Settlement, Hydro-Collapse Potential, and Ground Improvement for Risk Reduction

A Case Study of the Sunset Road Project in Tucson, Arizona

Randy Post, PE
Assistant Vice President, Geotechnical Engineer

Project Overview


Santa Catalina Mountains
Project Area
CDO Wash
Santa Cruz River
Rillito Creek
Tucson Mountains
Rincon Mountains
ORO VALLEY
TUCSON
Davis Monthan Air Force Base
Davis Monthan Air Force Base
Saguaro National Park Tucson Mountain District
Tucson Mountain Park
Coronado National Forest
W AVRA VALLEY RD
W TWIN PEAKS RD
W LAMBERT LN
W LINDA VISTA BL
W OVERTON RD
W HARDY RD
W CORTARO FARMS RD
W MAGEE RD
W INA RD
E INA RD
W ORANGE GROVE RD
E ORANGE GROVE RD
E SKYLINE DR
W PICTURE ROCKS RD
W SUNSET RD
E SUNRISE DR
W RIVER RD
E RIVER RD
W EL CAMINO DEL CERRO
W RUTHRAUFF RD
W SWEETWATER DR
W PRINCE RD
E PRINCE RD
E FORT LOWELL RD
W GORDET RD
W IRONWOOD HILL DR
W GRANT RD
E GRANT RD
E PIMA ST
W SPEEDWAY BL
E SPEEDWAY BL
W ANKLAM RD
W SAINT MARYS RD
E 6TH ST
E 5TH ST
W CONGRESS ST
E BROADWAY BL
W STARR PASS BL
W 22ND ST
E 22ND ST
E 29TH ST
E AVIATION PW
E 36TH ST
E GOLF LINKS RD
W AJO WY
E AJO WY
W BOPP RD
W AJO HY
W IRVINGTON RD
E IRVINGTON RD
E ESCALANTE RD
W DREXEL RD
E DREXEL RD
W BILBY RD
E BILBY RD
W VALENCIA RD
E VALENCIA RD
E CLOUD RD
E WRIGHTSTOWN RD
E TANQUE VERDE RD
E SNYDER RD
E CATALINA HY
E FORT LOWELL RD
N KINNEY RD
S KINNEY RD
S SAN JOAQUIN RD
N SILVERBELL RD
N ORACLE RD
N STONE AV
N 6TH AV
N EUCLID AV
N CAMPBELL AV
N COUNTRY CLUB RD
N ALVERNON WY
N SWAN RD
N CRAYCROFT RD
N KOLB RD
N SABINO CANYON RD
N PANTANO RD
N CAMINO SECO
N HARRISON RD
N BEAR CANYON RD
N SOLDIER TR
N FREEMAN RD
N TANQUE VERDE LOOP RD
S 4TH AV
S 6TH AV
S 12TH AV
S PARK AV
S MISSION RD
S CALLE SANTA CRUZ
S JOSEPH AV
S CARDINAL AV
S TUCSON BL
S PALO VERDE RD
S CRAYCROFT RD
S WILMOT RD
S HARRISON RD
S CAMINO SECO
S PANTANO RD
S FREEMAN RD
S OLD SPANISH TR
S KOLB RD
E OLD SPANISH TR
S MELPOMENE WY
N TANQUE VERDE LOOP RD
Rillito Creek
Tanque Verde Creek
Pantano Wash
0
1
2mi

