GEOTECHNICAL STUDY FOR
FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA) PARTIAL CERTIFICATION
CAMELBACK RANCH LEVEE SOUTH
MARICOPA COUNTY, ARIZONA

Prepared for

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

Prepared by

AMEC Earth & Environmental, Inc.
1405 West Auto Drive
Tempe, Arizona 85284

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Registered Professional Engineer (Civil)
CERTIFICATE NO.
23982
TONY J.
FREIMAN
Date Signed 3/18/2011
ARIZONA, U.S.A.
Expires 12/31/2011

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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 levee systems shown on 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 the 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 CF 65.10 will be provided to FEMA within 24 months.

FEMA has indentified the Camelback Ranch Levee South, located along the east bank of the Agua Fria River from Camelback Road to north of Indian School Road, in Maricopa County, as a structure that provides flood protection and affects the flood hazard information presented on the effective flood maps. FEMA has requested that the levee be investigated and reaccredited as meeting the criteria of 44 CFR 65.10. 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 levee owner as compliant with the established FEMA levee criteria.

AMEC Earth & Environmental, Inc. (AMEC) has been authorized by the Flood Control District of Maricopa County (District) to provide professional engineering services to collect and review available data, provide engineering analyses based upon the available data and information, and conduct field reconnaissance as necessary to demonstrate whether the requirements of 44 CFR 65.10, Section (b) Design criteria, subsections 4) Embankment and Foundation Stability, and 5) Settlement have been met.

2.0 FEMA 65.10 REQUIREMENTS

As part of a mapping project, it is the levee owner's or community's responsibility to provide data and documentation to show that a levee meets the requirements of Section 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, operation, 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 community. The FEMA review is solely to establish 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 following items:

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 at the downstream end of the levee.

2.2.2 Closures

The levee closure requirement is that all openings must be provided with closure devices that are structural parts of the system during operation and design according to sound engineering practice.

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 factors that shall be addressed in the analyses include:

- 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) for evacuating 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 depicting 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 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 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
- Provision 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:

> § 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 purposes 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

The geotechnical investigation report (ATL, Inc. 1996a) and geotechnical design calculation package (ATL, Inc. 1996b), both prepared by ATL, Inc., geotechnical consultants were reviewed. 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 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.

4.0 DESCRIPTION OF LEVEE SYSTEM

Camelback Ranch Levee South is owned, maintained and operated by the District The levee extends north along the eastern side of the Agua Fria River, from the existing transverse dike at about 1,746 feet north of Indian School Road (Station 8+50) to the downstream end of the eastern abutment of the Camelback Road Bridge (Station 45+58). Figure 4-1 presents the location of the levee. The Agua Fria River is ephemeral, flowing in response to rainfall and releases from upstream retention. The confluence of the New River and Agua Fria River is about 0.5 mile north of Camelback Road.

4.1 History

The need for the levee was recognized during the 1980s when the adjacent Camelback Ranch development was initially planned and permitted. The development was delayed due to economic reasons. Concurrently, increases in the design storm flow in the Agua Fria River, caused by the construction of the Arizona Canal Diversion Channel, resulted in the Camelback Ranch property being designated within the Standard Project Flood zone. A stipulation for the authorization of the Arizona Canal Diversion Channel from the USACE was that the District provide flood protection to properties under the Standard Project Flood. The depressed real estate market in the early 1990s permitted the District to temporarily purchase the Camelback Ranch property to provide a flood control easement. The location studies for levee were completed in the early to mid-1990s. The final design for the Camelback Ranch Levee South was completed in 1996 and constructed in late 1997. The project was accepted by FEMA on April 16, 1998, per Letter of Map Revision (LOMR) Case Number 98-09-226P. The levee is shown on the effective FEMA Federal Insurance Rate Map, Panels 04013C1620H and 04013C2085G, both dated September 30, 2005.

FEMA had requested that the levee be investigated and reaccredited as meeting the criteria of 44 CFR 65.10. In a letter dated March 27, 2009, FEMA provided the District the opportunity to receive a PAL designation for the levee. The District signed the PAL agreement and provided the required information. FEMA accepted the agreement and granted the PAL designation. The two-year deadline date for providing all the 44 CFR 65.10 data to FEMA is June 25, 2011.

4.2 Description of Levee

The Camelback Ranch Levee South is about 3,700 feet long and consists of a trapezoidal embankment section with a 16-foot-wide top composed of a 9-foot-wide soil-cement bank protection on the riverside, and on the landside a 7-foot-wide embankment with an aggregate base surface. The landside embankment slope ratio is 3 horizontal to 1 vertical. The riverside has a slope ratio of 1 horizontal to 1 vertical above the foundation line and a slope ratio of 1.8 horizontal to 1 vertical below the foundation line. The embankment ranges from about 10 to 20 feet in height. Four feet of excavation was specified beneath the embankment section. The elevation of the levee ranges from 1,021 to 1,027.6 feet (National Geodetic Vertical Datum [NGVD] 1929). A typical cross section of the levee is presented in Figure 4-2.

