ADVANCED DESIGN AND CONSTRUCTION OF SECANT PILE PROJECTS

June 22, 2011

ADSC
The International Association of Foundation Drilling

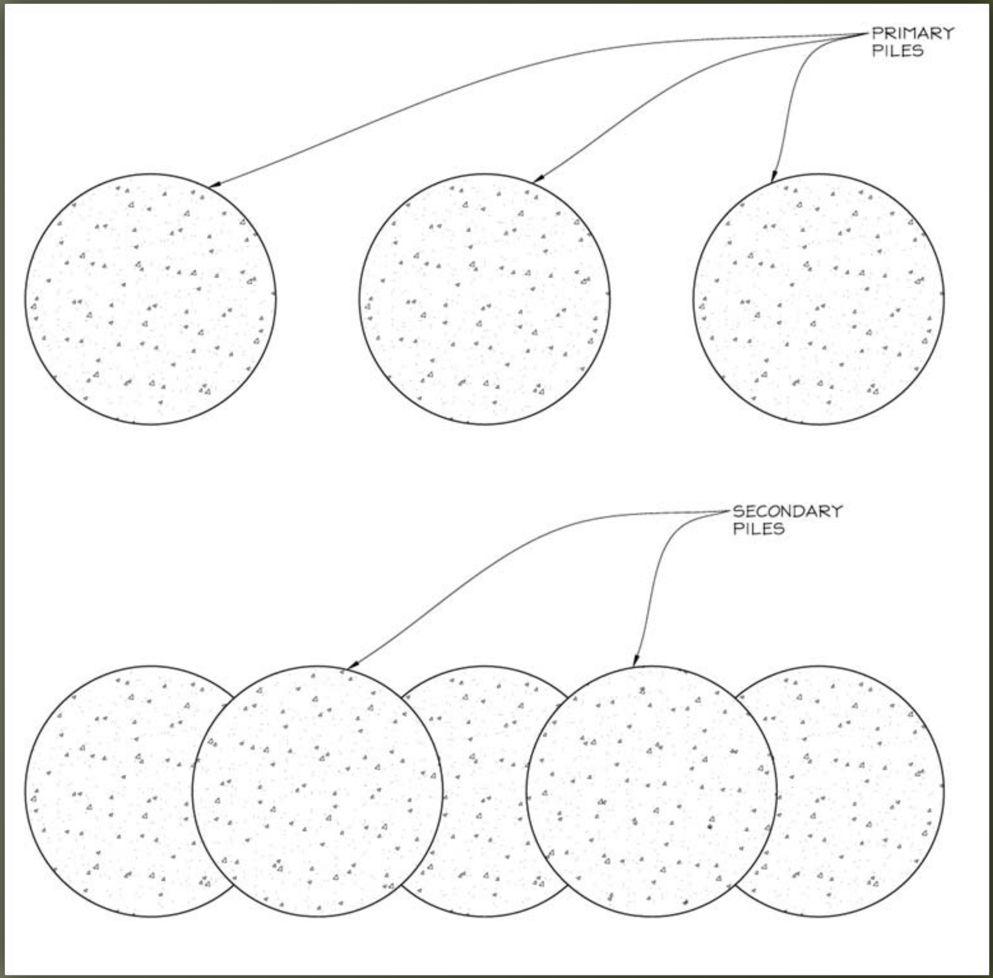
BLCE
BERTI-LINDQUIST CONSULTING ENGINEERS, INC.
a Division of Brierley Associates, Inc.

SECANT PILES

- Secant pile walls are formed by constructing a series of overlapping concrete-filled drill holes to form a continuous, relatively watertight wall.

CONSTRUCTION PROCESS

- Alternate primary ("female") and secondary ("male") piles.
- Primary piles are installed first followed by the secondary piles. Secondary piles are "cut in" to the primary piles.
- Piles can be filled with either structural or lean concrete.



CONSTRUCTION PROCESS

o Drilling Methods

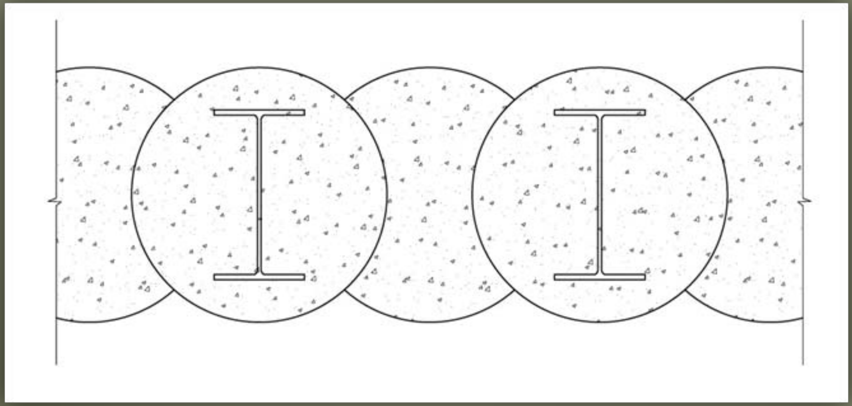
- Augercast (CFA): High productivity at relatively low cost.
- Suitable for installation depths of around 45 feet in soil and soft rock.
- Pile diameters: 24” to 36”.
- 500 to 1000 lineal feet per shift.
- Double rotary (cased) CFA drilling can increase viable depth to around 60 feet.

CONSTRUCTION PROCESS

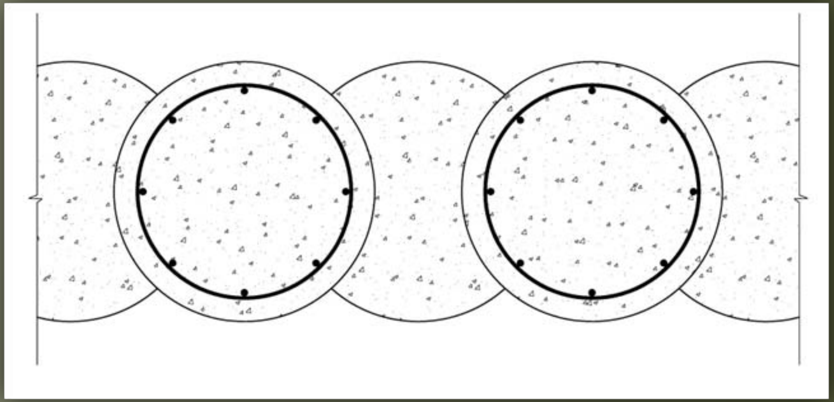
- Drilling Methods
  - Kelly drilling: Allows a range of soil and rock tooling to be utilized within a cased hole as the hole is advanced.
  - Sectional heavy wall drill casing, advanced concurrently with the drill tool maintains hole stability and stiffens the drill string.
  - Top drive rotary crawler drills ideally suited for secant pile drilling.
  - Pile diameters: 24”-48”.
  - Oscillator attachment can be used to assist casing advance and extraction.

REINFORCING OPTIONS

- Typically secondary piles are reinforced. Much less common to reinforce both the primary and secondary piles.



Wide Flange Insert



Rebar Cage

SECANT PILE APPLICABILITY

- Groundwater cut-off
- Minimize ground Loss
- Applicable for almost all geotechnical conditions, including:
  - Loose, cohesionless soil below the groundwater table
  - Soils with cobbles and boulders
  - Rock, including penetration into hard rock when required

COMPARISON WITH OTHER RELATIVELY WATERTIGHT SHORING WALL TYPES

- Sheet Piles:
  - Secant piles can be used for a broader range of geotechnical conditions since sheet piles cannot be readily driven into very dense soils, soils with significant amounts of cobbles or boulders, or bedrock.
  - Secant pile installation generally slower than sheet piles.
  - Secant pile installation generally vibration-free in comparison to sheet piles driven with a vibratory hammer.
  - Sheet piles generally less expensive especially when sheets can be extracted and re-used.