Project Location

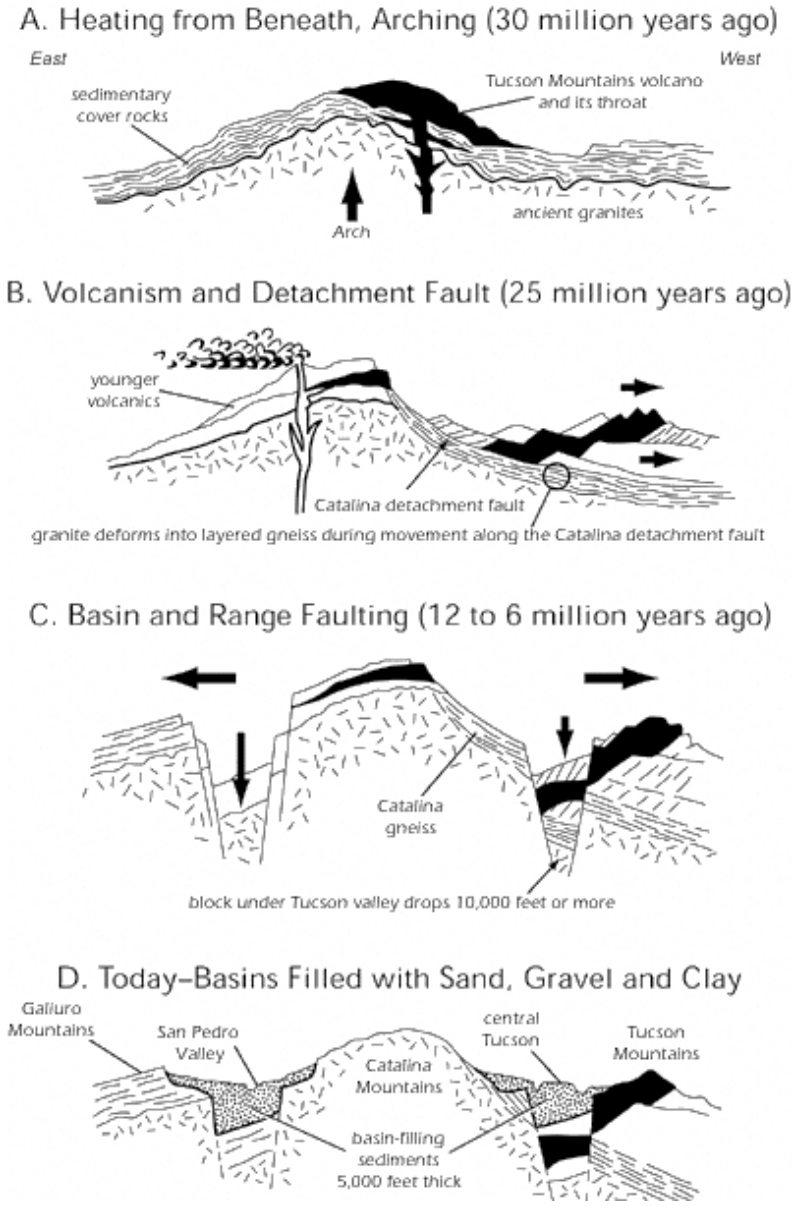
Site and Regional Geology

Basin and Range Geology of Tucson

Key Points for this Project

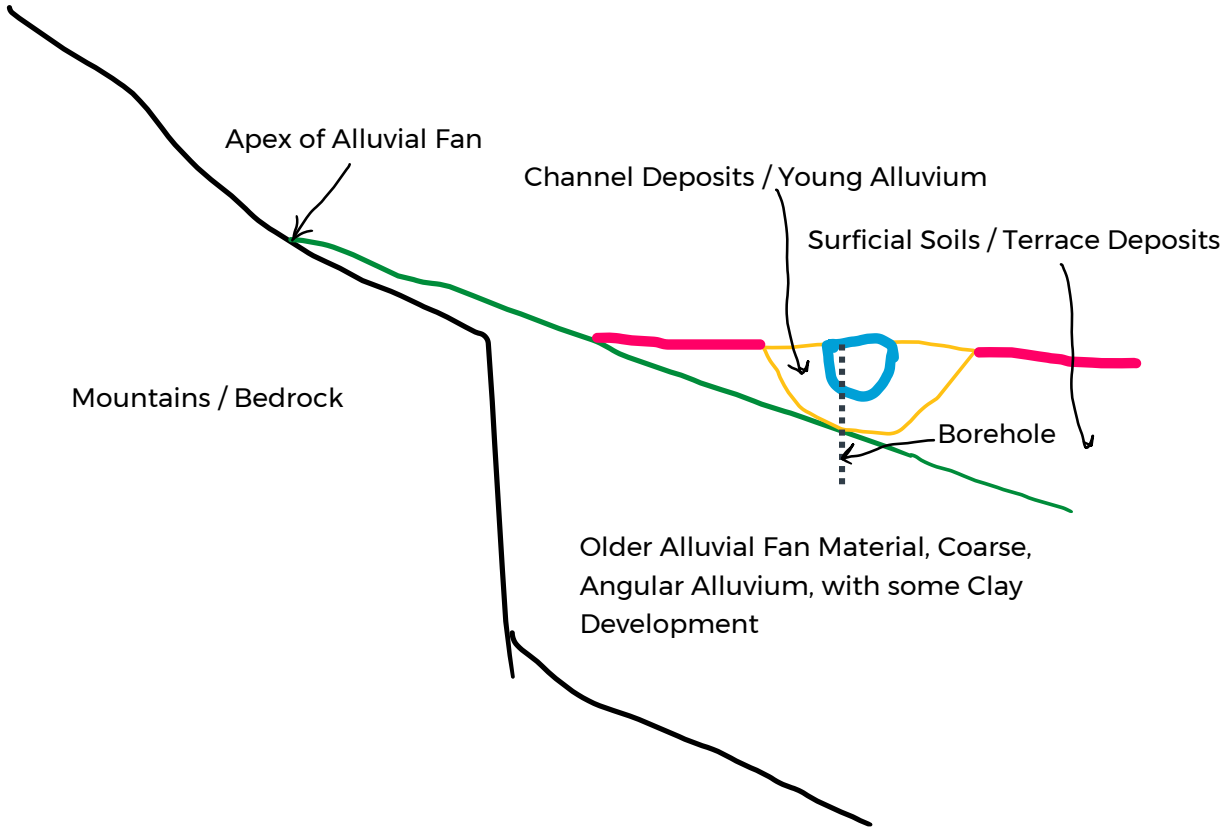
- Over last 6M Years, Tucson Basin Filled with Sediment
- Close to Mountains – Alluvial Fans
- Central Basin – Finer-Grained Alluvium

Deepest Units Encountered on Project, Probably Pleistocene in Age (1.7 to 1.3 MYA)



Randy's Interpretation of Site Geology

Please use your imagination!



Channel Deposits – Sands and Gravels, well-graded

Surficial Soils / Overbank Deposits – Less Dense, Hydro-Collapse Potential

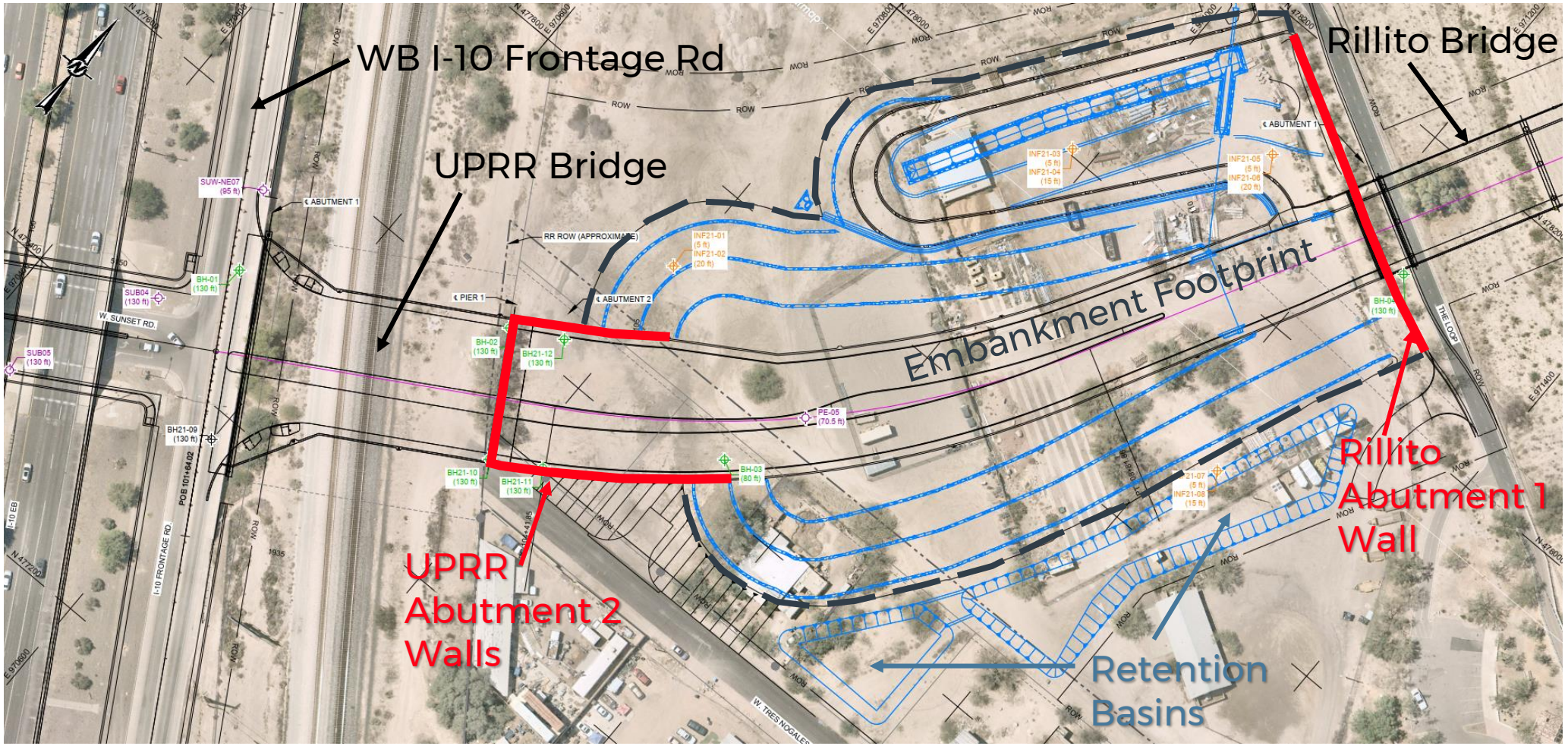
Gravel Layers Deeper

Deeper, Older Layers are part of Alluvial Fans from Tucson Mountains

Those Layers are Good Bearing Layers, Very Dense, Angular, But with some Clay Development

