GEOTECHNICAL STUDY FOR FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA) PARTIAL CERTIFICATION PAL ID NO. 33 SALT RIVER LEVEE TEMPE, ARIZONA

Prepared for:

Flood Control District of Maricopa County
2801 West Durango Street
Phoenix, Arizona 85009

Prepared by:

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Expires 12/31/2011

June 2011

AMEC Project No. 17-2011-4021

FCD Contract 2006C020, Assignment 8

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June 17, 2011
AMEC Project No. 17-2011-4021

Flood Control District of Maricopa County
Structures Management Branch
2801 West Durango Street
Phoenix, Arizona 85009

Re: Partial Certification of Levee System
Embankment Stability, Seepage and Settlement
Salt River Levee, PAL ID No. 33
Tempe, Arizona
AMEC Project Number 17-2010-4021

AMEC Earth and Environmental, Inc. (AMEC) has completed the authorized levee study. The focus of this study was to determine compliance of the subject levee system with the geotechnical design criteria set forth in Section 65.10 of the National Flood Insurance Program (NFIP) regulations, which are codified at Title 44, Code of Federal Regulations Part 65.10, Section (b), Subsections (4) and (5). Based on our findings from this study, we have determined the subject levee system meets the requirements.

Enclosed with this letter, you will find documentation of our study including the criteria used, assumptions made, and the geotechnical analyses conducted to assist with the partial levee certification determination. The enclosed documentation includes certification of the stated criterion by a registered professional engineer.

The following excerpt is from the Section 65.2 of the NFIP regulation, which presents a definition for certification as it is applied to this study:

> …certification by a registered professional engineer or other party does not constitute a warranty or guarantee of performance, expressed or implied. Certification of data is a statement that the data is accurate to the best of the certifier's knowledge. Certification of analyses is a statement that the analyses have been performed correctly and in accordance with sound engineering practices. Certification of structural works is a statement that the works are designed in accordance with sound engineering practices to provide protection from the base flood. Certification of "as built" conditions is a statement that the structure(s) has been built according to the plans being certified, is in place, and is fully functioning.

Should you have any questions, feel free to contact us.

Respectfully submitted,

AMEC Earth & Environmental, Inc.

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1.0 INTRODUCTION

As part of the flood map modernization effort, the Federal Emergency Management Agency (FEMA) has implemented procedures to verify that levee systems shown on the effective National Flood Insurance Program (NFIP) flood maps as providing protection from the 1-percent-annual-chance flood continue to meet the levee requirements outlined in the NFIP regulations. The regulatory requirements for FEMA to accredit a levee system as providing flood protection are promulgated in Title 44, Chapter 1, of the Code of Federal Regulations, Part 65.10 (44 CFR 65.10).

FEMA does not certify a levee or perform levee evaluations; it is the responsibility of the levee owner or community seeking recognition of the levee to document compliance with 44 CFR 65.10. FEMA is responsible for the review of the information provided and either accredits the levee system as providing the 1-percent-annual-chance flood protection on the flood map or, if the levee system is shown to be inadequate, to indicate the risk exceeding the 1-percent-annual-chance flood protection by mapping the landside of the levee as within the Special Flood Hazard Area (SFHA).

Levee systems currently shown as providing 1-percent-annual-chance flood protection on a Digital Flood Rate Insurance Rate Map (DFIRM) may qualify for the Provisionally Accredited Levee (PAL) designation. A PAL is a levee FEMA has previously accredited as providing flood protection on a flood map and for which FEMA is waiting for documentation to demonstrate that the levee system is compliant with 44 CFR 65.10. This designation allows a levee to be shown on a DFIRM as providing flood protection while the levee owner compiles the information. The area on the landside is shown as shaded Zone X (outside the SFHA). To qualify for the PAL designation, the levee owner must sign and return an agreement to FEMA that the data and documentation to comply with 44 CFR 65.10 will be provided to FEMA within 24 months.

FEMA has identified the Salt River levees, located along the banks of the Salt River from Tempe Town Lake to State Route 143, in Maricopa County, as structures that provide flood protection and affect the flood hazard information presented on the effective flood maps. FEMA had requested that the levees be investigated and reaccredited as meeting the criteria of 44 CFR 65.10. A letter from FEMA provided the Flood Control District of Maricopa County (District) with the opportunity to receive a PAL designation for the levee. The District signed the PAL agreement and provided the required information on June 8 and 11, 2009. FEMA accepted the agreement and granted the PAL designation (PAL ID No 33).

The two-year deadline date for providing all the 44 CFR 65.10 data to FEMA is June 25, 2011. The effort involves collecting flood insurance study data, design information, as-built drawings, construction quality control/assurance test results, geotechnical data, operation and maintenance procedures, hydrology and hydraulic data, and topographic mapping. The data are evaluated through engineering studies and calculations to determine if the structure is acting as a levee and to support and recommend that the structure continue to be accredited and certified by the levee owner as compliant with the established FEMA levee criteria.

AMEC Earth & Environmental, Inc. (AMEC) has been authorized by the District to provide professional engineering services for the portion of the Salt River Levee described above (including a review of available data), provide engineering analyses based upon the available data and information, and to conduct field reconnaissance as necessary to demonstrate whether the requirements of the following subsections of 44 CFR 65.10, Section (b), "Design Criteria," have been met: (4) "Embankment and Foundation Stability," and (5) "Settlement."

2.0 FEMA 65.10 REQUIREMENTS

As part of a mapping project, it is the responsibility of the levee owner or community to provide data and documentation to show that a levee meets the requirements of 44 CFR 65.10 of the NFIP regulations. The FEMA requirements in Section 65.10 are separated into five categories:

- General criteria
- Design criteria
- Operations plans and criteria
- Maintenance plans and criteria
- Certification requirements

2.1 General Criteria

As mentioned above, FEMA will recognize only the levee systems that meet minimum design, operational and maintenance standards that are consistent with the level of protection sought. Section 65.10 describes the types of information FEMA needs to recognize that a levee system provides protection from the base flood; that information must be supplied to FEMA by the levee owner The FEMA review is solely to establish an appropriate risk zone determination for NFIP maps.

2.2 Design Criteria

FEMA has established levee design criteria for levee freeboard, closures of penetrations through the levee, levee embankment protection, levee embankment and foundation stability, settlement, interior drainage, and other design criteria. These criteria are summarized in the subsections below.

2.2.1 Freeboard

For riverine levees, a minimum freeboard of 3 feet above the water-surface level of the base flood must be provided. An additional 1 foot of freeboard must also be provided within 100 feet on either side of structures (e.g., bridge) or wherever the flow is constricted. An additional 0.5 feet of freeboard must be provided at the upstream ends of the levee, tapering to the minimum freeboard at the downstream end of the levee.

2.2.2 Closures

The levee closure requirement is that, according to sound engineering practices, all openings must be provided with closure devices that are structural parts of the system during operation and design. The unclosed openings will be evaluated as described in Section 2.2.6.

2.2.3 Embankment Protection

Engineering analyses must be submitted to demonstrate that no appreciable erosion of the levee embankment can be expected during the base flood, as a result of either currents or waves, and that anticipated erosion will not result in failure of the levee embankment or foundation directly or indirectly through reduction of the seepage path and subsequent instability.

2.2.4 Embankment and Foundation Stability

Engineering analyses that evaluate levee embankment stability must be submitted. The analyses provided shall evaluate expected seepage during loading conditions associated with the base flood and shall demonstrate that seepage into or through the levee foundation and embankment will not jeopardize embankment or foundation stability. The following factors shall be addressed in the analyses:

- Depth of flooding
- Duration of flooding
- Embankment geometry and length of seepage path at critical locations
- Embankment and foundation materials
- Embankment compaction
- Penetrations
- Other design factors affecting seepage (e.g., drainage layers)
- Other design factors affecting embankment and foundation stability (e.g., berms)

2.2.5 Settlement

Engineering analyses must be submitted that assess the potential and magnitude of future losses of freeboard as a result of levee settlement and demonstrate that freeboard will be maintained within the minimum freeboard standards set forth in Section 2.2.1 . This analysis must address:

- Embankment loads
- Compressibility of embankment soils
- Compressibility of foundation soils
- Age of the levee system
- Construction compaction methods

A detailed settlement analysis using procedures such as those described in U.S. Army Corps of Engineers (USACE) Engineering Manual No. EM 1100-2-1904 must be submitted.

2.2.6 Interior Drainage

An analysis must be submitted that identifies the source(s) of such flooding, the extent of the flooded area, and, if the average depth is greater than 1 foot, the water-surface elevation(s) of the base flood. This analysis must be based on the joint probability of interior and exterior flooding and the capacity of facilities (such as drainage lines and pumps) to evacuate interior floodwaters. Interior drainage systems usually include storage areas, gravity outlets, pumping stations, or a combination thereof. For areas of interior drainage that have average depths greater than 1 foot, mapping must be provided that depicts the extents of the interior flooding, along with supporting documentation.

2.2.7 Other Design Criteria

In unique situations, such as those where the levee system has relatively high vulnerability, FEMA may require that other design criteria and analyses be submitted to show that the levees provide adequate protection. In such situations, sound engineering practice will be the standard on which FEMA will base its determinations. FEMA also will provide the rationale for requiring this additional information.

2.3 Operations

For a levee system to be recognized, the operational criteria must be as described below. All closure devices or mechanical systems for internal drainage, whether manual or automatic, must be operated in accordance with an officially adopted operation manual, a copy of which must be provided to FEMA by the operator when levee or drainage system recognition is being sought or when the manual for a previously recognized system is revised in any manner. All operations must be under the jurisdiction of a federal or state agency, an agency created by federal or state law, or an agency of a community participating in the NFIP.

2.3.1 Closures

Operation plans for closures must include the following:

- Documentation of the flood warning system, under the jurisdiction of federal, state, or community officials, that will be used to trigger emergency operation activities; and a demonstration that sufficient flood warning time exists for the completed operation of all closure structures, including necessary sealing, before floodwaters reach the base of the closure
- A formal plan of operation, including specific actions and assignments of responsibility by individual name or title
- Provisions for periodic operation, at not less than one-year intervals, of the closure structure(s) for testing and training purposes

2.3.2 Interior Drainage Systems

Interior drainage systems associated with levee systems usually include storage areas, gravity outlets, pumping stations, or a combination thereof. FEMA will recognize these drainage systems on NFIP maps for flood protection purposes only if the following minimum criteria are included in the operation plan:

- Documentation of the flood warning system, under the jurisdiction of federal, state, or community officials, that will be used to trigger emergency operation activities; and a demonstration that sufficient flood warning time exists to permit activation of mechanized portions of the drainage system
- A formal plan of operation, including specific actions and assignments of responsibility by individual name or title
- Provisions for manual backup for the activation of automatic systems
- Provisions for periodic inspection of interior drainage systems and periodic operation of any mechanized portions for testing and training purposes (No more than one year shall elapse between either the inspections or the operations.)

2.3.3 Other Operation Plans and Criteria

FEMA may require other operating plans and criteria to ensure that adequate protection is provided in specific situations. In such cases, sound emergency management practice will be the standard upon which FEMA determinations will be made.

2.4 Maintenance

For levee systems to be recognized as providing protection from the base flood, the following maintenance criteria must be met:

- Levee systems must be maintained in accordance with an officially adopted maintenance plan, and a copy of this plan must be provided to FEMA by the owner of the levee system when recognition is being sought or when the plan for a previously recognized system is revised in any manner.
- All maintenance activities must be under the jurisdiction of a federal or state agency, an agency created by federal or state law, or an agency of a community participating in the NFIP that must assume ultimate responsibility for maintenance.
- The maintenance plan must document the formal procedure that ensures that the stability, height, and overall integrity of the levee and how its associated structures and systems are maintained.
- At a minimum, the maintenance plan shall specify maintenance activities to be performed, frequency of their performance, and the person, by name or title, responsible for their performance.

2.5 Certification

Data submitted to support that a given levee system complies with the requirements set forth above must be certified by a registered/licensed professional engineer. Also, certified as-built plans of the levee must be submitted. Certifications are subject to the definition given in 44 CFR Section 65.2 of the NFIP regulations, as follows:

> Section 65.2 Definitions.
> (b) For the purpose of this part, a certification by a registered professional engineer or other party does not constitute a warranty or guarantee of performance, expressed or implied. Certification of data is a statement that the data is accurate to the best of the certifier's knowledge. Certification of analyses is a statement that the analyses have been performed correctly and in accordance with sound engineering practices. Certification of structural works is a statement that the works are designed in accordance with sound engineering practices to provide protection from the base flood. Certification of "as built" conditions is a statement that the structure(s) has been built according to the plans being certified, is in place, and is fully functioning.
>
> (c) For the purposes of this part, "reasonably safe from flooding" means base flood waters will not inundate the land or damage structures to be removed from the Special Flood Hazard Area (SFHA) and that any subsurface waters related to the base flood will not damage existing or proposed buildings.

In lieu of these structural requirements, a federal agency with responsibility for levee design may certify that the levee has been adequately designed and constructed to provide protection against the base flood.

3.0 PURPOSE

The purpose of this study was to provide the geotechnical engineering evaluation for the levee certification per 44 CFR 65.10 with regard to the stability of the levee system as a result of the base flood, as summarized in Sections 2.2.4 and 2.2.5 of this report.

3.1 Scope of Work

3.1.1 Review of Available Geotechnical Information

Considerable reports and plan sets were reviewed for information pertaining to the Salt River levees, but the following documents were the predominate sources of information used for this analysis: Geotechnical investigation reports by Sergent, Hauskins and Beckwith Consulting Geotechnical Engineers (SHB 1988) and AMEC (2010), along with as-builts from the Arizona Department of Transportation (ADOT) Highway Department (ADOT 1989), Maricopa County Highway Department (MCDOT 1989) and USACE (2003). A discussion of our review of these documents is presented in Sections 5.1 and 5.2.

3.1.2 Geotechnical Stability/Settlement/Seepage Analyses

The stability and seepage assessments used existing data and the data developed by the study to evaluate the slope and foundation stability of the levee. Seepage analyses were performed at the critical sections of the levee to evaluate foundation and embankment seepage and to develop the phreatic surfaces necessary to perform the various stability analyses. Slope stability analyses of levee embankments were performed using limit equilibrium stability analysis methods in accordance with the methodology outlined in USACE Engineering Manual No. EM 1110-2-1913, for existing levees. The critical cross sections were analyzed for each of the following cases:

- Case 1: End of construction for the riverside slope and landside slope
- Case 2: Sudden drawdown from 100-year pool for the riverside slope
- Case 3: Steady-state seepage from 100-year flood stage for the landside slope
- Case 4: Pseudostatic analysis for the riverside and landside ends of construction cases

Selected levee critical sections were evaluated for settlement potential. The analyses are described and the results presented in Section 6.0. Appendix A includes results of AMEC's engineering analyses for the north and south banks.

4.0 DESCRIPTION OF LEVEE SYSTEM

The Salt River levees are owned, maintained and operated by the District. The portions of the Salt River levees examined consists of the north side of the subject levee system starting at State Route 143 (Station 160+00) and extending to Tempe Town Lake (Station 249+54.9), and of the south side starting at State Route 143 (Station 155+00) and extending to Tempe Town Lake (Station 249+73.1). This area is between State Route 202L and the Rio Salado Parkway alignment. Figure 1 shows the project vicinity map, and Figures 2a to 2c presents the levee with critical cross section locations.

4.1 History

The Salt River channelization efforts were undertaken to mitigate historical flooding as part of a plan to provide standard flood protection. Five phases of channelization were completed within the Salt River levee system. The first phase extended from approximately 40th Street to the Southern Pacific Railroad Bridge near Mill Avenue. This phase covered the current project. It was completed in 1990 by ADOT in collaboration with the District, the Salt River Project, and the cities of Tempe and Phoenix. The next phase was from Mill Avenue to McClintock Road. The third channelization phase was between McClintock Road and State Route 101 Loop, and the fourth phase was the south bank from State Route 101 Loop to Country Club Drive and the north bank from State Route 101 Loop to approximately 1,800 feet west of Alma School Road. The last phase and most recent one to receive channelization was between the Interstate 10 Bridge and 19th Avenue in Phoenix (District 2011).

The Salt River channelization provides 100-year flood protection and was completed between 1991 and 2002.

4.2 Description of Levee

The north levee along the Salt River is about 1.7 miles long and generally consists of a two-tier levee system. The top tier is a trapezoidal embankment section with a 14-foot-wide top and a 12-inch deep gabion mattress placed on the riverside along the length of the levee slope. The bottom tier of the levee, separated by a minimum 8-foot-wide terrace from the embankment, is a minimum 8-foot-wide cement stabilized alluvium (soil cement) bank. The north bank levee section from Station 159+00 to Station 174+00 has a minimum 8-foot-wide soil cement layer instead of the gabion mattress, with a 6-foot-wide embankment. From Station 174+00 to Station 207+50, the levee is a one-tiered system with a 14-foot-wide top trapezoidal embankment section composed of a minimum 8-foot-wide stabilized alluvium-soil cement bank on the riverside, and a 6-foot-wide embankment with an aggregate base surface on the landside. The landside embankment slope ratio is 3 horizontal to 1 vertical, and the riverside has a slope ratio of 1.5 horizontal to 1 vertical for the soil-cement portion and 3 horizontal to 1 vertical for the gabion mattress portion. The embankment ranges from about 22 to 26 feet in overall height. The elevation of the levee ranges from 1,137.0 to 1,157.7 feet (National Geodetic Vertical Datum 1929).

The south levee along the Salt River is about 1.8 miles long and generally consists of a two-tier levee system. The top tier is a trapezoidal embankment section with a 14-foot-wide top and a

12-inch gabion mattress placed on the riverside along the length of the levee slope. The bottom tier of the levee, separated by a minimum 8-foot-wide terrace from the embankment, is a minimum 8-foot-wide, cement-stabilized, alluvium (soil-cement) bank. The landside embankment slope ratio is 3 horizontal to 1 vertical, and the riverside has a slope ratio of 1.5 horizontal to 1 vertical for the soil-cement portion and 3 horizontal to 1 vertical for the gabion mattress portion. The embankment ranges from about 22 to 23 feet in overall height. The elevation of the levee ranges from 1135.8 to 1157.7 feet (National Geodetic Vertical Datum 1929).

4.3 Levee Inspections

A field reconnaissance of the Salt River levees, for this project, was conducted by representatives of AMEC on May 5 and 6, 2011. The inspection consisted of walking the riverside toe of the levee and the crest of the embankment. Photographs from the field reconnaissance are presented in Appendix B. No indications of differential embankment settlement, seepage/piping or embankment instability were observed. The inspection revealed that the Salt River Levees between the Tempe Town Lake and State Route 143 are in a serviceable condition.

The District performed its latest inspection of the Salt River Levee from State Route 143 to Dobson Road in October 2008. Minor erosion and deterioration of the cement-stabilized alluvium/soil cement was noted. Vegetation and debris were recommended to be removed from the downstream side.

5.0 GEOTECHNICAL STUDY

The purpose of the current project is to provide 44 CFR 65.10 certification, if possible, through review of design documentation and engineering analyses that show that (1) seepage into or through the levee system will not jeopardize embankment or foundation stability; (2) considering future levee settlements, freeboard will be maintained with the minimum standards; and (3) as a result of the base flood, the anticipated erosion will not result in instability of the levee embankment or foundation.

5.1 Previous Geotechnical Studies

Two geotechnical investigations, conducted between 1989 and 2010, were reviewed to obtain subsurface information about the foundation and embankment area.

A geotechnical investigation performed in 1988, by SHB, under contract with ADOT, examined the channel of the Salt River and surroundings between Mill Avenue and 40th Street. This investigation consisted of 24 exploratory borings, 112 test pits and 13 gas monitor wells. The borings were advanced to depths ranging from 25 to 49 feet, and the test pits depths ranged from 3 to 12 feet. Select soils recovered were tested for grain-size analysis and moisture content, along with some R-values for soils that were used for roadway embankments. The study concluded that the majority of the soils in the area are coarse-grained fluvial deposits. This deposit consists of dense to very dense sand, gravel, and cobble (SGC) mixtures with some boulders and occasional lenses of silty and clayey gravel. In isolated sections, silty sands and gravel extended from the surface to a depth of approximately 5 feet. Generally the upper 20 to 30 feet of the SGC materials are uncemented to weakly cemented and relatively clean. The report concluded that for the channel bank protection with the cemented alluvium, a slope of 1.5 horizontal to 1 vertical would be adequate for design (SHB 1988).

A geotechnical investigation performed in 2009 by AMEC, under contract with Kimley-Horn and Associates, Inc., examined the stretch of Salt River channel for the widening of the State Route 143. This investigation consisted of seven exploratory borings within the channel. Select soils recovered were tested for moisture content, grain-size analysis, and Atterberg limits. The study concluded that the soils consists predominantly of sandy gravel and cobbles with a small amount of silt. The riverbed surface is for the most part covered with coarse-grained gravel to cobble-sized material up to 18 inches in diameter. The subsurface is predominantly gravel and sand with some silt and occasional clay down to an approximate elevation of 1,080 feet (National Geodetic Vertical Datum 1929). Soil below that is generally sand with considerable clay and silt and some gravel. The clayey soil in this area is medium to low plasticity. The SGC contains a very high percentage of quartzite, chert and other very hard particles (AMEC 2010).

As-built plans completed by DMJM for the Priest Drive bridge, under contract with the Maricopa County Highway Department, included soil boring logs that were taken into consideration for the soil analysis. The soils encountered for the Priest Drive bridge consisted predominantly of sandy gravel and cobbles with small amount of silt, and the logs agreed with the two geotechnical investigations reports by SHB and AMEC that were discussed earlier.

A geotechnical investigation was performed by the USACE for the Rio Salado Environmental Restoration Project, extending from Tempe Town Lake to Priest Drive. They excavated 15 test trenches. The soil in the trenches consisted of SGC mixtures (USACE 2003).

Other geotechnical investigation reports for the bridges and roadways, as well as other public and private development projects, were reviewed by AMEC to gain a further understanding of the geotechnical condition of the site vicinity.

5.2 Cement-Stabilized Alluvium

Cement-stabilized alluvium was used to channelize the Salt River through Tempe, Arizona. A minimum compressive strength of 750 pounds per square inch was required in the mix design, which specified no aggregate material greater than 3 inches in any dimension. The material from the riverbed was screened to produce the aggregate for the stabilized alluvium for 3-inch maximum stone. The cement-stabilized alluvium was compacted to achieve a 98 percent to 100 percent density throughout each 9-inch lift layer, and was required to fully cure all exposed surfaces for seven days to achieve the minimum compressive strength. Fly ash was used in the mix design to substitute for 25 percent by weight of the portland cement, primarily to help reduce cost (Gehring 1991).

5.3 Groundwater Conditions

Groundwater was encountered during the geotechnical investigation activities discussed above. The water levels measured ranged from 3 to 34 feet below existing grade. However, groundwater levels in the area will be significantly influenced by the water levels in the Salt River.

5.4 Geologic Setting

The project site is in the Basin and Range geologic province of the southwestern United States. The Basin and Range province is characterized by a landscape consisting of broad alluvial valleys interspersed with, and bounded by, uplift and fault-block mountain ranges, often with well-developed pediments and alluvial fans. The mountain ranges generally consist of Precambrian to Tertiary bedrock and the basins are filled with Tertiary to Quaternary sediments. The Precambrian granite, also known as Tovrea granite, is exposed as discontinuous outcrops along the Salt River channelization near Priest Drive. East of Priest Drive, the bedrock varies from 11 to 33 feet, with an outcrop about 1,600 feet east of Priest Drive (National Geodetic Vertical Datum 1929). West of Priest the bedrock depth increases to about 135 feet at 48th Street. Fluvial deposits of Quaternary age occur within the floodplain of the Salt River and almost entirely comprise the geologic unit exposed in the Salt River channel. The thickness of the fluvial deposit ranges from 29 to 68 feet and increases to 135 feet westward.

5.4.1 Seismic

The project site is within the Sonoran Zone described in ADOT Report No. AZ92-344 (Euge and others 1992). The Sonoran Zone is not considered to be seismically active and is not in the vicinity of a seismically active area. The maximum credible earthquake for the project area is conservatively estimated at a magnitude of 6.5. The ADOT report indicates a peak ground acceleration (PGA) of 0.028 g with a 10 percent probability of exceedance in 50 years. The *LRFD Bridge Design Specifications* (AASHTO 2007) present a PGA of 0.052 g with a 7 percent probability of exceedance in 75 years.

6.0 GEOTECHNICAL ANALYSES

6.1 Selection of Critical Cross Sections

Seven representative levee cross sections were selected for analysis along the north and south banks of the Salt River, three sections on the north side and four sections on the south side. Critical cross sections were chosen based on typical geometric attributes and levee embankment heights.

Cross sections at the following locations were selected as representative sections and analyzed for seepage, stability and settlement. The cross-sectional breakdown is as follows:

- Typical Section No. 2 – Station 100+35 to Station 160+00
  - South: Station 155+20
- Typical Section No. 3 – Station 160+00 to Station 174+00
  - South: Station 174+00
  - North: Station 172+00
- Typical Section No. 4 – Station 176+00 to Station 206+00
  - South: Station 206+00
  - North: Station 206+00
- Typical Section No. 5 – Station 206+00 to Station 249+73
  - South: Station 248+00
  - North: Station 247+36

6.2 Soil Engineering Parameters

The geotechnical parameters required for slope stability analysis include unit weights, shear strength for each material present in a cross section, and location of the phreatic surface within the cross section. The required parameters, in particular the soil shear strength, were obtained using previous geotechnical report soil data and based on AMEC's experience with similar soils. Conservative shear strength and hydraulic parameters used in the stability and seepage analysis are presented in Table 6-1.

Table 6-1 Soil Parameters Used in Analyses

Description	Moist Unit Weight, γ (pcf)	Effective Friction Angle, Φ' °	Effective Cohesion, c' psf	Saturated Hydraulic Conductivity, K_{sat} cm/s	Young's Modules E' psf
Embankment	125	33	100	1×10^{-5}	1×10^{6}
Cement-stabilized alluvium/soil cement	125	20	1000	1×10^{-7}	1×10^{7}
Foundation backfill	125	33	100	1×10^{-3}	1×10^{6}
Native soil	130	36	0	1×10^{-3}	1×10^{5}

Notes: cm/s = centimeters per second, pcf = pounds per cubic foot, psf = pounds per square foot

6.3 Seepage Analyses

Steady-state seepage analyses were completed to assess the development of a phreatic surface within the landside slope of the embankment resulting from the 1-percent flood condition in the Salt River. Steady-state seepage analyses were completed using the two-dimensional finite element computer program SEEP/W (Geo-Slope International, Ltd. 2007a) and saturated hydraulic conductivity values for the various elements of the levee embankment and the foundation soils. SEEP/W is a computer code used to model the saturated and unsaturated flow of water within porous materials. Analyses were completed using triangular and quadrilateral elements to develop the finite-element mesh, and solutions were obtained using four-point integration techniques.

The 1-percent flood condition for the steady-state seepage analysis for each typical section was obtained from the maximum modeled flood level based on the 100-year flood event (Fuller 2011). In general accordance with No. EM 1110-2-1913 (USACE 2000), In Appendix B, Section B-5, page B-12, a maximum exit gradient ($i_{max} = 0.5$) is used as an acceptance criterion for seepage exiting the toe of the levee and corresponds to a factor of safety of about 1.6. The critical sections were analyzed for seepage, where seepage is allowed to pass through the entire cross section of the levee. The assumed steady-state seepage condition is very conservative, as the 100-year flood level will not last long enough to develop full saturation.

Table 6-2 Seepage Results

Critical Section	Exit Gradient i_{max} (ft/ft)	Factor of Safety
Salt River Levee North Bank		
172+00	0.05	10
206+00	0 (a)	N/A
247+36	0 (a)	N/A
Salt River Levee South Bank		
155+20	0 (a)	N/A
174+00	0.06	8.3
206+00	0.10	5
248+00	0 (a)	N/A

Note: No. EM 1110-2-1913, Paragraph B-5b, stipulates the following criteria for levee evaluation: i_{max} <= 0.5 foot/foot (ft/ft).
(a) Final phreatic surface below ground surface – no exit gradient exists.
N/A = not applicable

The seepage analyses indicate that exit gradients at the toe of the critical sections of the levee are equal to or less than the maximum permitted exit gradient of i_{max} = 0.5 foot per foot referenced in USACE Design Manual No. EM-1110-2-1913. The results of the current seepage analyses of the critical sections are included in Appendix A.