COMPARISON WITH OTHER RELATIVELY WATERTIGHT SHORING WALL TYPES

o Deep Soil Mixing (DSM):

- Secant piles can be used in a broader range of geotechnical conditions since DSM can be difficult to install through cobbles/boulders or into hard rock.
- Secant pile installation generally slower than DSM.
- Secant piles and DSM are both relatively vibration-free.
- DSM typically less expensive than secant piles.

DESIGN CONSIDERATIONS

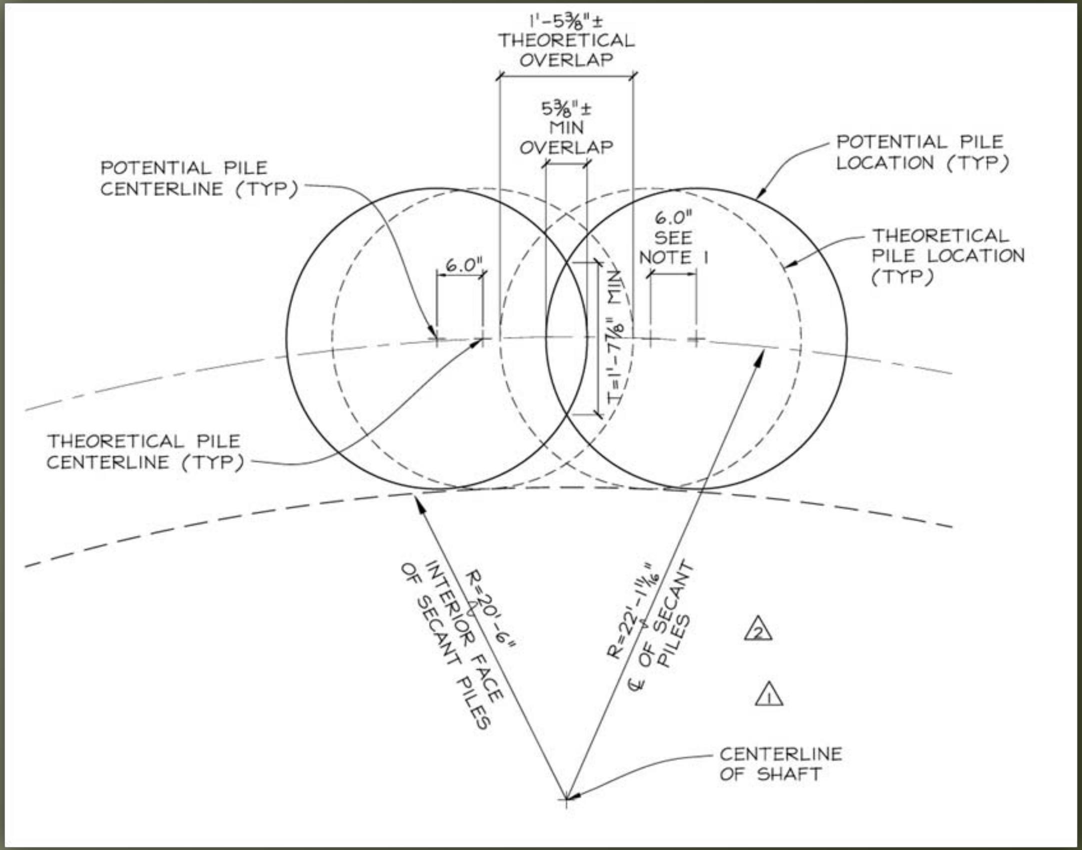
- Designed and analyzed similar to other "continuous" wall systems (e.g. sheet piles, DSM)
- Reinforced piles are typically designed to act as beams spanning in the vertical direction.
- Concrete between reinforced elements acts as "lagging."
- Cantilever or restrained (e.g. cross-lot bracing or tiebacks) wall systems are feasible.
- When used for deep excavation shoring systems below the groundwater table, typical toe embedment issues must be checked, including the potential for piping in permeable soils and bottom heave in clay.

DESIGN CONSIDERATIONS

- Can also be designed to act as unreinforced concrete ring structures.
- Design should be based upon the minimum effective compression ring thickness that can be developed by the overlapping piles with installation tolerances considered.
- Structurally-efficient.
- Very stiff, system installed prior to excavation that will allow very little ground movement.
- Design can be based on ACI-318 provisions for plain (unreinforced) concrete.

INSTALLATION TOLERANCE

- In order for a secant pile wall to perform as intended overlap must be maintained between the primary and secondary piles.
- Specified pile diameter and spacing (which define the theoretical overlap) must allow for installation tolerance.
- Tolerances to consider:
  - Accuracy or pile placement at the ground surface.
  - Verticality.



INSTALLATION TOLERANCE

- Layout accuracy allows increases cost-efficiency. For example, pile quantity can be reduced by 8% to 10% in a 40-foot diameter shaft if location tolerance is controlled to within +/-1" in plan, compared to an industry standard of +/-3".
- Verticality tolerances of 0.5% (1 in 200) or stricter are typically necessary for secant piling projects, compared with standard requirements of 1% to 1.5% (ACI 336.1) for drilled piers. Pile spacing is maximized for economy, and therefore successful secant piling projects require exceptional attention to drilling procedures, equipment, and quality control to ensure overlap is maintained. Drilling methods and equipment selection are integrally linked in the construction process.

TOLERANCE CONTROL

o Ground surface location

- Survey alone (least accurate)
- Guide trench
- Template

Guide Trench

Template

TOLERANCE CONTROL

0 Controlling verticality

- Verify plumbness of the drill string when starting and during the drilling process.
- Use of stiff drill string.
- Downhole survey techniques.

DOWNHOLE SURVEY TECHNIQUES

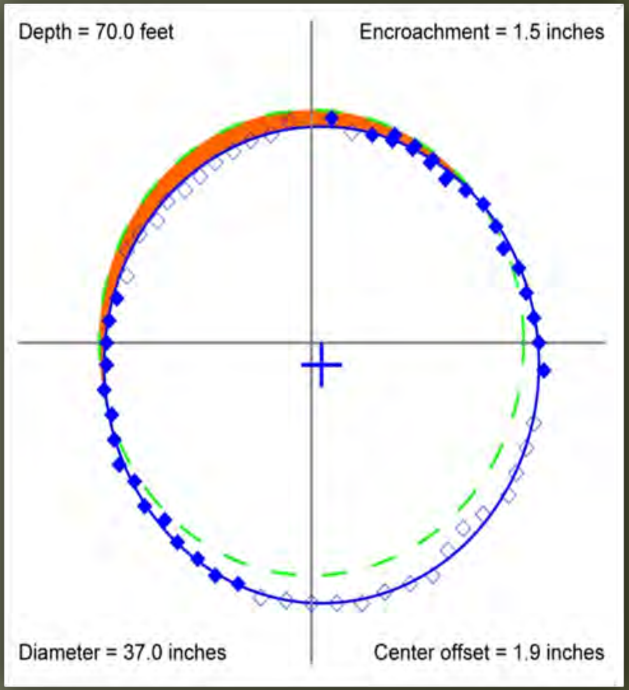
o Sonicaliper® (Loadtest)

- Uses sonar to provide a 360 degree profile of the drillhole at any depth.
- Can make measurements in a dry hole, under water or through bentonite or polymer slurry.
- Readings can be taken in cased or uncased holes.

DOWNHOLE SURVEY TECHNIQUES

- Sonicaliper® (Loadtest)

Sonicaliper® Instrument



Sonicaliper® Reading

DOWNHOLE SURVEY TECHNIQUES

- Inclination Measuring Instrument (Bauer)
  - Can be used to survey cased drillholes.
  - Similar to a large-scale inclinometer probe.