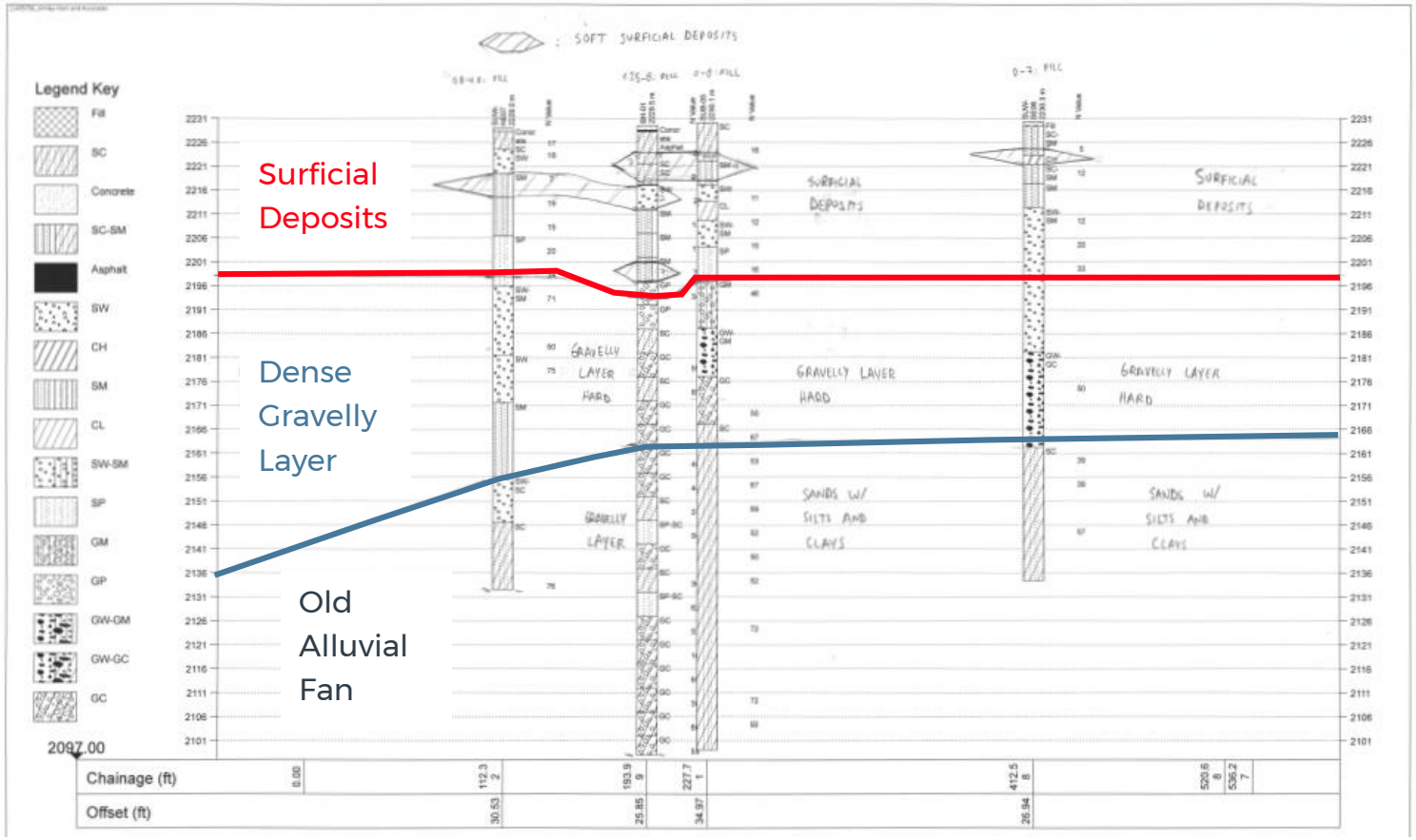
Geotechnical Investigations and Key Findings

Field Investigation



Investigation Photos

Subsurface Profile and Material Properties



Three Layers

Surficial Deposits (Hydro-Collapsible)

Dense Gravels (Not Hydro-Collapsible) – At Depths of 25 to 35 feet

Old, Dense Alluvial Fan

Collapsible Soils - A Potential Problem

Collapsible Soils Generally…

- PI < 10
- Dry density < 95 pcf
- Moisture content < 8%
- SPT N-Value < 15 blows/ft

14 Lab Collapse Tests

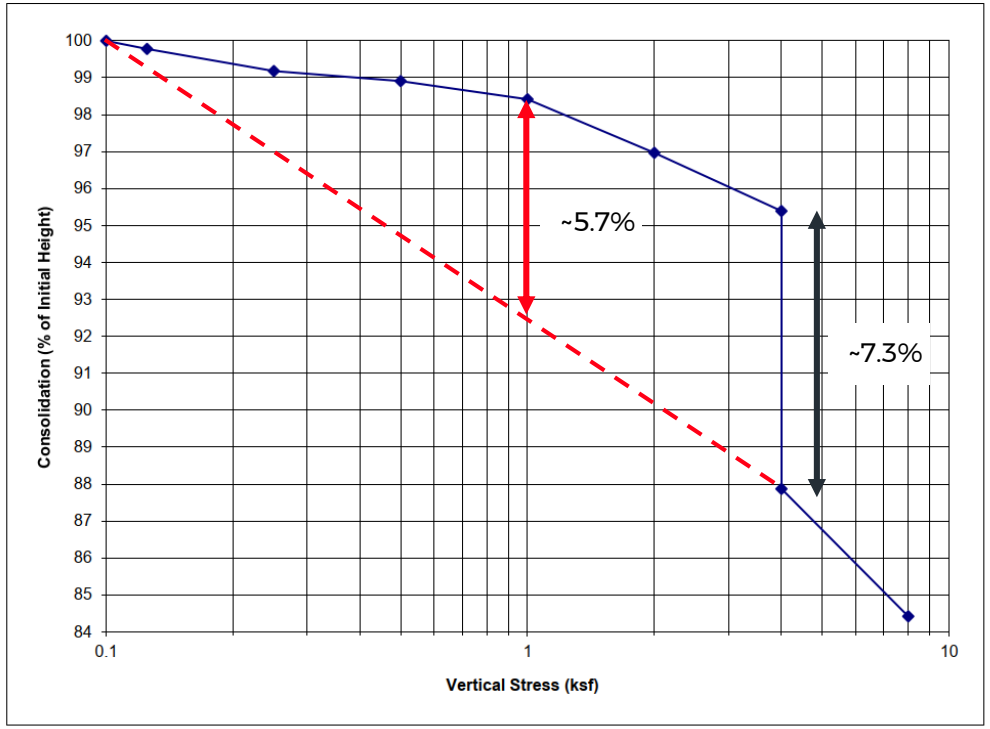
Results ranged from slight to severe (10% or more)

