Determination of In-Situ Density of Planned Roadway Cuts in Cemented and Coarse-Grained Soils Using Seismic Geophysical Methods to Estimate Earthwork Factors

By

Daniel Fréchette, PhD, PE

AMEC Environment & Infrastructure, Inc.

ACKNOWLEDGEMENTS

Michael Rucker, PE

AMEC Environment & Infrstructure, Inc.

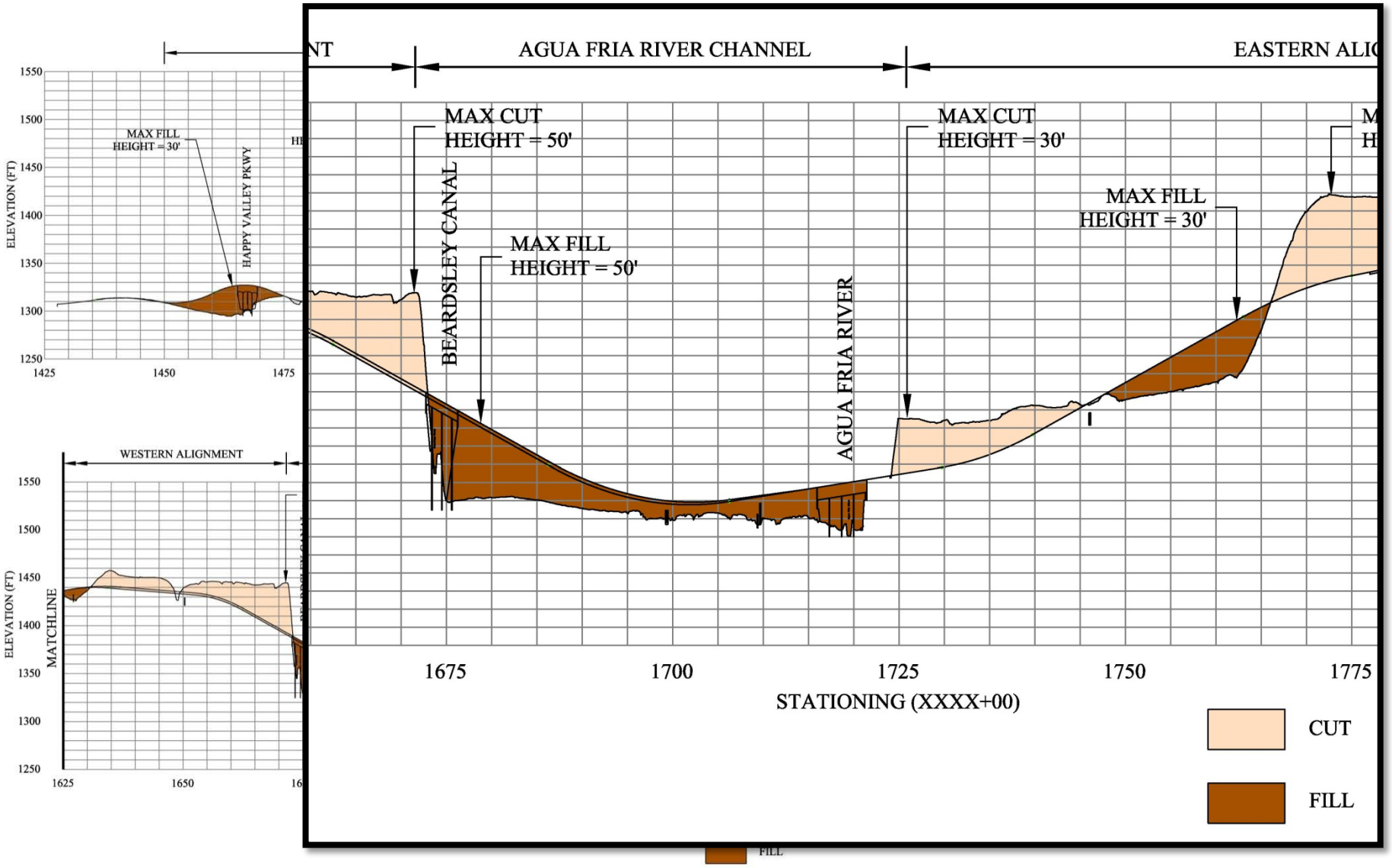
OUTLINE

- Introduction
- Geologic Setting and Geotechnical Profile
- Determination of Earthwork Factors
- Subsurface Investigation
- Determination of In-Situ Density
- Comparison of Various Methods to Measure In-Situ Density
- Determination of Density of Compacted Embankment
- Conclusion

INTRODUCTION

- ADOT and MAG design and construct the State Route 303 Loop
- Connects I-10 and I-17 in NW Phoenix
- Happy Valley Pkwy to Lake Pleasant Pkwy
- Seven Miles Long
- Native Undeveloped Desert
- Maximum Cut 50 Feet
- Maximum Fill Embankment 50 Feet
- 4.3 Million Cubic Yards of Excavation
- 2.6 Million Cubic Yards of Embankment