MORMON ISLAND AUXILIARY DAM KEY BLOCK

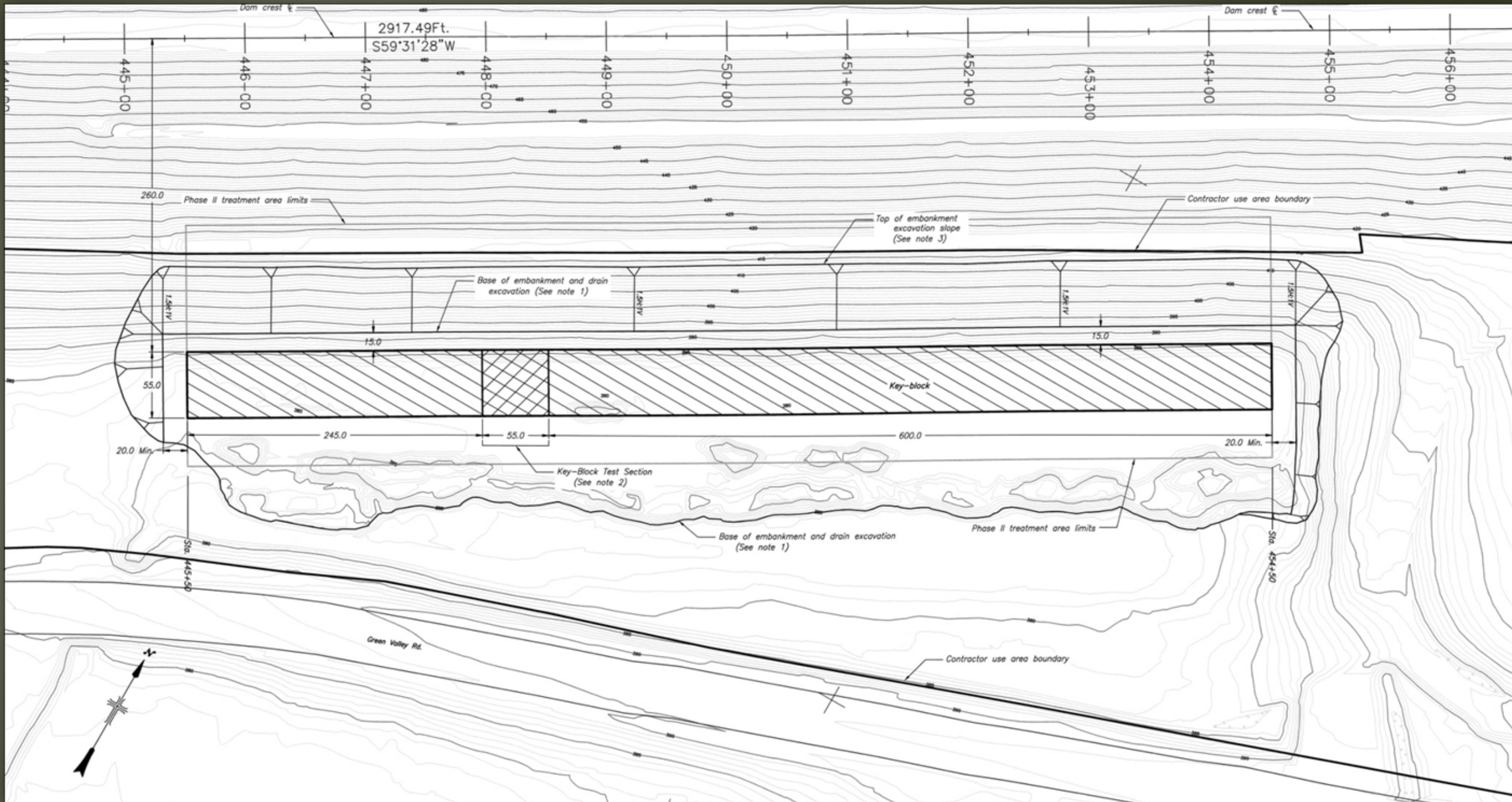
Project Overview

- MIAD is located about 20 miles northeast of Sacramento, California.
- 4800-foot long, 110-foot high earth dam that helps impound the American River to form Folsom Lake.
- United States Bureau of Reclamation (BOR) has determined that some of the downstream soils are susceptible to liquefaction during a large earthquake.
- BOR designed a 900-foot long by 55-foot wide “Key Block” downstream of the toe of the existing dam to mitigate potential problems resulting from liquefaction.
- Key Block excavation to be keyed into moderately weathered bedrock and backfilled with lean concrete and engineered fill.
- Owner: United States Bureau of Reclamation.
- General Contractor: Shimmick Construction.
- Secant Piling Contractor: Malcolm Drilling Company.

