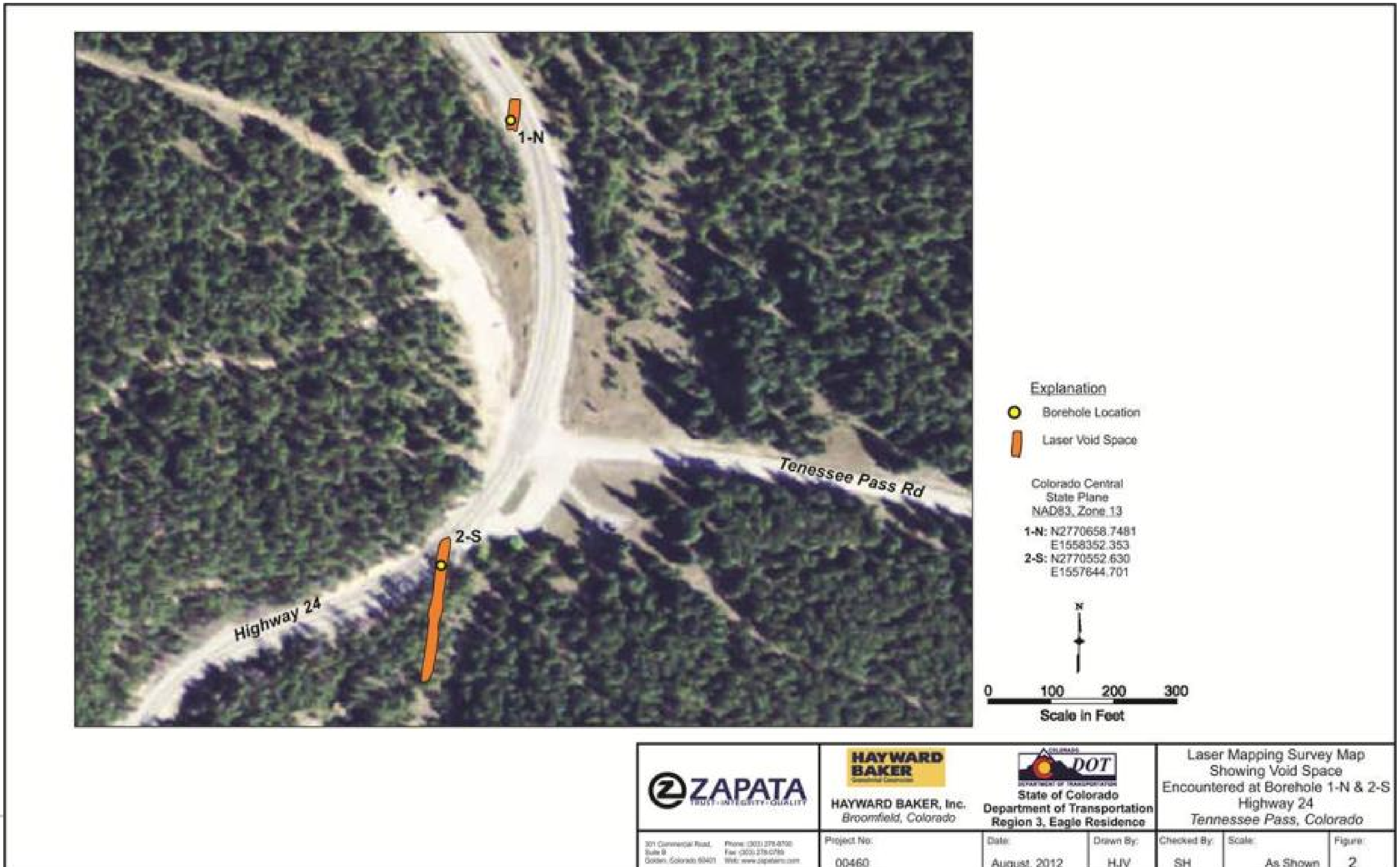
- MDL: C-ALS
- Scans: 3-D or 2-D horizontal and vertical slices
- Equipped with video camera (~20 ft)
- Distance measurements: 500 ft
- Accuracy ± 0.5 degree

Downhole Video Camera Void Imaging (Air-filled or water-filled void)