The construction special provisions specified that the embankment materials and foundation excavation backfill were to consist of granular materials meeting the gradation requirements listed in Table 4-1.

Table 4-1

Embankment Fill Gradation

Sieve Size	Percent Passing by Weight
2-inch	100
No. 4	30 to 70
No. 16	20 to 55
No. 50	5 to 35
No. 200	0 to 12

The maximum plasticity index was set at 7. Embankment fill and foundation excavation backfill was specified to be compacted to at least 95 percent of the maximum dry density and within 2 percent of the optimum moisture content, as determined by ASTM D698.

The soil cement bank protection was constructed of Type II portland cement stabilized granular aggregate meeting the gradation requirements listed in Table 4-2. The mix design for the soil-cement bank protection was specified to have a minimum compressive strength of 750 pounds per square inch after a seven-day curing period, plus an additional 2 percent cement to compensate for variations in the aggregate, mixing, and placement.

Table 4-2

Soil Cement Aggregate Gradation

Sieve Size	Percent Passing by Weight
2-inch	100
No. 4	50 to 80
No. 200	0 to 20

The maximum plasticity was limited to 5. The soil cement was specified to be compacted to an average density of 98 percent with no single test being less than 95 percent of the maximum dry density determined in accordance with ASTM D 558.

Improvements to Camelback Road, at the northern terminus of the Camelback Ranch Levee South, included construction of a 60-inch-diameter storm drain that extended through the levee at Station 41+85. The invert of the storm drain is at about elevation 1,007.5 (NGVD 1929) at the outlet. The storm drain outfall included an apron, baffles, wingwalls, flap gate, and a debris shield. The construction drawings for the penetration through the embankment required that the soil cement bank protection removed to permit construction of the drain was replaced with Maricopa Association of Governments (MAG) Standard Specification Class B portland cement concrete. The specifications for MAG Class B concrete require a minimum 28-day compressive strength of 2,500 pounds per square inch. The portion of the embankment that was directly beneath the bank protection was specified to be replaced with a one-sack controlled low-strength material in accordance with MAG Specifications 604 and 728. A new ramp, consisting of cement-stabilized alluvium, was constructed in front of the levee from about Station 41+85 to Station 44+35.

4.3 Summary of Reviewed Documents

The listed documents, specific to the Camelback Ranch Levee South design and construction, were reviewed as part of the geotechnical studies for the 44 CFR 65.10 certification of embankment and foundation stability, seepage, and settlement.

Table 4-3

Background Documents

	Document Title	Document Description	Date
1	LOMR 98-09-226P Levee Backup Data	Calculations and Analysis – Geotechnical Investigation ATL, Inc.	Sep 1996
2	Geotechnical Investigation Report	Geotechnical Investigation Report Camelback Ranch Levee ATL, Inc.	Sep 1996
3	National Flood Insurance Program Mapping	Flood Insurance Rate Maps Maricopa County, Arizona Panel 1620 of 4350 Panel 2085 of 4350	Sep 2005
4	Plans for the Construction of Camelback Ranch Levee - South	Flood Control District of Maricopa County	Feb 1997
5	Special Provisions for the Construction of Camelback Ranch Levee - South	Flood Control District of Maricopa County	Feb 1997
6	LOMR 98-09-226P Levee Backup Data	In-Place Density Test Results	Nov 1997
7	Camelback Road Improvements	Camelback Road, Agua Fria River to 99th Avenue, City of Phoenix Project ST83110057, Storm Drain Design Drawings	Nov 2006

4.4 Levee Inspections

A field reconnaissance of the Camelback Ranch Levee South was conducted by a representative of AMEC on June 29, 2010, accompanied by a representative of the District. 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. Minor to moderate erosion was noted at the toe of the soil-cement bank protection between about Station 38+20 and Station 41+60. No indications of differential embankment settlement, seepage/piping or embankment instability were observed. The inspection revealed, except for the erosion, that the Camelback Ranch Levee South was in serviceable condition.

The District conducted a maintenance inspection on February 29, 2008. The inspection recognized erosion at the base of the soil-cement bank stabilization near Station 40+00 and recommended periodic monitoring. The other inspection items commented upon were general maintenance of fencing, trash removal and signage.

An annual inspection of the levee was performed on March 4, 2009. The inspection included both the Camelback Ranch Levee South and the East Levee, located north of Camelback Road. Minor rilling of the embankment soils, adjacent to the soil-cement bank stabilization was noted on the crest. Minor, nonstructural cracking of the upstream soil-cement bank protection was noted on the riverside embankment slope and was recommended to be monitored. A box on the inspection form indicating settlement, slides, depressions and bulges of the upstream slope (riverside) was checked yes, without comment. The downstream embankment was noted to have minor rilling and erosion and was recommended to be monitored. Adverse vegetation was indicated and recommended to be repaired.