6.4 Slope Stability Analyses

Conventional static and pseudostatic stability analyses of typical levee embankment sections were performed using the computer program SLOPE/W (Geo-Slope International, Ltd. 2007c) and the phreatic surface imported from the SEEP/W seepage analysis, where appropriate. The comprehensive formulation of SLOPE/W and SEEP/W makes it possible to easily analyze both simple and complex slope stability problems using a variety of methods to calculate the factor of safety.

The slope stability analysis was performed in accordance with EM 1110-2-1913, Chapter 6, Section II (USACE 2000). Static stability analyses were completed for four cases:

- Case 1: End of Construction

  A. Landside – Static

  B. Riverside – Static

- Case 2: Sudden Drawdown Under 100-year Flood Stage

  A. Riverside – without Scour - Static

  B. Riverside – with Scour – Static

- Case 3: Steady State Seepage under 100-Year Flood Stage

  A. Landside – Static

- Case 4: End of Construction

  A. Landside – Pseudostatic

  B. Riverside – Pseudostatic

The steady-state seepage condition for landside was simulated using the SEEP/W program. Pseudostatic analyses, assuming a PGA of 0.1 g, based on a 2 percent exceedance in 50 years, were completed for the riverside and landside end-of-construction cases (see Section 5.4.1). The slopes were analyzed using the general limit equilibrium method that produces a circular failure surface. The minimum acceptable factors of safety for the existing levees from EM 1110-2-1913 (USACE 2000) were used as the acceptance criterion (see Table 6-3).

Table 6-3 Slope Stability Requirements[1]

Applicable Stability Conditions and Required Factors of Safety			
End of Construction (Static)	Sudden Drawdown[2]	Steady State Seepage	End of Construction (Pseudostatic)[3]
1.3	1.0-1.2	1.4	1.0

Notes: [1] EM 1110-2-1913, "Minimum Required Factors of Safety - Levee Slope Stability" (Table 6-1b)
[2] Sudden drawdown analyses. Factor of safety = 1.0 applies to stage levels prior to drawdown for conditions where these water levels are unlikely to persist for long periods preceding drawdown. Factor of safety. = 1.2 applies to stage level, likely to persist for long periods prior to drawdown.
[3] See ER 1110-2-1806 for guidance. An engineering manual for seismic stability analysis is under preparation.

Based on Federal Highway Administration Circular No. 3, Chapter 7.2.1, a minimum allowable seismic (pseudostatic) factor of safety of 1.0 was used. The analyses were performed on a two-dimensional representation of the levee's critical cross sections. Table 6-4 provides a summary of the slope stability factors of safety for each critical cross section. Analysis results for each of these cases are presented in Appendix A.

The results of the stability analyses indicate the existing embankment meets or exceeds USACE stability requirements. The critical sections were found to be at Salt River north bank Station 206+00 and section Station 155+20 of the south bank, where the factor of safety for Case 2B, "Sudden Drawdown with Scour Condition," is closest to 1.20, the required factor of safety. The 100-year modeled flood level used in the stability analysis is expected to exist only for a short time. The anticipated drawdown level for this section is also conservative, as it is based on maximum modeled scour level at this location (Fuller 2011).

In general, the simple effective strength approach used in the modeling sudden drawdown represents the worst-case scenario. This is because rapid drawdown seldom occurs instantaneously and pore water pressures in the riverside levee material tends to dissipate readily during the drawdown process.

Table 6-4 Slope Stability Results Summary

Typical Section	Case 1 – End of Construction (Static)		Case 2 – Sudden Drawdown		Case 3 – Steady State Seepage	Case 4 – End of Construction (Pseudostatic)	
	A - Land	B - River	A – No Scour	B - Scour	A - Land	A - Land	B - River
Salt River North Bank							
172+00	2.76	2.58	1.82	1.57	2.48	2.08	2.13
206+00	3.52	1.99	1.37	1.32	3.52	2.60	1.65
247+36	N/A	2.82	1.84	1.47	N/A	N/A	2.13
Salt River South Bank							
155+20	N/A	1.95	1.35	1.22	N/A	N/A	1.62
174+00	2.82	2.76	1.69	1.48	2.50	2.12	2.09
206+00	2.75	2.83	1.82	1.56	2.42	2.07	2.15
248+00	N/A	2.81	1.85	1.57	N/A	N/A	2.14
Required Factor of Safety	1.3		1.0 to 1.2		1.4	1.0	

Note: N/A = not applicable

6.5 Settlement Analysis

Settlement analyses were performed for all critical sections. In general, where foundation and levee soils are pervious or semipervious, potential settlements have generally dissipated shortly following construction. The levee's foundation soils are alluvial silty sand continuing to the extent of the borings. The settlement analysis was performed using the computer program SIGMA/W (Geo-Slope International, Ltd. 2007b). SIGMA/W is a finite-element software product that can be used to perform stress and deformation analyses of earth structures. The program's comprehensive formulation makes it possible to analyze both simple and highly complex problems using a simple linear elastic deformation analysis or a highly sophisticated, nonlinear, elastic-plastic effective-stress analysis.

The program analyzed the settlement of native and foundation soils under a load of levee embankment consisting of embankment fills and cement stabilized material. Conservative values of Young's modulus and volumetric water content functions were used for native foundation soils. Post-construction total settlements of the coarse-grained alluvial soils (sand and gravel mixtures) underlying the levees are estimated to be up to about 2.5 inch. The maximum vertical settlement contour for the typical sections are presented in Appendix A. Based upon the age of the levee embankment, it is concluded that most of the static settlement has already occurred.

6.6 Summary of Findings

The findings of the geotechnical evaluation of the north and south banks of the Salt River levee system from State Route 143 to Tempe Town Lake are as follows:

- *Seepage*: Steady-state seepage analysis performed at seven critical sections of the levee indicates that under the base flood scenario, seepage would neither exceed an exit gradient of imax = 0.5 foot per foot at the landside slope nor would cause seepage at the levee's toe. Thus the sections exceed present seepage criteria.
- *Slope stability:* The stability analyses performed at seven critical sections of the levee embankments determined safety factors meet or exceed the minimum factors of safety criteria stipulated in USACE Engineering Manual No. EM-1110-2-1913 (USACE 2000).
- *Settlement*: Future potential settlement of the levee under static conditions is considered to be negligible.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the geotechnical evaluation performed by AMEC, it is our opinion that there is reasonable certainty that the evaluated portions of the Salt River levee system meet or exceed the FEMA's 44 CFR 65.10 requirements for slope stability, seepage and ground subsidence/settlement.

The cover letter provides a certification letter indicating that the Salt River Levee meets 44 CFR 65.10, Section (b), Subsection (4), "Embankment and Foundation Stability," and Subsection (5), "Settlement."

7.1 Closure

This report is based on the project as described and the information obtained from the exploratory borings performed by others, as referenced in this report. The findings, conclusions and recommendations that AMEC may present are based in part upon data obtained from a necessarily limited number of observations, site visits, excavations, samples and tests, including those performed by others. Such information can be obtained only with respect to the specific locations explored, and, therefore, may not completely define the subsurface conditions throughout the levee alignment. Differing geotechnical or geologic conditions can occur within small distances and under varying climatic conditions. Furthermore, changes in subsurface conditions can and do occur over time. Our firm should be notified of any pertinent change in the project or field conditions. If geotechnical conditions are found to differ from those described herein, it may require a reevaluation of the recommendations presented.

This report has not been prepared for use by parties or projects other than those named or described within this report. It may not contain sufficient information for other parties or other purposes. It has been prepared in accordance with generally accepted geotechnical practices and makes no other warranties either express or implied, as to the professional advice or data included in it.

8.0 REFERENCES

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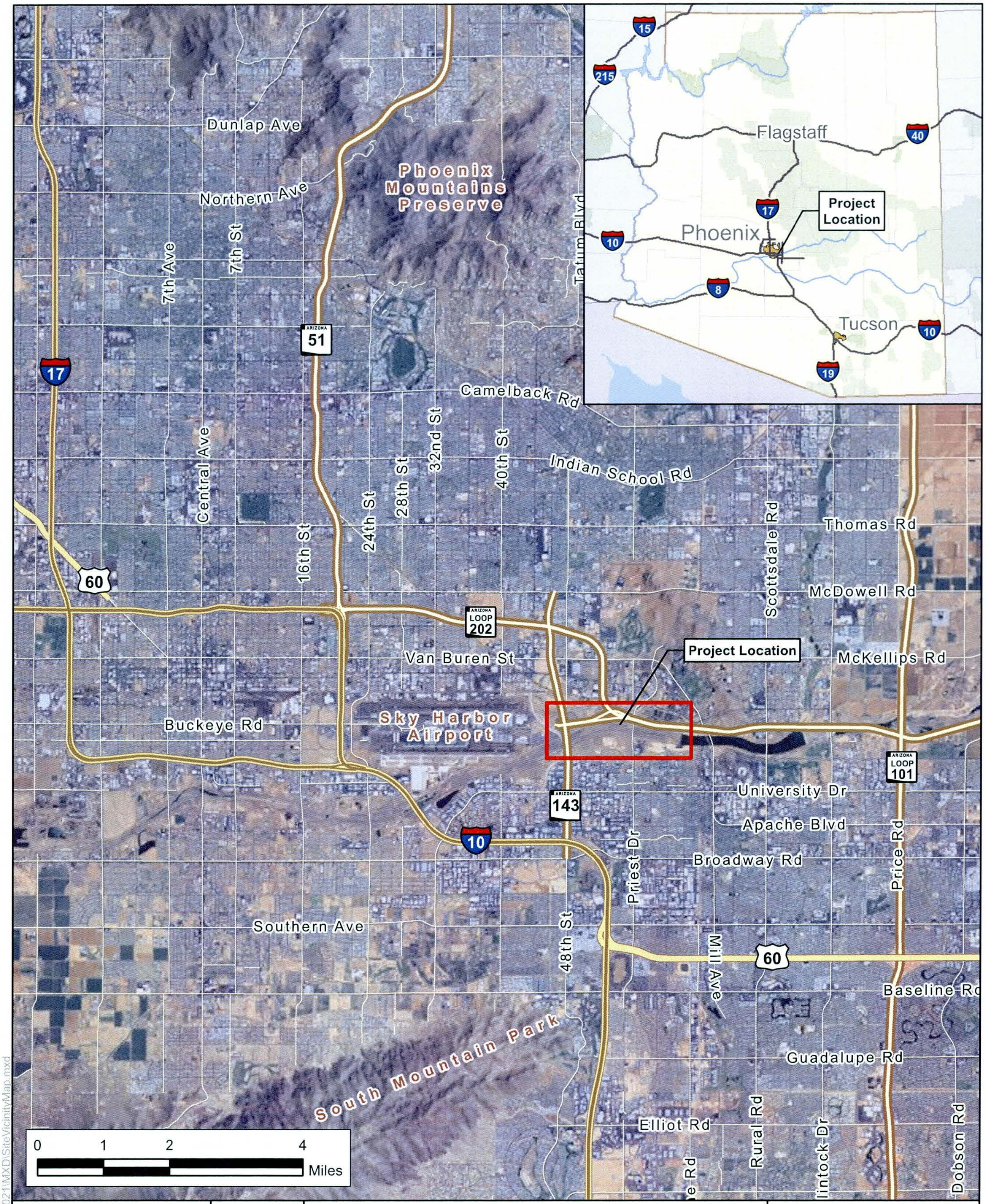
FIGURES



Job No.	17-2011-4021
PM:	TJF
Date:	05/2011
Scale:	1" = 2 miles

N

Salt River Levee
Tempe, Arizona

Project Vicinity Map

FIGURE
1

amec

The map shown here has been created with all due and reasonable care and is strictly for use with AMEC Project Number 17-2011-4021. This map has not been certified by a licensed land surveyor, and any third party use of this map comes without warranties of any kind. AMEC assumes no liability, direct or indirect, whatsoever for any such third party or unintended use.

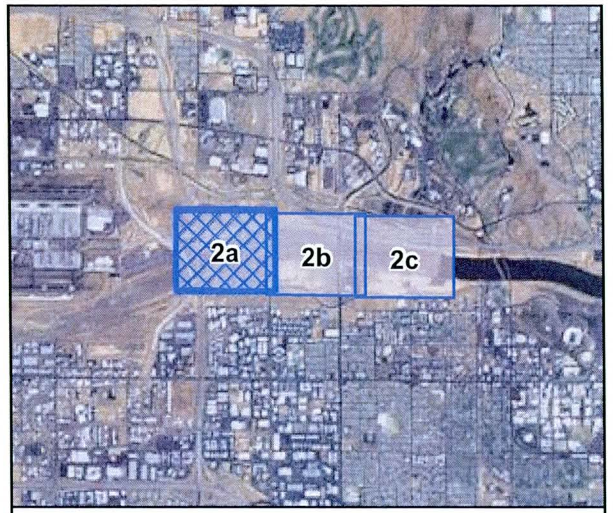


Figure Index

Legend

- Critical Levee Cross Section Locations
- North Bank of Levee
- South Bank of Levee
- Elevation Lines (10-Foot Intervals)

0 75 150 300 450 600 Feet

N

Salt River Levee
Tempe, Arizona

Figure 2a - Project Vicinity Map

Job No.	17-2011-4021
PM:	TJF
Date:	05/2011
Scale:	1" = 300'

Figure Index

Legend

- Critical Levee Cross Section Locations
- North Bank of Levee
- South Bank of Levee
- Elevation Lines (10-Foot Intervals)

0 75 150 300 450 600 Feet

N

Salt River Levee
Tempe, Arizona

Figure 2b - Project Vicinity Map

Job No.	17-2011-4021
PM:	TJF
Date:	05/2011
Scale:	1" = 300'

amec

Figure Index

Legend

- Critical Levee Cross Section Locations
- North Bank of Levee
- South Bank of Levee
- Elevation Lines (10-Foot Intervals)

0 75 150 300 450 600 Feet

N

Salt River Levee
Tempe, Arizona

Figure 2c - Project Vicinity Map

Job No.	17-2011-4021
PM:	TJF
Date:	05/2011
Scale:	1" = 300'

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FIGURES

APPENDIX A
ENGINEERING ANALYSES

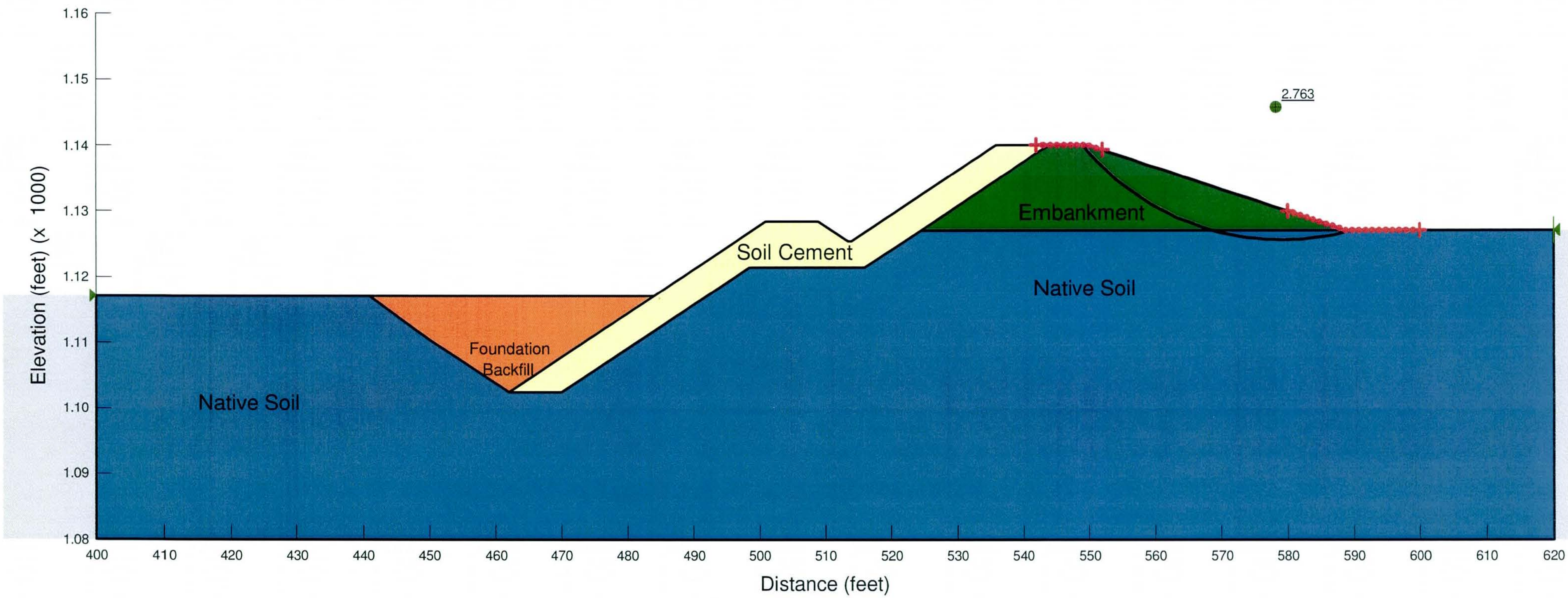
- Salt River North Bank
- Salt River South Bank

SALT RIVER NORTH BANK

Job No. 17-2011-4021
Salt River North Bank - Station 172+00

Case 1A - End of Construction
Landside - Static

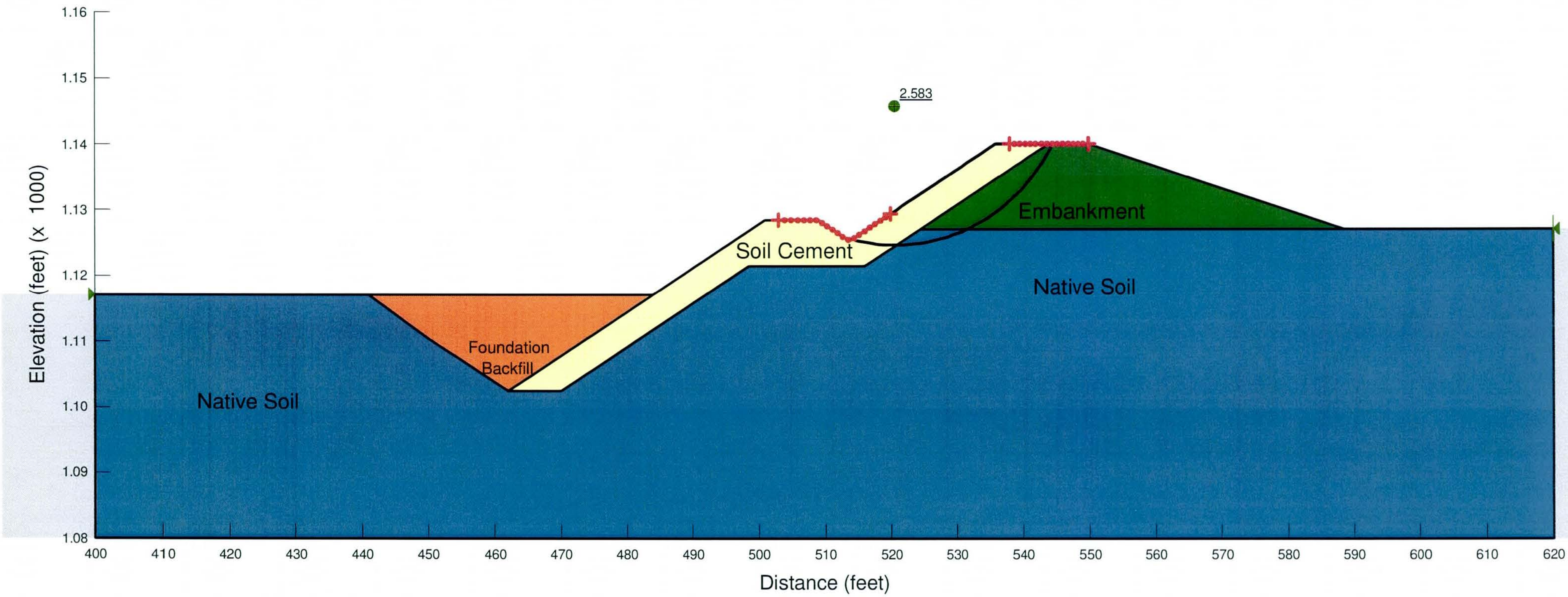
Factor of Safety = 2.76



Job No. 17-2011-4021
Salt River North Bank - Station 172+00

Case 1B - End of Construction
Riverside - Static

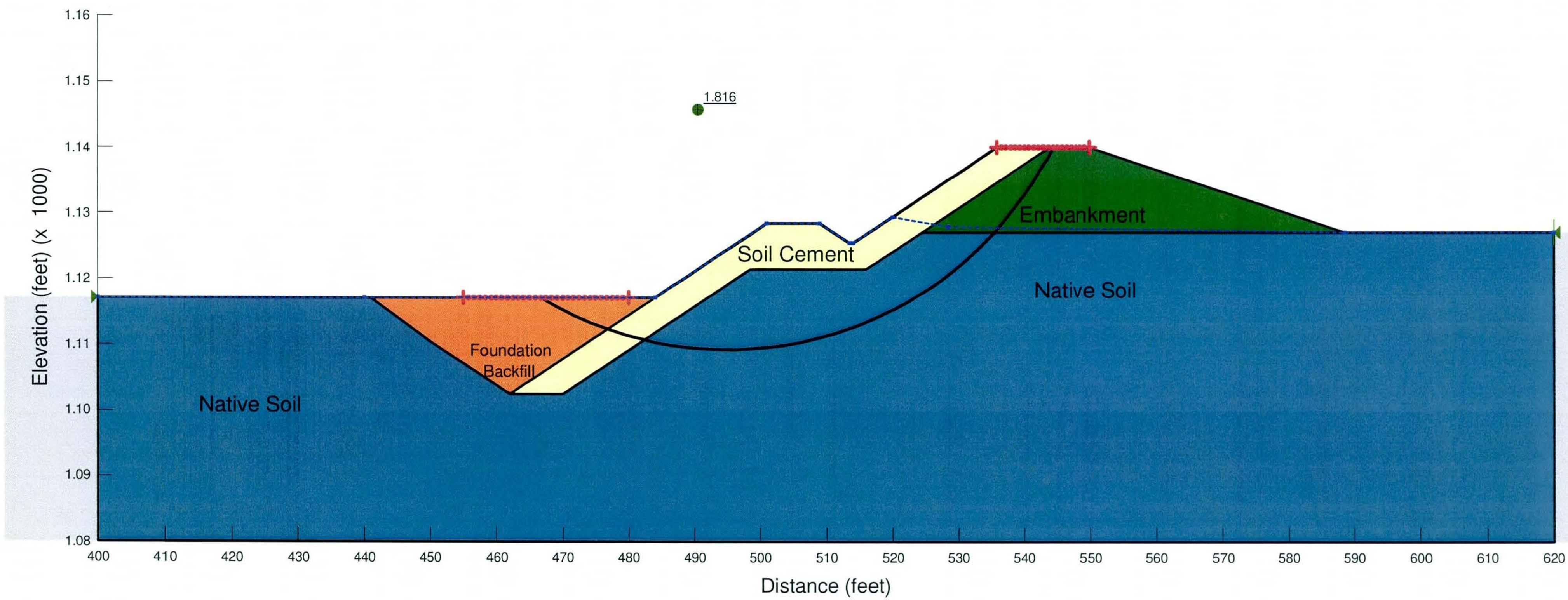
Factor of Safety = 2.58



Job No. 17-2011-4021
Salt River North Bank - Station 172+00

Case 2A - Sudden Drawdown
Riverside - Static

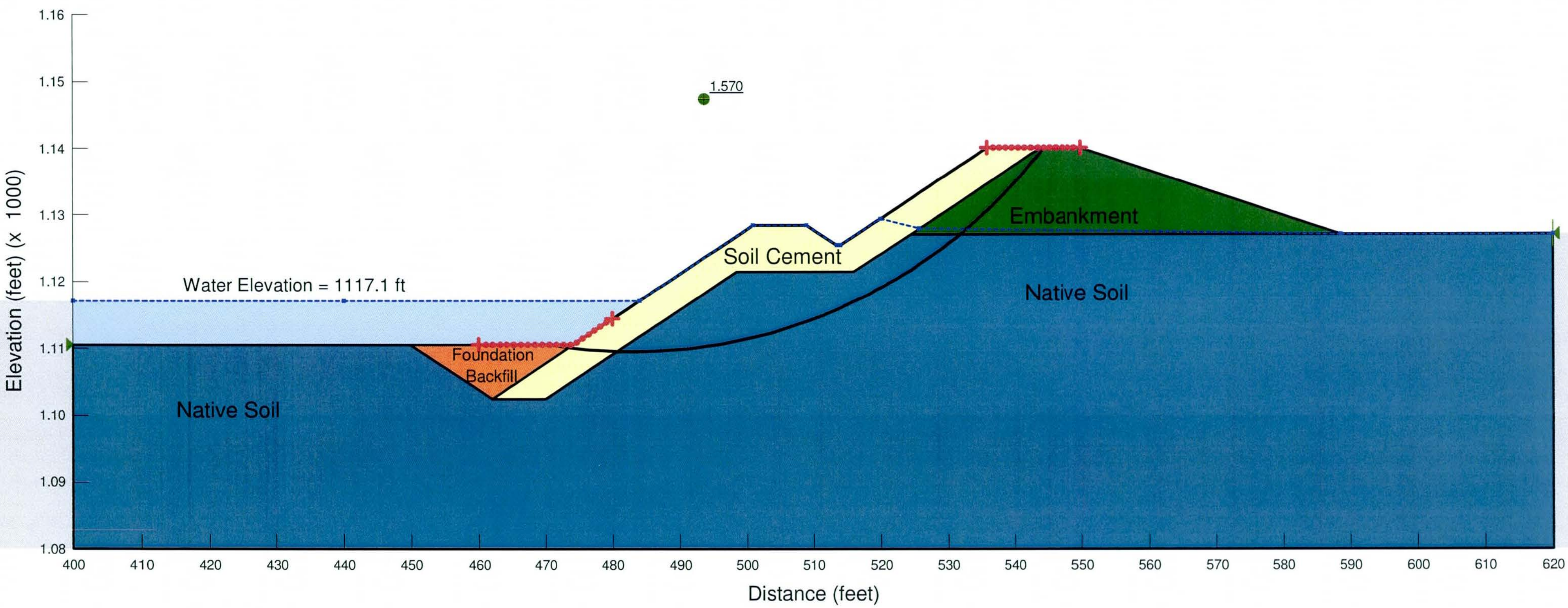
Factor of Safety = 1.82



Job No. 17-2011-4021
Salt River North Bank - Station 172+00

Case 2B - Sudden Drawdown with Scour Condition
Riverside - Static

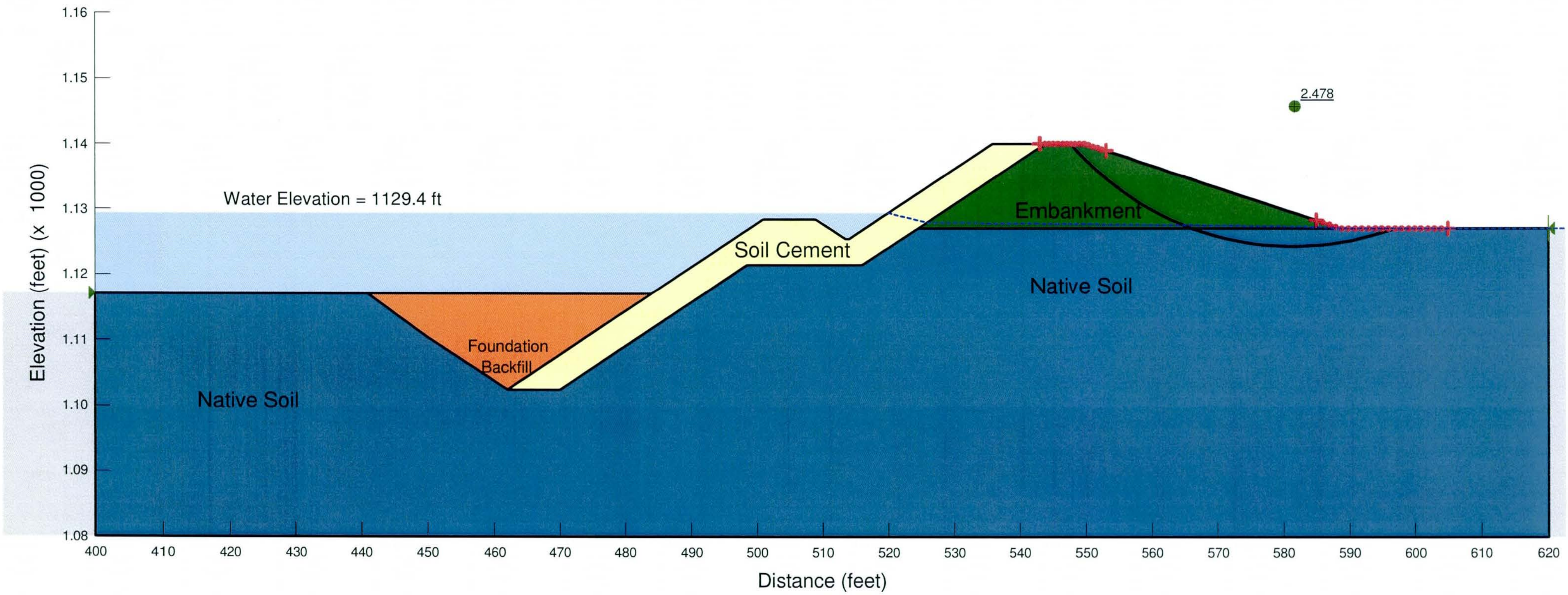
Factor of Safety = 1.57



Job No. 17-2011-4021
Salt River North Bank - Station 172+00

Case 3A - Steady State Seepage Under 100-year Flood Level Condition
Landside - Static