MORMON ISLAND AUXILIARY DAM KEY BLOCK

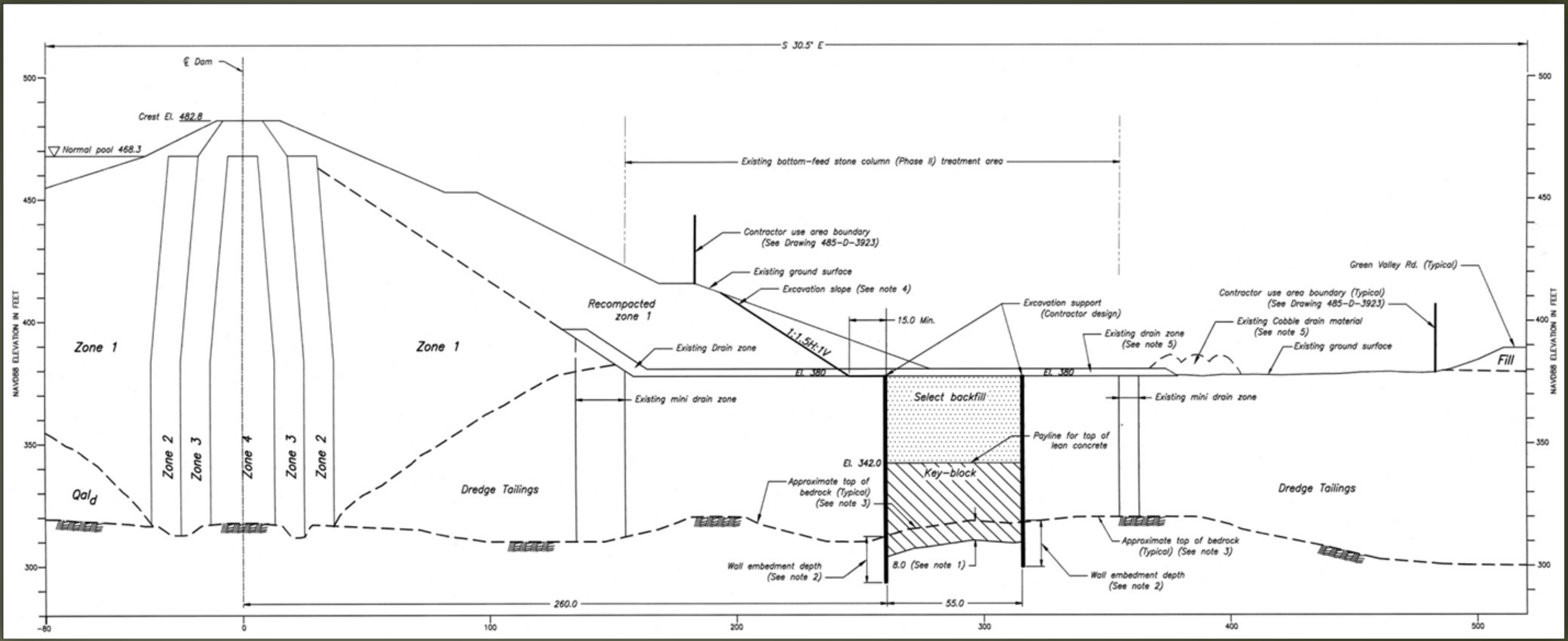
Satellite View

MORMON ISLAND AUXILIARY DAM KEY BLOCK



Contract Drawing - Plan View

MORMON ISLAND AUXILIARY DAM KEY BLOCK



Contract Drawing - Section View

MORMON ISLAND AUXILIARY DAM KEY BLOCK

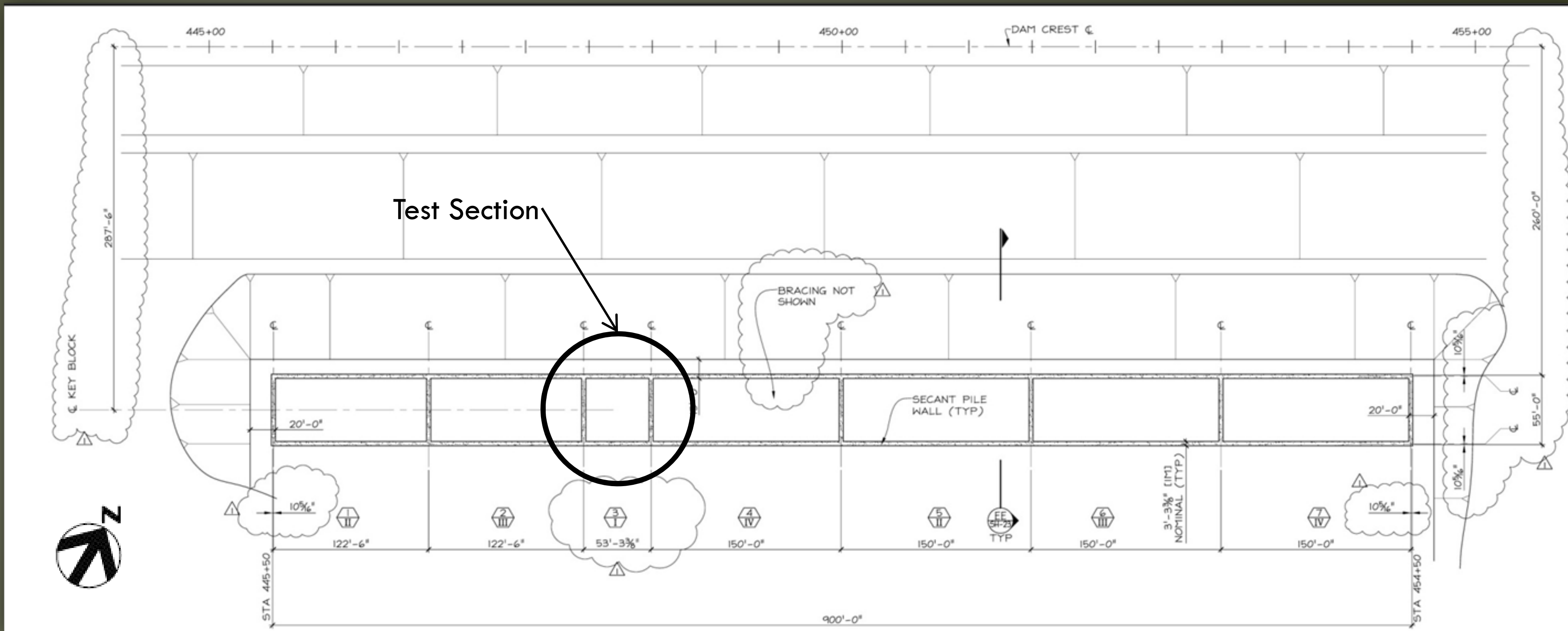
Geotechnical Conditions

- Soil Profile:
  - Dredged alluvium: Poorly graded to silty sand and gravel with cobbles and occasional boulders. (Dredge tailings from old gold mining operations.) Material generally becomes siltier/finer-grained with depth.
  - Colluvium: Sporadic thin deposit of gravelly clay sitting on the bedrock in some borings.
  - Soil mass in the area of the Key Block was previously treated with thousands of stone columns.
  - Bedrock: Amphibolite Schist. Typically intensely fractured with steeply dipping schistosity. Variably weathered. Hard where relatively fresh and very soft to soft where intensely weathered. Anticipated to have very low permeability. Depth to bedrock ranges from about 52 to 72 feet.
- Groundwater:
  - At ground surface.