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 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

A geotechnical investigation was performed in 1996, by ATL, Inc., under District contract number FCD 95-15 to support the design of the Camelback Ranch Levee South. Six test borings were advanced using hollow-stem auger methods to depths of 26 feet. The results of preliminary soil-cement mix designs, developed using aggregate from borrow sources adjacent to the project, were also presented.

Recommendations for the construction of the levee were provided in the ATL, Inc. geotechnical investigation report. Foundation preparation was recommended to consist of removal of 4 feet of material from beneath the embankment section. The overexcavated surface was compacted to a minimum of 90 percent of the maximum density, as determined in accordance to ASTM D698. The foundation backfill and embankment materials were recommended to be compacted, in 12-inch maximum thickness lifts to a minimum of 95 percent of the maximum dry density, with the moisture content with 2 percent of optimum, determined in accordance with ASTM D698.

Recommendations for the slope configuration of the embankment and the toe down were also provided. The riverside, soil-cement bank-protected embankment slope ratio was recommended to be 1 horizontal to 1 vertical. The landside slope ratio was recommended to be 3 horizontal to 1 vertical. The toe-down excavation slope, from the bottom of the overexcavation was recommended to be no steeper than 1.8 horizontal to 1 vertical. The recommendations from the ATL, Inc. geotechnical investigation report were incorporated into the project drawings and special provisions.

5.2 Review of Geotechnical Design Analyses

The ATL, Inc. design calculations were reviewed. The immediate settlement of the levee was calculated to be 0.41 inches. Secondary settlement was not expected due to the cohesionless granular soils underlying the embankment sections. The recommended settlement for design purposes was 0.75 inches.

A summary of the slope stability analyses was presented in the ATL, Inc. calculation package. The only analysis presented was for the end-of-construction condition of a section at Station 41+40, resulting in a calculated safety factor of 1.44. The ATL, Inc. geotechnical investigation report presented a discussion that a rapid drawdown condition would not develop in the levee.

5.3 Surface and Subsurface Conditions

5.3.1 Subsurface Conditions

Six test borings were advanced, in 1996 by ATL, Inc., along the Camelback Ranch Levee South alignment to depths of 26 feet. The encountered soils were composed primarily of poorly graded, nonplastic silty sands, with traces of gravel. Subordinate amounts of clayey sand were also encountered.

5.3.2 Groundwater Conditions

Groundwater was not encountered during the 1996 ATL, Inc. geotechnical investigation activities. Based on mapping of groundwater conditions in the Phoenix area, groundwater is located at depths of 60 to 175 feet below existing grades (Bascona 2003). Perched groundwater will occur as a result of flows within the Agua Fria or New rivers.

5.4 Geologic Setting

The Camelback Ranch Levee South site is in the western portion of the Salt River Valley. The western alluvial-filled Salt River Valley is a typical component of the Sonoran region of the Basin and Range physiographic province. The upper alluvium is composed of Late Tertiary and Quaternary clastic material, derived locally from the surrounding bedrock terrain and deposited over older basin-fill deposits. The thickness of upper alluvial unit is from 700 feet to 1,200 feet deep.

5.4.1 Seismic

The project site is within the Sonoran region of the Basin and Range physiographic province. The Sonoran region is not considered to be seismically active and is not near a seismically active area. The maximum credible earthquake for the project area is conservatively estimated at a magnitude of 6.5. The peak ground acceleration with a 2 percent exceedance in 50 years was determined to be 0.08 g, based upon data presented on the 2008 National Seismic Hazard Maps (Petersen and others 2008).

6.0 GEOTECHNICAL ANALYSES

6.1 Selection of Critical Cross Sections

Three representative sections were selected within the Camelback Ranch Levee South. Critical cross sections were chosen where the combination of attributes might result in failure of the levee at that location prior to failing at other locations. Some attributes that are considered in selecting a critical section include the following:

- High levee embankment heights
- Geometric anomalies
- Areas of scour or erosion

Cross sections at the following locations were selected as representative sections and analyzed for seepage, stability and settlement:

- Station 15+00
- Station 41+40
- Station 42+00

6.2 Soil Engineering Parameters

The geotechnical parameters required for slope stability analysis include unit weights, shear strength parameters for each material present in a cross section, and location of the phreatic surface within the cross section. The required parameters, in particular shear strength, were obtained from previous geotechnical reports and AMEC's experience with similar soils. The strength parameters for the embankment fill zones were selected to represent the anticipated average shear strengths of materials which were utilized to construct the embankments. 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
Embankment	120	28.5	200	$3x10^{-4}$
Soil Cement	115	20	3000	$3x10^{-6}$
Backfill	110	33.5	200	$3x10^{-4}$
Native soil	120	30	200	$3x10^{-4}$

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

6.3 Seepage Analyses

A steady-state seepage analysis was 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 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 100-year flood event (Fuller 2010). In general accordance with USACE Engineering Manual No. EM 1110-2-1913 (USACE 2000), Appendix B, Section B-5 (page B-12), a maximum exit gradient ($i_{max} = 0.5$) is used as acceptance criteria 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 only exists for a few days.