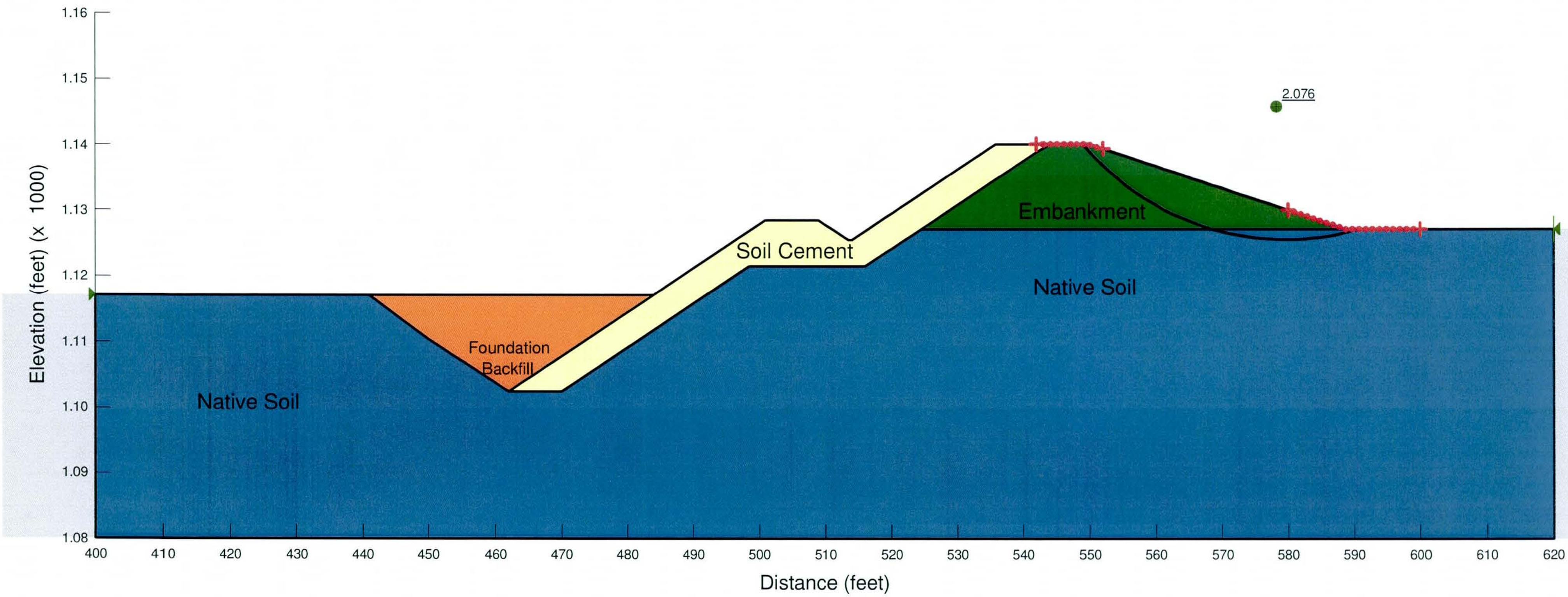
Factor of Safety = 2.48



Job No. 17-2011-4021
Salt River North Bank - Station 172+00

Case 4A - End of Construction
Landside - Pseudo Static (a=0.1g)

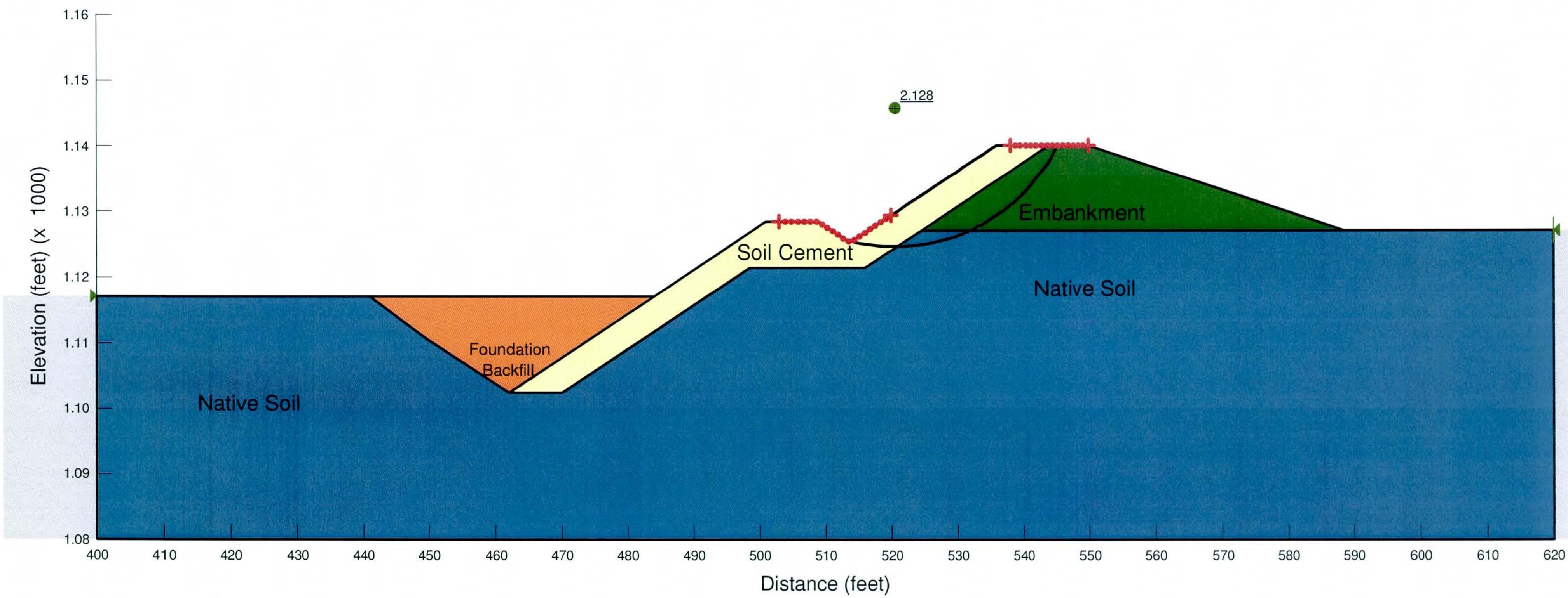
Factor of Safety = 2.08



Job No. 17-2011-4021
Salt River North Bank - Station 172+00

Case 4B - End of Construction
Riverside - Pseudo Static (a=0.1g)

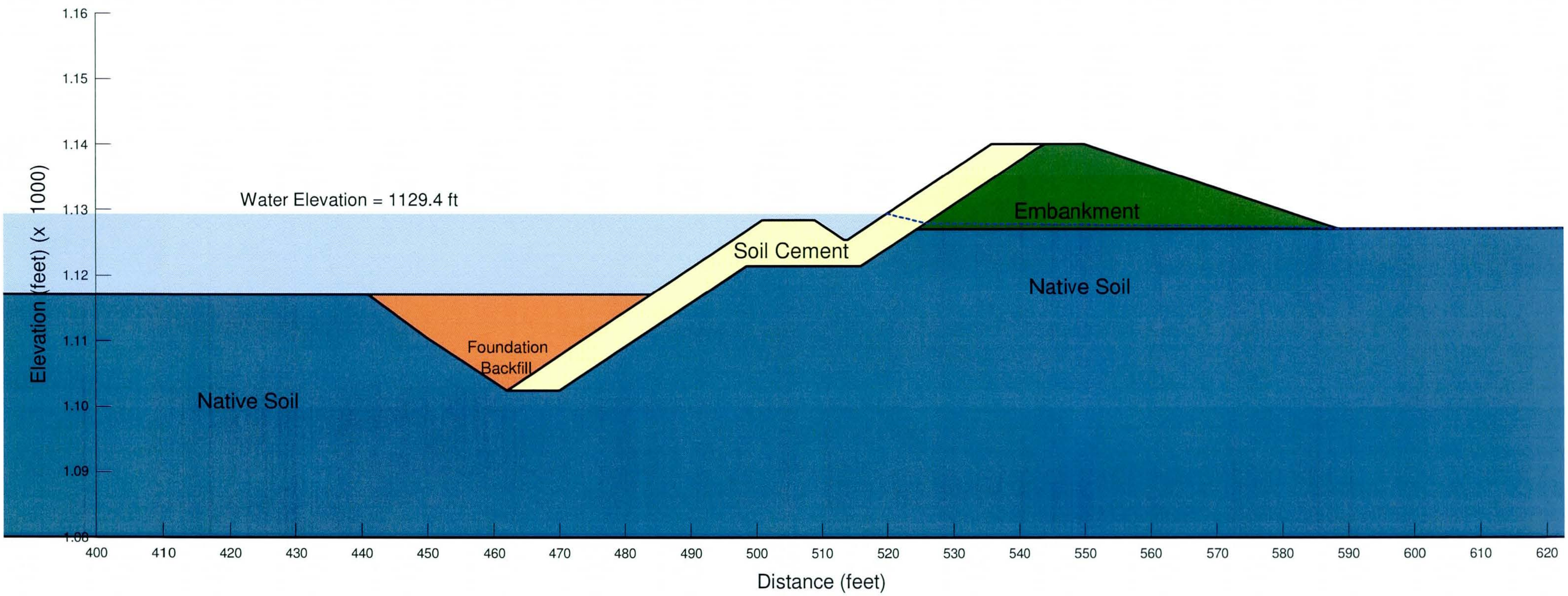
Factor of Safety = 2.13



Job No. 17-2011-4021
Salt River North Bank - Station 172+00

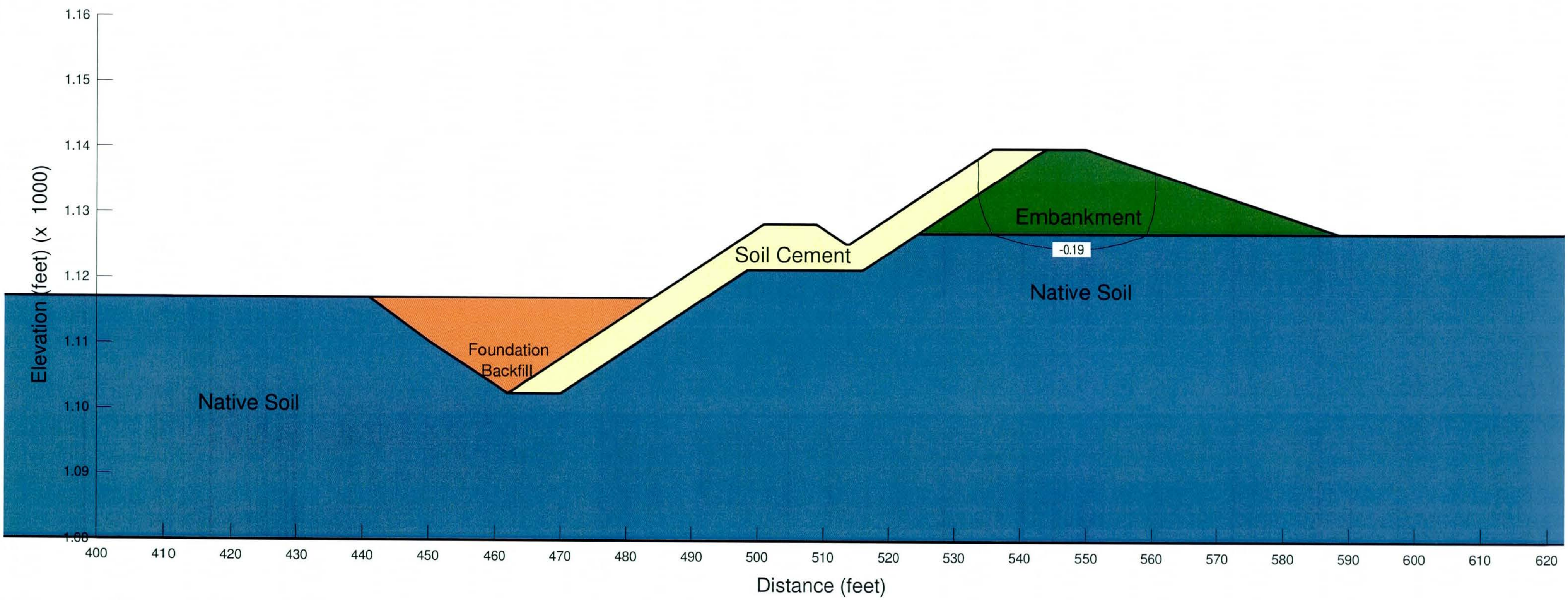
Steady State Seepage Analysis

Maximum Exit Gradient = 0.05



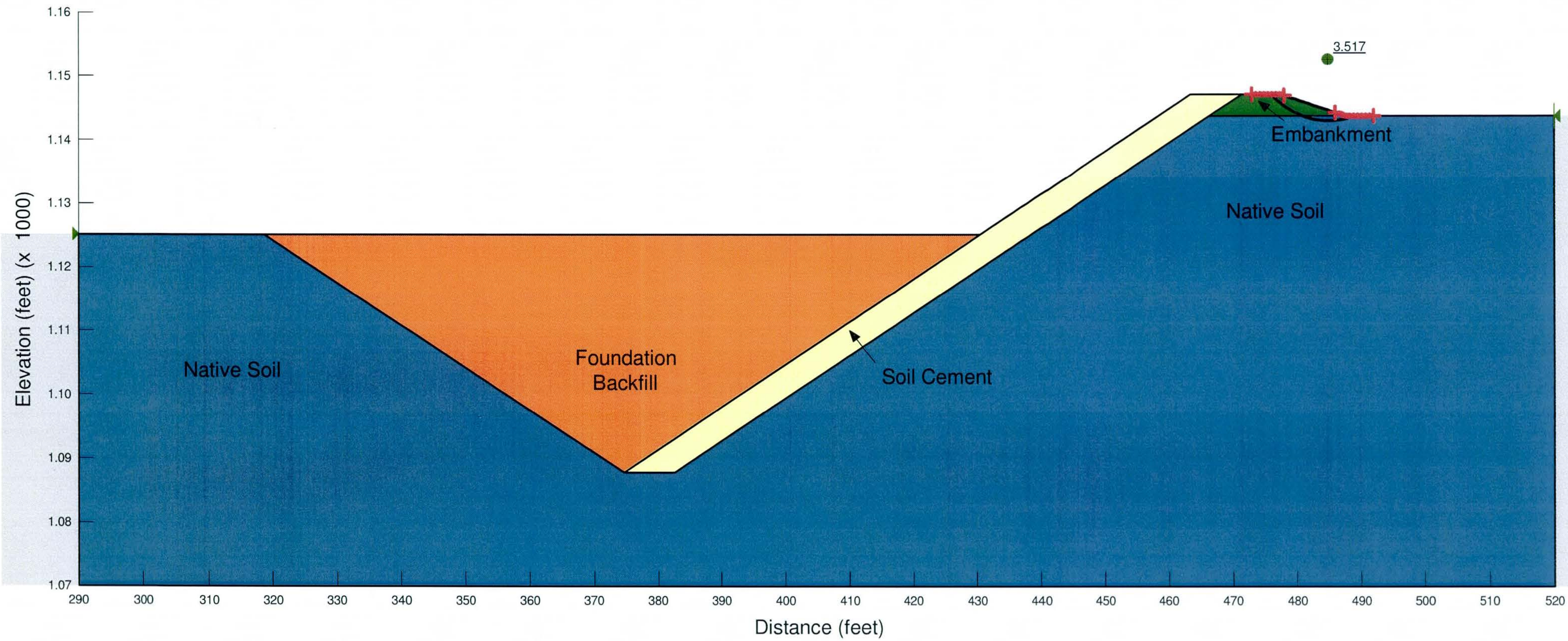
Job No. 17-2011-4021
Salt River North Bank - Station 172+00

Settlement Analysis
Maximum Vertical Settlement Contour in Feet



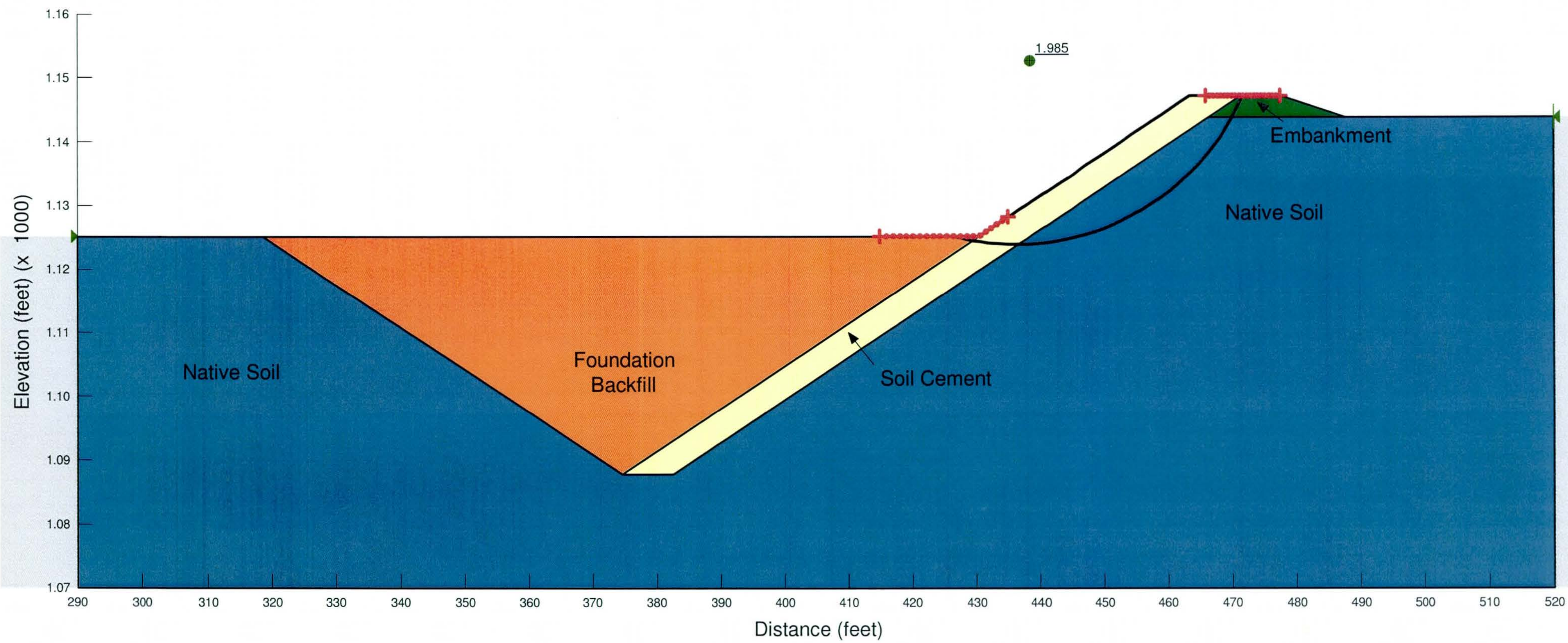
Job No. 17-2011-4021
Salt River North Bank - Station 206+00
Case 1A - End of Construction
Landside - Static

Factor of Safety = 3.52



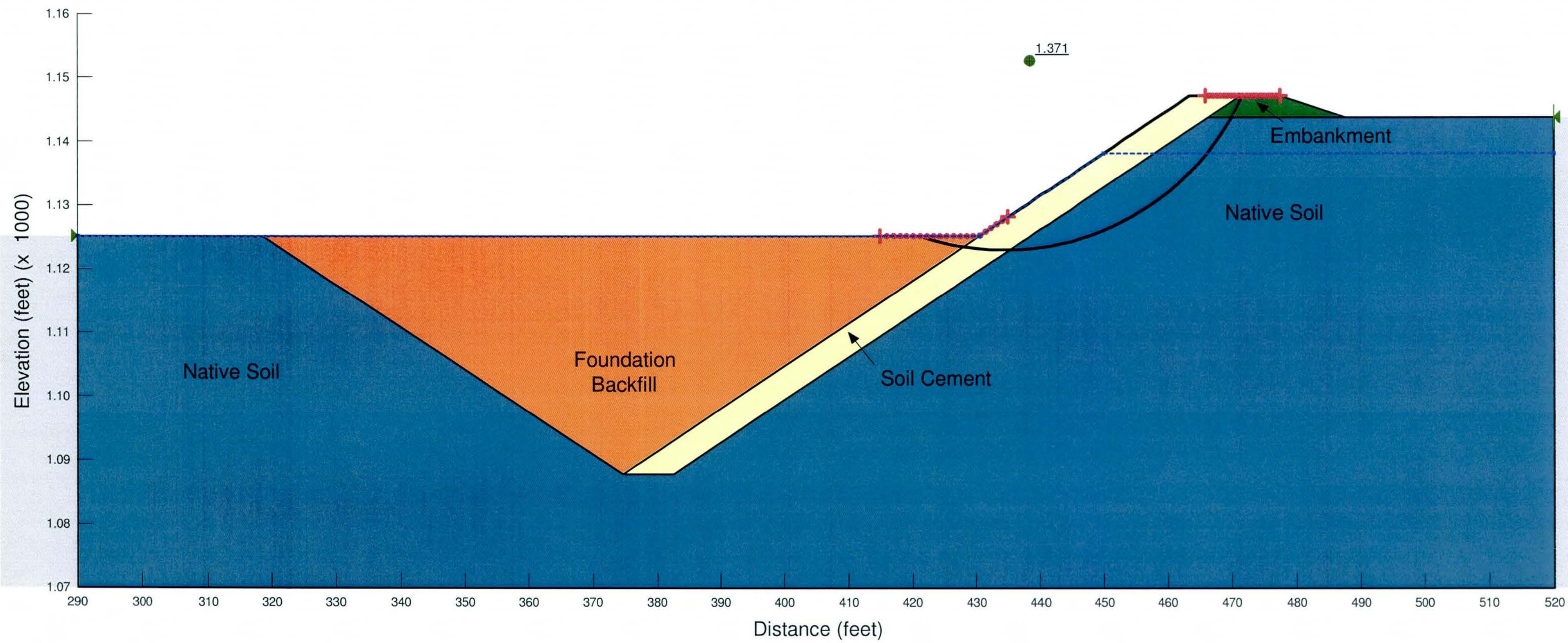
Job No. 17-2011-4021
Salt River North Bank - Station 206+00
Case 1B - End of Construction
Riverside - Static

Factor of Safety = 1.99



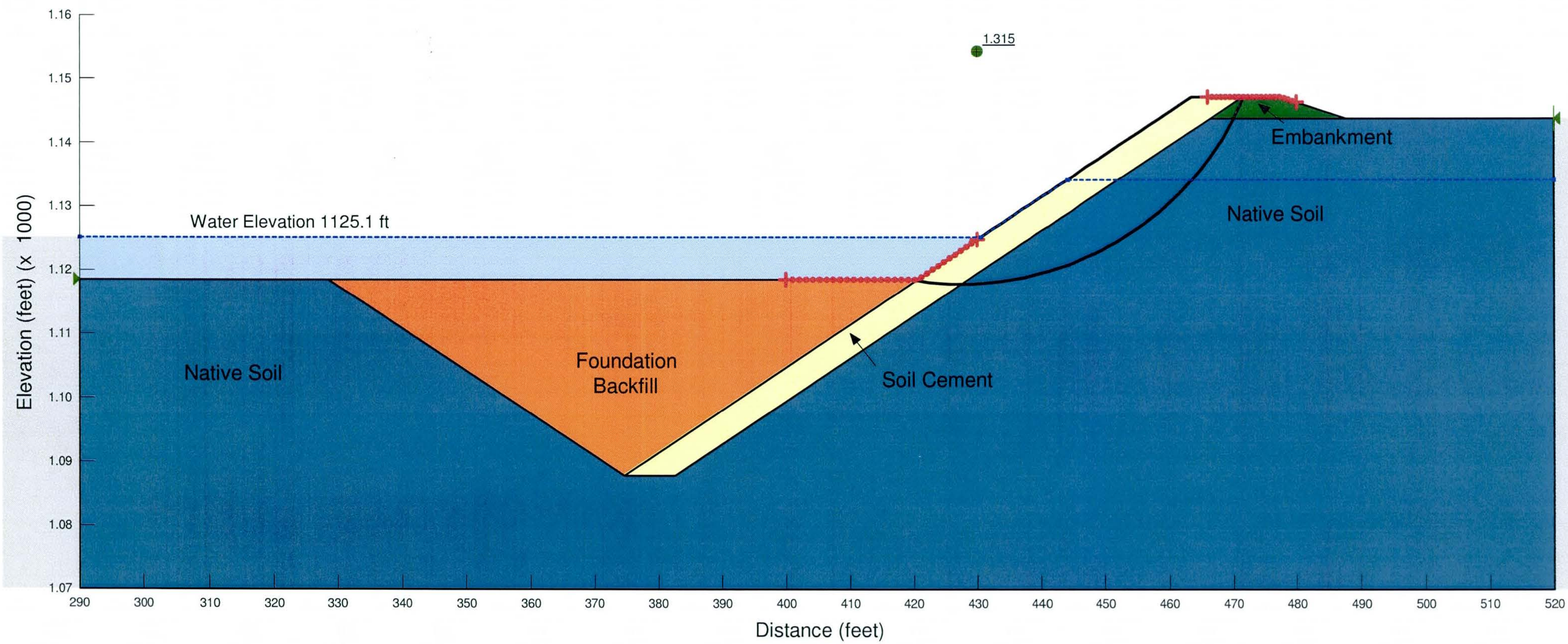
Job No. 17-2011-4021
Salt River North Bank - Station 206+00
Case 2A - Sudden Drawdown
Riverside - Static

Factor of Safety = 1.37



Job No. 17-2011-4021
Salt River North Bank - Station 206+00
Case 2B - Sudden Drawdown with Scour Condition
Riverside - Static