MORMON ISLAND AUXILIARY DAM KEY BLOCK

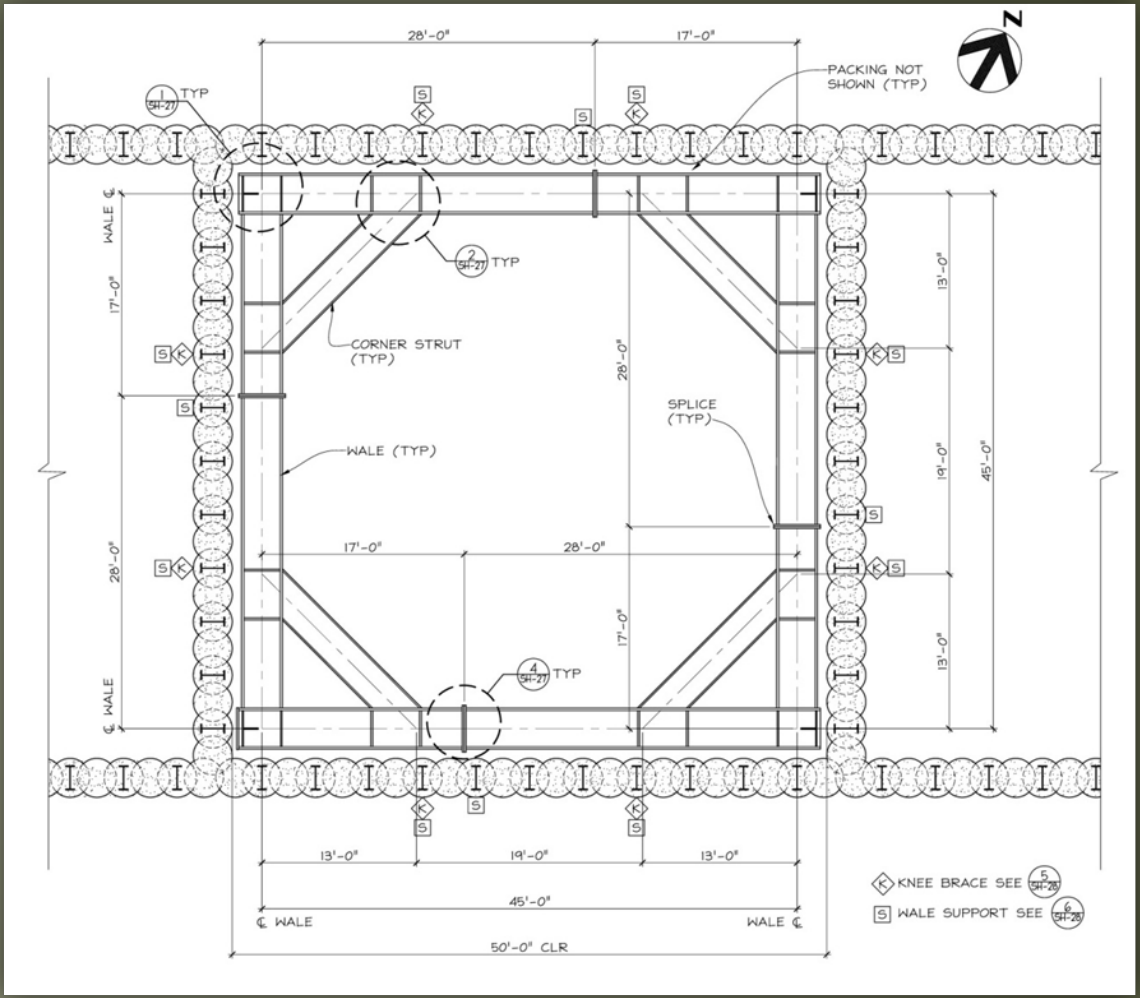
View Looking West

MORMON ISLAND AUXILIARY DAM KEY BLOCK



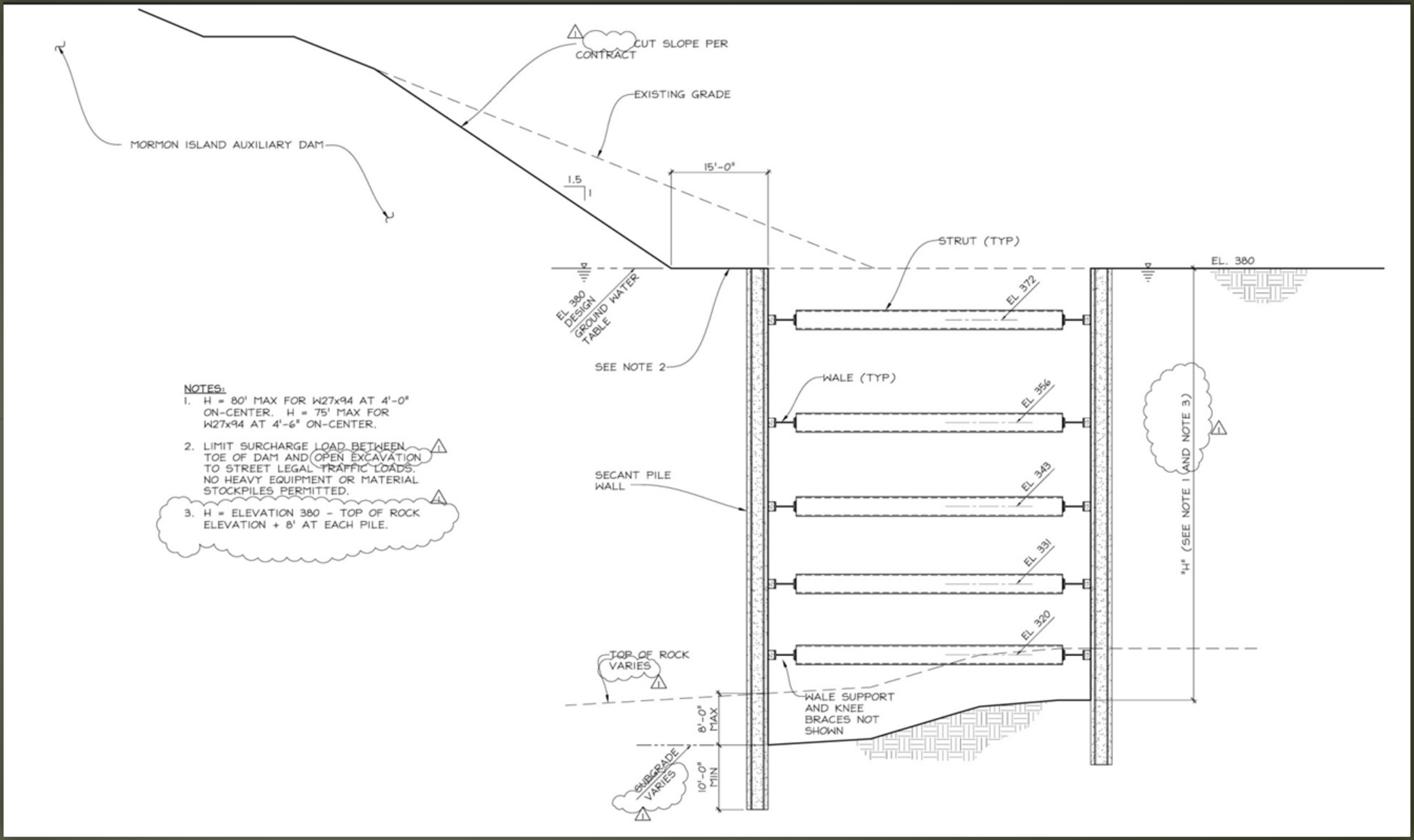
Secant Pile Wall Plan Layout

MORMON ISLAND AUXILIARY DAM KEY BLOCK



Detail Plan at Test Section

MORMON ISLAND AUXILIARY DAM KEY BLOCK



Typical Section

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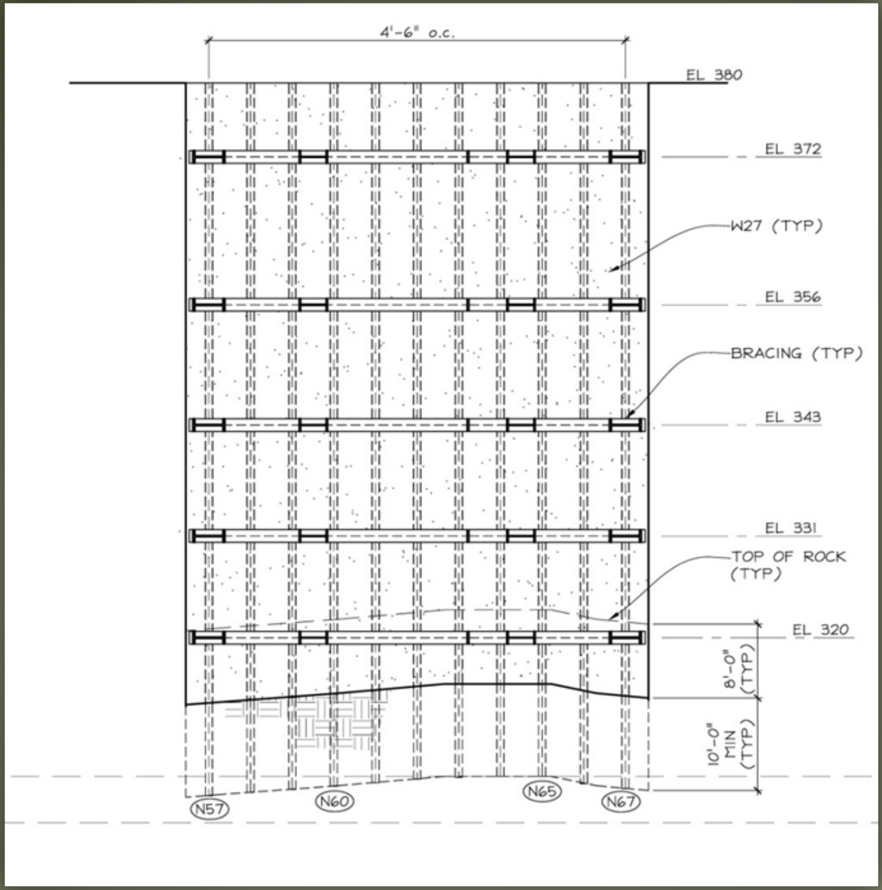
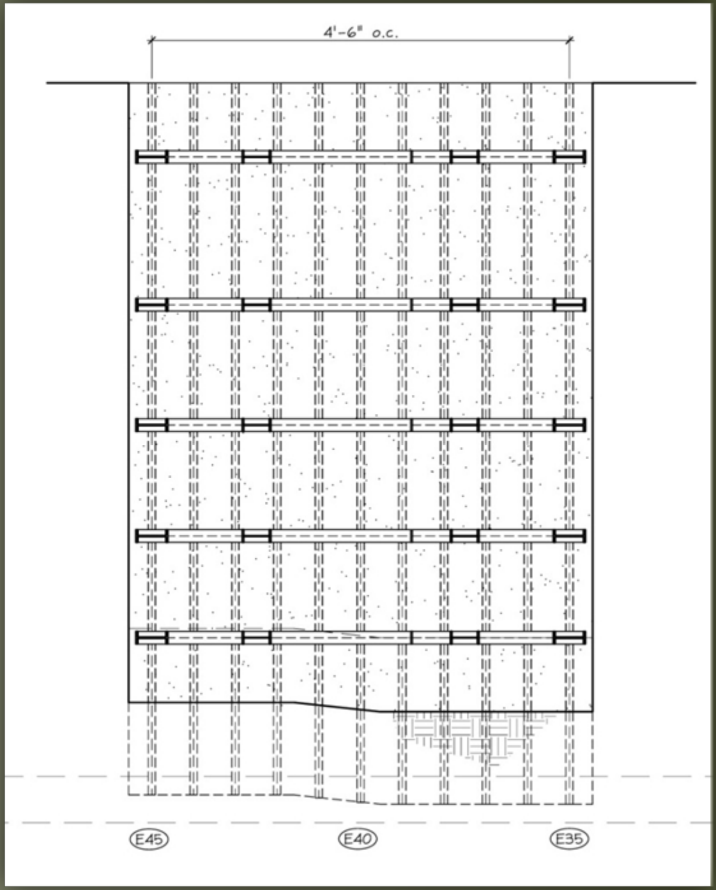


North Wall Elevation



East Wall Elevation

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MORMON ISLAND AUXILIARY DAM KEY BLOCK

Test Section Secant Pile Construction

- Bauer BG40 drill rig used to install piles.
- Holes cased with sectional heavy wall casing. Casing oscillator used to extract casing.
- Sonicaliper® downhole surveys were performed periodically to confirm that verticality tolerance was being achieved.
- Holes tremie-concreted. Wide flange inserts stabbed into concrete-filled hole.
- During excavation, observations of the as-built piles indicated that, for the most part, installation tolerance was excellent. Leakage through secant piles was minimal.