Most in the 7-9% Range

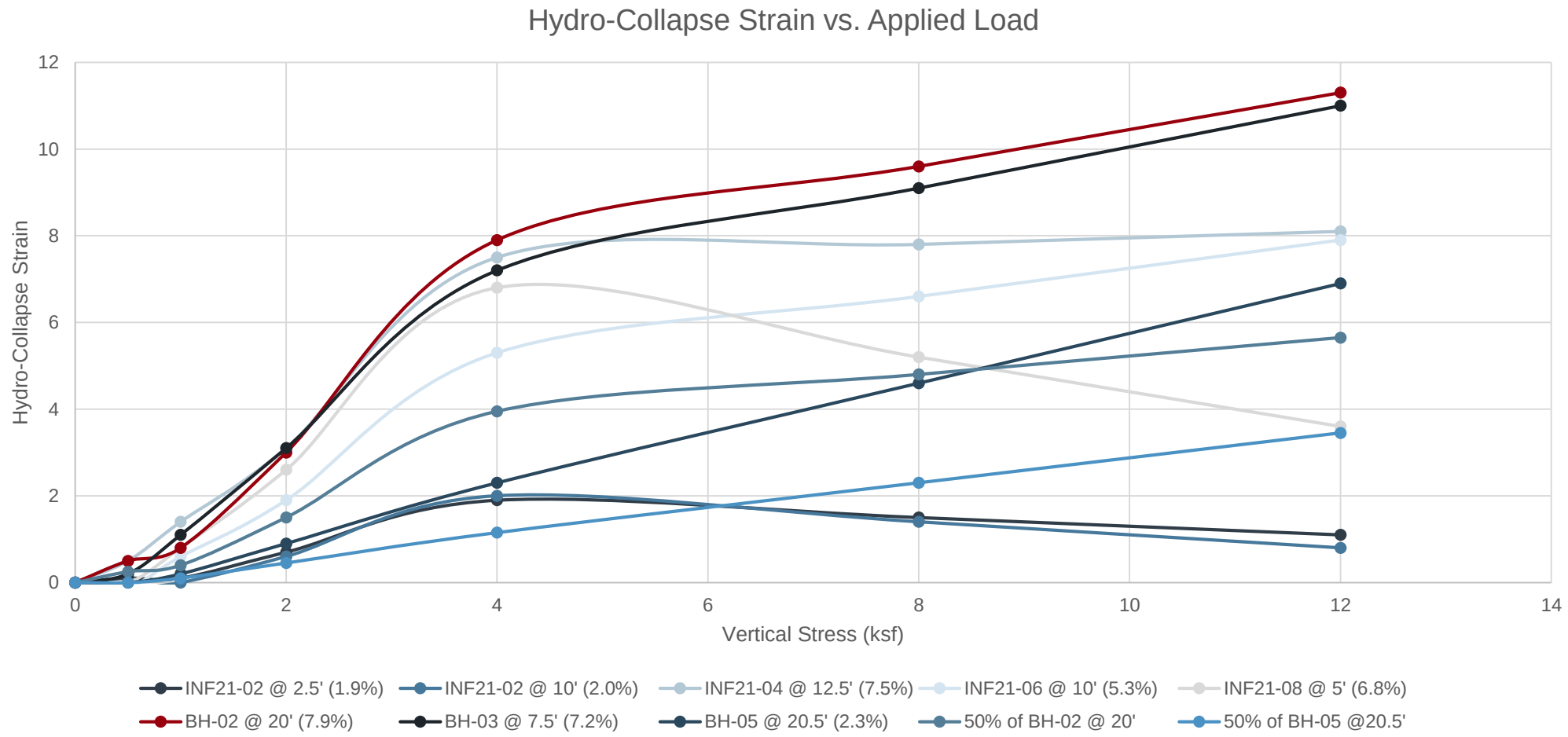
Lab values have been know to over-predict field collapse by factor of 2

One-Dimensional Consolidation Properties of Soils (ASTM D2435)

Initial Volume (cu.in)	4.60	Final Volume (cu.in)	3.89
Initial Moisture Content	8.5%	Final Moisture Content	23.3%
Initial Dry Density(pcf)	85.1	Final Dry Density(pcf)	100.8
Initial Degree of Saturation	24%	Final Degree of Saturation	100%
Initial Void Ratio	0.9	Final Void Ratio	0.6
Estimated Specific Gravity	2.59	Saturated at	4 ksf



From Lab Collapse to Project Significance



Borehole Infiltration Tests

GOLDER
MEMBER OF WSP

Borehole Hydraulic Conductivity Test - ASTM D 6391 Method B (Single Trial)

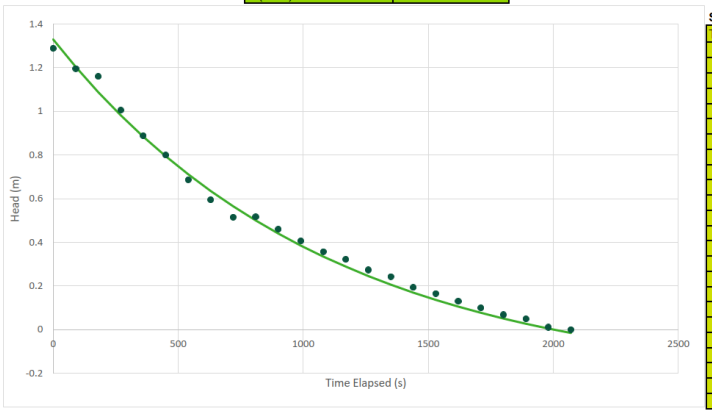
Date:	6/9/2021	**Made by:**	Rayanna Pearson
Project No.:	21455756	**Checked by:**	Randy Post
Subject:	Hydraulic Conductivity Calculations	**Reviewed by:**	Randy Post
Project Short Title:	KH Sunset Rd. I10 to River Final Design	**TEST LOC.:**	INF21-06 @ 14.5'