Factor of Safety = 1.32



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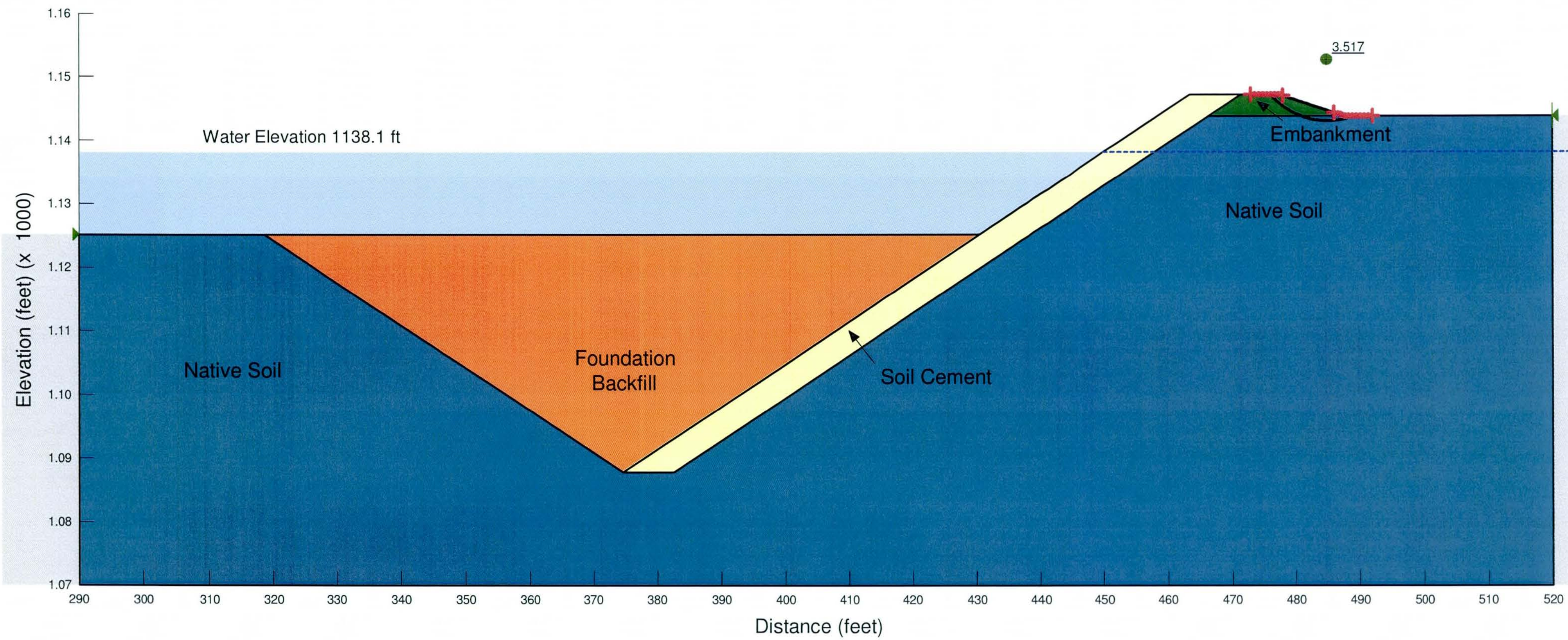
Salt River North Bank - Station 206+00
Case 3A - Steady State Seepage Under 100-year Flood Level Condition
Landside - Static

Factor of Safety = 3.52



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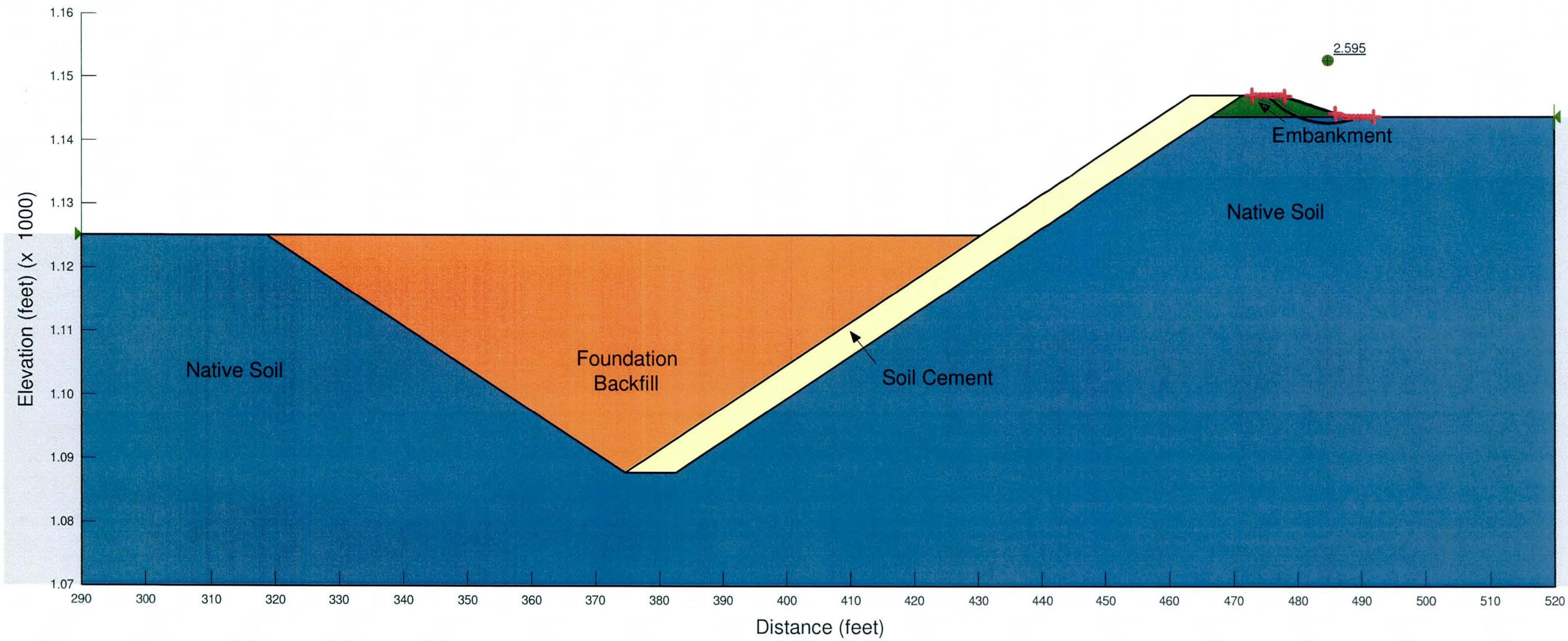
Salt River North Bank - Station 206+00
Case 4A - End of Construction
Landside - Pseudo Static (a=0.1g)

Factor of Safety = 2.60



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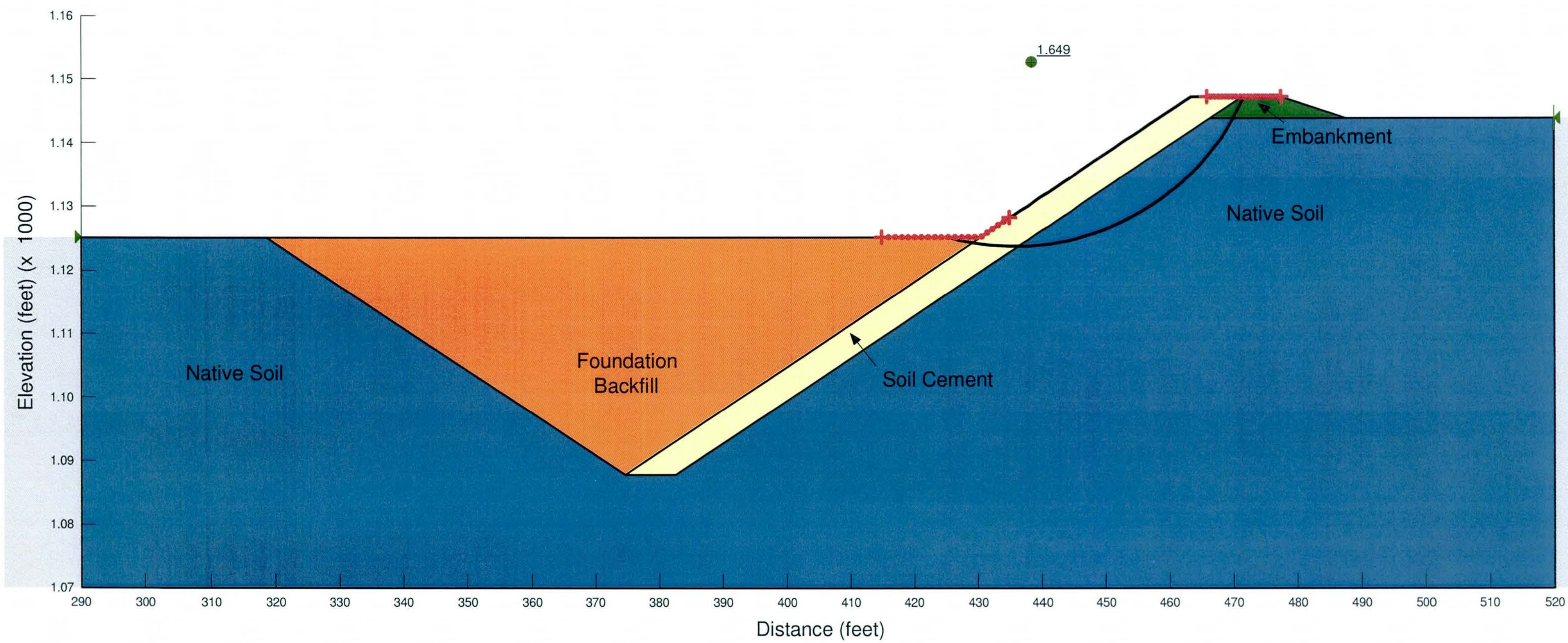
Salt River North Bank - Station 206+00
Case 4B - End of Construction
Riverside - Pseudo Static (a=0.1g)

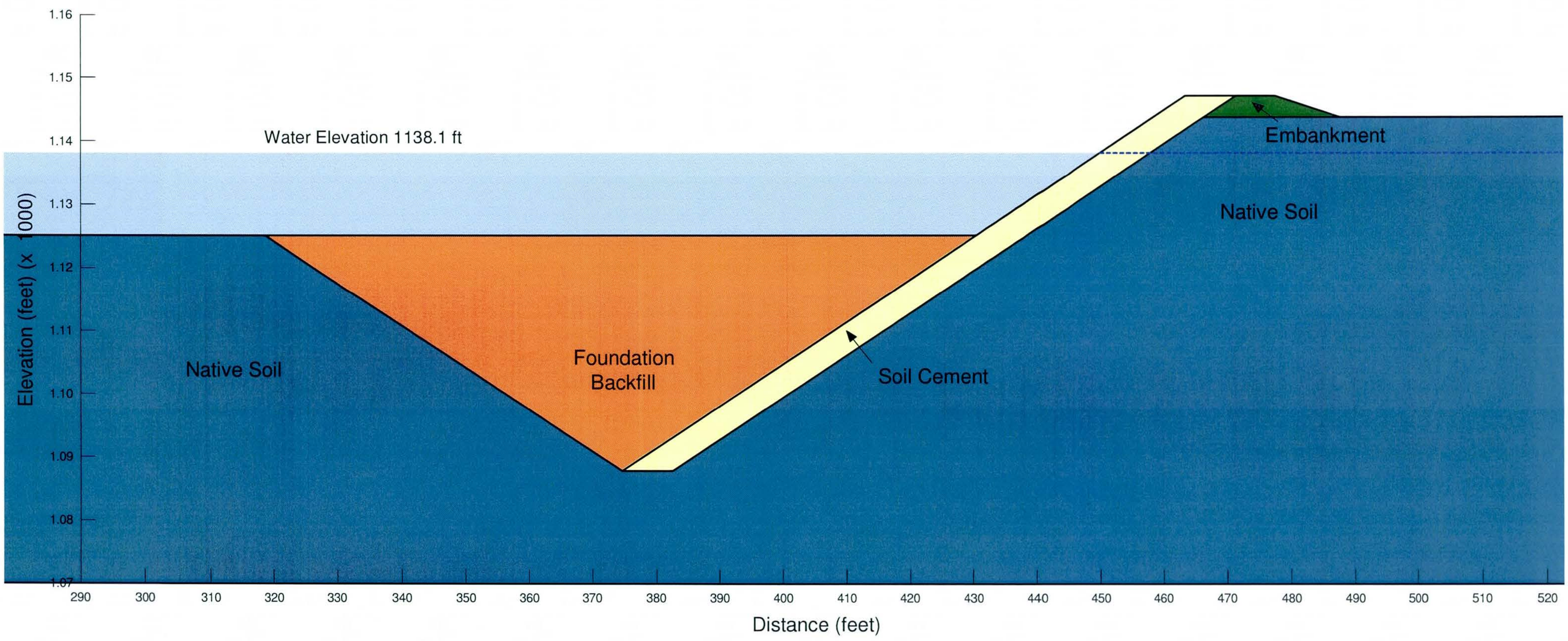
Factor of Safety = 1.65



Job No. 17-2011-4021
Salt River North Bank - Station 206+00

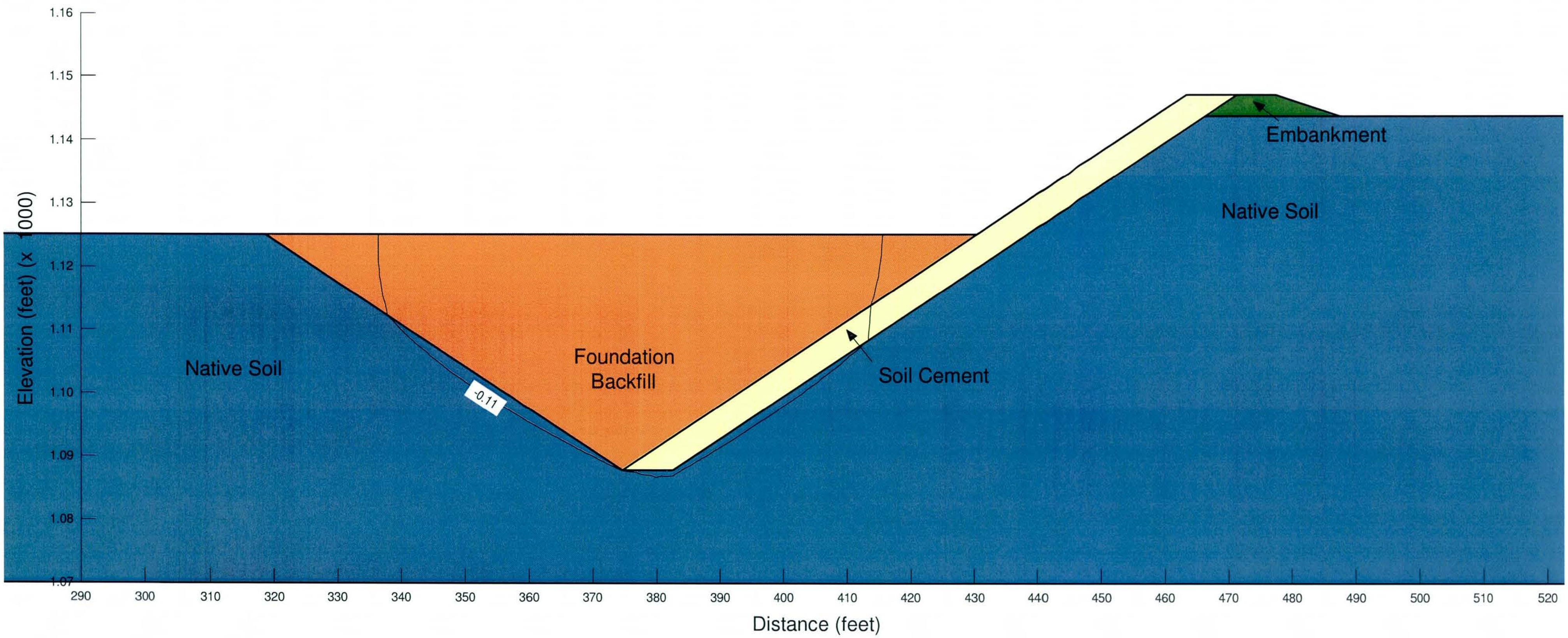
Steady State Seepage Analysis

Maximum Exit Gradient = 0



Job No. 17-2011-4021
Salt River North Bank - Station 206+00

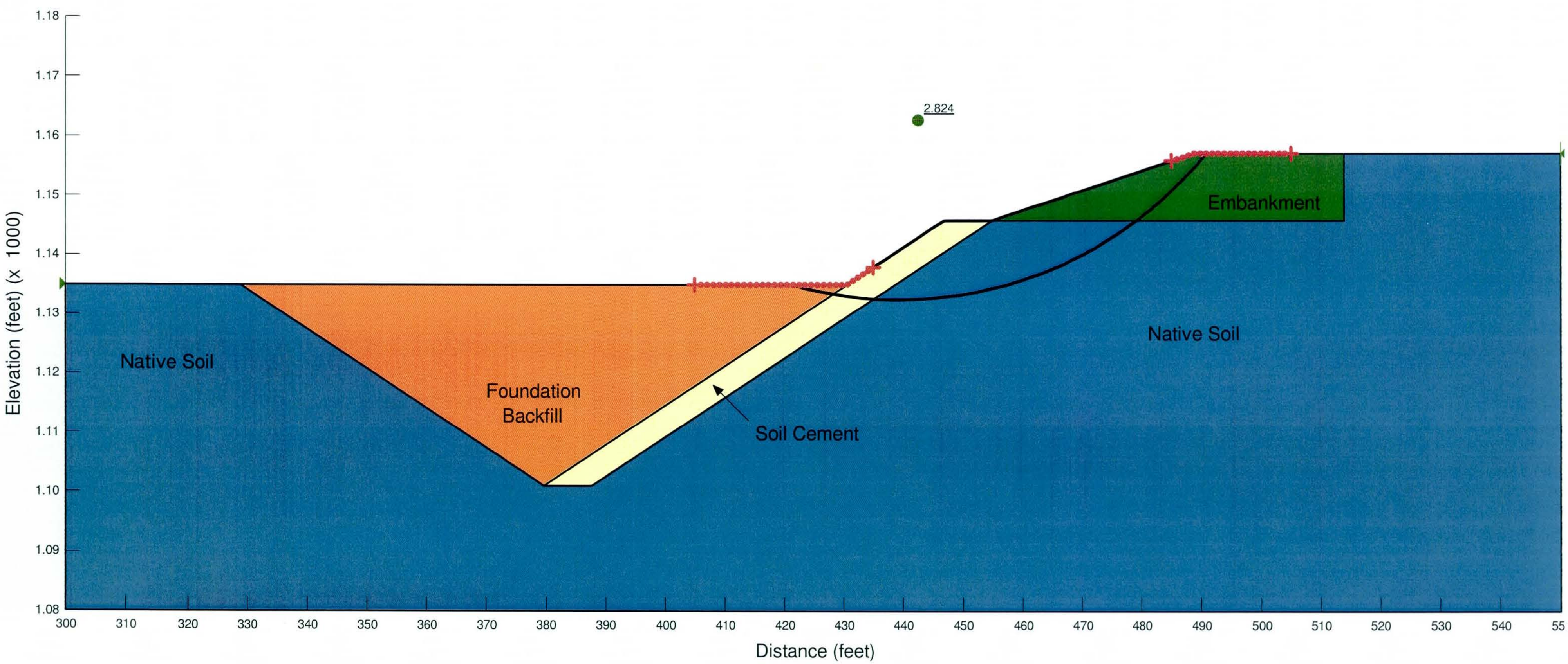
Settlement Analysis
Maximum Vertical Settlement Contour in Feet



Job No. 17-2011-4021
Salt River North Bank - Station 247+36

Case 1B - End of Construction
Riverside - Static

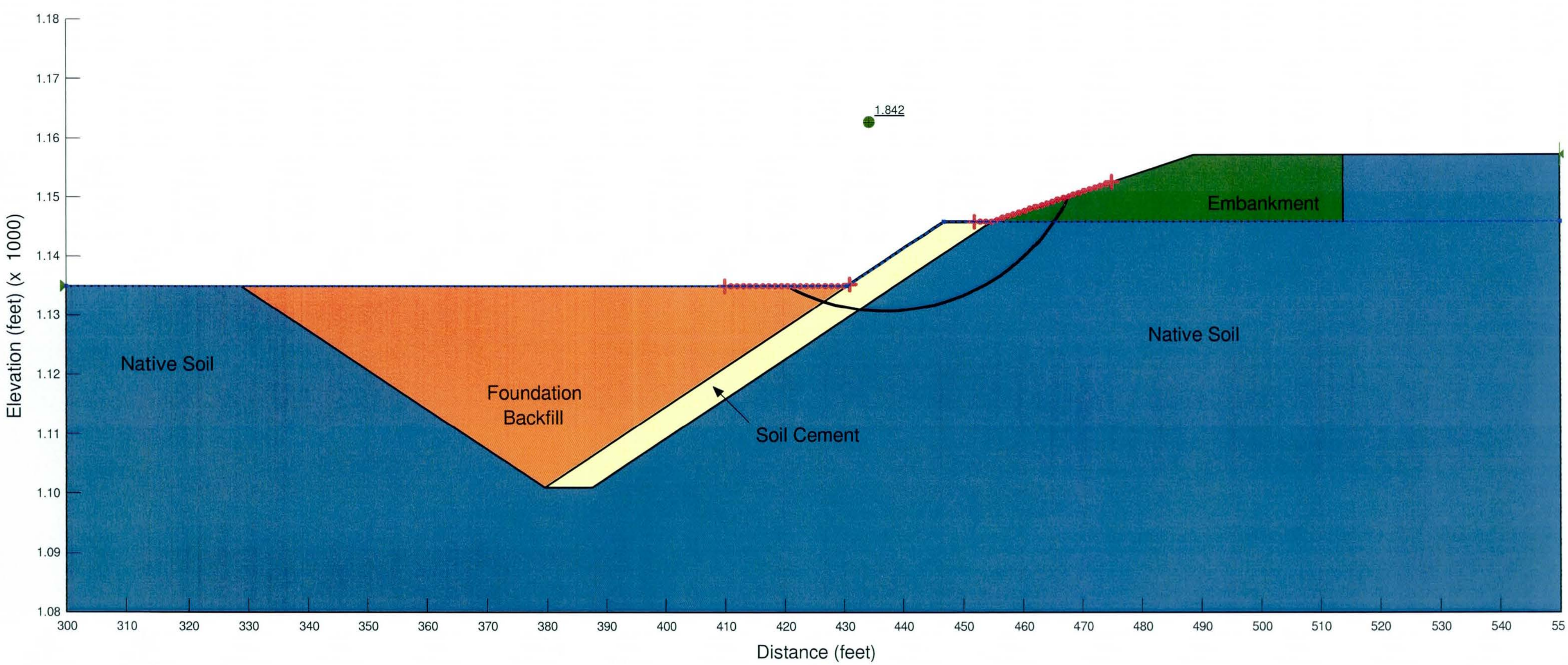
Factor of Safety = 2.82



Job No. 17-2011-4021
Salt River North Bank - Station 247+36

Case 2A - Sudden Drawdown
Riverside - Static

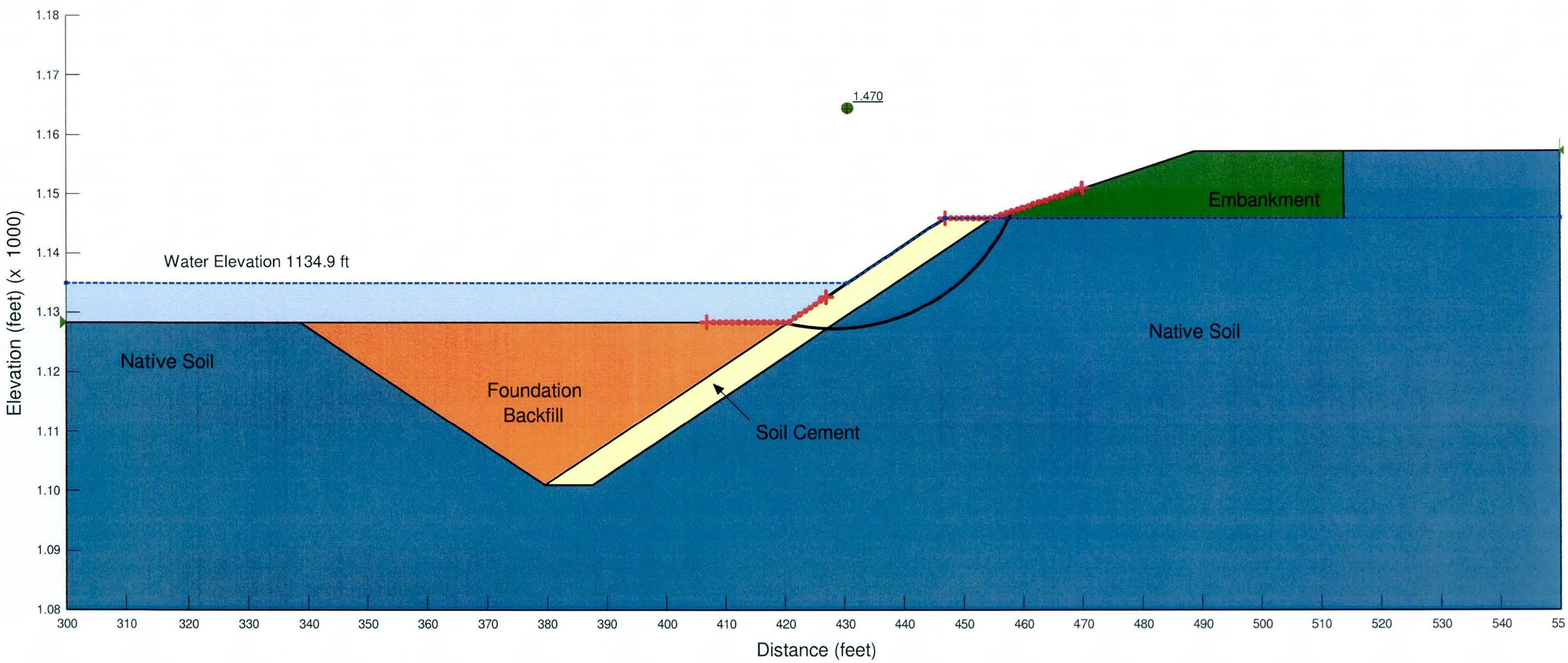
Factor of Safety = 1.84



Job No. 17-2011-4021
Salt River North Bank - Station 247+36

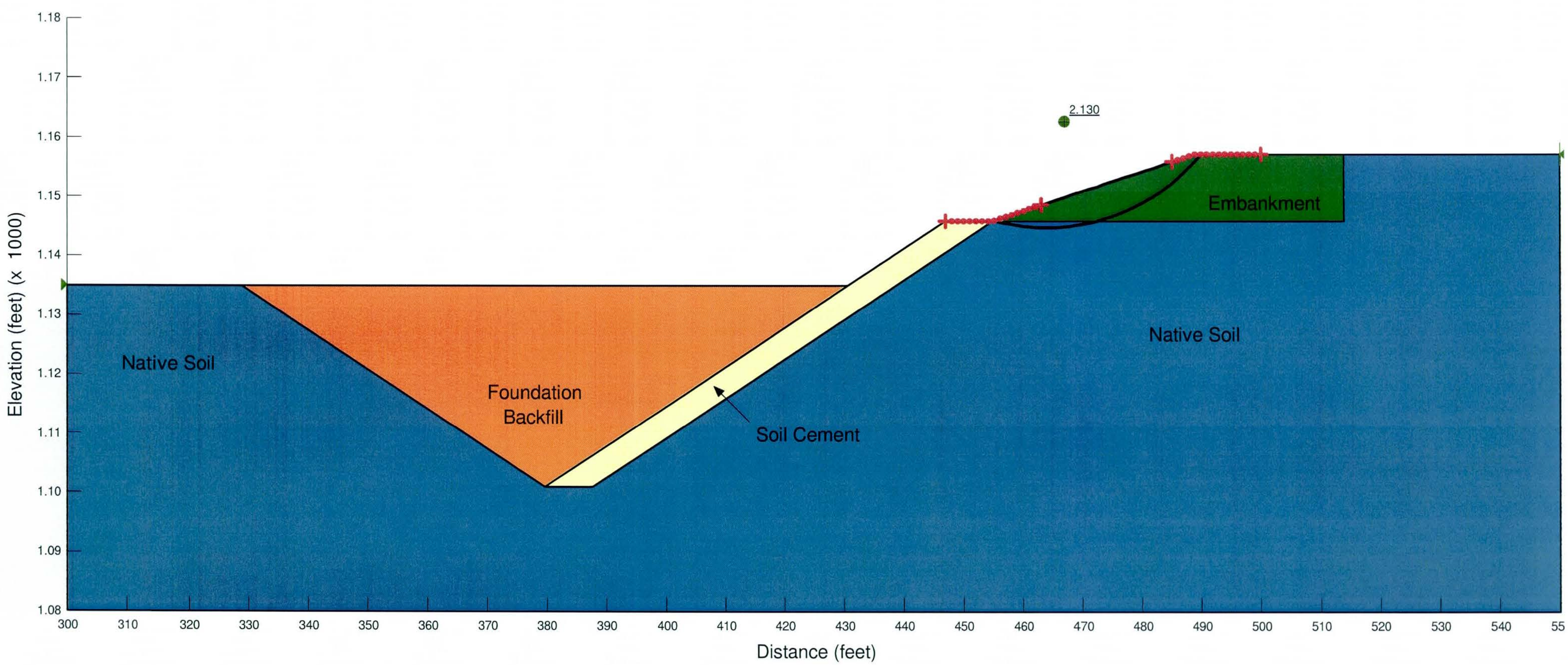
Case 2B - Sudden Drawdown with Scour Condition
Riverside - Static