MORMON ISLAND AUXILIARY DAM KEY BLOCK

Drill Rig and Casing Oscillator

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Drilling Template

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View from Top of Test Section Excavation

MORMON ISLAND AUXILIARY DAM KEY BLOCK

Secant Pile Overlap

Muck Box Being Used to Remove Soil

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Bracing Levels 2, 3 and 4

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Knee Braces and Concrete Packing

MORMON ISLAND AUXILIARY DAM KEY BLOCK

Test Section Shoring Performance

- Secant pile wall essentially watertight under up to 60 feet of hydrostatic head.
- Excellent drilling tolerance achieved under difficult drilling conditions.
- Secant pile wall was very stiff. Inclinometers indicated less than about ½” of deflection.
- Pre-fabricated bracing frames and concrete packing proved to be very efficient.

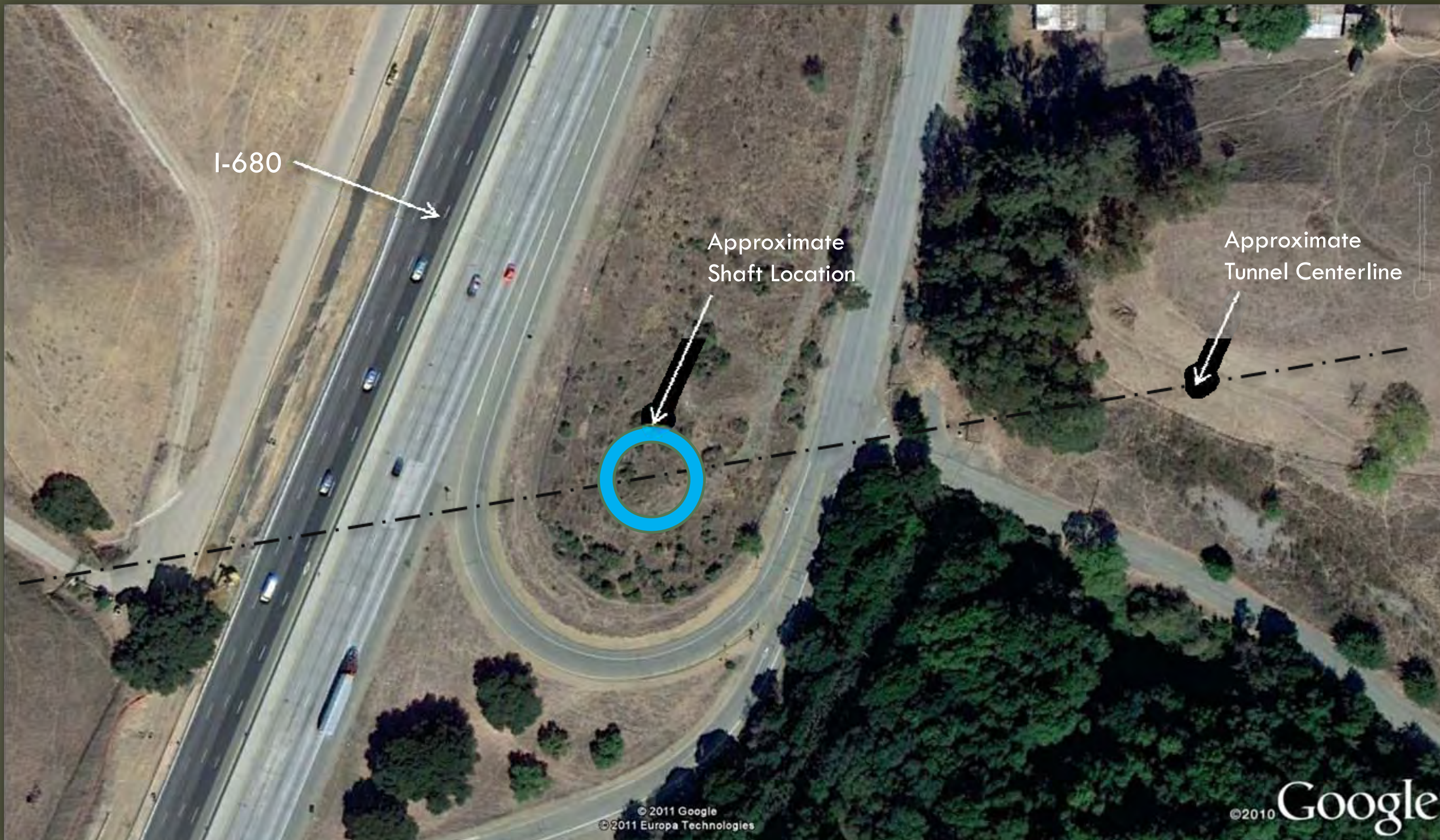
Test Section at Full Depth

NEW IRVINGTON TUNNEL – VARGAS SHAFT

Project Overview

- 3.5 mile long New Irvington Tunnel being constructed to provide a seismically sound alternate to the existing tunnel which connects San Francisco's water sources in the Sierra Nevada and Alameda County to the Bay Area's water supply systems.
- Project includes a 115-foot deep, 41-foot diameter shaft to create access to drive the 13-foot diameter tunnel in two directions.
- Owner: San Francisco Public Utilities Commission.
- General Contractor: Southland Contracting/Tutor-Perini, JV.
- Secant Piling Contractor: Malcolm Drilling Company.