ROADWAY PROFILE

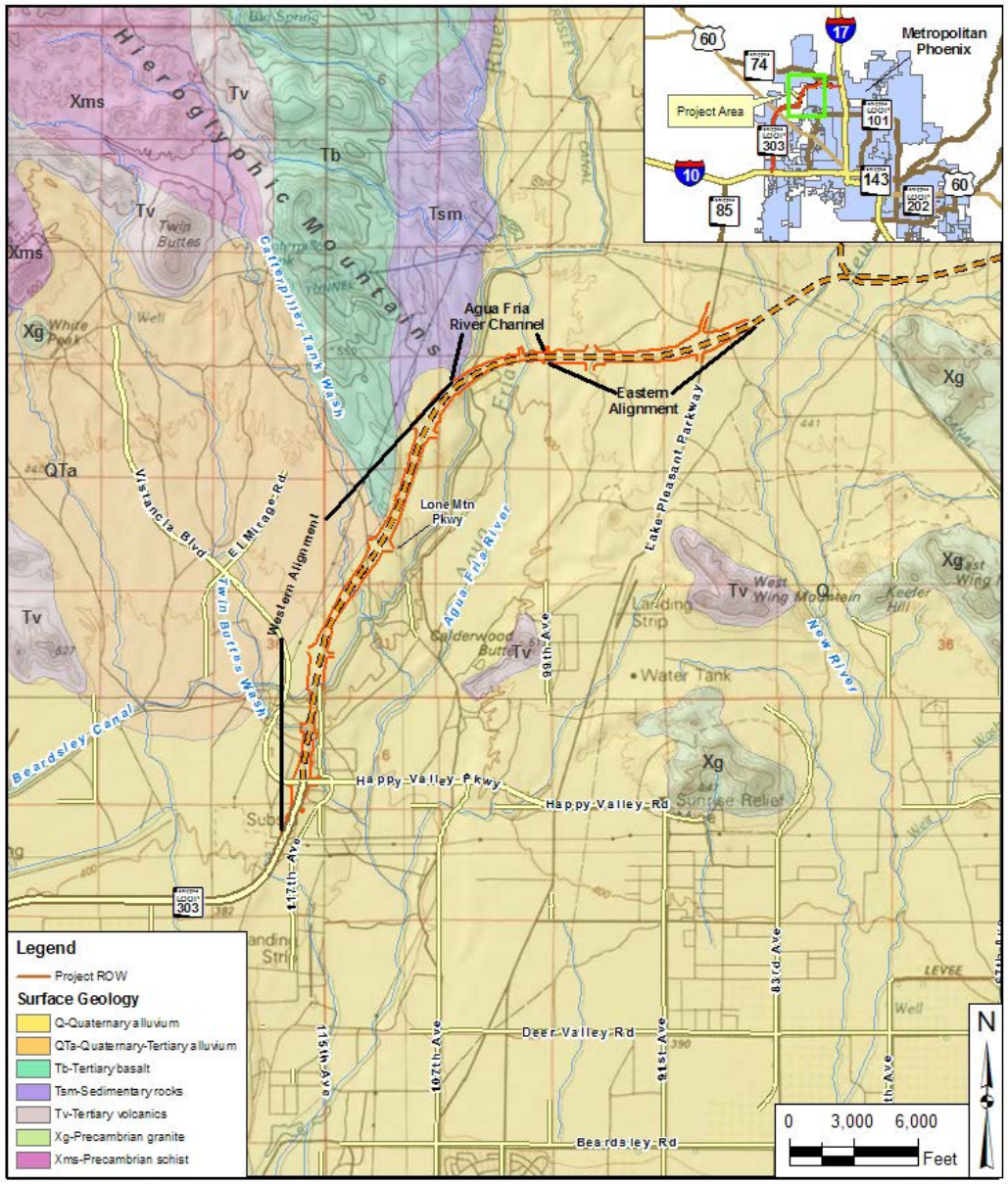


EXISTING GROUND – Western Alignment

EXISTING GROUND – Eastern Alignment

GEOLOGIC SETTING - REGIONAL

- Regional Setting
  - Basin and Range
  - Hieroglyphic Mtns.
  - Quarternary Alluvium
- Local Setting
  - Western Alignment
  - Agua Fria River Channel
  - Eastern Alignment



GEOTECHNICAL PROFILE

- Stratum A – SC and SM with fines content > 30%
- Stratum B – Sand and Gravel with silt and clay
  - Fines content < 12%
- Stratum C – Sand and Gravel in fine-grained matrix with cementation. Weak rock at depth similar to conglomerate.

Depth of Soil Strata for Local Geologic Units			
	Depth of Soil Strata (feet)		
Stratum	Western Alignment	Agua Fria River Channel	Eastern Alignment
A	0 – 3 to 10	0 – 25 (when present)	0 – 3 to 8 feet
B	> 3 to 10	< 85 to 100	> 3 to 8 feet
C	---	> 85 to 100	---

GEOTECHNICAL PROFILE – Stratum A

- Clayey Sand and Silty Sand with Fines Content > 30%
- Variable Mod. to Strong Cementation

GEOTECHNICAL PROFILE – Stratum B

- Sand and Gravel with Silt and Clay
  - Fines content < 12%
- Considerable Cobbles
- Occasional Boulders

GEOTECHNICAL PROFILE – Stratum C

- Sand and Gravel in Fine-Grained Matrix with Varying Degree of Cementation
- Weak rock (Conglomerate) at depth

DETERMINATION OF EARTHWORK FACTORS

- What Information Do We Need?
- How Do We Calculate Earthwork Factors?
- % Shrink =$[1-\gamma_{ex}/\gamma_{emb}] \times 100$
- where:
- γ_{ex} = In-Situ Dry Density of Material to be Excavated
- γ_{emb} = Dry Density of Compacted Embankment Material

DETERMINATION OF EARTHWORK FACTORS

- What Information Do We Need?
- How Do We Calculate Earthwork Factors?
- % Shrink =$[1-\gamma_{ex}/\gamma_{emb}] \times 100$
- where:
- γ_{ex} = In-Situ Dry Density of Material to be Excavated
- γ_{emb} = Dry Density of Compacted Embankment Material