Table 6-2 Seepage Results

Critical Section	Exit Gradient i_{max} (ft/ft)	Factorof Safety
15+00	0.03	26.7
41+40	0.40	2.0
42+00	0.27	3.0

Note: 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.

The seepage analyses indicate that exit gradients at the toe of the critical sections of the levee are equal to or less than EM 1110-2-1913's maximum permitted exit gradient of i_{max} = 0.5 ft/ft. The results of the current seepage analyses of the critical sections are included in Appendix A.

6.4 Slope Stability Analyses

Conventional static and pseudo-static stability analyses of a typical levee embankment sections was performed using the computer program SLOPE/W (Geo-Slope International, Ltd. 2007b) 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 *Design and Construction of Levees,* No. EM 1110-2-1913, Chapter 6, Section II (USACE 2000). Static stability analyses were completed for four cases:

- Case 1: End of construction for the riverside slope and landside slope
- Case 2: Sudden drawdown from 100-year flood stage 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

The steady-state seepage condition for landside was simulated using the SEEP/W program. Pseudostatic analyses, assuming a peak ground acceleration of 0.08 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 factor of safety for the existing levees, from No. EM 1110-2-1913 (USACE 2000) was used as acceptance criteria (see Table 6-3).

Table 6-3 Slope Stability Requirements[1]

Applicable Stability Conditions and Required Factors of Safety			
End-of-Construction	**Long-Term Flood Stage**	**Sudden Drawdown[2]**	**Earthquake[3]**
1.3	1.4	1.0-1.2	1.0

Based upon 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 section was found to be Station 41+40, where the factor of safety for Case 2 (sudden drawdown) scenario is 1.14. The 100-year modeled flood level used in the stability analysis is expected to exist only for 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 2010).

[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.

Table 6-4 Slope Stability Results Summary

Case	Description	Typical Section	Computed FOS	Minimum FOS
1	End of Construction, Riverside	15+00 41+40 42+00	2.98 2.67 3.93	1.3
1	End of Construction, Landside	15+00 41+40 42+00	4.82 4.33 4.33	1.3
2	Sudden Drawdown for 100 Year Pool, Upstream	15+00 41+40 42+00	2.23 1.14 3.34	1.0
3	Steady-State Seepage with 100 Year Pool, Landside	15+00 41+40 42+00	4.19 3.76 3.76	1.4
4	End of Construction, Pseudostatic, Riverside	15+00 41+40 42+00	2.60 2.35 3.46	1.0
4	End of Construction, Pseudostatic, Landside	15+00 41+40 42+00	3.78 3.45 3.45	1.0

Note: FOS = factor of safety

6.5 Settlement Analysis

Settlement analyses were performed for the three typical 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 extending to the extent of the borings. The settlement analysis was performed using the computer program SIGMA/W (Geo-Slope International, Ltd. 2007c). SIGMA/W is a finite-element software product that can be used to perform stress and deformation analyses of earth structures. Its 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 soil-cement material. Conservative values of Young's modulus and volumetric water content functions were used for native foundation soils. Postconstruction total settlements of the coarse-grained alluvial soils (sand) underlying the levees are estimated to be up to about 0.6 inches. 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 static settlement has already occurred.

6.6 Summary of Findings

The findings of the geotechnical evaluation of the subject levee system are as follows:

Seepage: Steady-state seepage analysis performed at three critical sections of the levee indicates that under the base flood scenario, seepage would either not exceed an exit gradient, i_{max} = 0.5 ft/ft at the landside slope or not cause seepage at the levee's toe.

Slope Stability: The stability analyses performed at 3 critical sections of the levee embankments results in safety factors meeting or exceeding the minimum factors of safety criteria stipulated in EM-1110-2-1913, *Design and Construction of Levees* (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 Camelback Ranch Levee South meets or exceeds the FEMA 65.10 requirements for slope stability, seepage, and ground subsidence/settlement.

The erosion of the soil cement bank protection between Stations 38+20 to 41+60 should be monitored periodically.

A certification letter, indicating that the Camelback Ranch Levee South meets 44 CFR 65.10, Section (b), Subsection (4) Embankment and Foundation Stability and Subsection (5) Settlement, is presented in Appendix C.

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 above. 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

ATL, Inc. (ATL). 1996a. *Geotechnical Investigation Report, Camelback Ranch Levee.* September.

_____. 1996b. *Calculations and Analysis, Geological Investigation for LOMR 98-09-226P.* September.

Basona, S.J. 2003. *Maps Showing Groundwater Conditions in the Phoenix Active Management Area.* Arizona Department of Water Resources. Map 35.