D (cm)	10.16	a	0.0009
d (cm)	10.16	Z*	-0.2514
Avg. Temp. (°C)	28.91783077	Z_0	1.5804
R_T	0.815021004	Σx^2	0.0133
		K (cm/s)	2.2E-03

Location Properties
Location Name = 5A
Location ID = ab822c58-460d-4dad-a6ba-085996

Report Properties
Start Time = 2021-05-24 14:38:01.595
Duration = 00:34:31
Readings = 208
Time Offset = -07:00:00

Instrument Properties
Device Model = Level TROLL 500
Device SN = 704095
Device Firmware = 3.06



Simplified Data: *Adjusted from 810-1800 seconds

Time Elapsed (s)	Head (m)	Head Fit (m)	x^2
0	1.2885347	1.32896554	0.00163465
90	1.1959249	1.2035919	5.8783E-05
180	1.1597039	1.08816429	0.00511792
270	1.0056747	0.98189368	0.00056554
360	0.8877415	0.88405365	1.36E-05
450	0.7993474	0.79397537	2.8859E-05
540	0.6859471	0.71104311	0.00062981
630	0.5946023	0.63468996	0.00160702
720	0.5143488	0.56439399	0.00250452
810	0.516663797	0.49967467	0.00028863
900	0.46043849	0.44008962	0.00041408
990	0.40683879	0.38523152	0.00046687
1080	0.35747009	0.33472537	0.00051732
1170	0.32180939	0.28822593	0.00112785
1260	0.27376969	0.24541534	0.00080397
1350	0.24274689	0.20600097	0.00135026
1440	0.19357289	0.16971339	0.00056928
1530	0.16515809	0.13630453	0.00083253
1620	0.13077139	0.10554605	0.00063632
1710	0.09959549	0.07722766	0.00050032
1800	0.06802359	0.05115581	0.00028452
1890	0.0492371	0.02715227	0.00048774
1980	0.010779003	0.00505295	3.2788E-05
2070	0	-0.0152932	0.00023388

We know soils are collapsible…

But will water infiltrate beneath our structures?