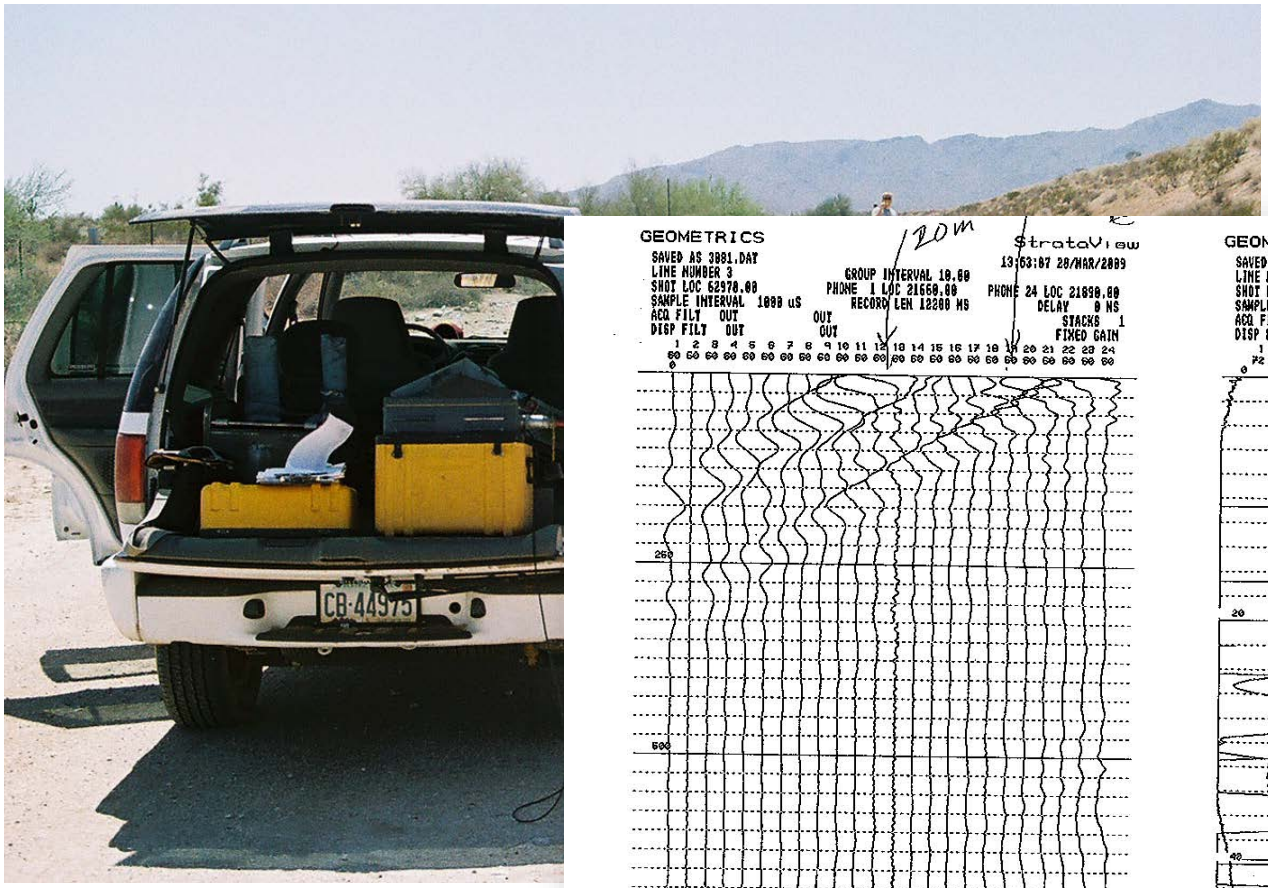
SUBSURFACE INVESTIGATION

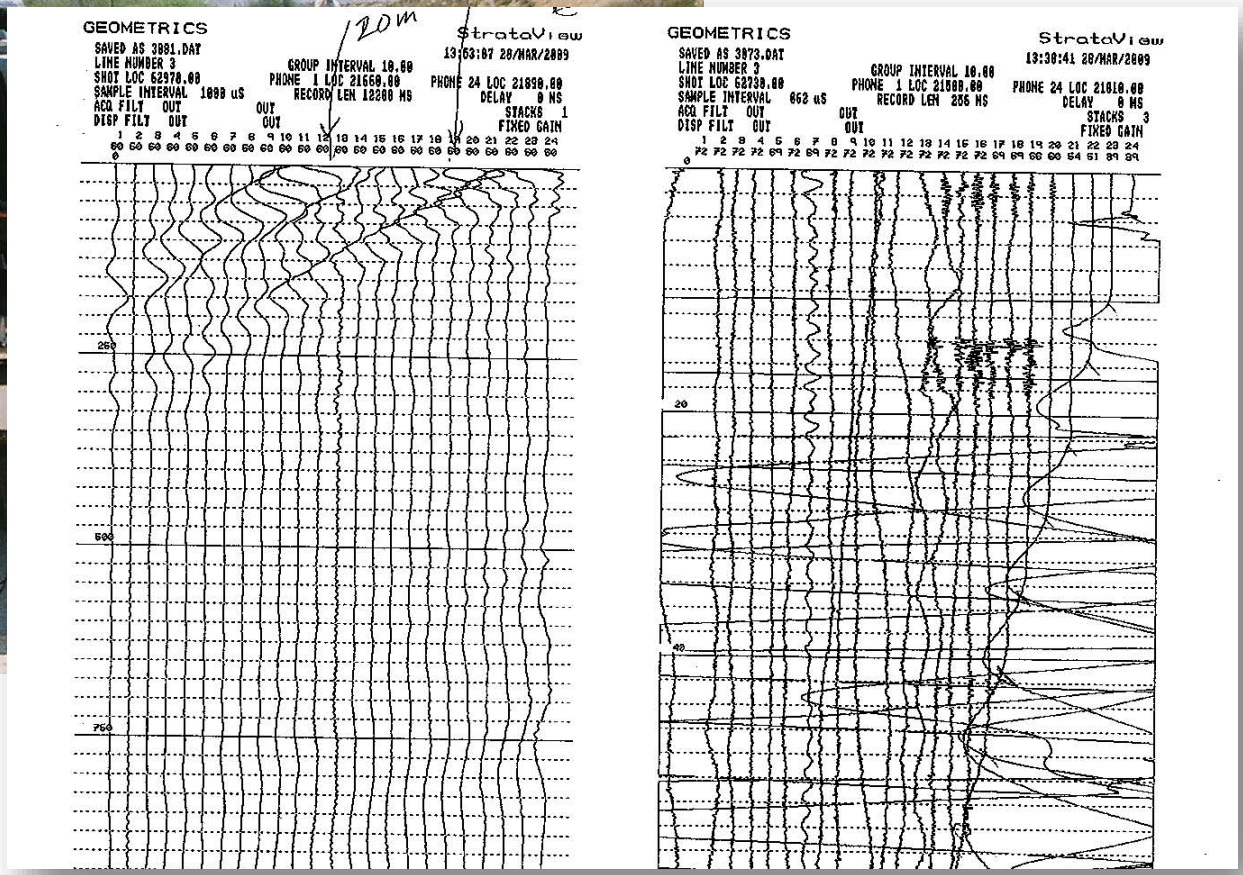
- How Do We Sample the Site Soils?
- Typical Subsurface Investigation
  - Drilling with Auger Rig
  - Drilling with Tubex (Hammer) Rig
  - Conventional Test Pits
- Supplemental Investigative Methods
  - Drilling – Soil Cores
  - Large Test Pits
  - Surface Seismic Investigations