City of Phoenix, Street Transportation Department, Camelback Road, Aqua Fria River to 99th Avenue, Storm Drain Project ST831100579 dated November 10, 2006.

Federal Emergency Management Agency (FEMA), National Flood Insurance Program, Flood Insurance Rate Map Panels 0413C 1620H and 04013C 2085G, dated September 30, 2005

Flood Control District of Maricopa County (District). 1997a. *Plans for the Construction of Camelback Ranch Levee – South.* February.

_____. 1997b. *Special Provisions for the Construction of Camelback Ranch Levee – South.* February.

Fuller. 2010. Data Collection and Levee Characterization Report for Camelback Road Levee South, Maricopa County, Arizona.

Geo-Slope International, Ltd. 2007a. SEEP/W (software). Calgary, Alberta, Canada.

_____. 2007b. SLOPE/W (software). Calgary, Alberta, Alaska.

_____. 2007c. SIGMA/W (software). Calgary, Alberta, Alaska.

Petersen, Mark D., Arthur D. Frankel, Stephen C. Harmsen, Charles S. Mueller, Kathleen M. Haller, Russell L. Wheeler, Robert L. Wesson, Yuehua Zeng, Oliver S. Boyd, David M. Perkins, Nicholas Luco, Edward H. Field, Chris J. Wills, and Kenneth S. Rukstales. 2008, *Documentation for the 2008 Update of the United States National Seismic Hazard Maps.* U.S. Geological Survey Open-File Report 2008–1128.

US Army Corps of Engineers. 2000. *Design and Construction of Levees.* Engineering Manual EM 1110-2-1913. April 30.