Factor of Safety = 1.47



Job No. 17-2011-4021
Salt River North Bank - Station 247+36
Case 4B - End of Construction
Riverside - Pseudo Static (a=0.1g)

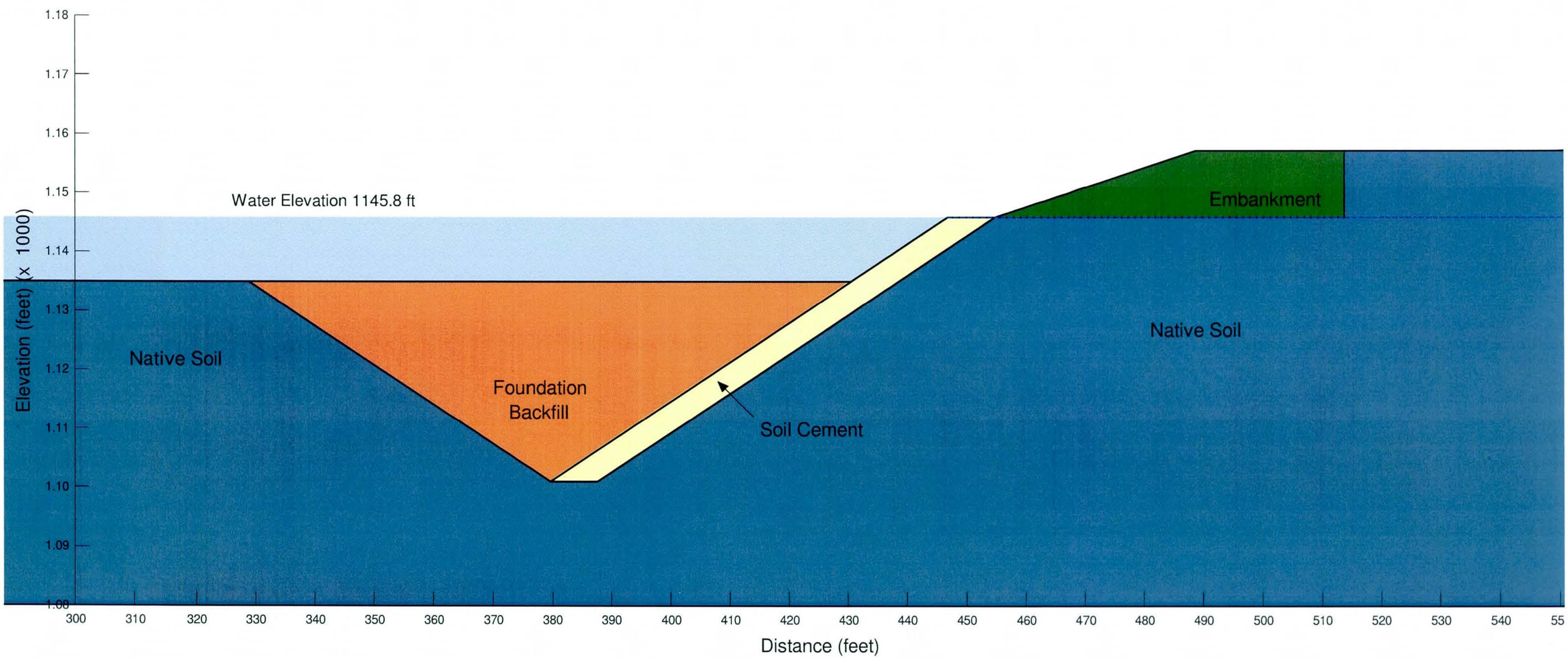
Factor of Safety = 2.13



Job No. 17-2011-4021
Salt River North Bank - Station 247+36

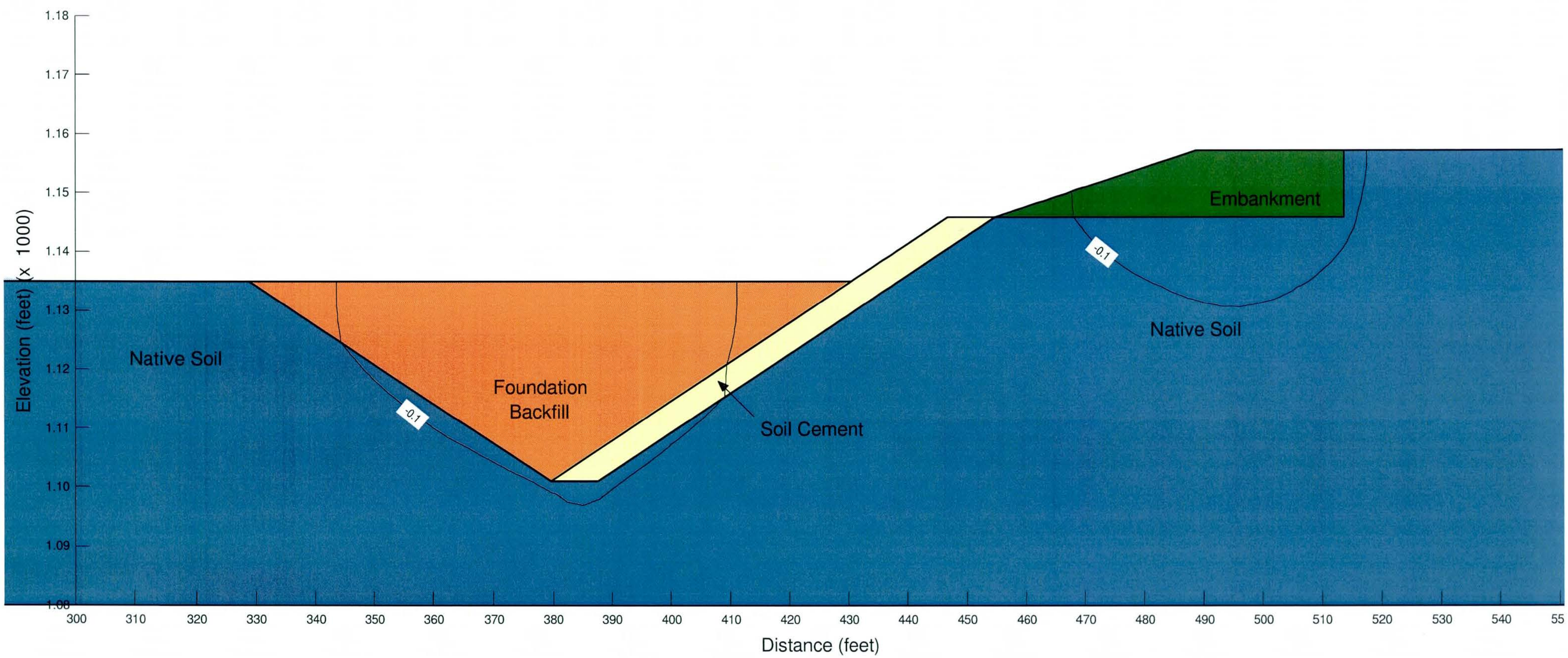
Steady State Seepage Analysis

Exit Gradient = 0



Job No. 17-2011-4021
Salt River North Bank - Station 247+36

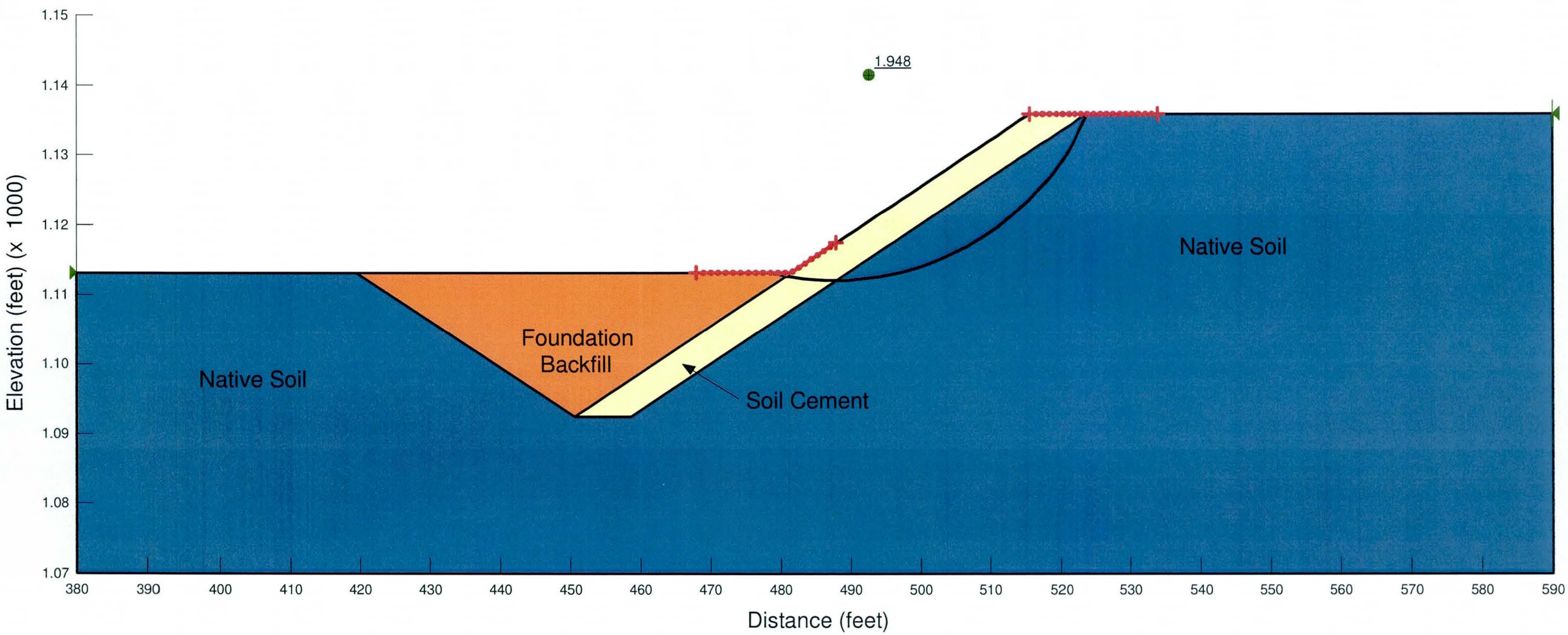
Settlement Analysis
Maximum Vertical Settlement Contour in Feet



SALT RIVER SOUTH BANK

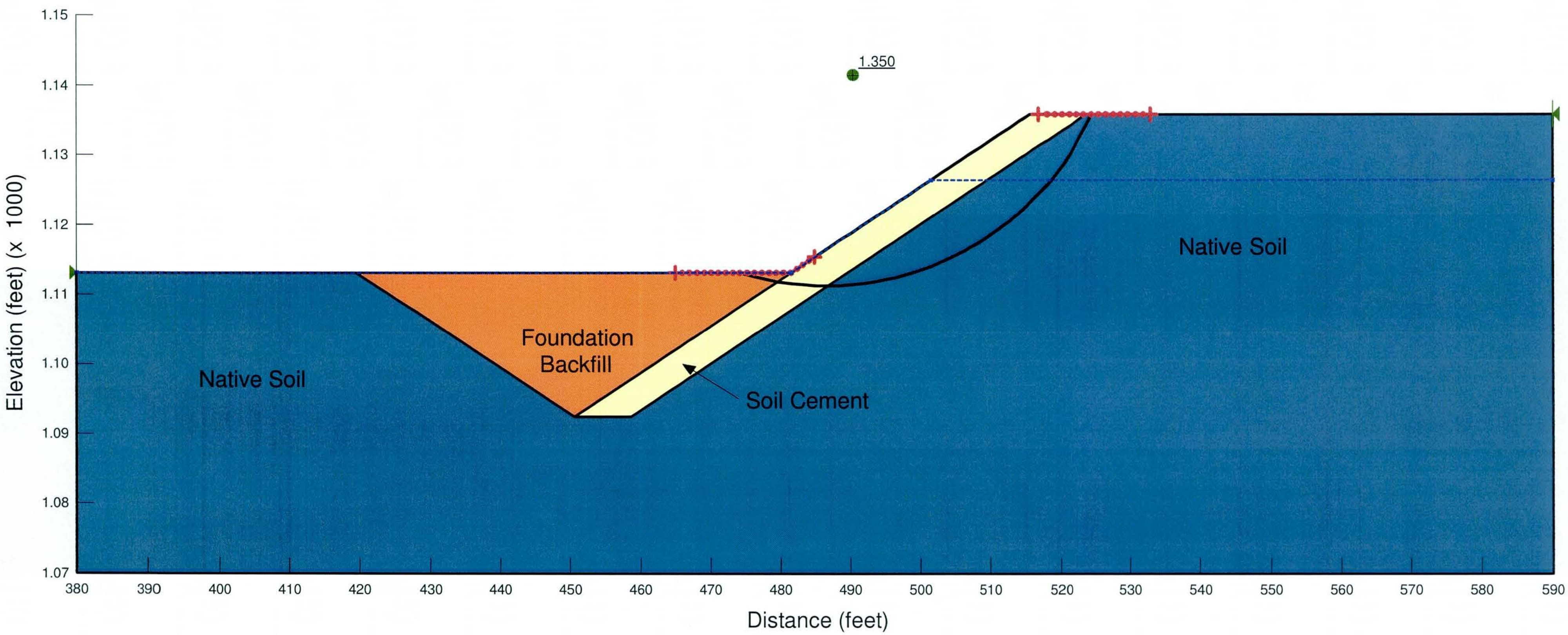
Job No. 17-2011-4021
Salt River South Bank - Station 155+20
Case 1B - End of Construction
Riverside - Static

Factor of Safety = 1.95



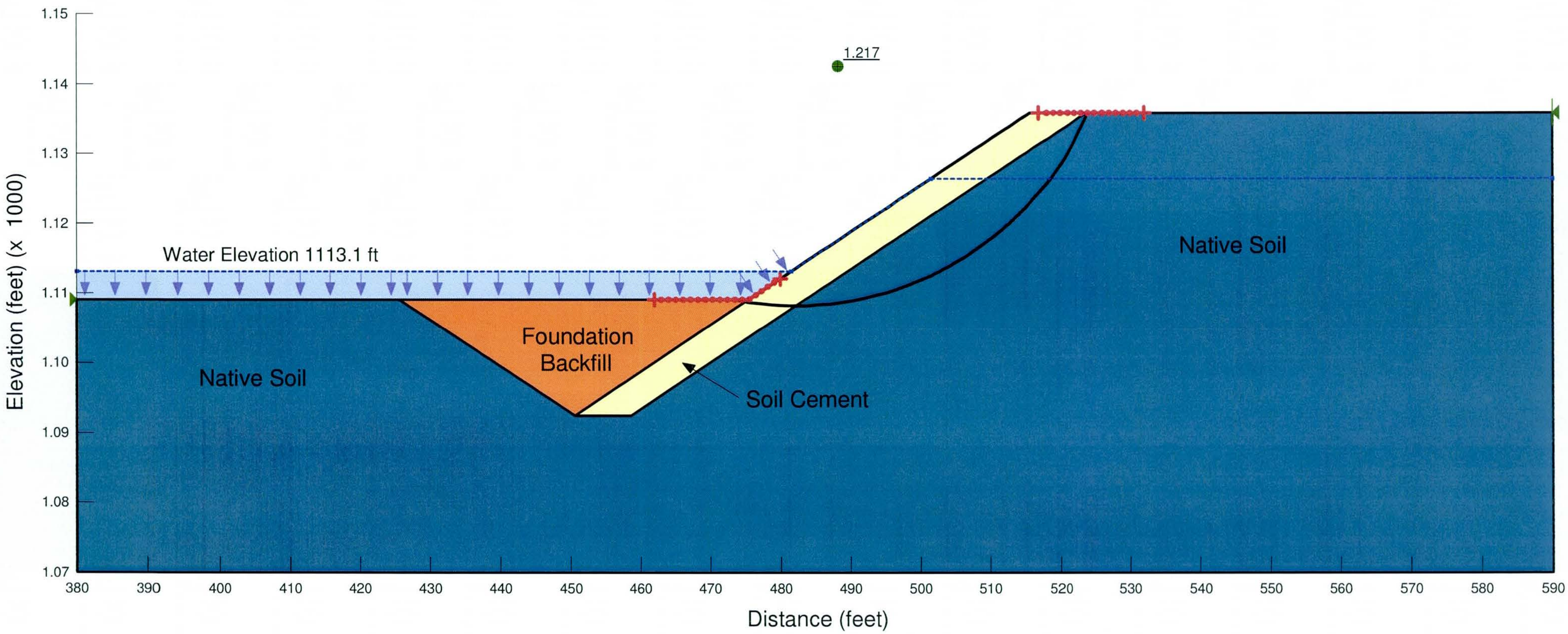
Job No. 17-2011-4021
Salt River South Bank - Station 155+20
Case 2A - Sudden Drawdown
Riverside - Static

Factor of Safety = 1.35



Job No. 17-2011-4021
Salt River South Bank - Station 155+20
Case 2B - Sudden Drawdown with Scour Condition
Riverside - Static

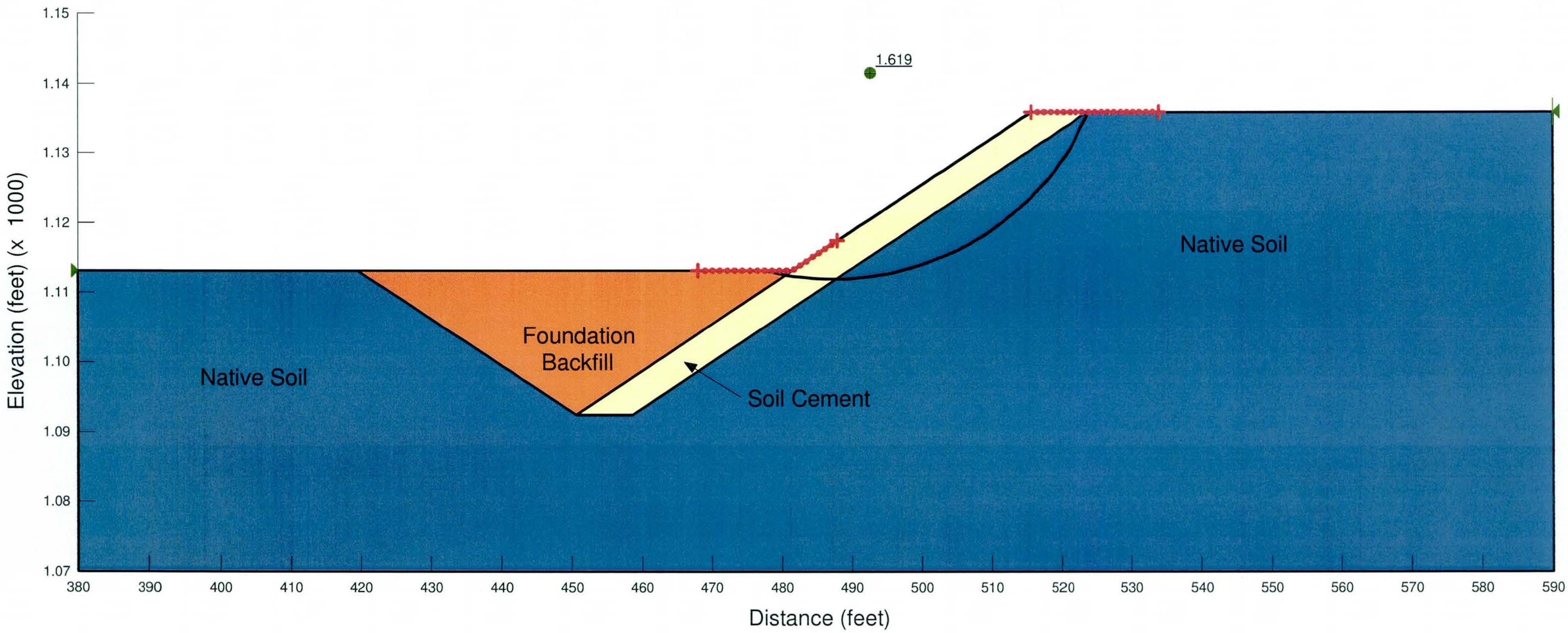
Factor of Safety = 1.22



Job No. 17-2011-4021
Salt River South Bank - Station 155+20

Case 4B - End of Construction
Riverside - Pseudo Static (a=0.1g)

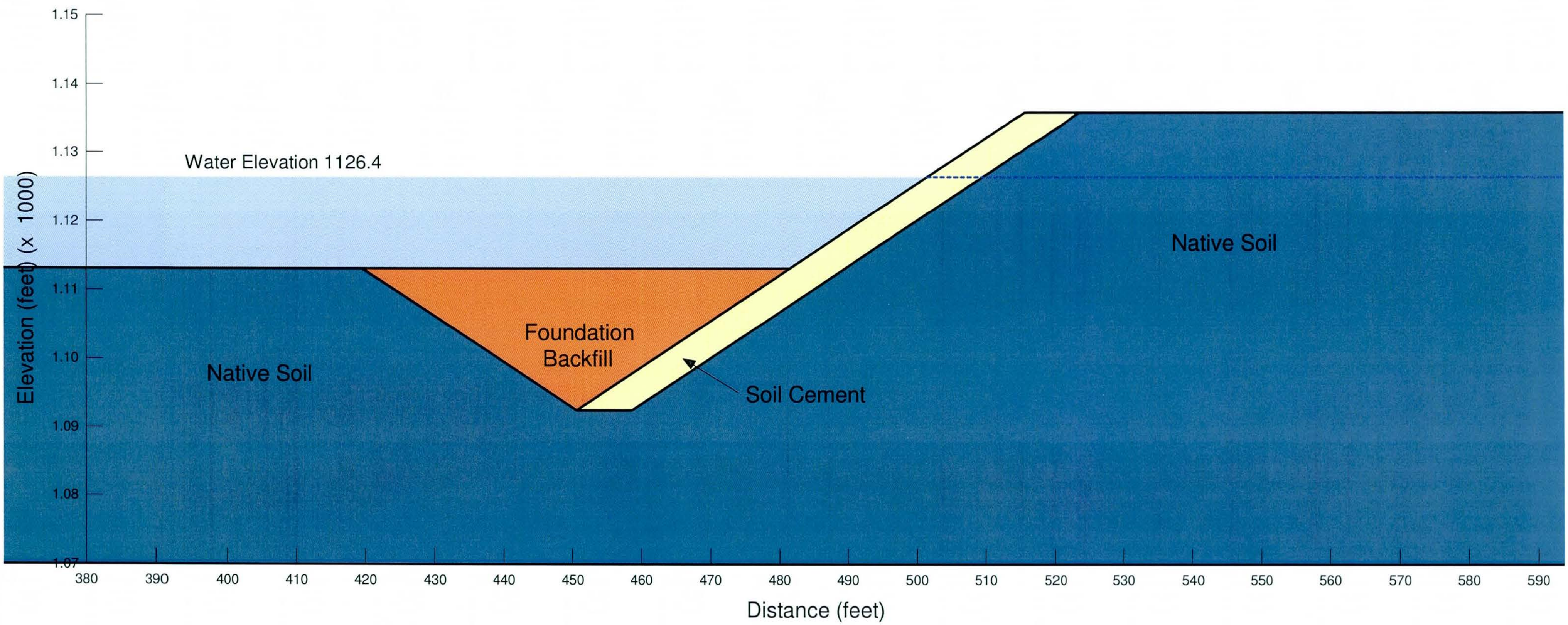
Factor of Safety = 1.62



Job No. 17-2011-4021
Salt River South Bank - Station 155+20

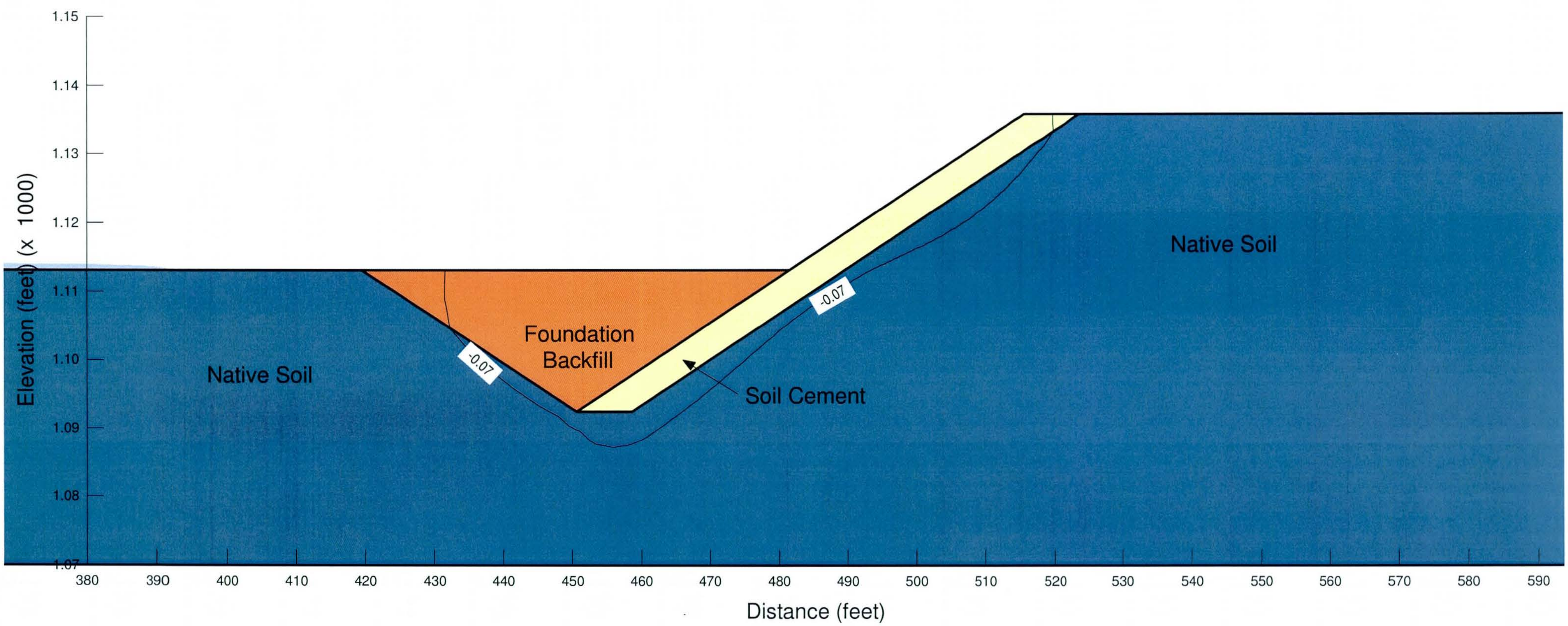
Steady State Seepage Analysis

Exit Gradient = 0



Job No. 17-2011-4021
Salt River South Bank - Station 155+20

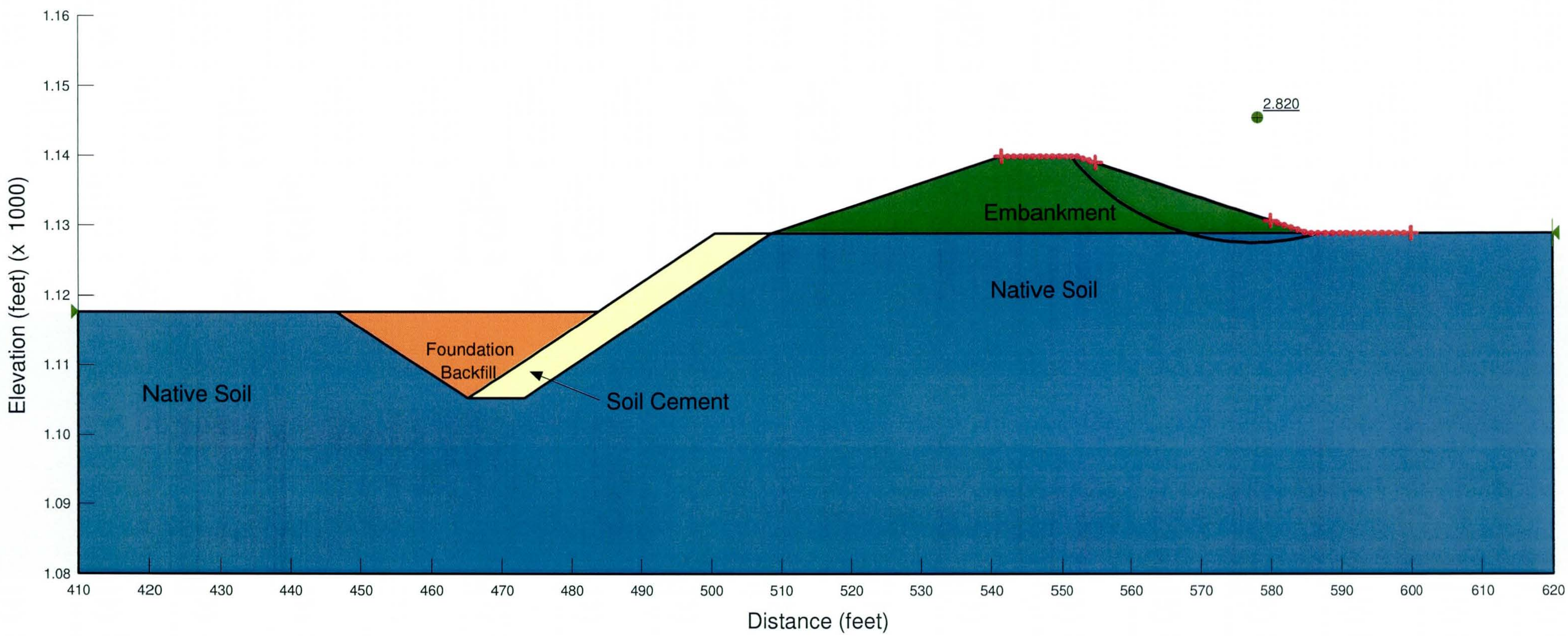
Settlement Analysis
Maximum Vertical Settlement Contour in Feet