SUBSURFACE INVESTIGATION – Soil Cores

SUBSURFACE INVESTIGATION – Large Test Pits

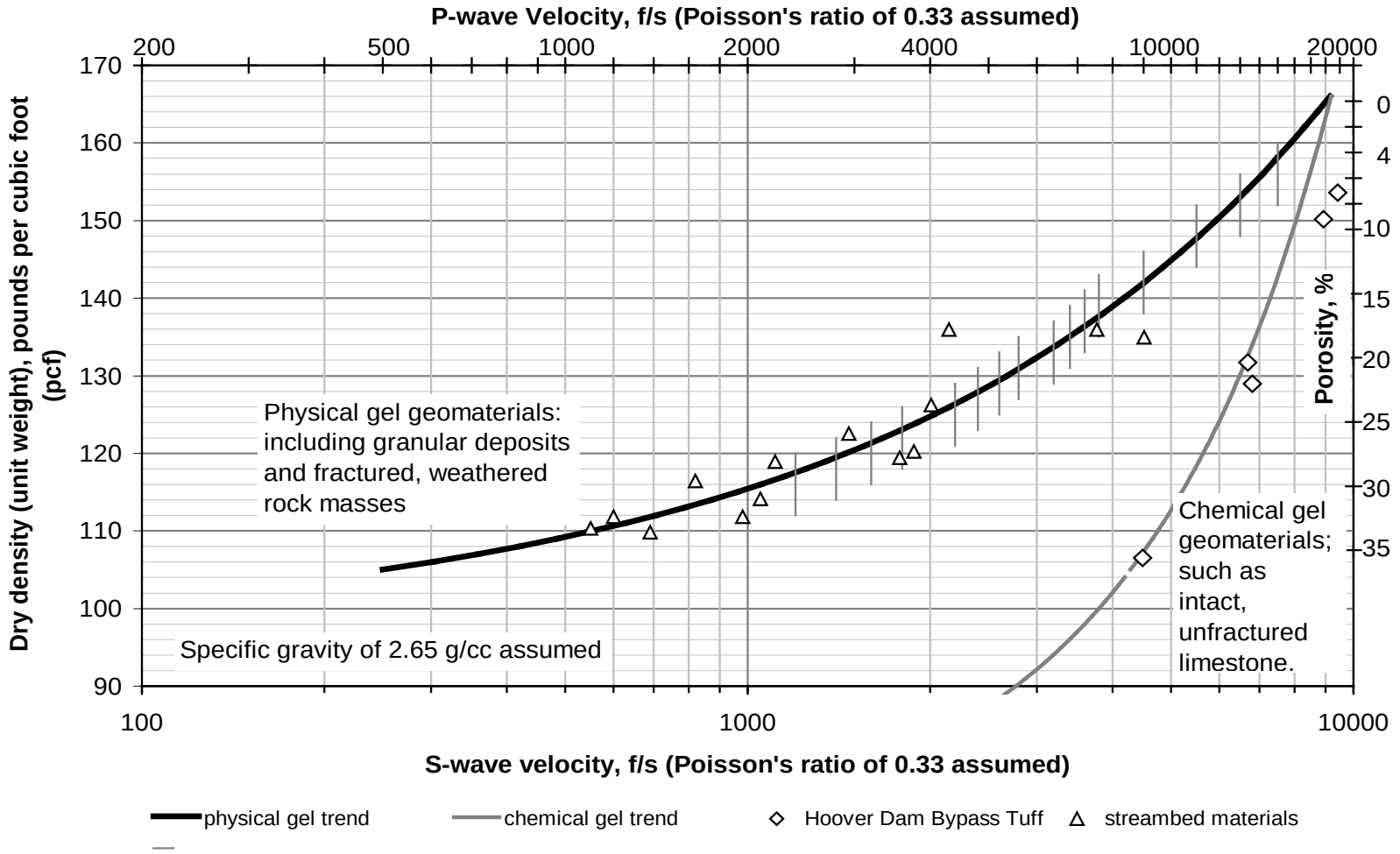
SUBSURFACE INVESTIGATION –
Surface Seismic Investigations





SUBSURFACE INVESTIGATION – Surface Seismic Investigations

Relationship between Seismic Velocity and Dry Density



DETERMINATION OF IN-SITU DENSITY

- Soil Cores
  - Laboratory Density of Intact Cores
    - Fine-Grained Cohesive
    - Cemented
- Large Test Pits
  - In-Situ Density of Soils
    - Sand Cone Method
    - Nuclear Method
- Surface Seismic Investigations
  - Measure Velocity of Compression (p-wave) and Shear Waves (s-wave)
  - Correlate Velocities with Unit Weight