8 infiltration tests

Results used for transient seepage analyses

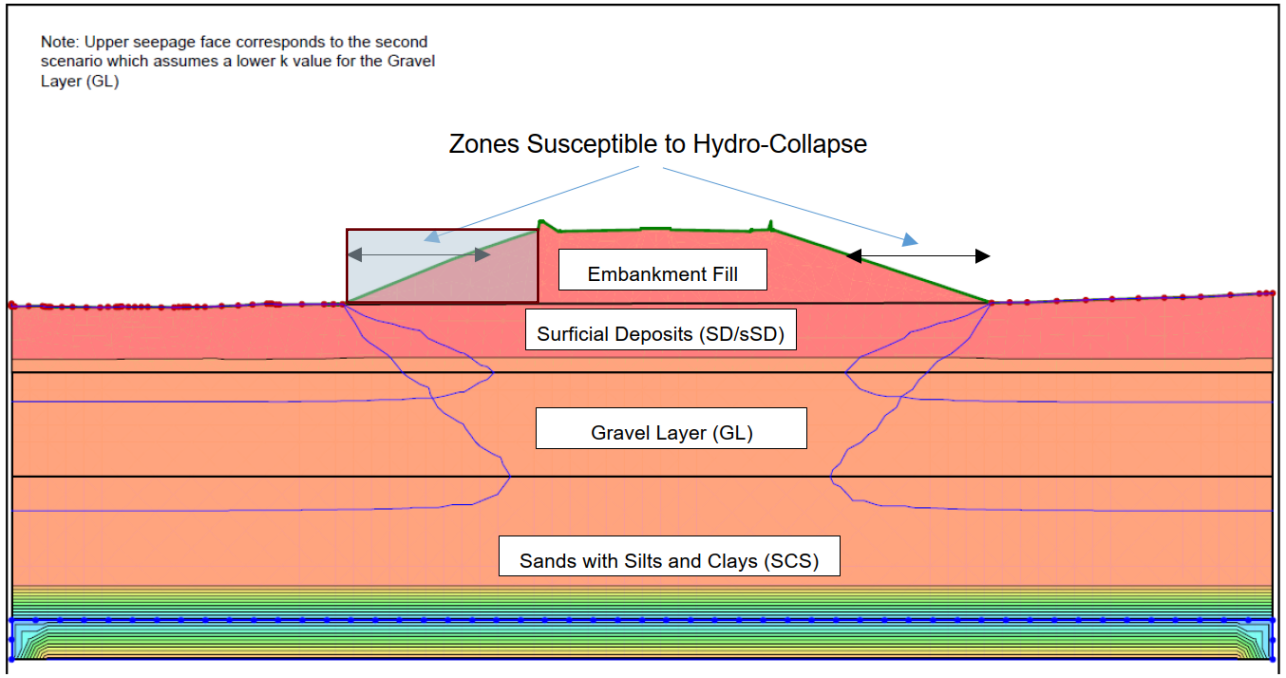
Seepage Analysis

100 Year Water Surface Elevation Doesn't Reach Walls/Embankment

Detention Basins are Adjacent to Embankment

Used Infiltration Tests to Simulate 15 Days of Water Ponding in Basins

Seepage Face Doesn't Extend Under



Design Elements – Settlement Analysis and Ground Improvement

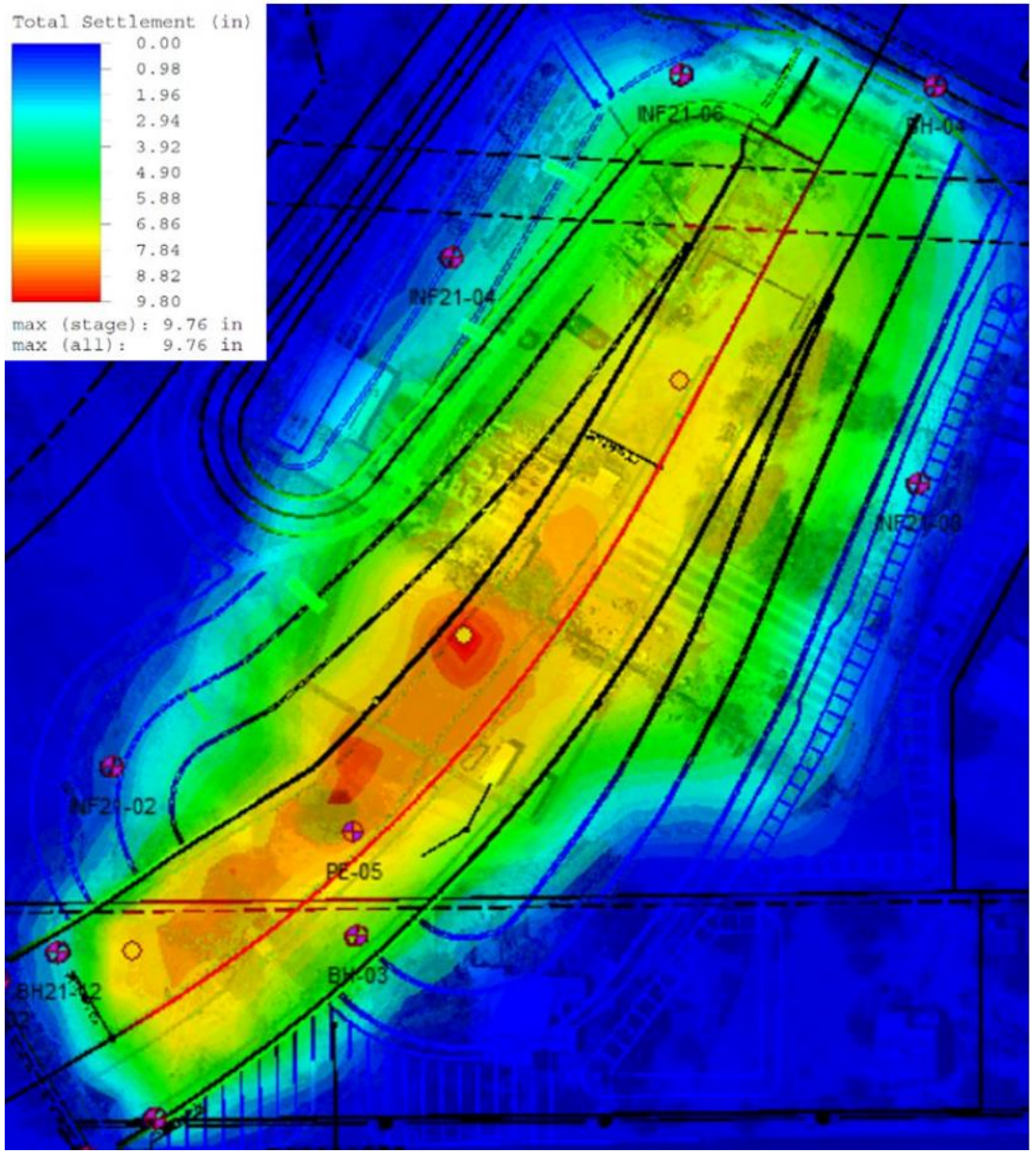
Immediate Settlement

Settle 3D (Elastic Settlement)