Job No. 17-2011-4021
Salt River South Bank - Station 174+00

Case 1A - End of Construction
Landside - Static

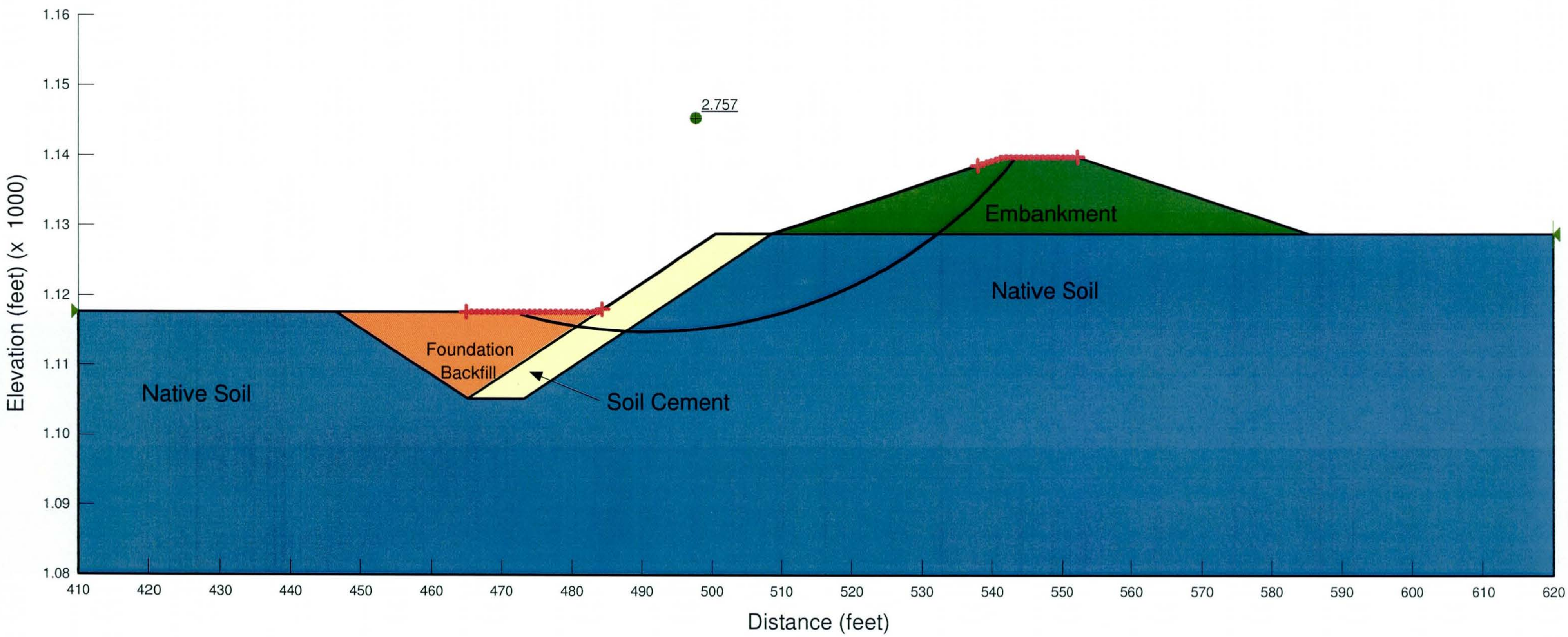
Factor of Safety = 2.82



Job No. 17-2011-4021
Salt River South Bank - Station 174+00

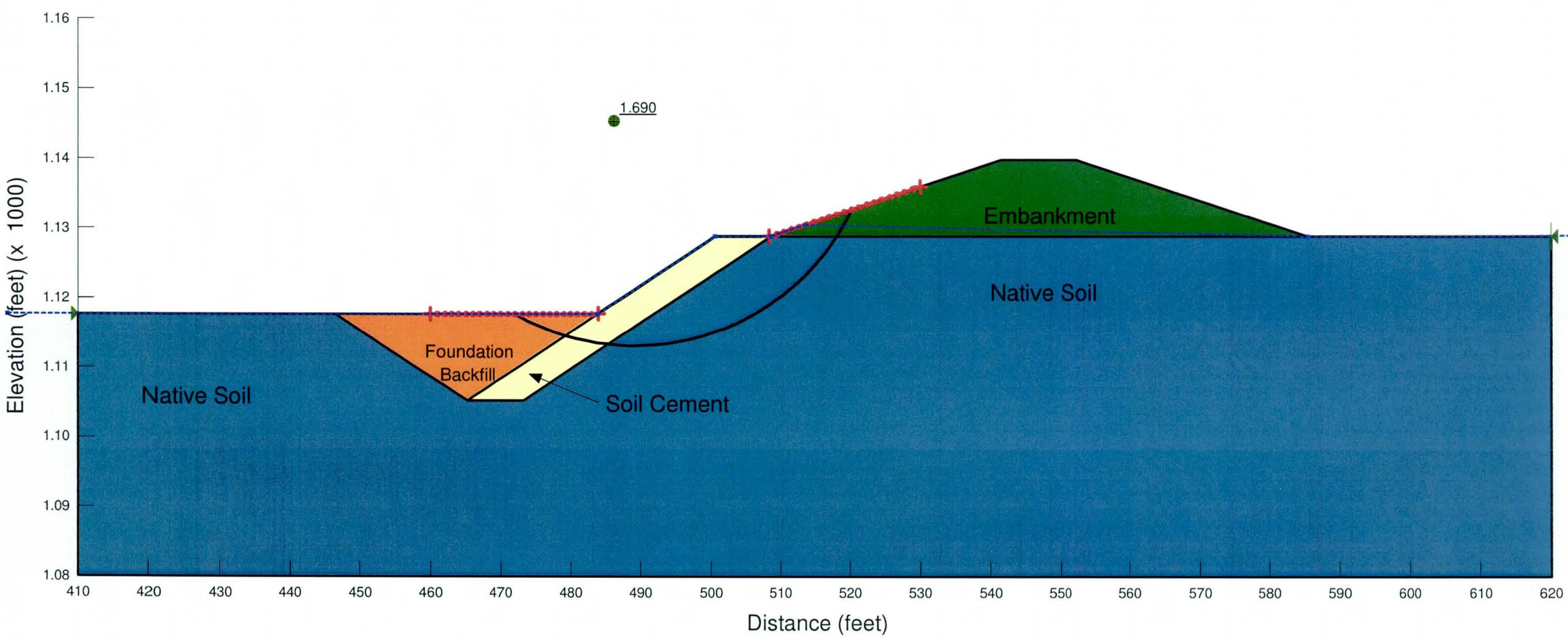
Case 1B - End of Construction
Riverside - Static

Factor of Safety = 2.76



Job No. 17-2011-4021
Salt River South Bank - Station 174+00
Case 2A - Sudden Drawdown
Riverside - Static

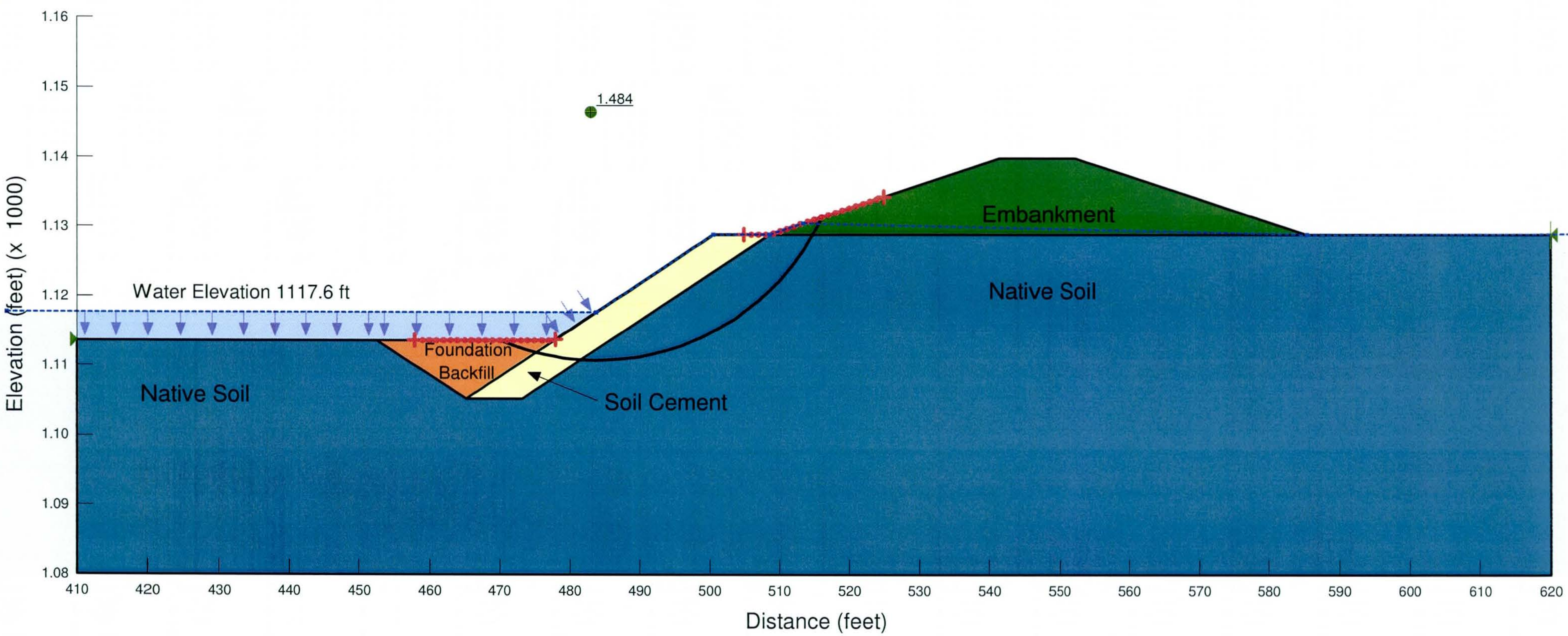
Factor of Safety = 1.69



Job No. 17-2011-4021
Salt River South Bank - Station 174+00

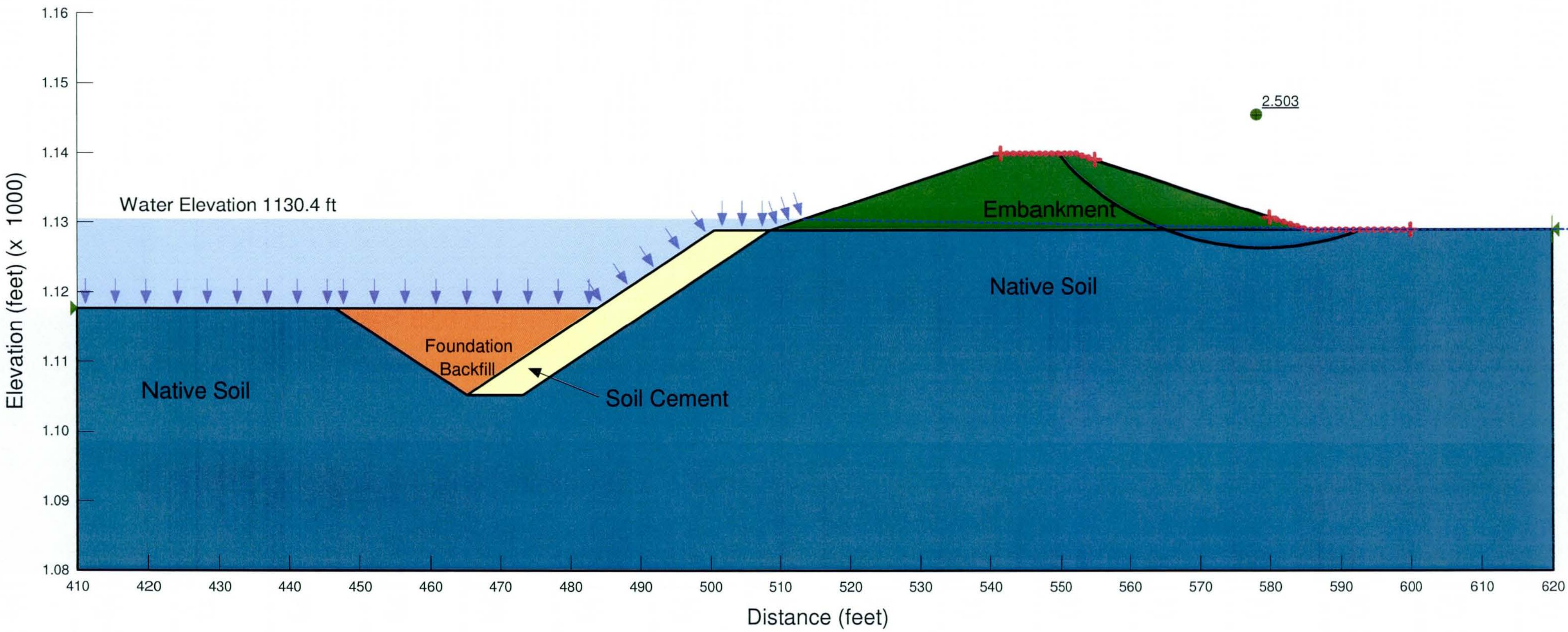
Case 2B - Sudden Drawdown with Scour Condition
Riverside - Static

Factor of Safety = 1.48



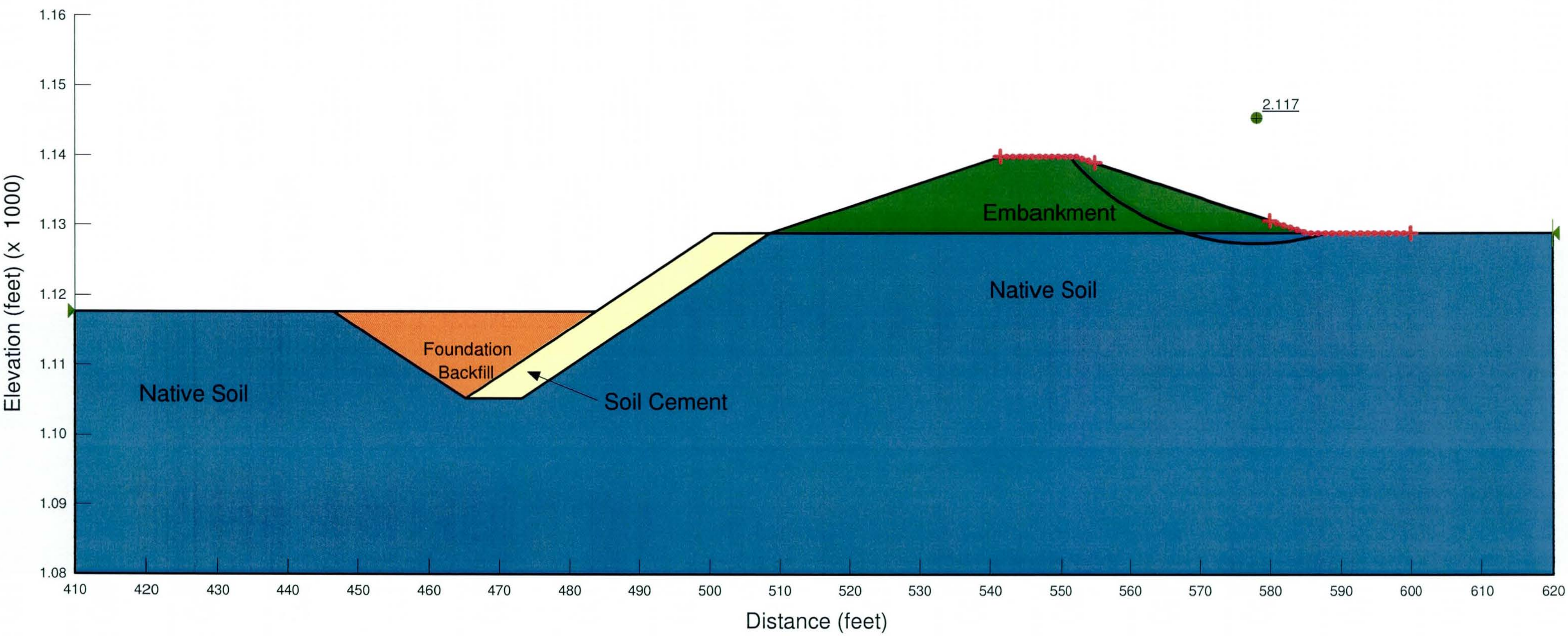
Job No. 17-2011-4021
Salt River South Bank - Station 174+00
Case 3A - Steady State Seepage Under 100-year Flood Level Condition
Landside - Static

Factor of Safety = 2.50



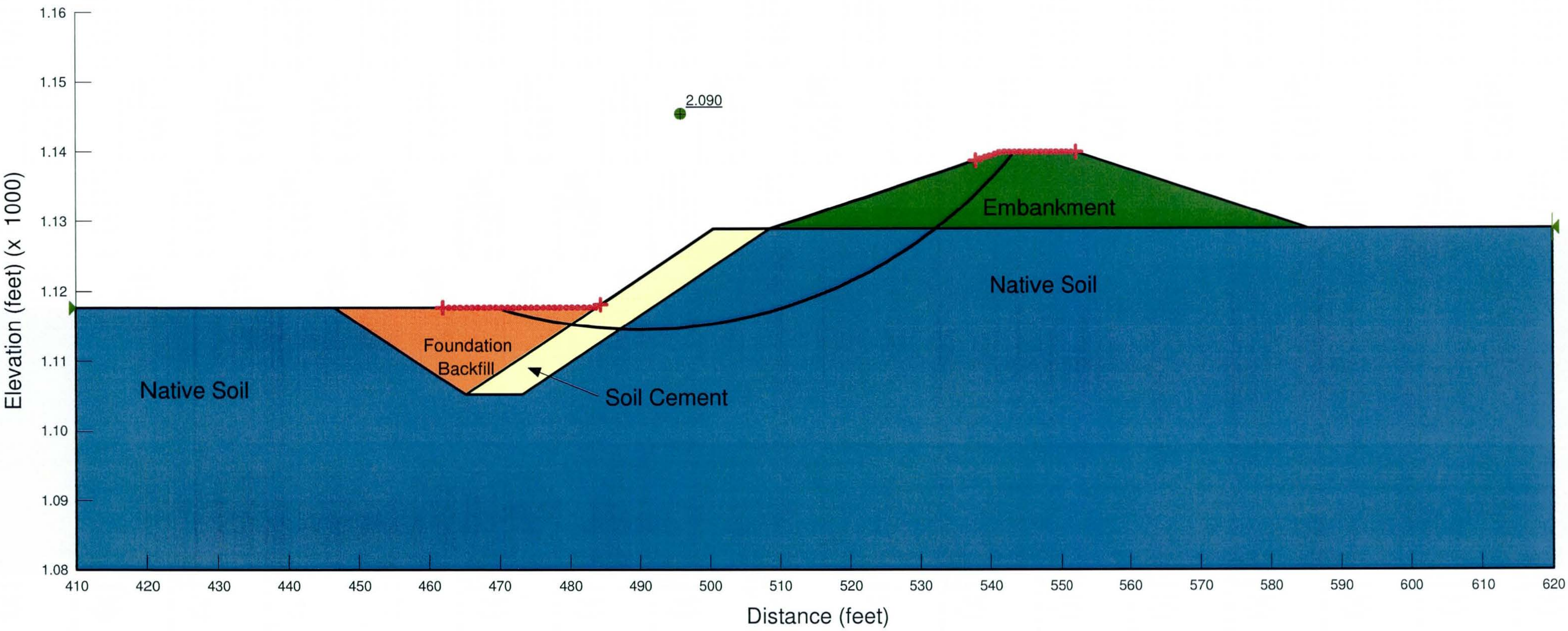
Job No. 17-2011-4021
Salt River South Bank - Station 174+00
Case 4A - End of Construction
Landside - Pseudo Static (a=0.1g)

Factor of Safety = 2.12



Job No. 17-2011-4021
Salt River South Bank - Station 174+00
Case 4B - End of Construction
Riverside - Pseudo Static (a=0.1g)

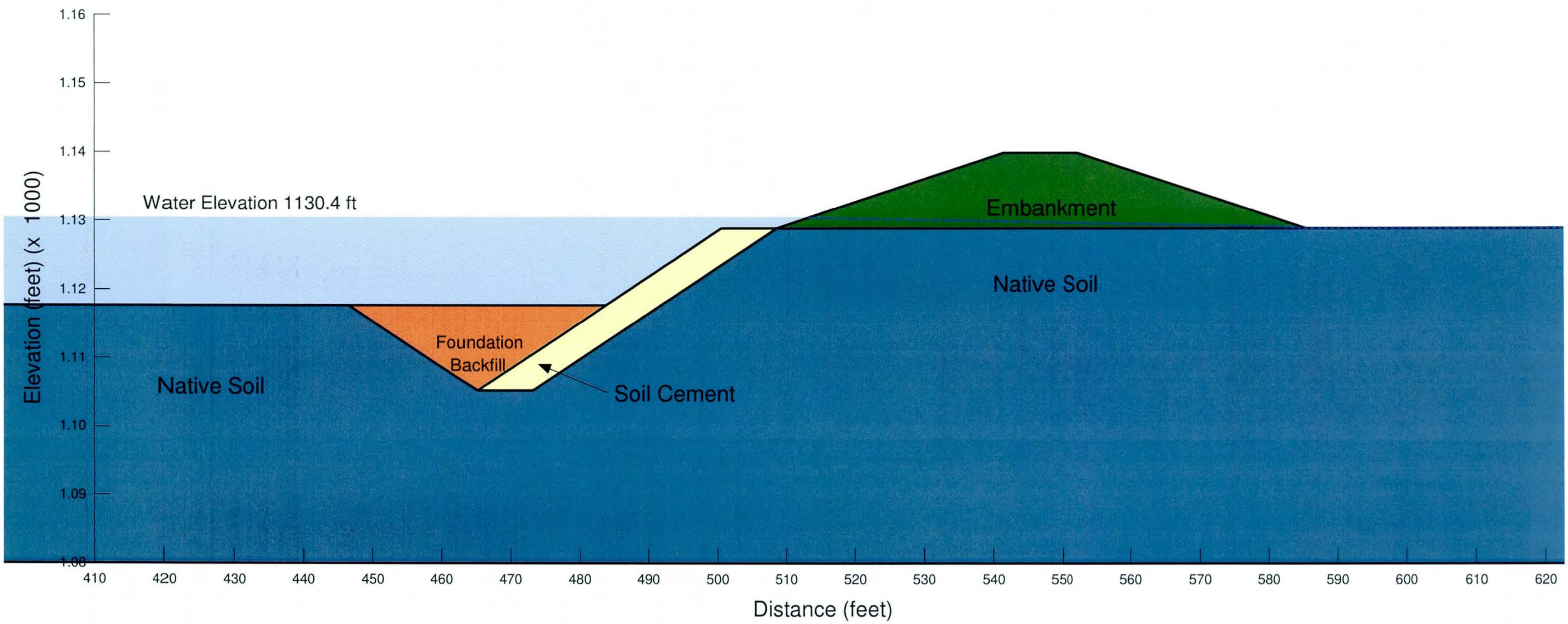
Factor of Safety = 2.09



Job No. 17-2011-4021
Salt River South Bank - Station 174+00

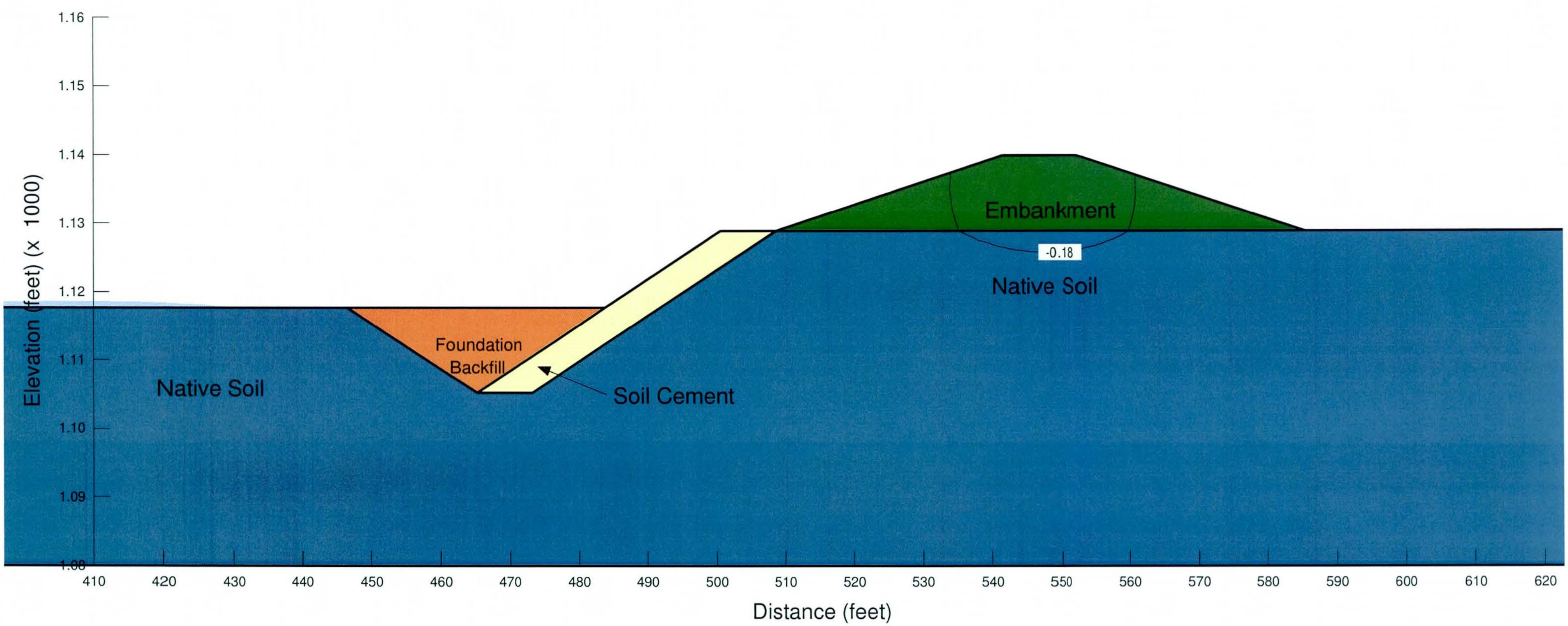
Steady State Seepage Analysis

Exit Gradient = 0.06



Job No. 17-2011-4021
Salt River South Bank - Station 174+00

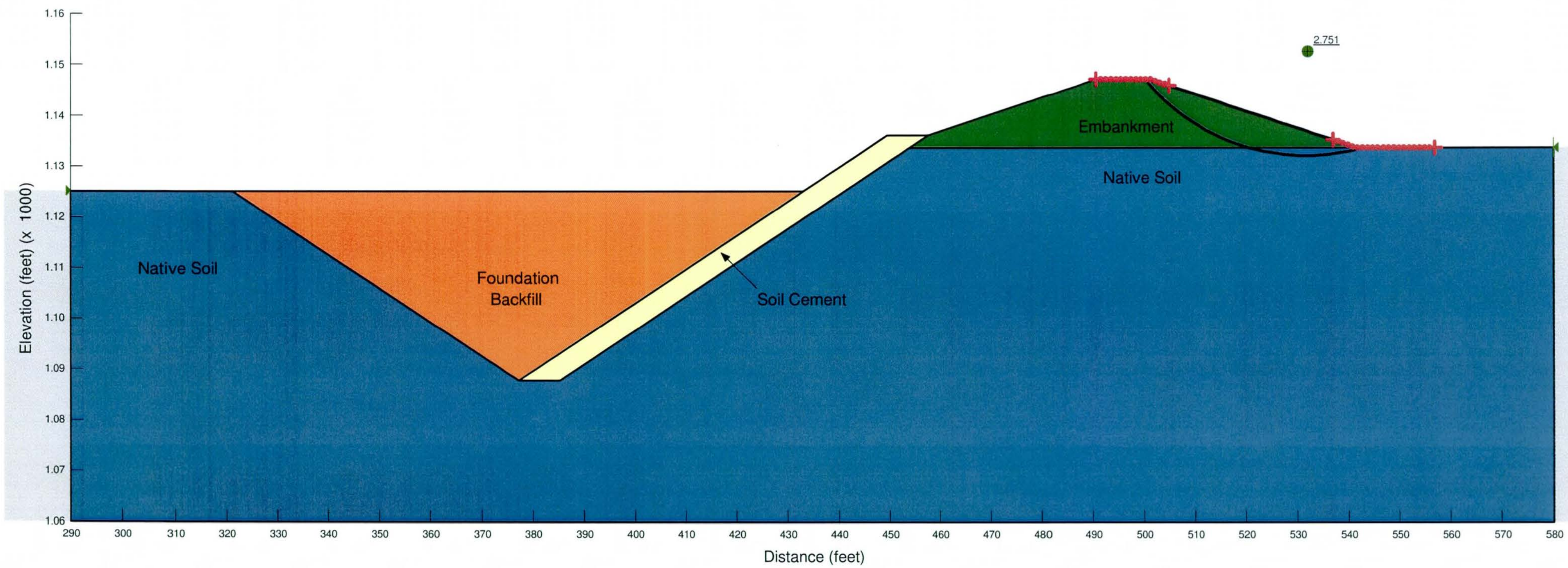
Settlement Analysis
Maximum Vertical Settlement Contour in Feet