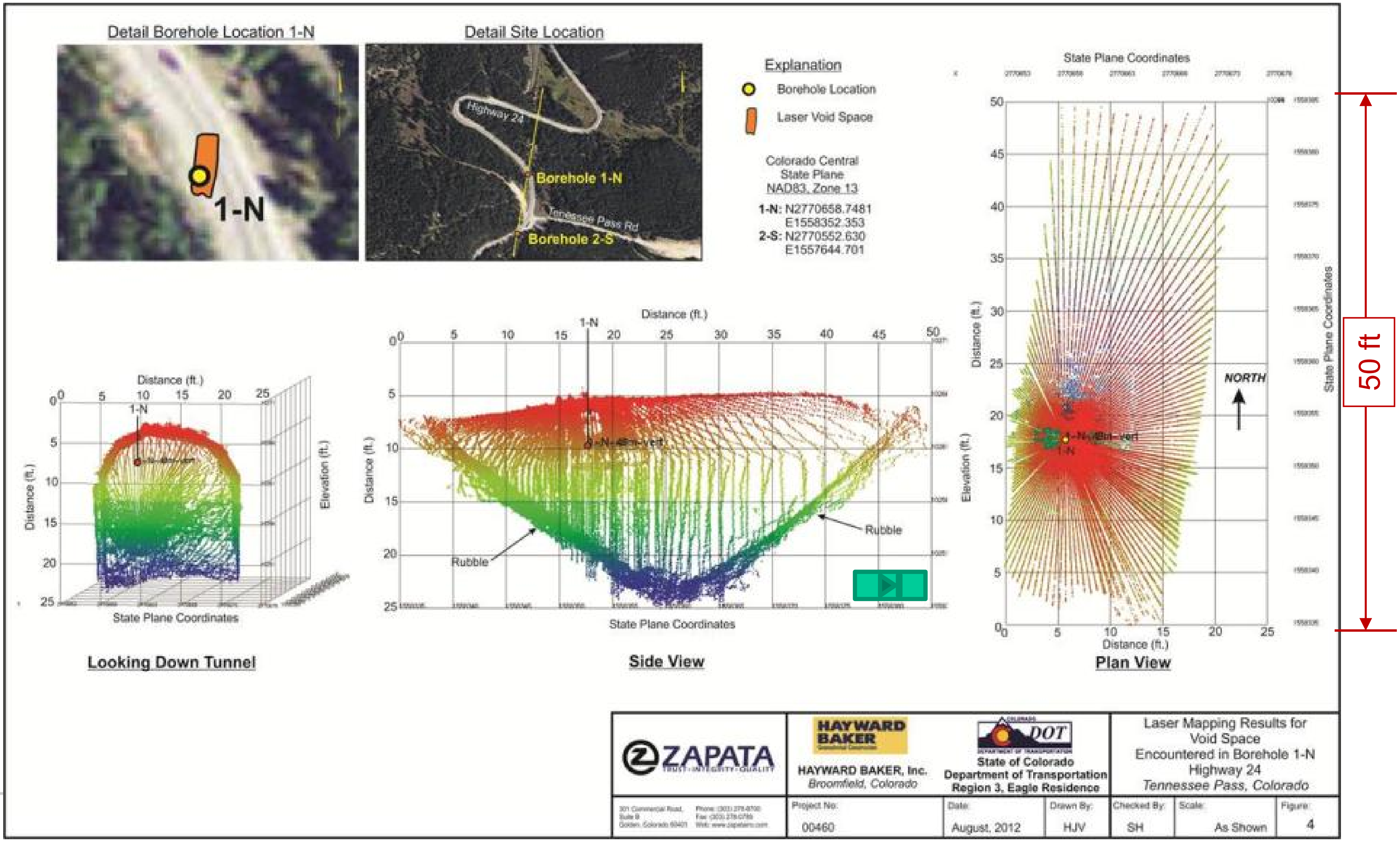
- Images: Vertical and horizontal control
- Video recording capabilities
- Distance measurements ~ 25 ft