NEW IRVINGTON TUNNEL – VARGAS SHAFT



Satellite View

NEW IRVINGTON TUNNEL – VARGAS SHAFT

View of Shaft Collar Looking South

NEW IRVINGTON TUNNEL – VARGAS SHAFT

Geotechnical Conditions

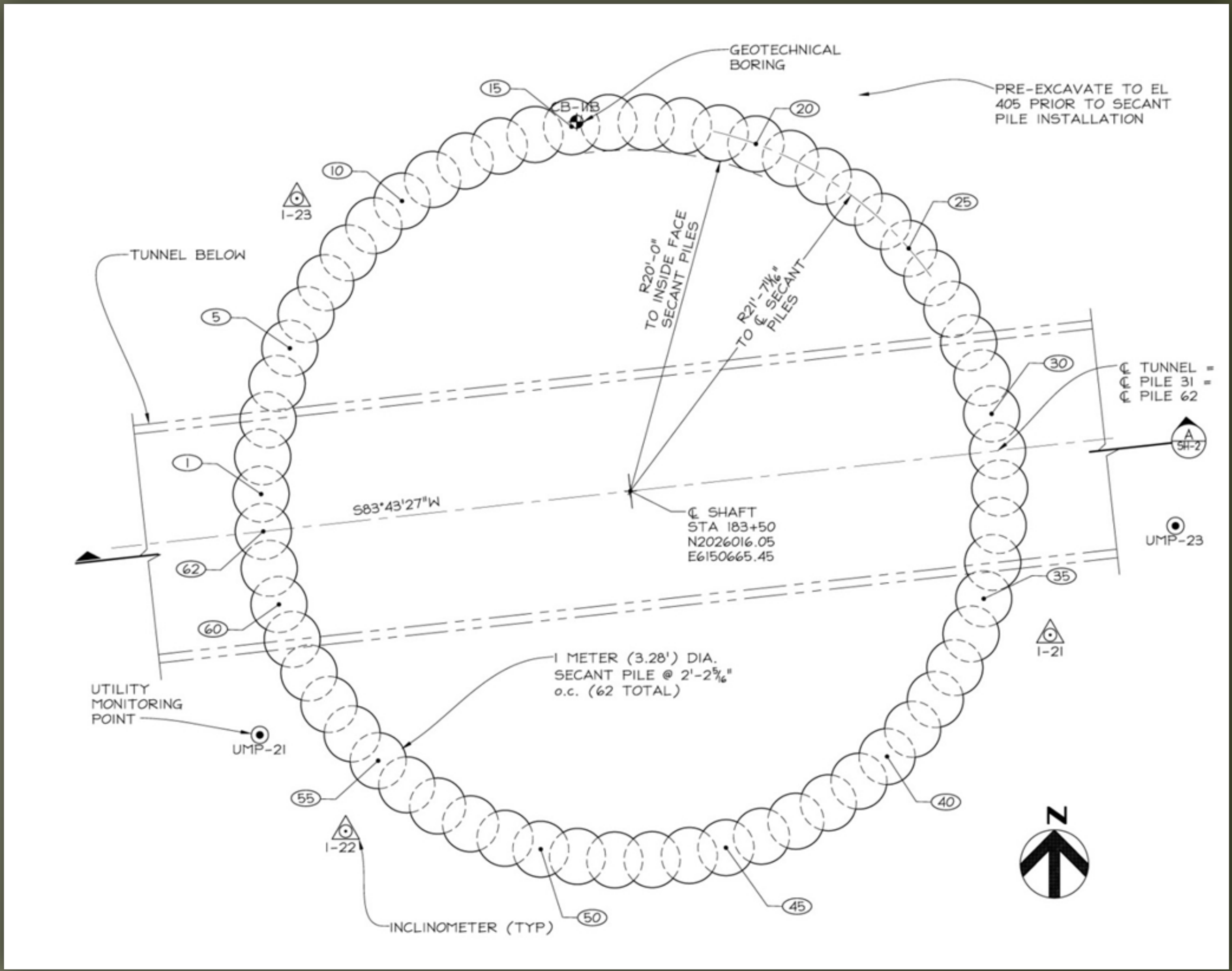
- Soil Profile:
  - Fill: 10 to 20 feet of loose to very dense silty sand with gravel and cobbles.
  - Alluvium: about 20 feet of loose poorly graded sand with gravel and cobbles and medium stiff sandy lean clay.
  - Bedrock: anticipated to be about 5 to 8 feet of very weak siltisone overlying weak to moderately strong, highly to moderately fractured sandstone
  - Some shear zones in rock.
- Groundwater:
  - About 14 feet below ground surface.

NEW IRVINGTON TUNNEL – VARGAS SHAFT

Original Shaft Support Plan

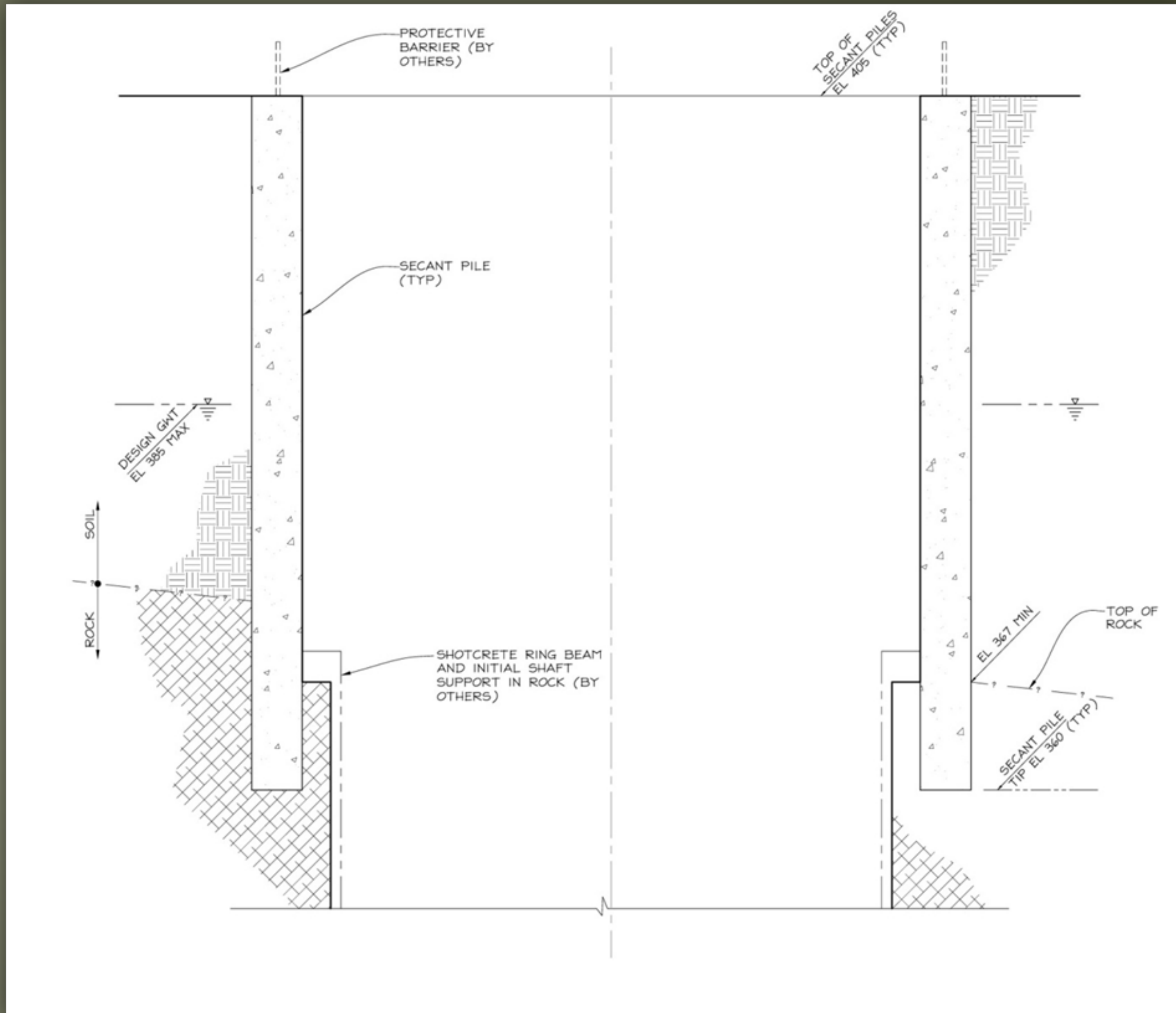
- Secant pile compression ring penetrating a few feet into bedrock.
- Rock dowels and shotcrete installed in a top-down manner in bedrock.