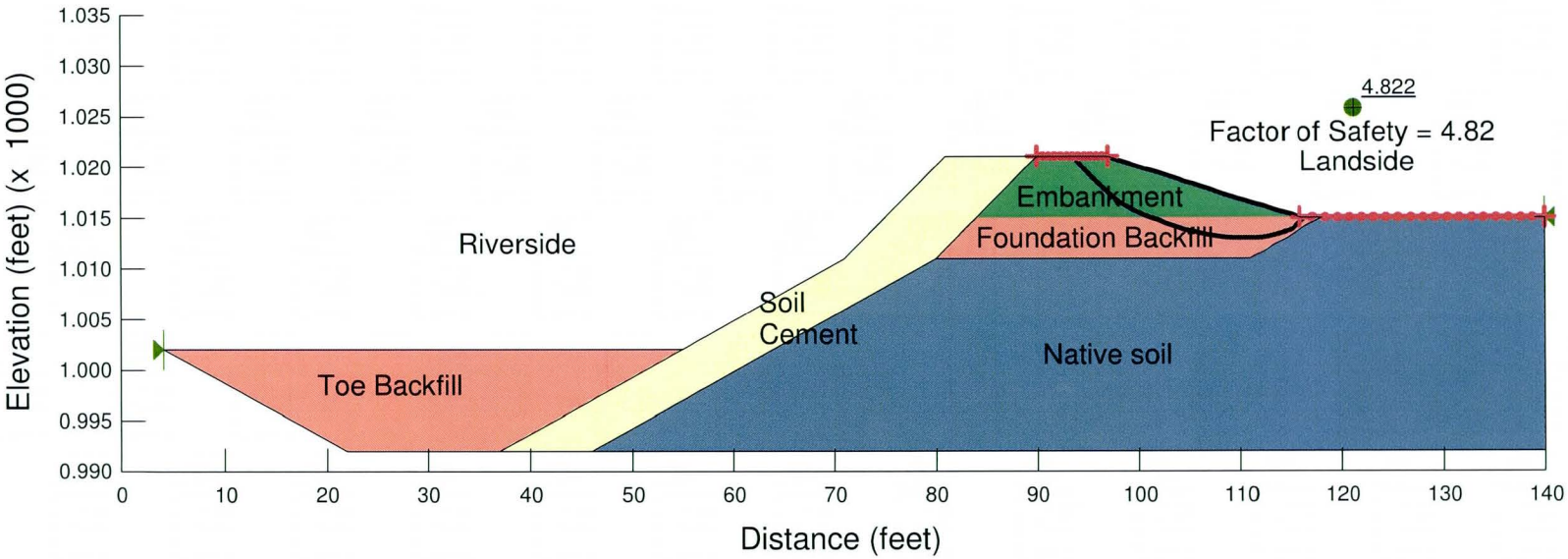
APPENDIX A
ENGINEERING ANALYSES

- Slope Stability Analyses
- Seepage Analyses
- Settlement Analyses

SLOPE STABILITY ANALYSES

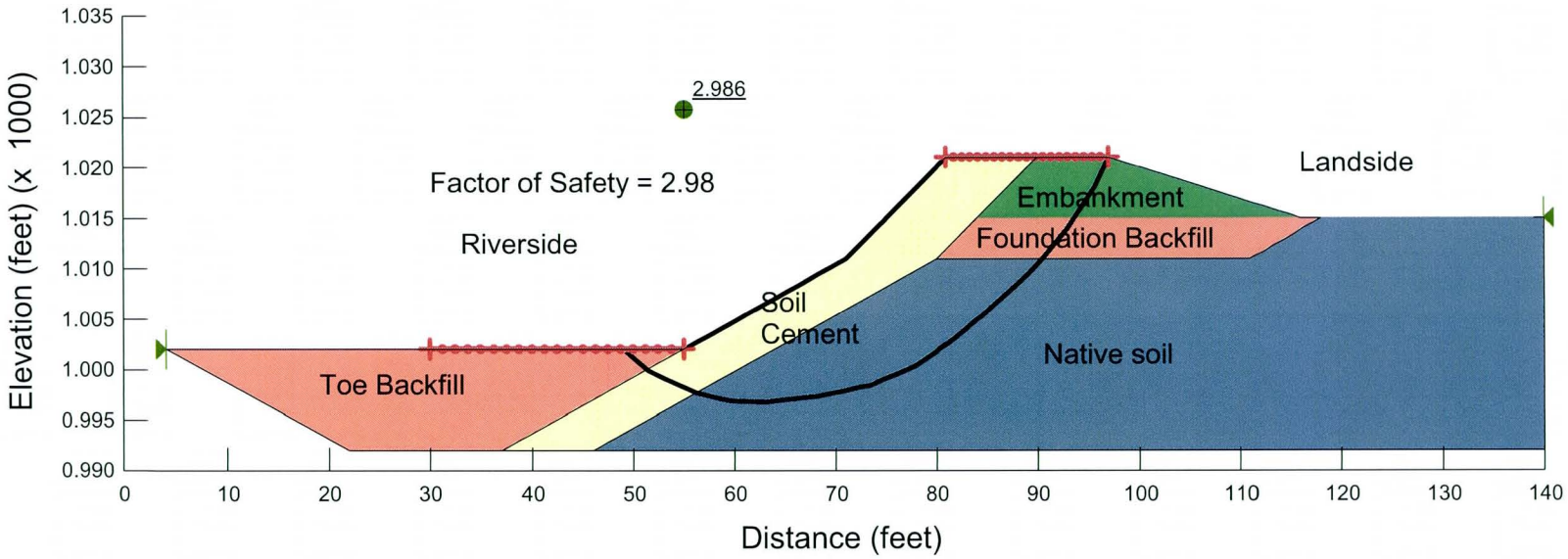
Camelback Ranch Leeve- South
Station 15+00

Case 1 - End of Construction
Landside (static)



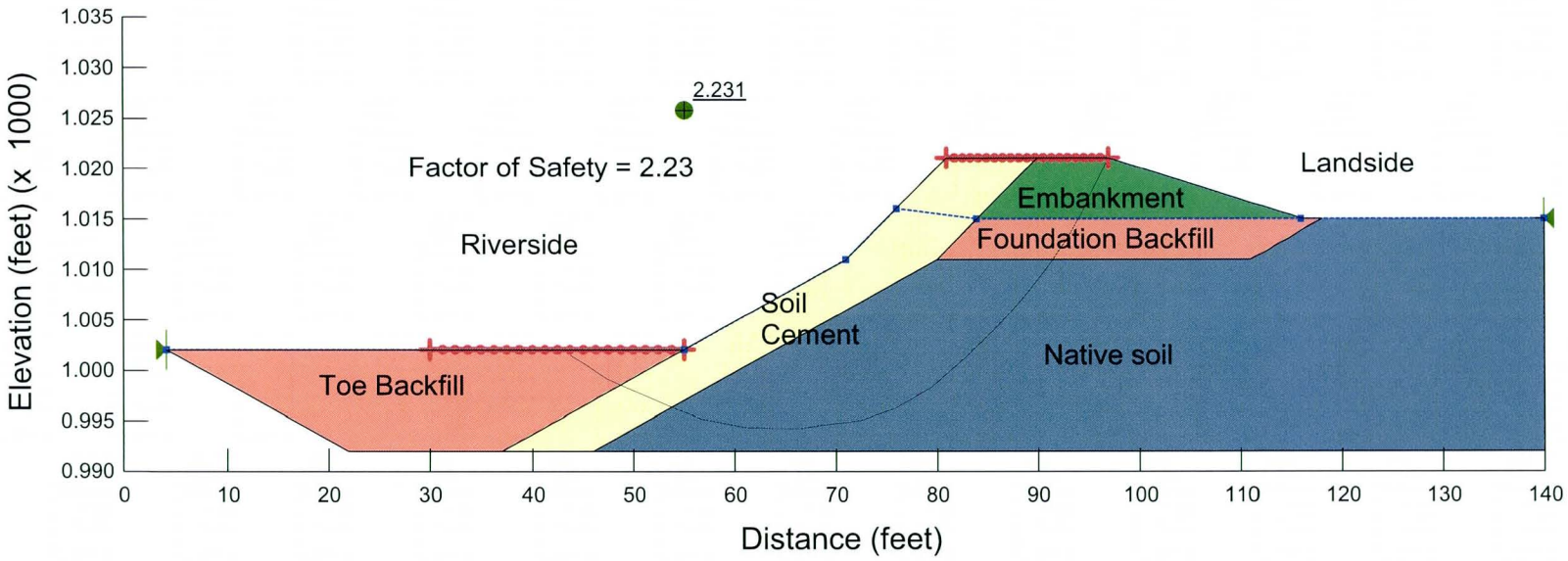
Camelback Ranch Leeve- South
Station 15+00