Drilling, downhole laser and video camera systems

Laser Mapping Survey Map: Showing void space in Boreholes 1-N & 2-S

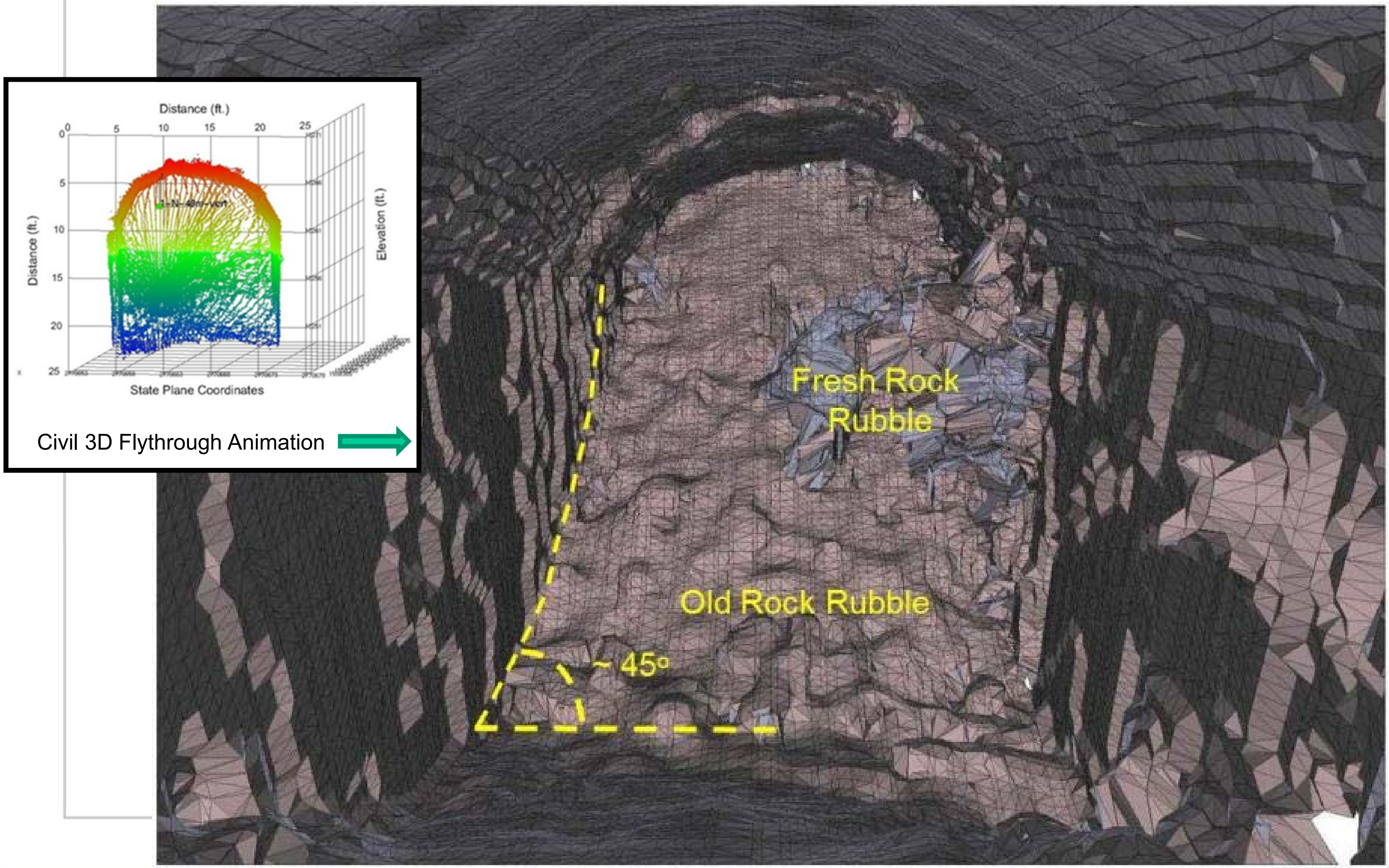


2D/3D Laser Views – Tunnel void space in Borehole 1-N