UPRR Approach Walls – About 6 -8 inches

Much Less Near Rillito Abutment

All Occurs Mostly During Construction

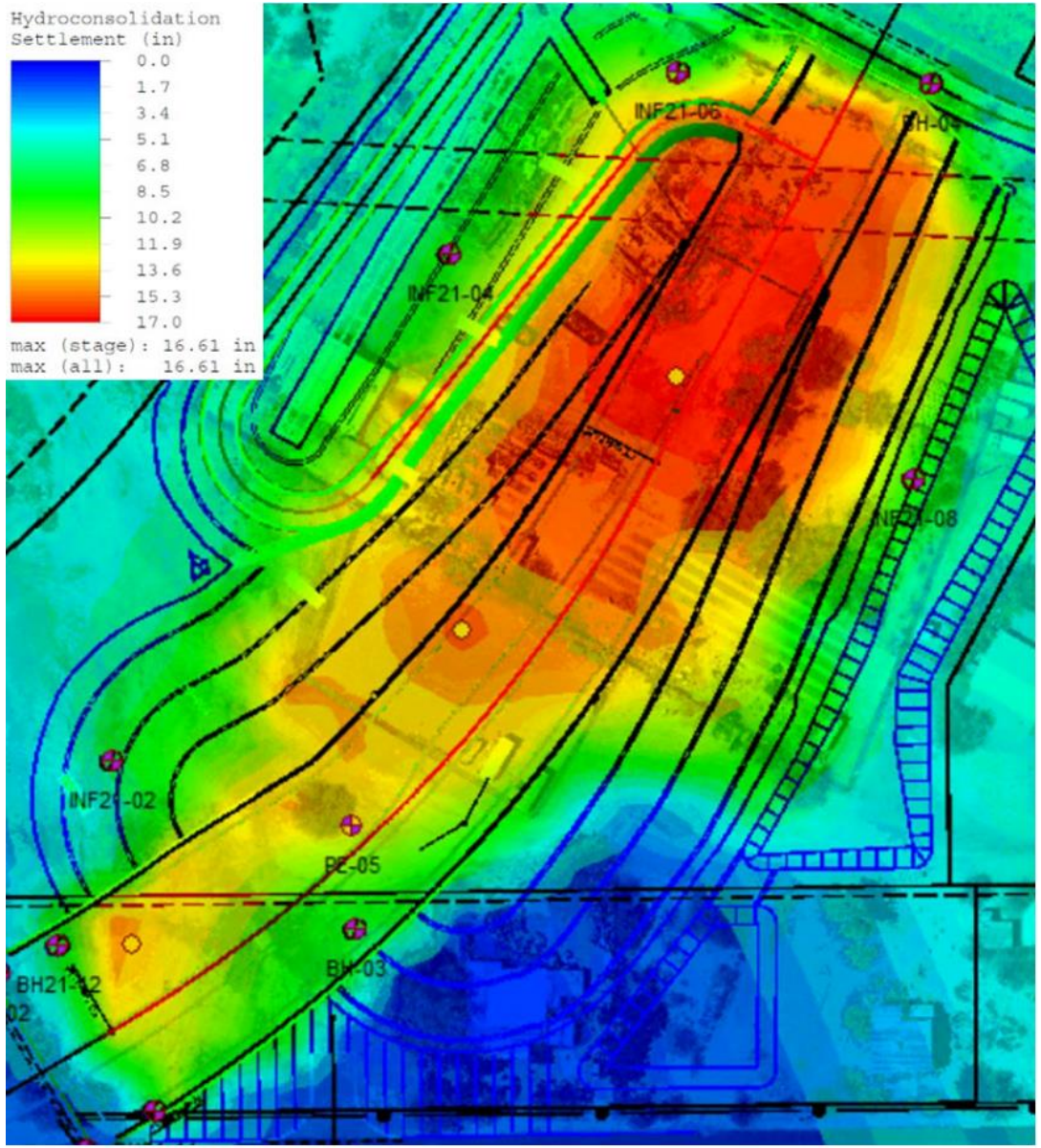


Potential Hydro-Collapse

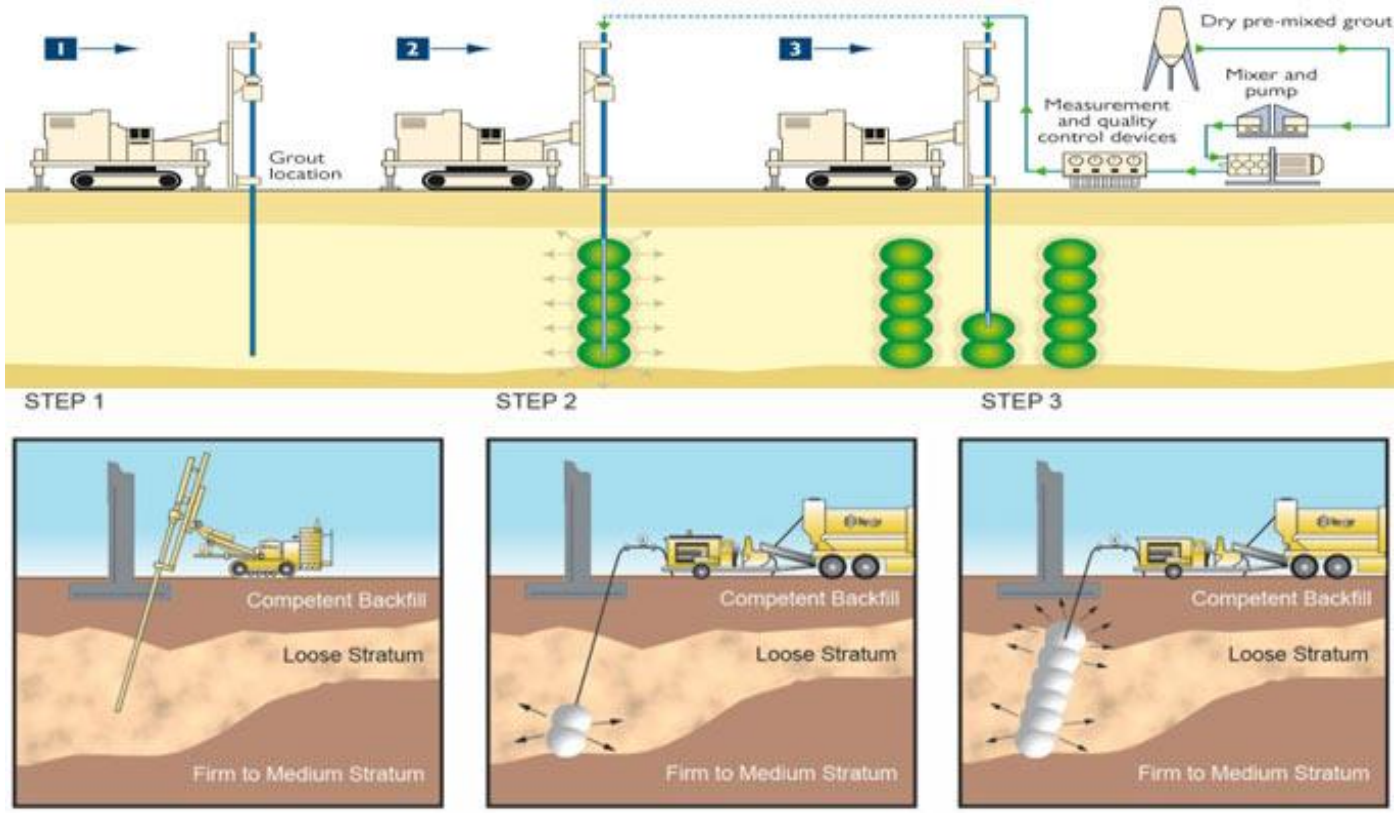
Embankment Area – Up to 17 inches

UPRR Abutment MSE Walls – Around 14 inches

Worst-Case Assuming Full Saturation of Collapsible Layers



Compaction Grouting Selected



Low Slump Grout (Like Canned Dog Food)

Densifies the Soil and forms a Column

Other Methods Considered include:

- Dynamic Compaction
- Vibro Compaction
- Aggregate Columns
- Over-excavation and Recompaction

Where to Mitigate?

It's about Risk and Cost

Project Element	Relative Magnitude of Potential Hydro-Collapse	Potential Impacts or Repair Costs	Final Decision for Mitigation
UPRR Abutment 2 Wall and Approach Walls	High	High	Yes
Rillito Bridge Abutment 1 Wall and Wingwalls	Moderate	Moderate – High	No
Catch Basins	Moderate	Low – Moderate	No
Multiuse Path Retaining Walls	Moderate	Low	No
Rillito Bridge Abutment 2 Walls and Wingwalls	Low	Moderate	No