NEW IRVINGTON TUNNEL – VARGAS SHAFT



Secant Pile Plan Layout - Original

NEW IRVINGTON TUNNEL – VARGAS SHAFT



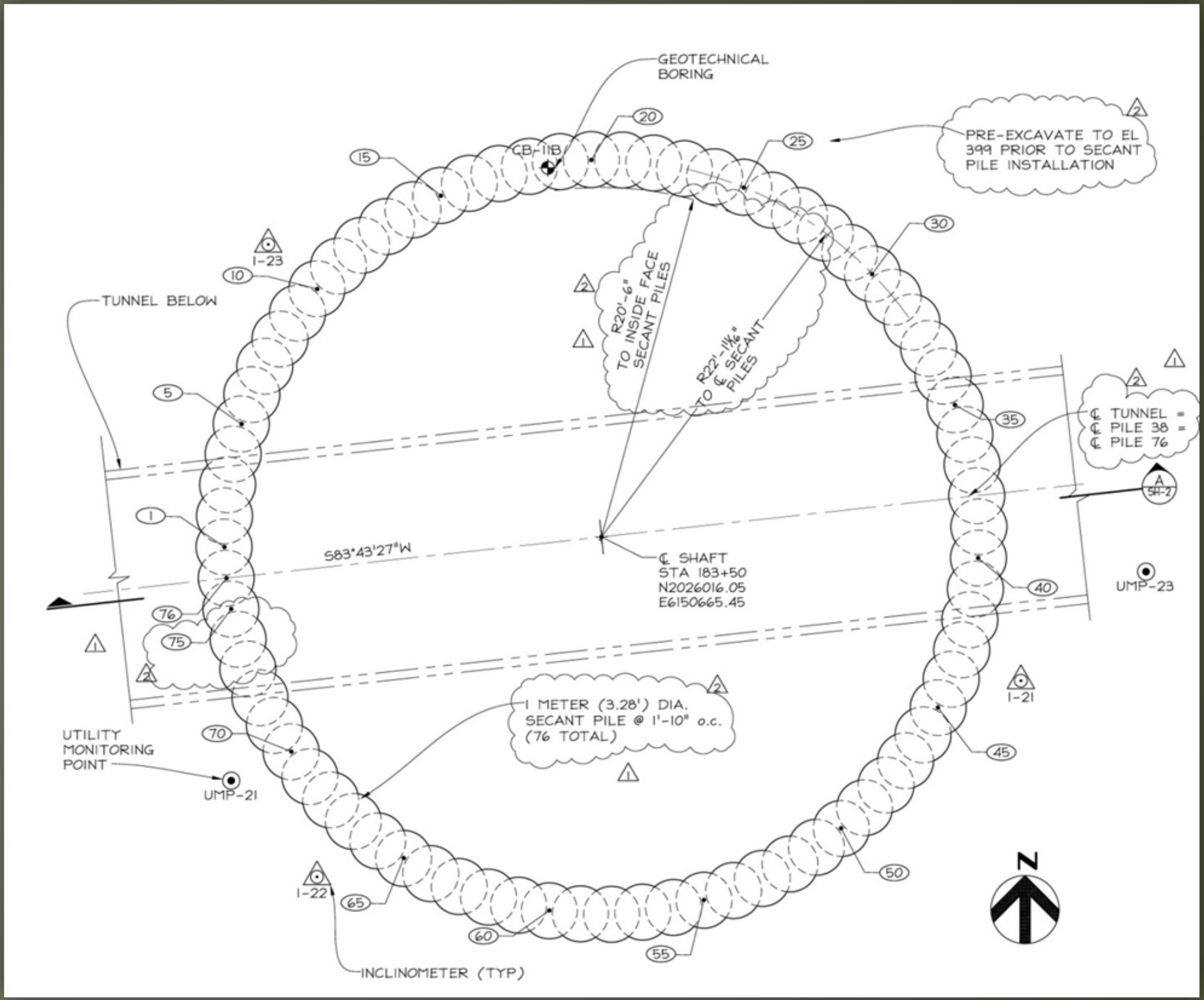
Shaft Section - Original

NEW IRVINGTON TUNNEL – VARGAS SHAFT

Revised Shaft Support Plan

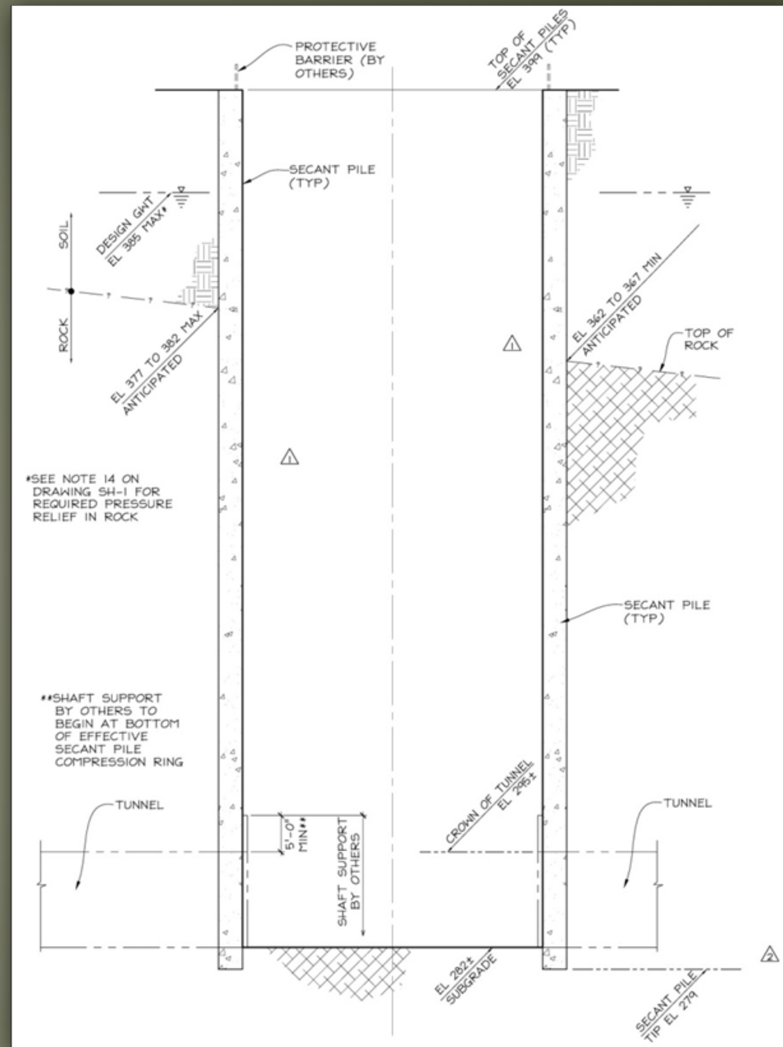
- During initial secant pile drilling it became evident that the top-down rock dowel and shotcrete support would be very challenging to install due to the quality of the bedrock being encountered to a depth of about 95 feet.
- Shaft support design was revised to extend the secant pile compression ring down to competent bedrock.
- Unprecedented depth of a secant pile compression ring.
- Concrete f'c = 3000 psi.
- Specified tolerances to maintain 5 inches of overlap between adjacent piles at a depth of 80 feet (in order to develop a 1.5-foot minimum thick effective compression ring).
  - Pile within 1 inch of theoretical location at ground surface. (Guide trench provided.)
  - 0.5% verticality tolerance.

NEW IRVINGTON TUNNEL – VARGAS SHAFT



Secant Pile Plan Layout - Revised

NEW IRVINGTON TUNNEL – VARGAS SHAFT



Shaft Section - Revised

NEW IRVINGTON TUNNEL – VARGAS SHAFT

Shaft Construction

- Bauer BG40 drill rig used to install piles.
- Holes cased with sectional heavy wall casing to a depth of approximately 100 feet. Uncased hole in hard rock below 100 feet.
- Sonicaliper® downhole surveys were performed on every hole at depths of 60 and 90 feet. Surveys generally indicated that the verticality tolerance was well within the 0.5% limit.
- Holes tremie-concreted. As-placed concrete volume about 25% more than theoretical hole volume.
- During excavation, observations of the as-built piles indicated that, for the most part, installation tolerance was excellent.
- Weep holes provided through secant pile wall to relieve groundwater pressure in rock.
- Shaft successfully supported to a depth of 100 feet without any supplemental support.

NEW IRVINGTON TUNNEL – VARGAS SHAFT

Shaft Excavated to 90 feet

NEW IRVINGTON TUNNEL – VARGAS SHAFT

Shaft at Full Depth

CONCLUSIONS

- Drilling equipment and methods are now capable of achieving tolerances that allow secant piles to be used in geotechnical conditions and to depths previously considered to be infeasible.
- Modern drill rigs and tooling allow cost-effective installation of secant piling excavation support systems suitable for depths up to 100 feet.
- Downhole survey techniques allow confirmation that critical drilling tolerances are met.

ACKNOWLEDGMENTS

MIAD Key Block

- Shimmick Construction
  Trace Porter, Project Manager
- Malcolm Drilling Company
  Rob Jameson, Project Manager
- United States Bureau of Reclamation

Vargas Shaft

- Malcolm Drilling Company
  Rob Jameson and Eleazar Sotelo, Project Managers
- Southland/Tutor-Perini, JV
  Michael Cash, Project Manager
- San Francisco Public Utilities Commission and their consultants

QUESTIONS AND COMMENTS