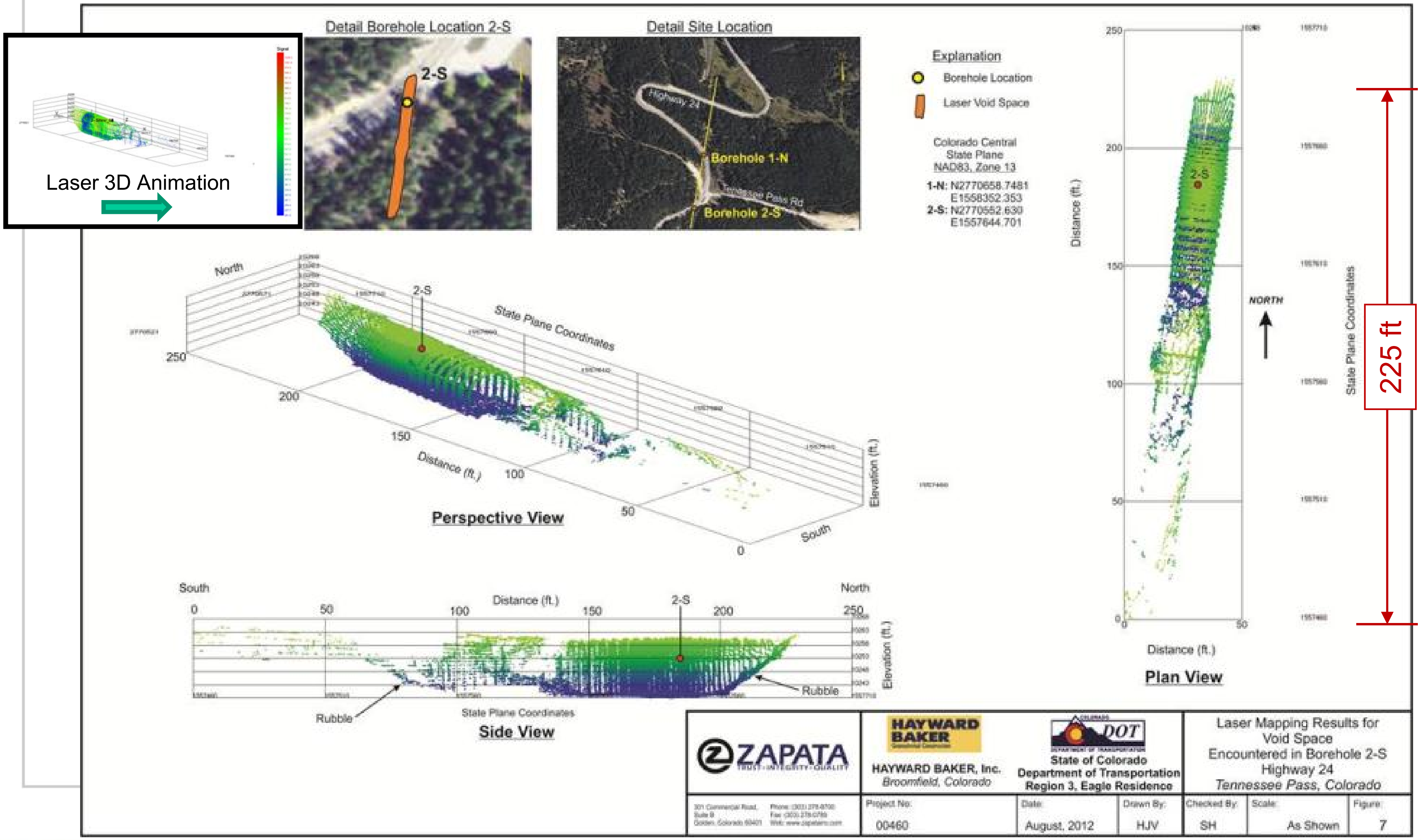


3D Laser snapshot – Looking south from inside the tunnel

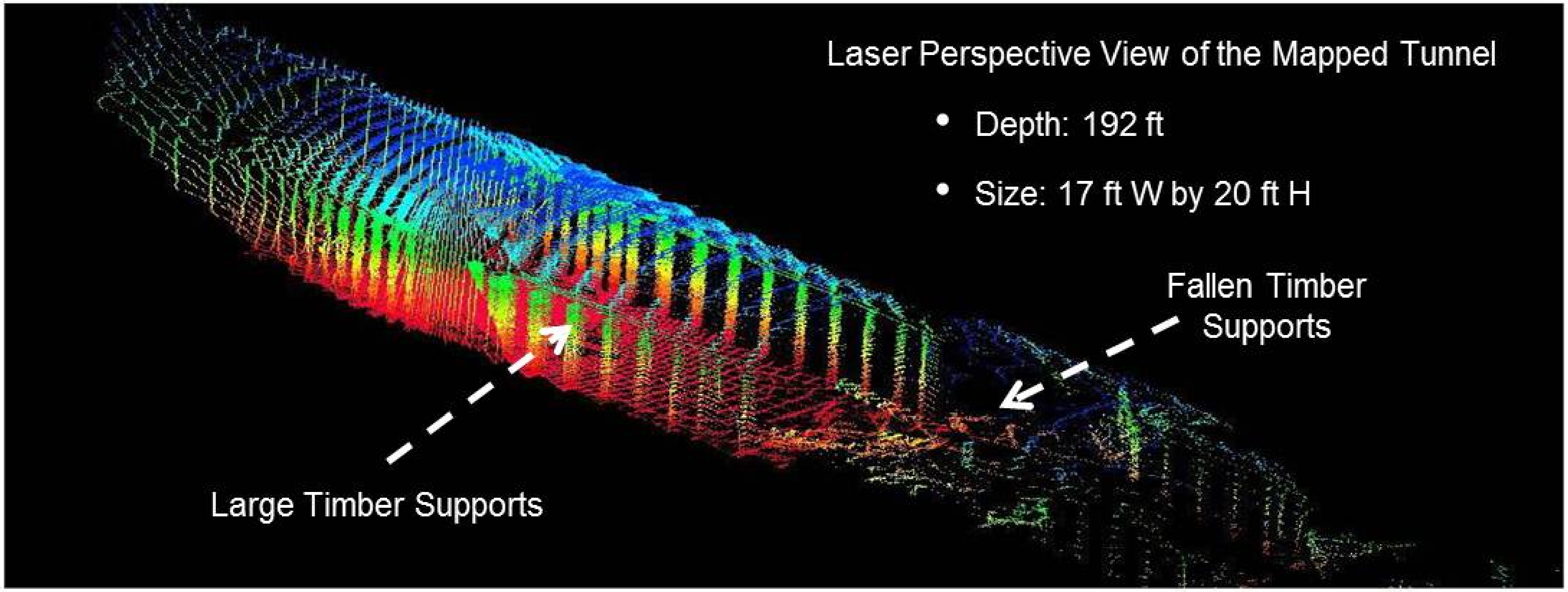
"Borehole 1-N showing collapsed portion of the tunnel"