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

Case 1A - End of Construction
Landside - Static

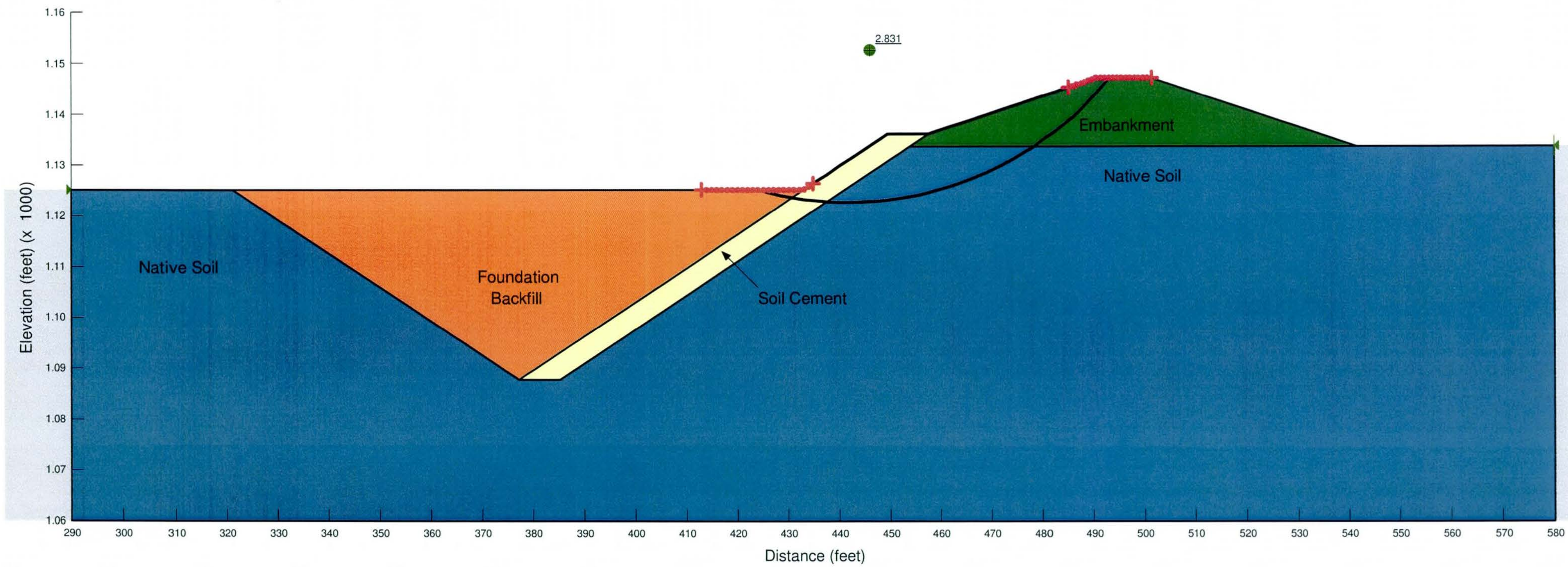
Factor of Safety = 2.75



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

Case 1B - Endo of Construction
Riverside - Static

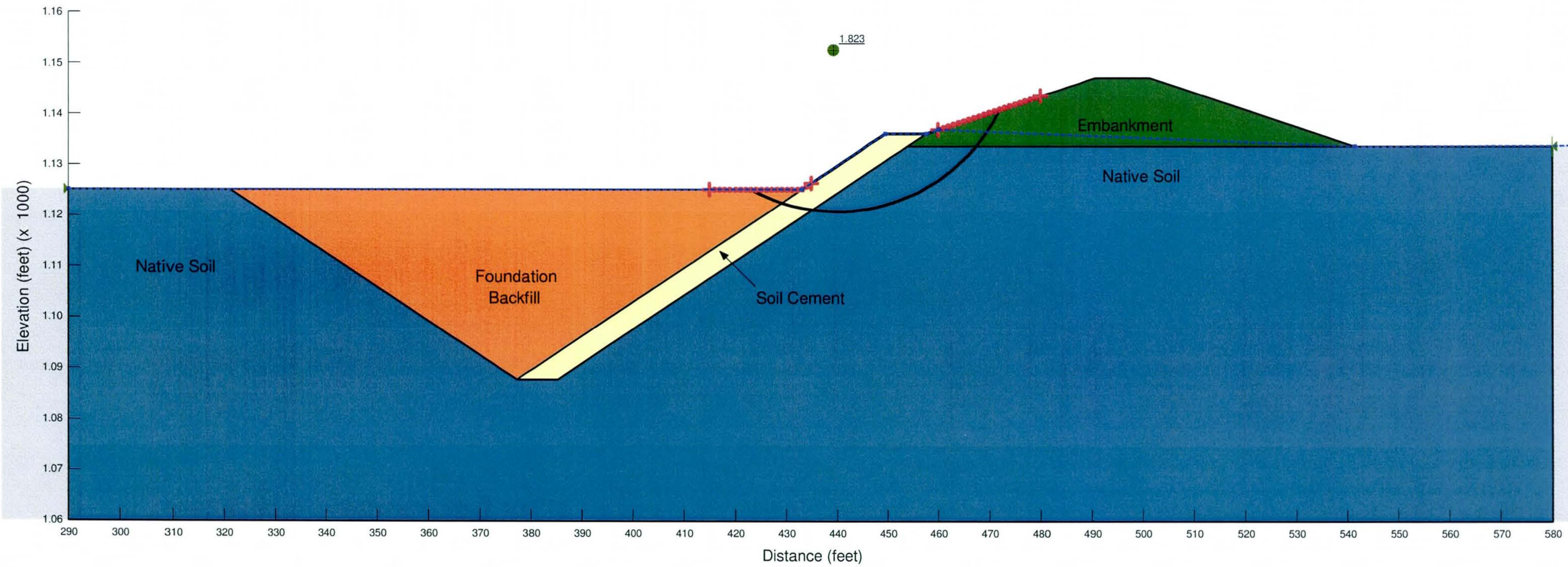
Factor of Safety = 2.83



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

Case 2A - Sudden Drawdown
Riverside - Static

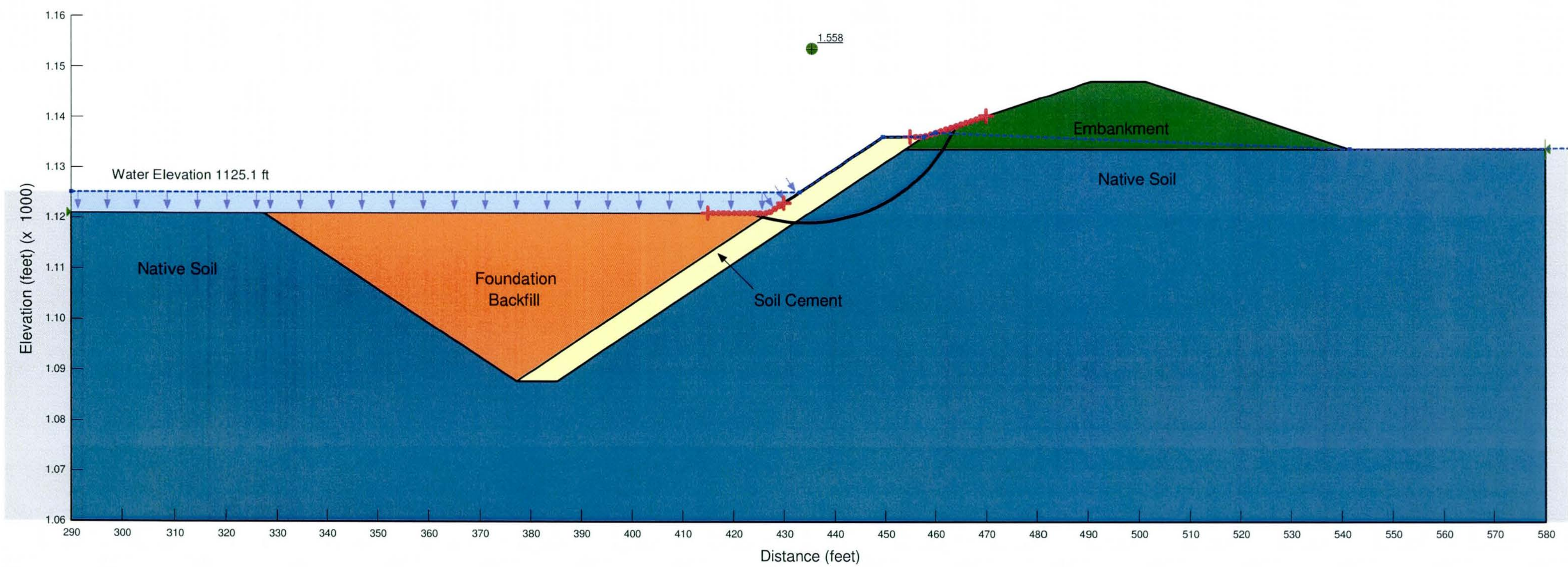
Factor of Safety = 1.82



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

Case 2B - Sudden Drawdown with Scour Condition
Riverside - Static

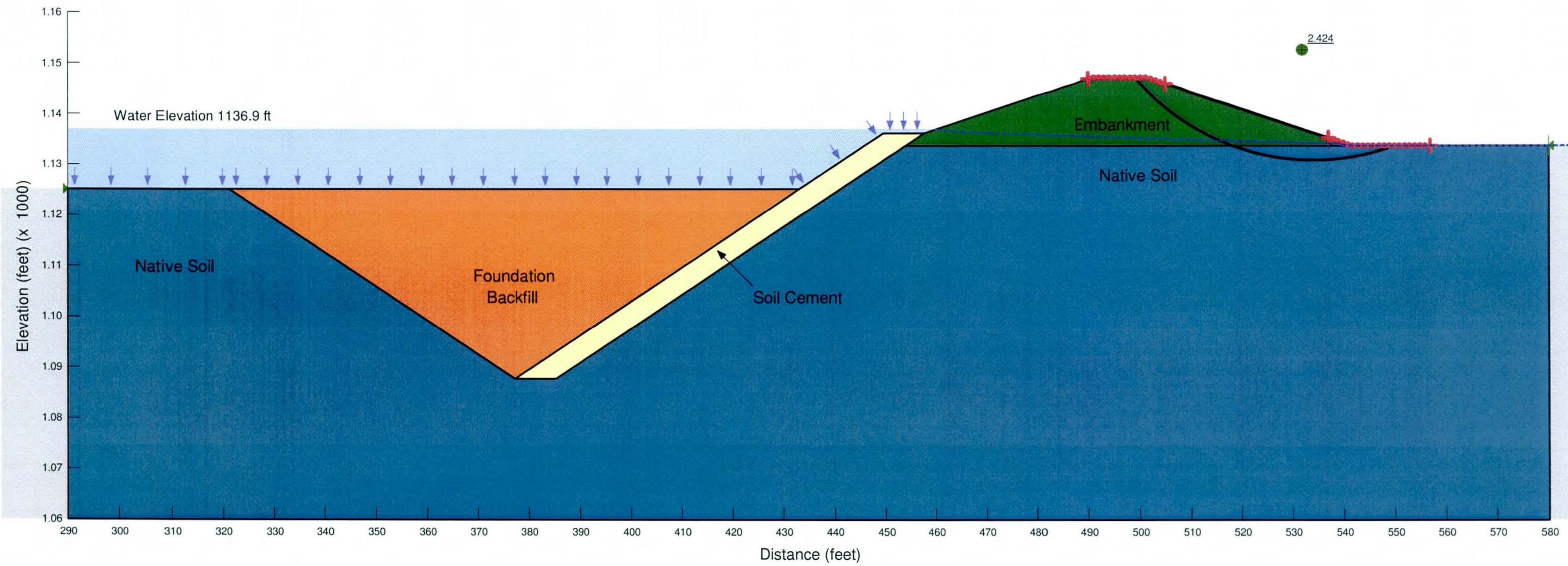
Factor of Safety = 1.56



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

Case 3A - Steady State Seepage Under 100-year Flood Level Condition
Landside - Static

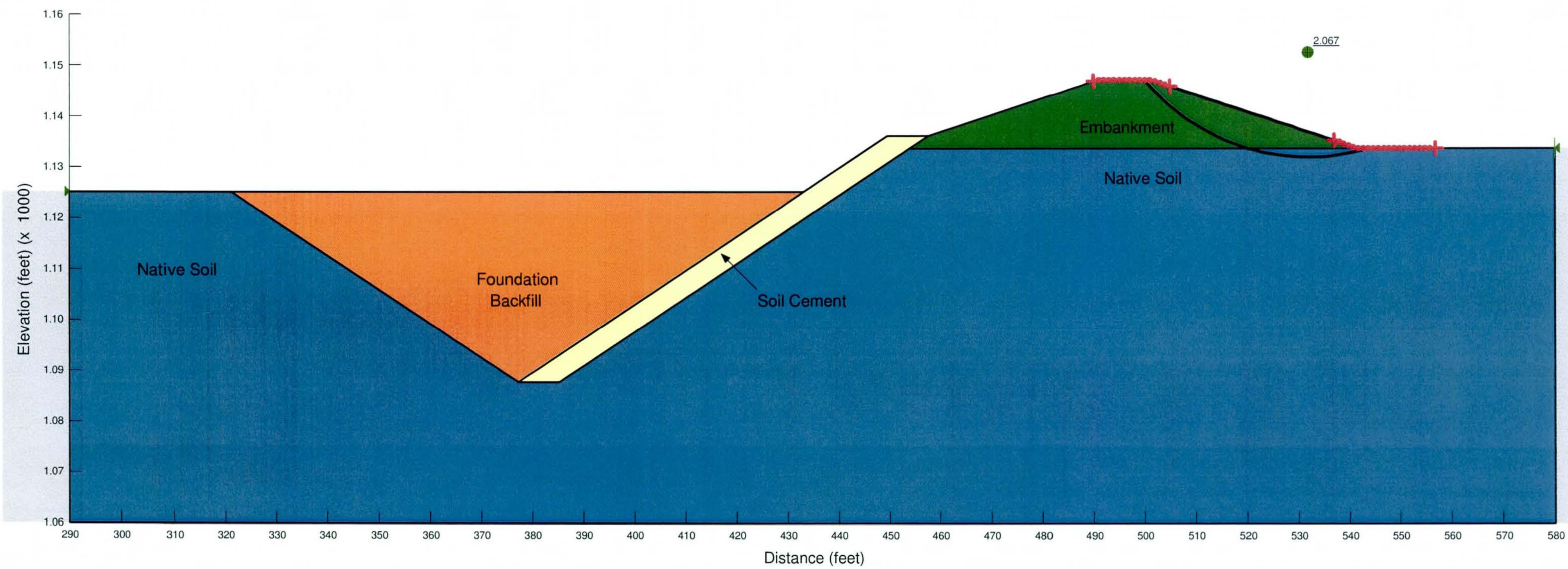
Factor of Safety = 2.42



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

Case 4A - End of Construction
Landside - Pseudo Static (a=0.1g)

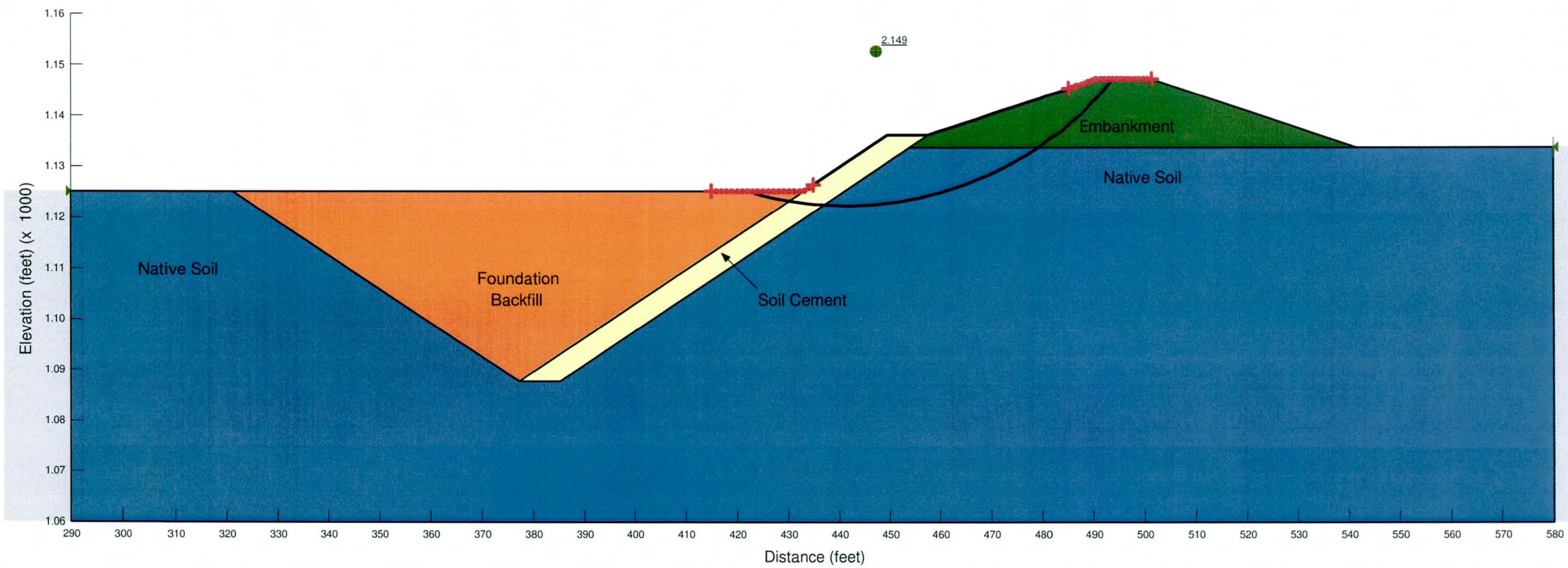
Factor of Safety = 2.07



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

Case 4B - End of Construction
Riverside - Pseudo Static (a=0.1g)

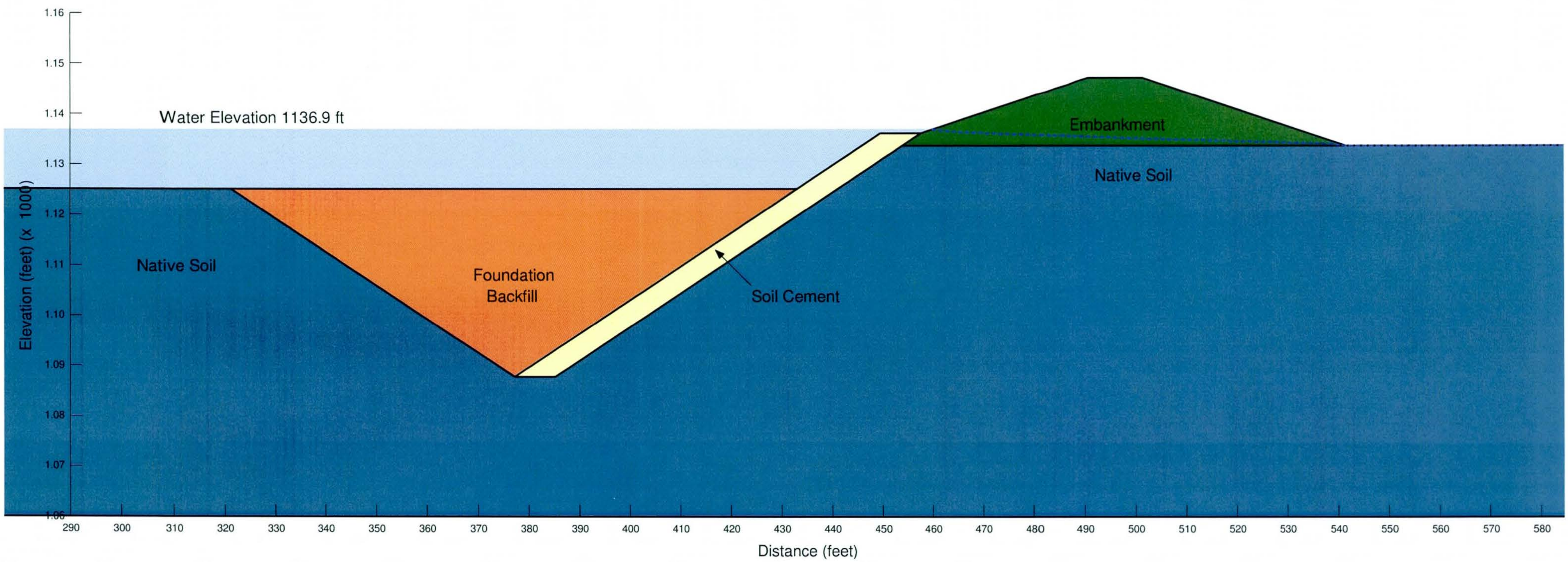
Factor of Safety = 2.15



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

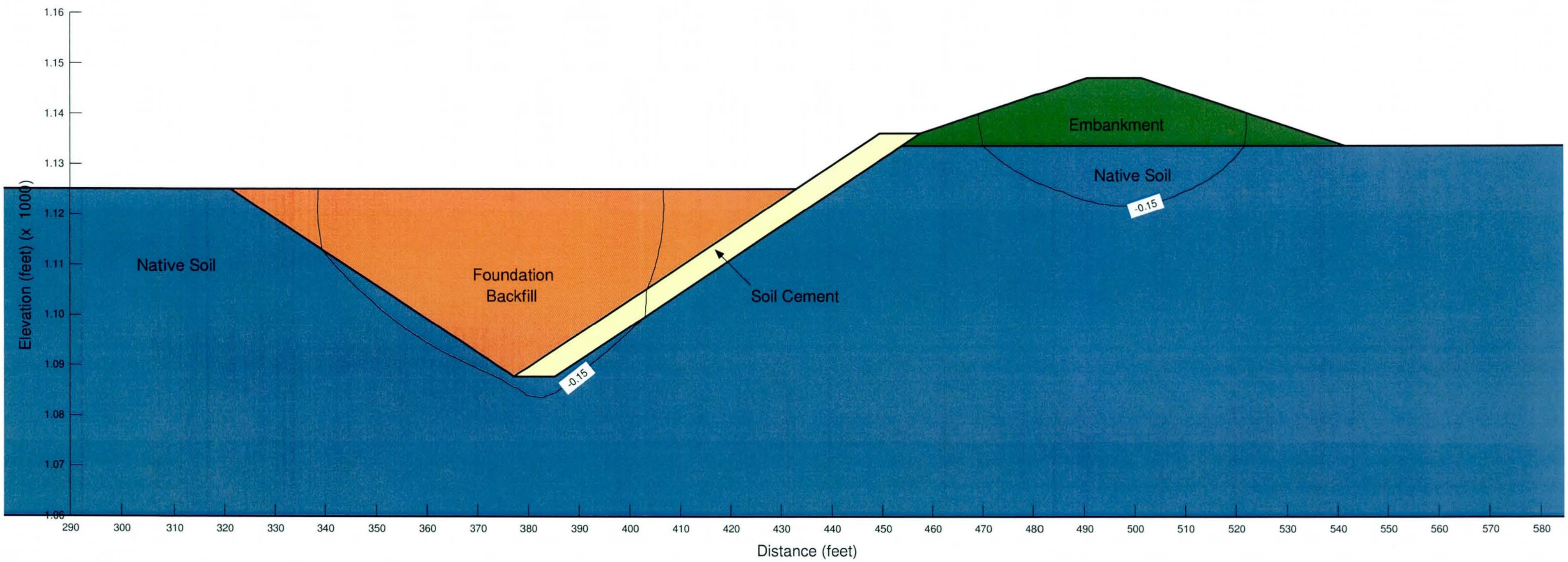
Steady State Seepage Analysis

Exit Gradient = 0.1



Job No. 17-2011-4021
Salt River South Bank - Station 206+00

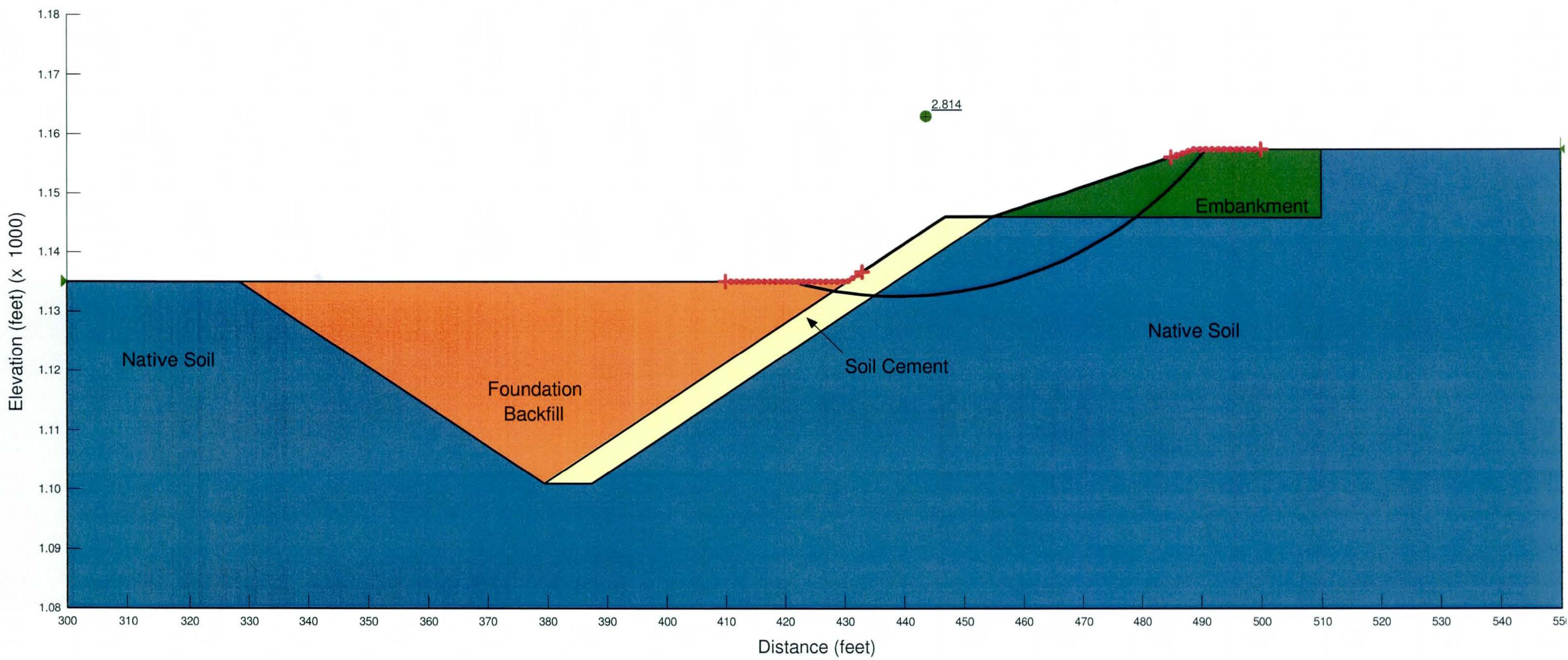
Settlement Analysis
Maximum Vertical Settlement Contour in Feet