COMPARISON OF SAND CONE, NUCLEAR AND SEISMIC GEOPHYSICAL METHODS

In-Situ Dry Density Versus Depth for Various Test Procedures					
			Dry Density (pcf[2])		
Depth	**USCS Soil Classification[1]**	**Degree of Cementation**	**Sand Cone Method**	**Nuclear Method**	**Seismic Methods**
0	GM/SM	Uncemented	104.2	103.5	108.9
2.5	GP-GM	Uncemented	93.0	96.4	108.9
5	GP-GM	Moderately to Strongly	---	101.1	128.0
7.5	GP-GM	Moderately to Strongly	81.5	127.5	128.0
10	GP	Weakly to Moderately	102.4	111.1	128.0
12.5	GP	Uncemented	102.3	116.1	117.8
15	GP	Uncemented	111.8	112.2	117.8
17.5	GP	Uncemented	---	113.8	117.8

- Notes: [1]Unified Soil Classification System classification
- [2]pounds per cubic foot

COMPARISON OF SOIL CORES AND SEISMIC GEOPHYSICAL METHODS

Comparison of In-Situ Dry Density for Soil Cores and Seismic Geophysical Methods as a Function of Soil Classification			
USCS Soil Classification[1]	**Average Dry Density (pcf[2])**		**Difference in Average Dry Density (pcf)**
	Soil Cores	**Seismic Methods**	
GC	117.0	109.5	7.4
GM	116.2	113.0	3.2
GP	134.8	125.7	9.1
GP/SP	130.2	124.0	6.2
GP-GC	139.8	117.5	22.3
GP-GM/SP-SM	122.6	120.7	1.9
ML/SM	107.2	102.8	4.4
SM/SP-SM	102.2	103.8	-1.6
		Average Difference[3]	**4.4**

- Notes: [1]Unified Soil Classification System classification
- [2]pounds per cubic foot
- [3]Average difference without GP-GC soil due to the large variance

DETERMINATION OF EARTHWORK FACTORS

- What Information Do We Need?
- How Do We Calculate Earthwork Factors?
- % Shrink =$[1-\gamma_{ex}/\gamma_{emb}] \times 100$
- where:
- γ_{ex} = In-Situ Dry Density of Material to be Excavated
- γ_{emb} = Dry Density of Compacted Embankment Material

DETERMINATION OF DENSITY OF COMPACTED EMBANKMENT

- Obtained Maximum Dry Density Using Standard Proctor Laboratory Test
  - Used Soil Samples from Soil Cores and Test Pit
- Seismic Refraction of Existing Roadway Embankment
  - No Existing Roadway Embankments Within the Project Vicinity

EARTHWORK FACTORS

- % Shrink =$[1-\gamma_{ex}/\gamma_{emb}] \times 100$

Earthwork Factors with Depth	
Depth (ft)	**Earthwork Factor (%)**
0 to 3 – 5	4 to 8 Shrink
3 – 5 to 20	4 to 10 Swell
Below 20	0 to 4 Swell

- The project has been completed and there were no disagreements on earthwork quantities.

CONCLUSION

- In-Situ Densities from Seismic Geophysical Methods:
  - Compared Favorably to Soil Cores in Cemented and Coarse-Grained Soils
  - Compared Favorably to Sand Cone and Nuclear Methods in Fine-Grained and Uncemented Soils
- Seismic Geophysical Methods Should be Considered as an Additional Tool to Obtain In-Situ Densities in Cemented and Coarse-Grained Soils for the Development of Earthwork Factors

CONSTRUCTION PHOTOS

CONSTRUCTION PHOTOS

CONSTRUCTION PHOTOS

CONSTRUCTION PHOTOS