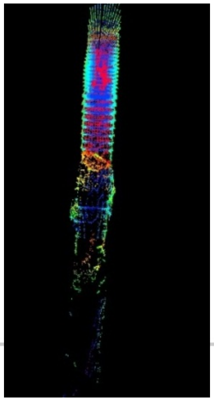


3D Laser mapping survey map: Showing void space in Borehole 2-S



3D Laser mapping survey: Perspective view of the tunnel from Borehole 2-S

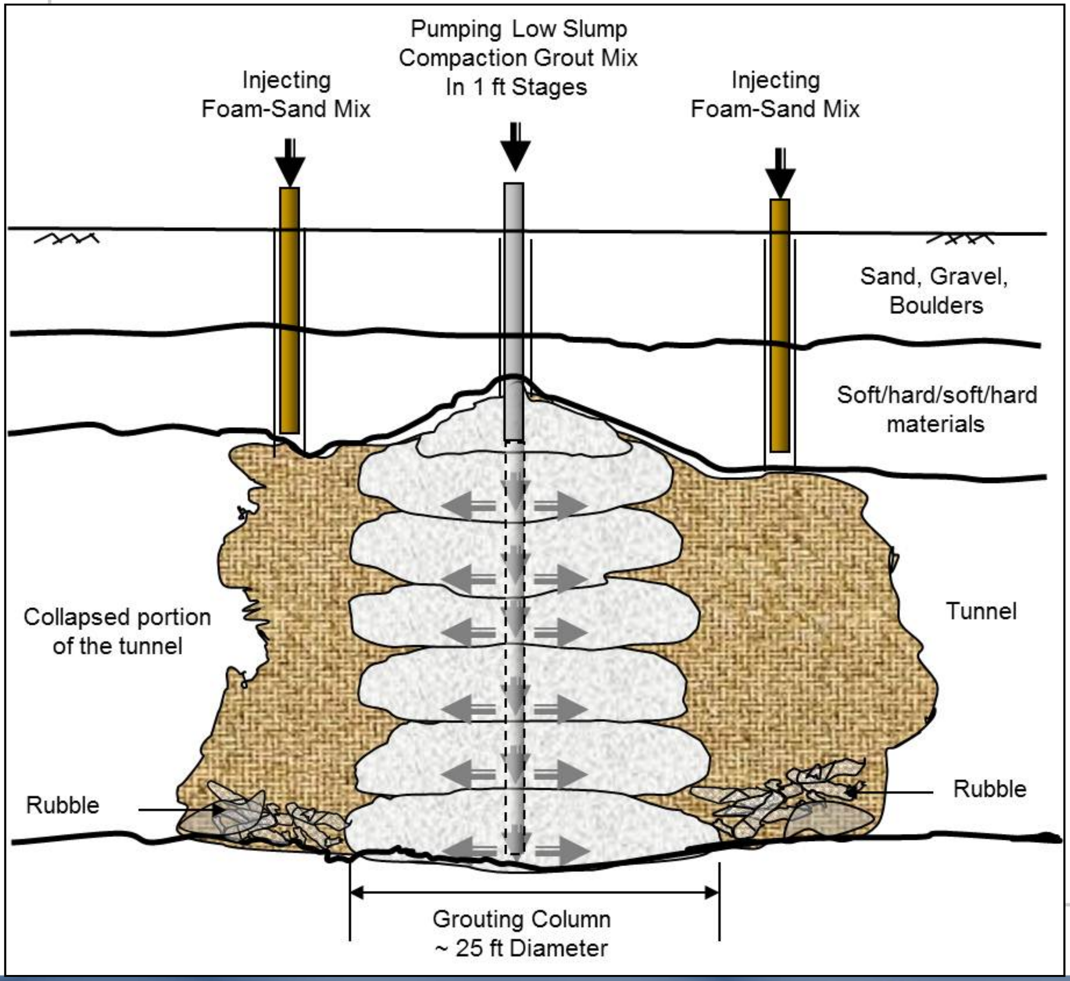


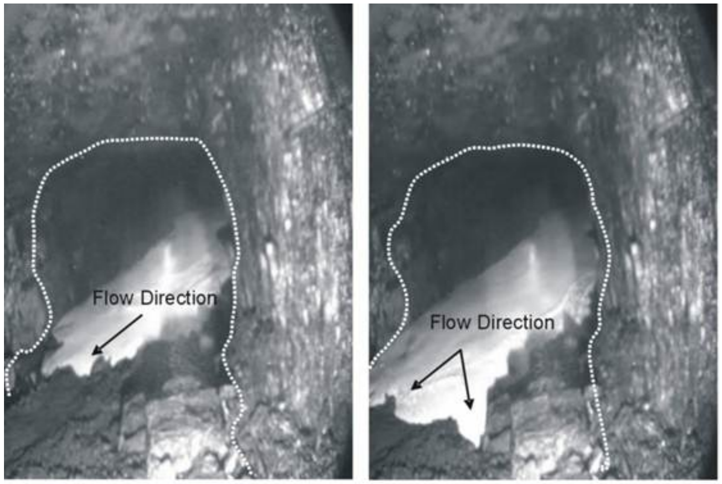


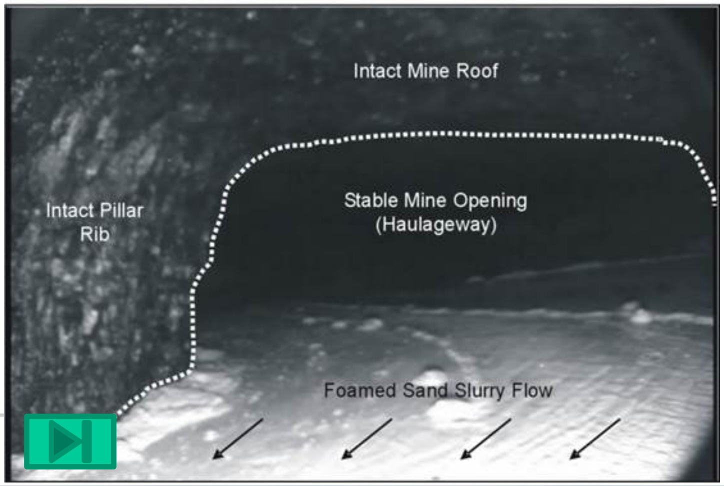
Civil 3D Flyaround Animation

A combination of compaction grout and foamed-sand filler methods

"To reduce/eliminate the risk for future highway settlement/sinkhole development"







Summary

- Total Cost ~$1.5M
- Flow Fill in Hole: 925 CY
- Low Mobility (Compaction) Grout: 667 CY
- 75 Holes and 6,375 LF of Drilling
- 23 Days to Complete (with added scope)
- Roadway fully opened Friday evening 8/10
- No Interruption to USA Pro Challenge Bike Race
- Accommodated Copper Triangle Bike Race