Case 1 - End of Construction
Riverside (static)



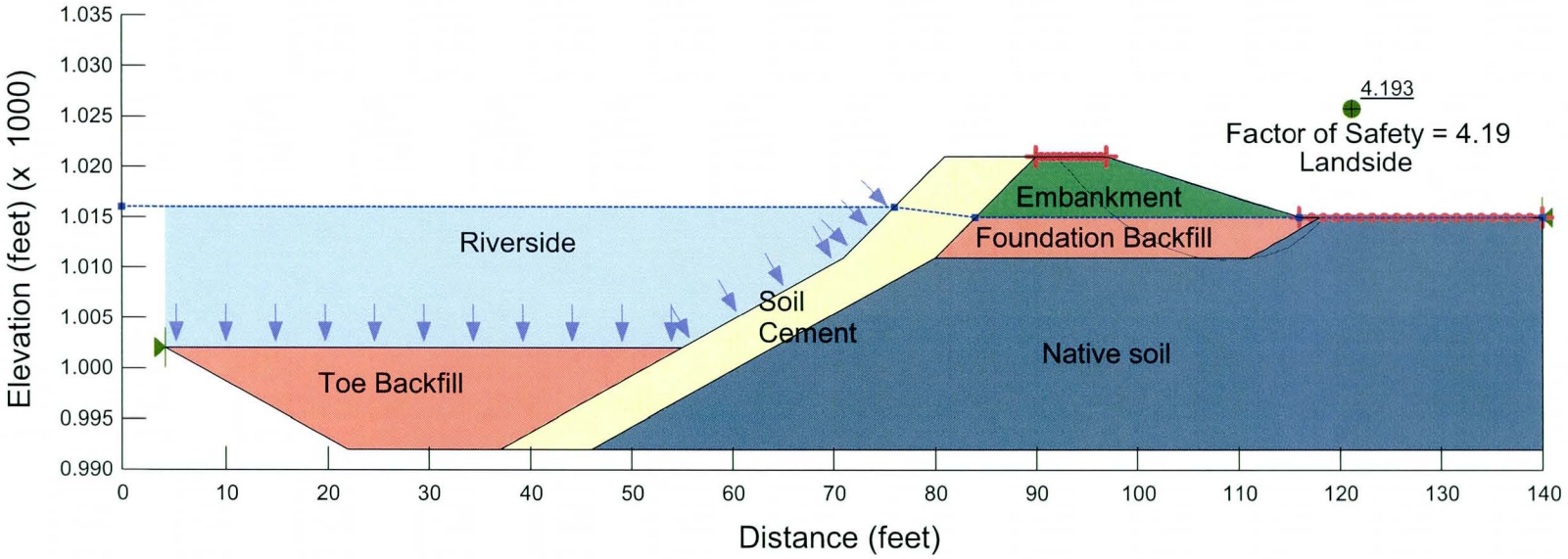
Camelback Ranch Leeve- South
Station 15+00

Case 2 - Sudden Drawdown
Upstream (static)