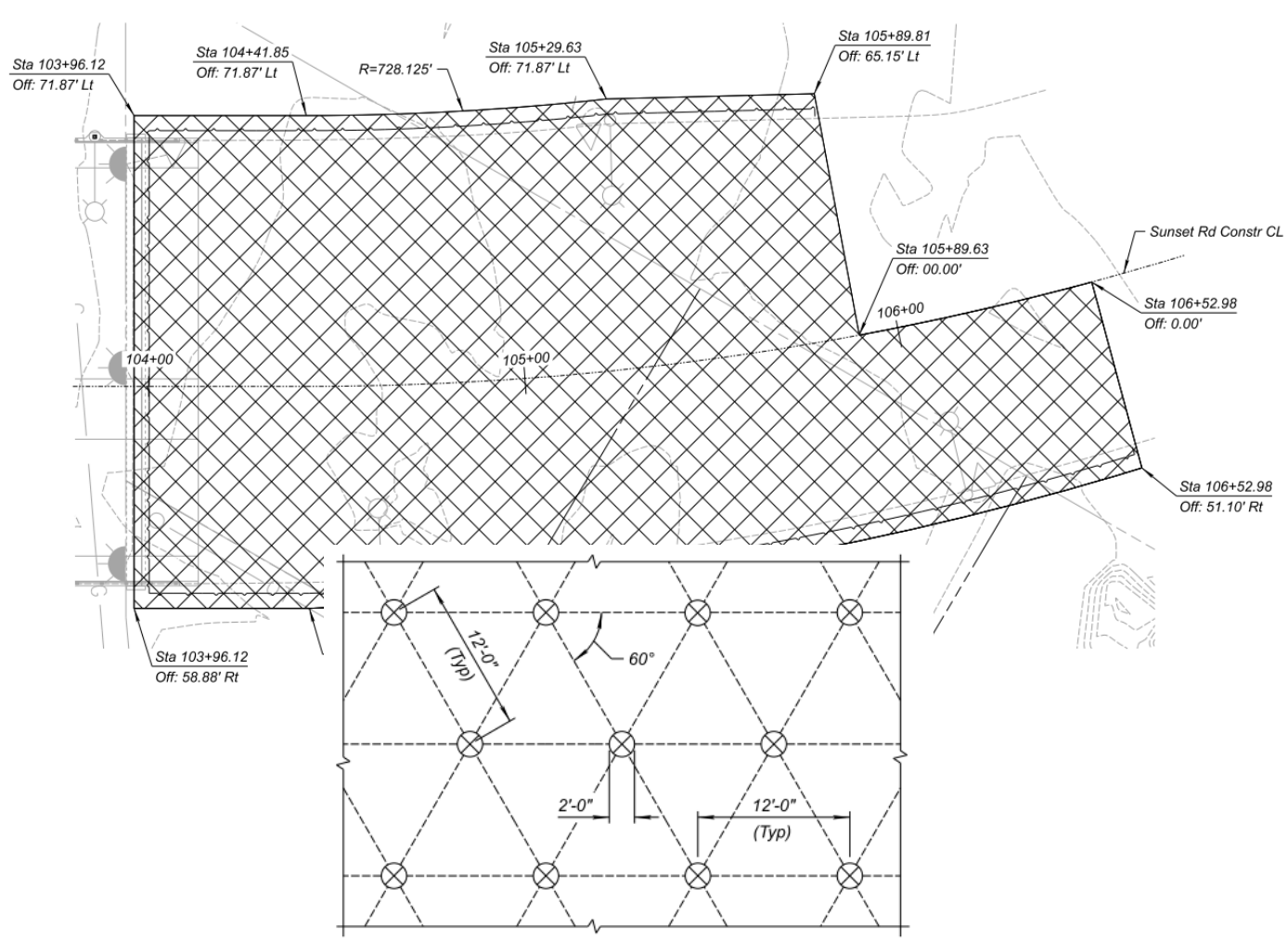
Compaction Grouting

Densify the Soil and Create 2’ Grout Columns

12’ Spacing

Treating to 35’ below grade (into dense gravel layer)

No Published Design Method for Mitigating Hydro-Collapse



COMPACTION GROUT COLUMN SUPPORT SYSTEM
TRIANGULAR ARRANGEMENT

Scale: $^{3}/_{16}$" = 1'-0"

NOTES:

1. Compaction grout column support system shall provided a 2'-0" diameter and 12'-0" spacing that results in an area replacement ratio of 2.5%.

$$\text{Area Replacement Ratio (ARR)} = \frac{\text{Total Area of Grout Columns}}{\text{Total Treatment Area}} \times 100\%$$

Compaction Grouting Construction

Compaction Grouting Construction

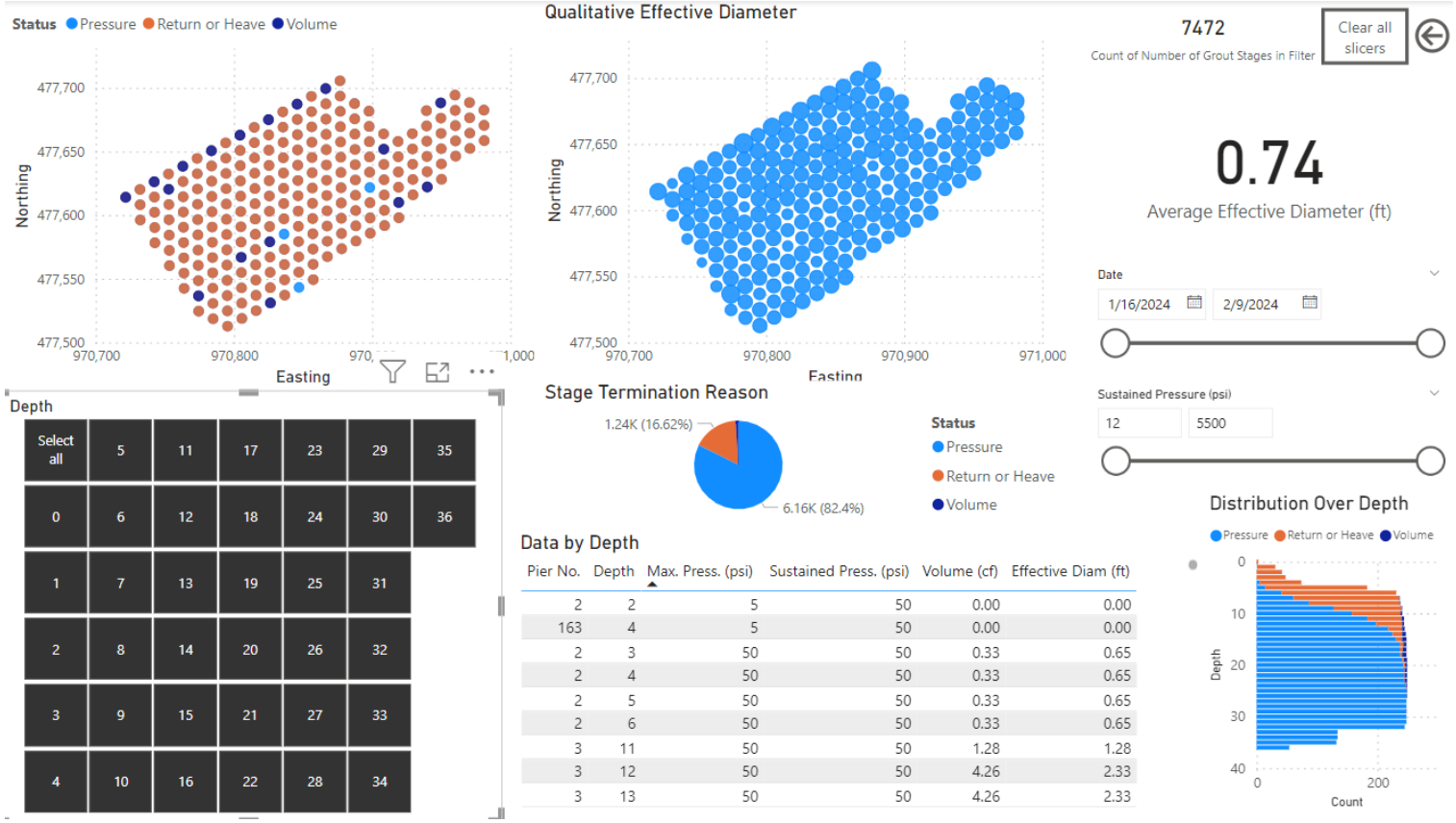
Lessons Learned on the Compaction Grouting

Drilled Displacement Columns Would Have been a Good Fit

Didn't Hit Target of 2' Diameter Columns

Should Had a Higher Volume Cutoff

Insights into Stratigraphy and Variability at Site



Thank you

Randy Post

randy..post@wsp.com