Job No. 17-2011-4021
Salt River South Bank - Station 248+00

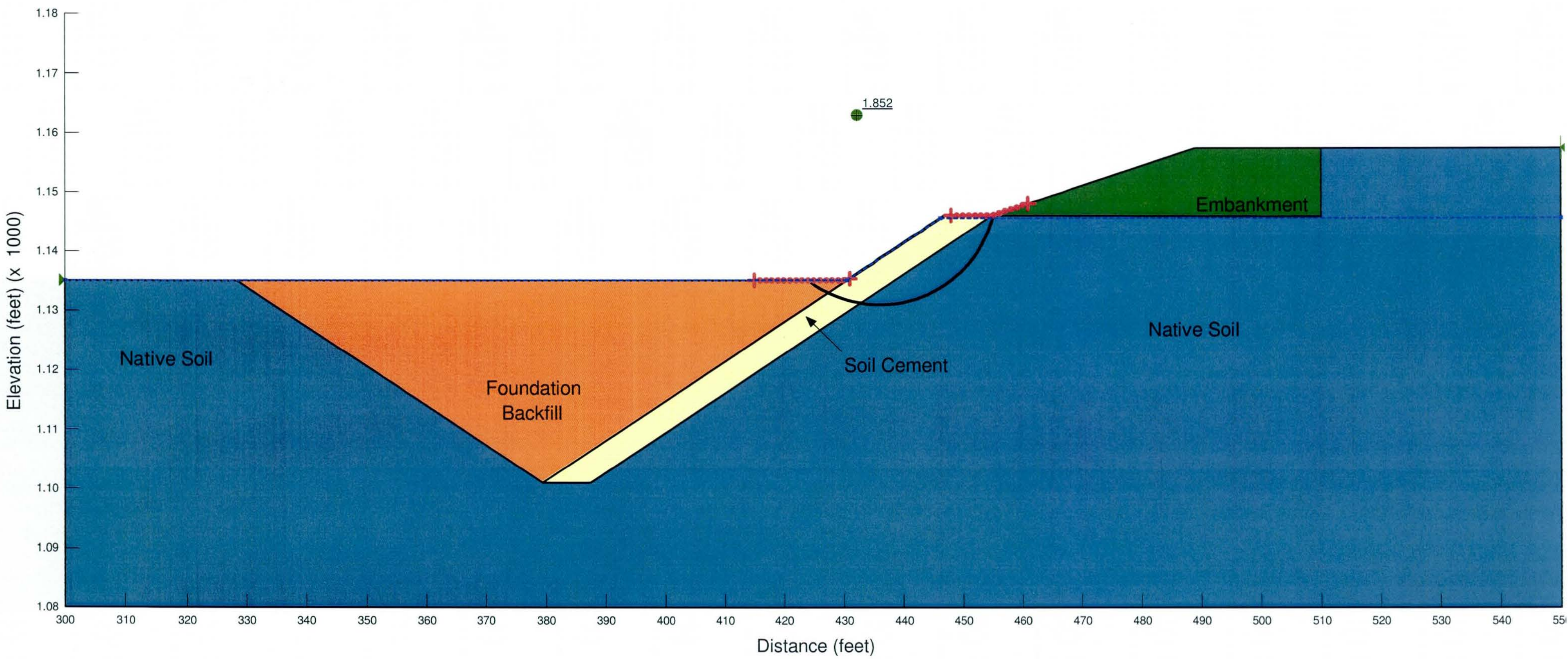
Case 1B - End of Construction
Riverside - Static

Factor of Safety = 2.81



Job No. 17-2011-4021
Salt River South Bank - Station 248+00
Case 2A - Sudden Drawdown
Riverside - Static

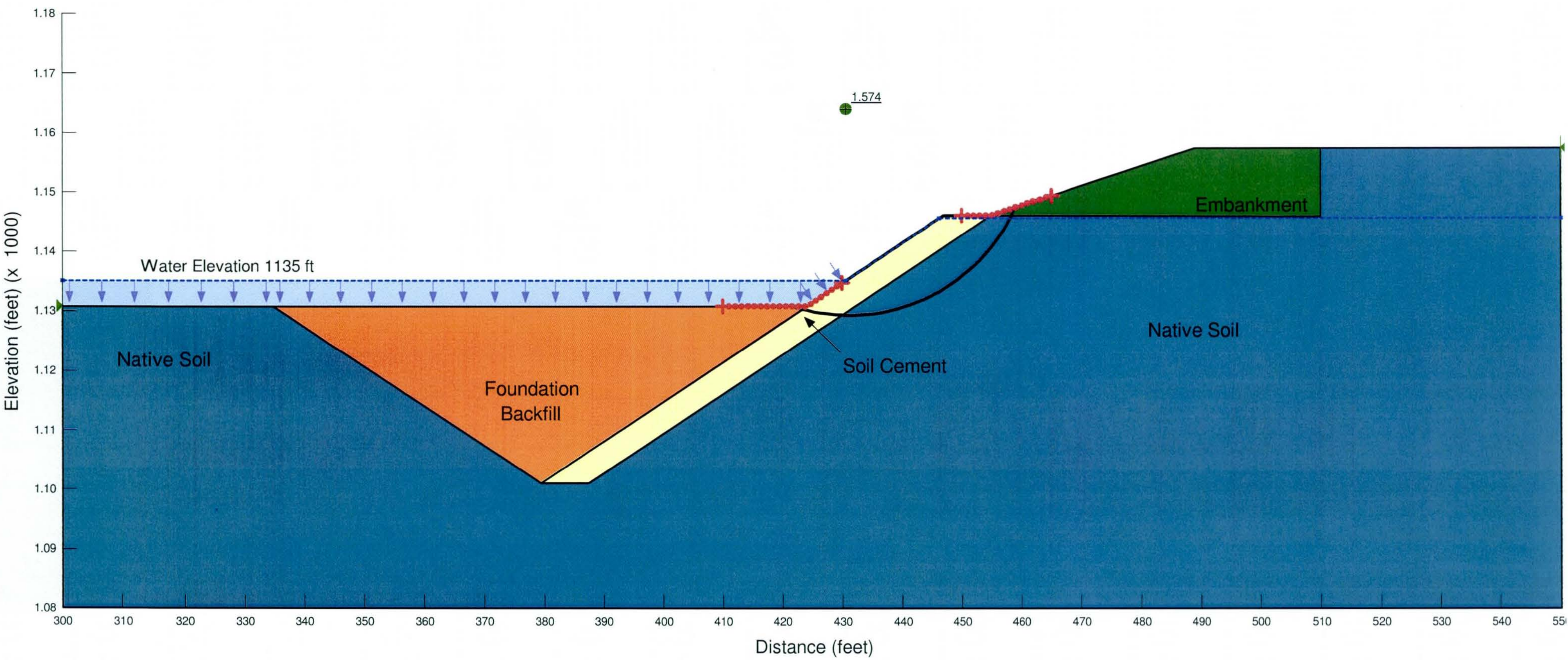
Factor of Safety = 1.85



Job No. 17-2011-4021
Salt River South Bank - Station 248+00

Case 2B - Sudden Drawdown with Scour Condition
Riverside - Static

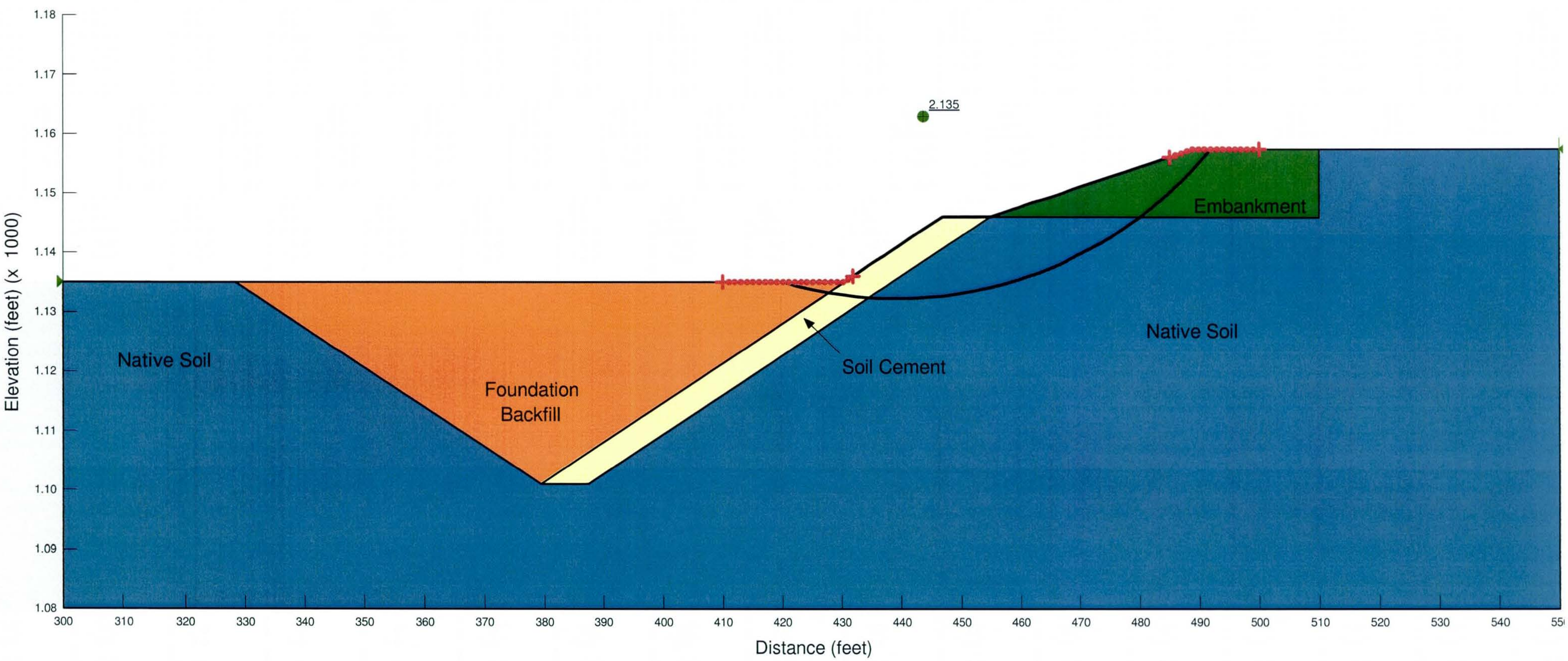
Factor of Safety = 1.57



Job No. 17-2011-4021
Salt River South Bank - Station 248+00

Case 4B - End of Construction
Riverside - Pseudo Static (a=0.1g)

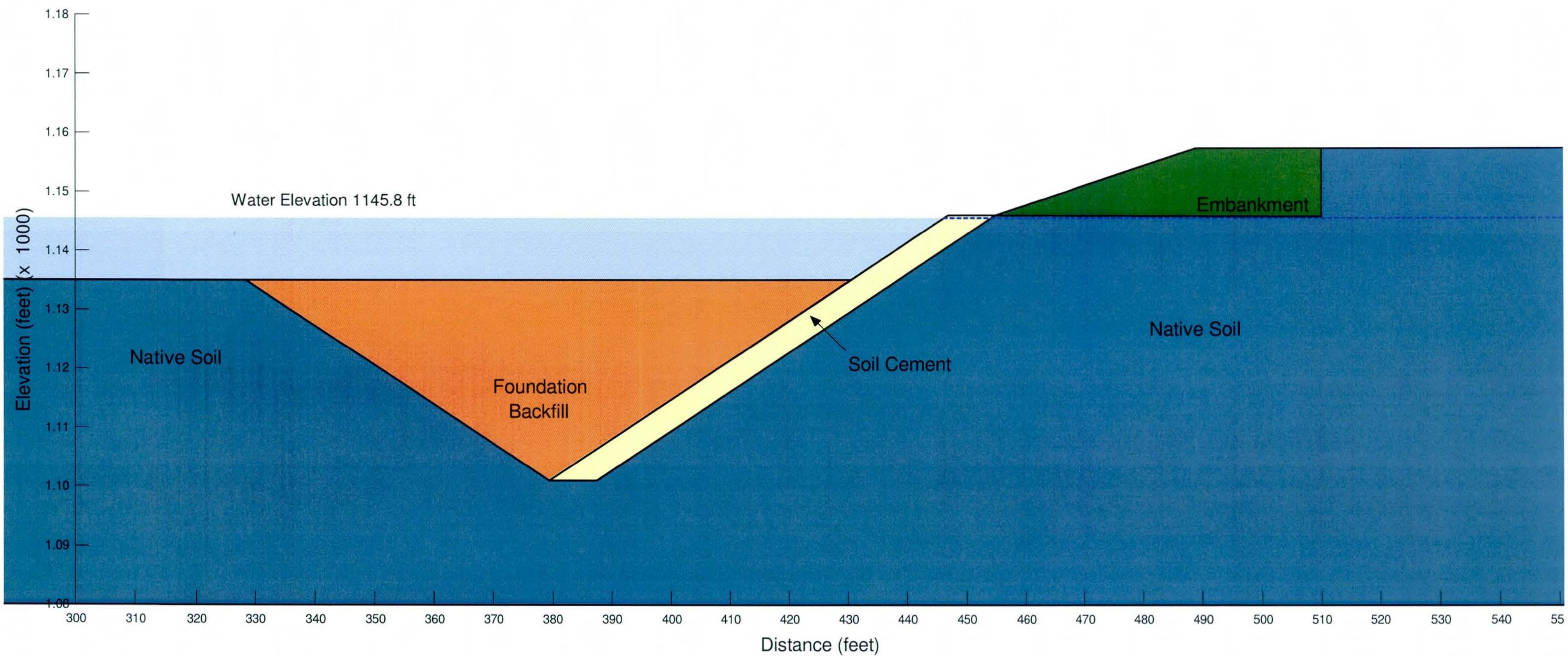
Factor of Safety = 2.14



Job No. 17-2011-4021
Salt River South Bank - Station 248+00

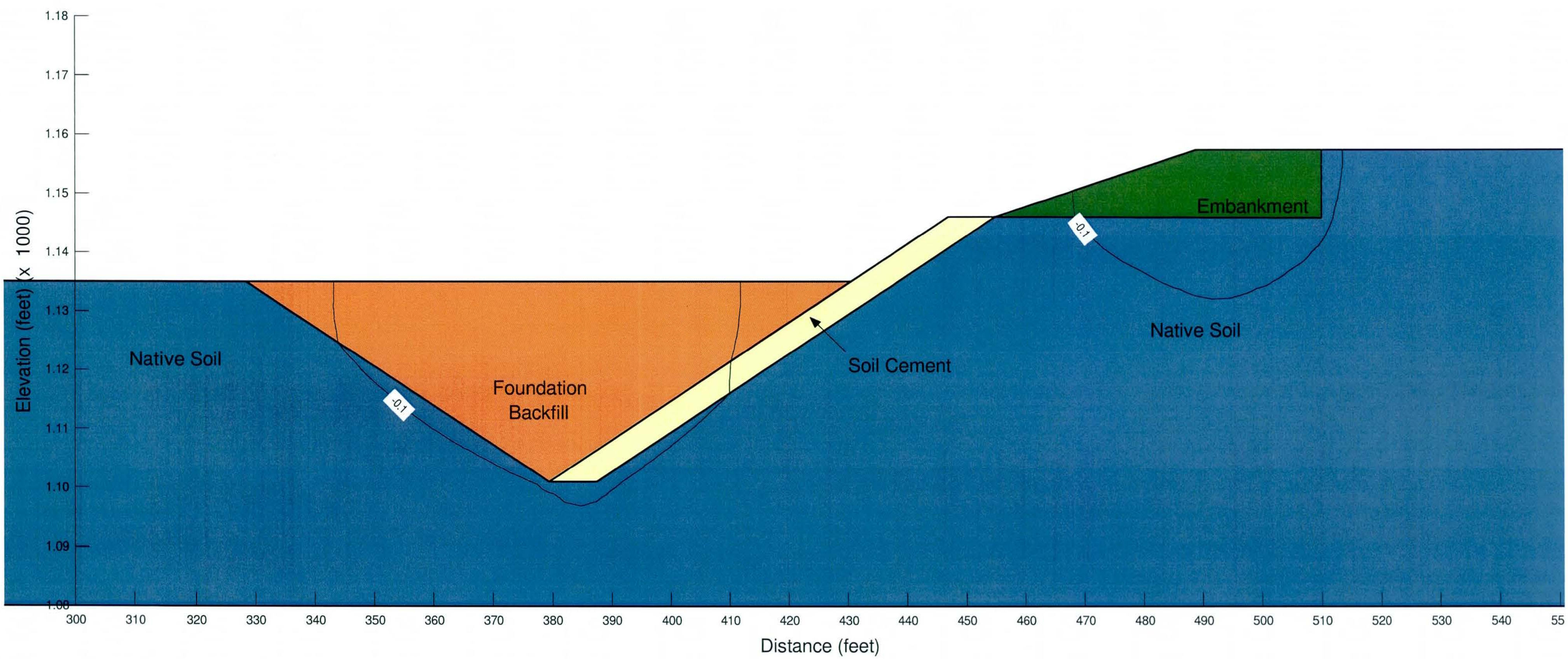
Steady State Seepage Analysis

Exit Gradient = 0



Job No. 17-2011-4021
Salt River South Bank - Station 248+00

Settlement Analysis
Maximum Vertical Settlement Contour in Feet



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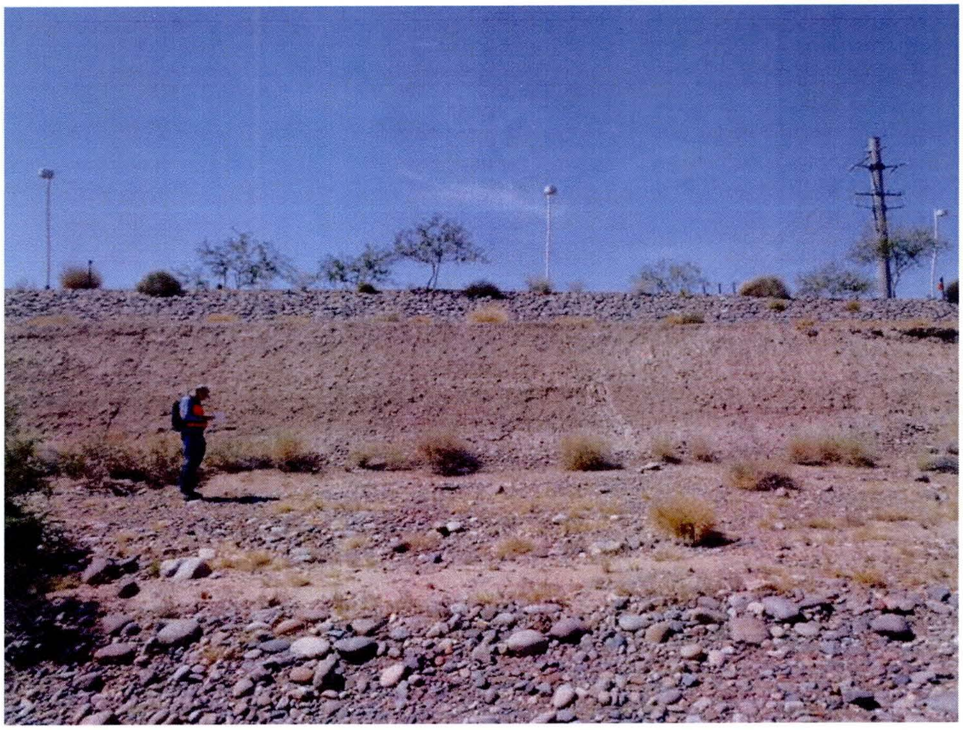
APPENDIX B
PHOTOGRAPHS

PHOTOGRAPH LOG

South Levee Sta. 241+00. Note mantle of soil over cement stabilized alluvium.



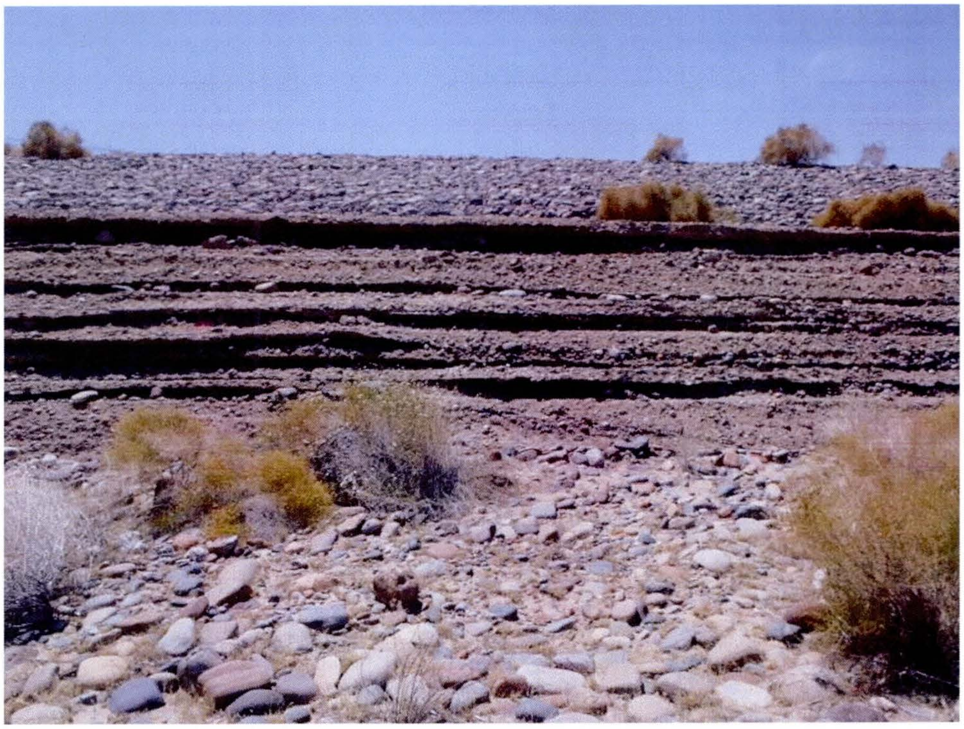
South Levee, near Sta. 236+00.

PHOTOGRAPH LOG

South Levee, Sta. 212+00. South abutment of Priest Drive bridge.

South Levee, Sta. 196+00. Bench mid levee, cement stabilized alluvium below and gabions above.

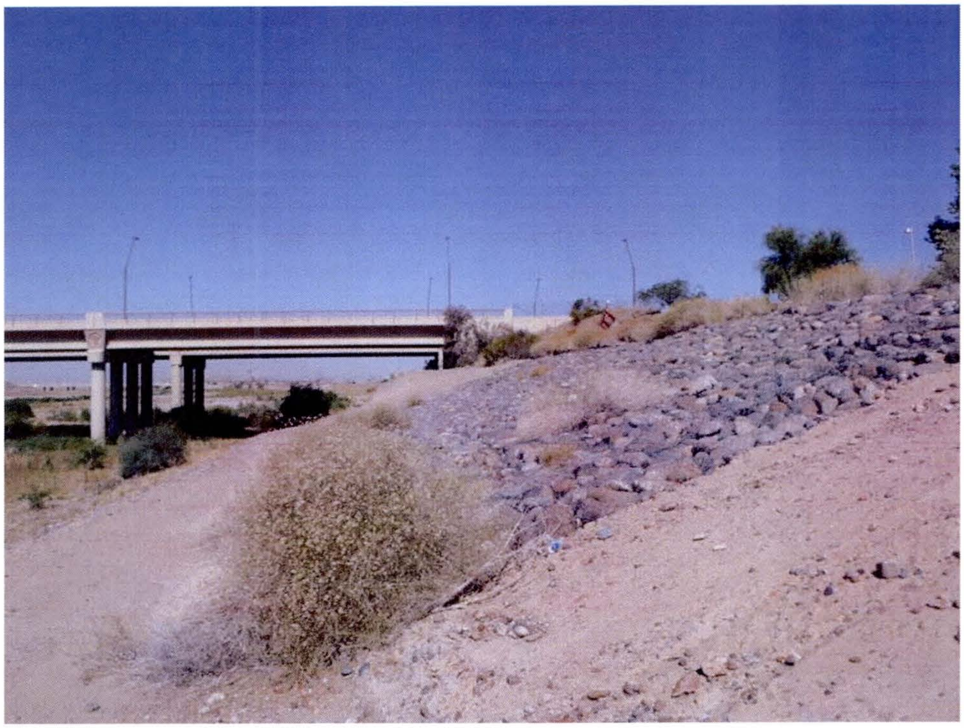
PHOTOGRAPH LOG



South Levee, Sta. 177+00. Erosion of cement stabilized alluvium.

North Levee Sta. 240+00. Mantle of alluvium and landscaping.

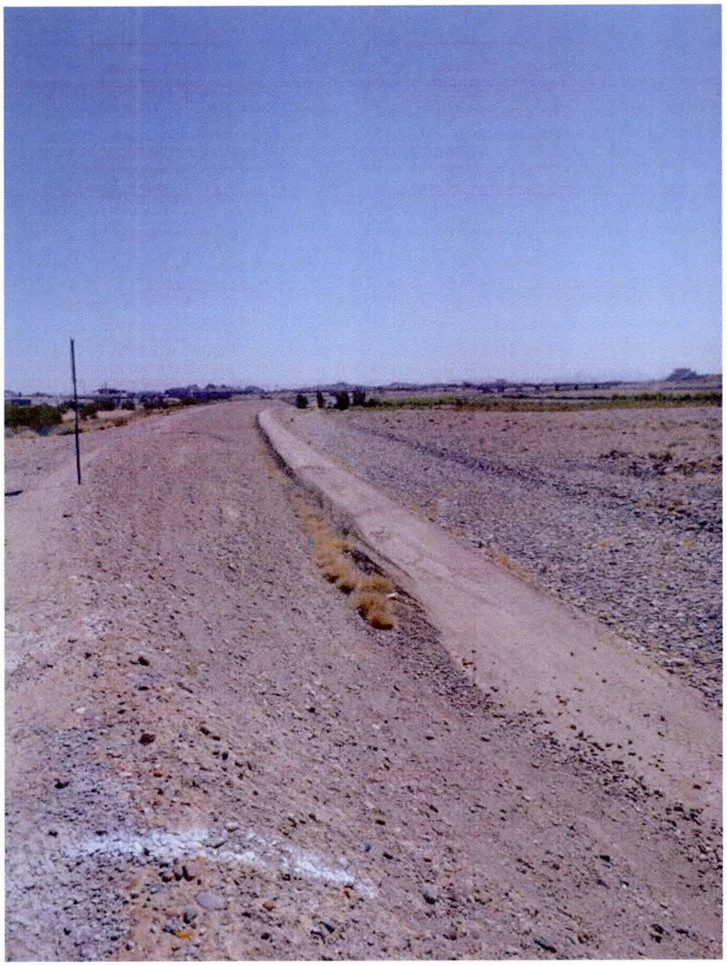
PHOTOGRAPH LOG



North Levee Sta. 213+00. North abutment of Priest Drive.

Sta. 208+00 Bedrock in Salt River channel bed.

PHOTOGRAPH LOG



North Levee Sta. 160+00. North Levee transition
Mid-levee crest.