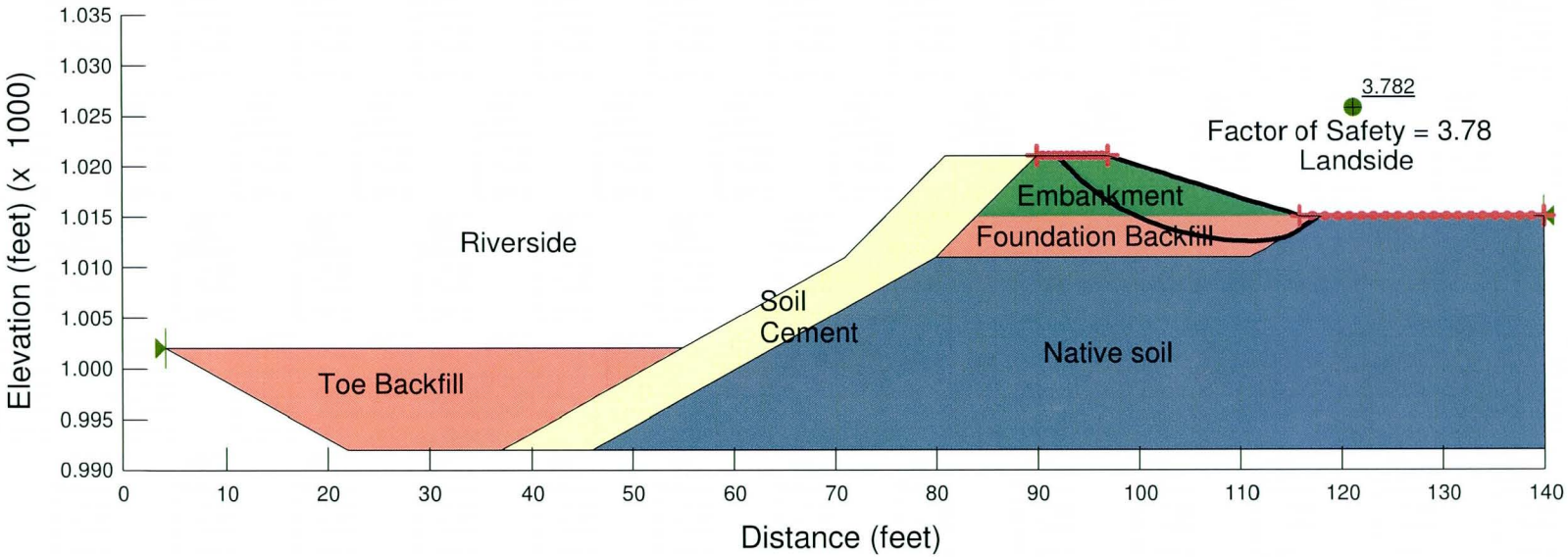
Camelback Ranch Leeve- South
Station 15+00

Case 3 - Steady State Seepage under 100-year Flood level Condition
Landside (static)



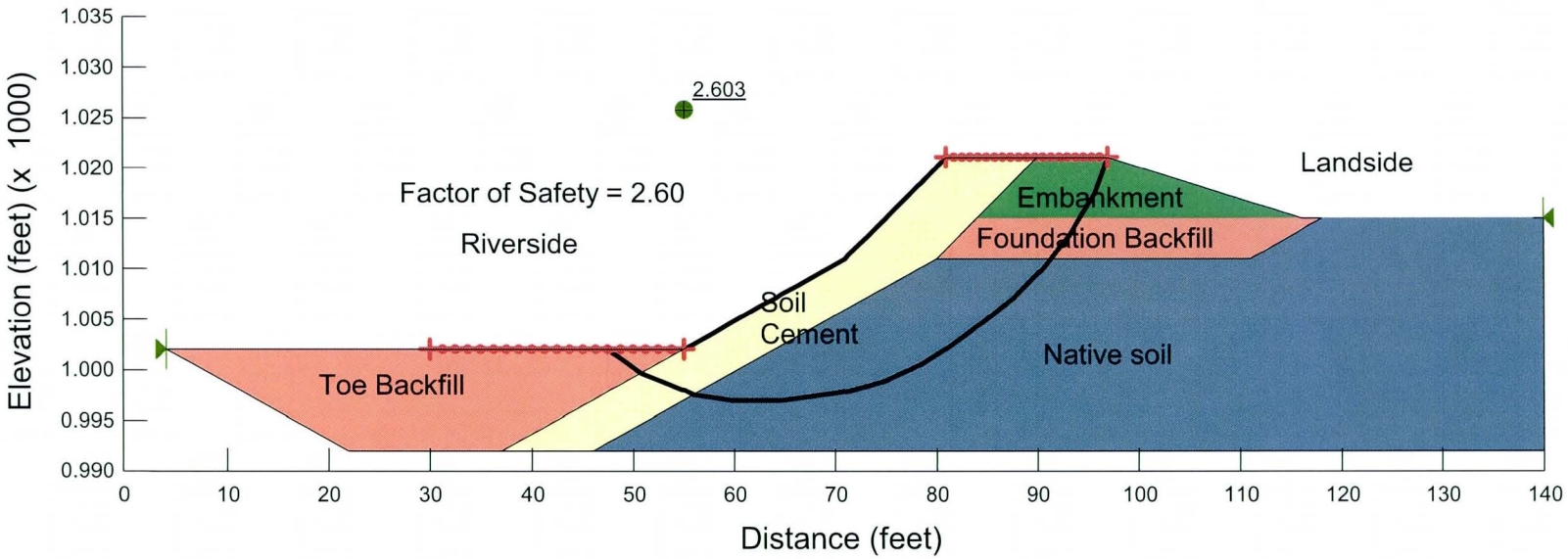
Camelback Ranch Leeve- South
Station 15+00

Case 4 - End of Construction
Landside (Pseudo-static Eq=0.08)



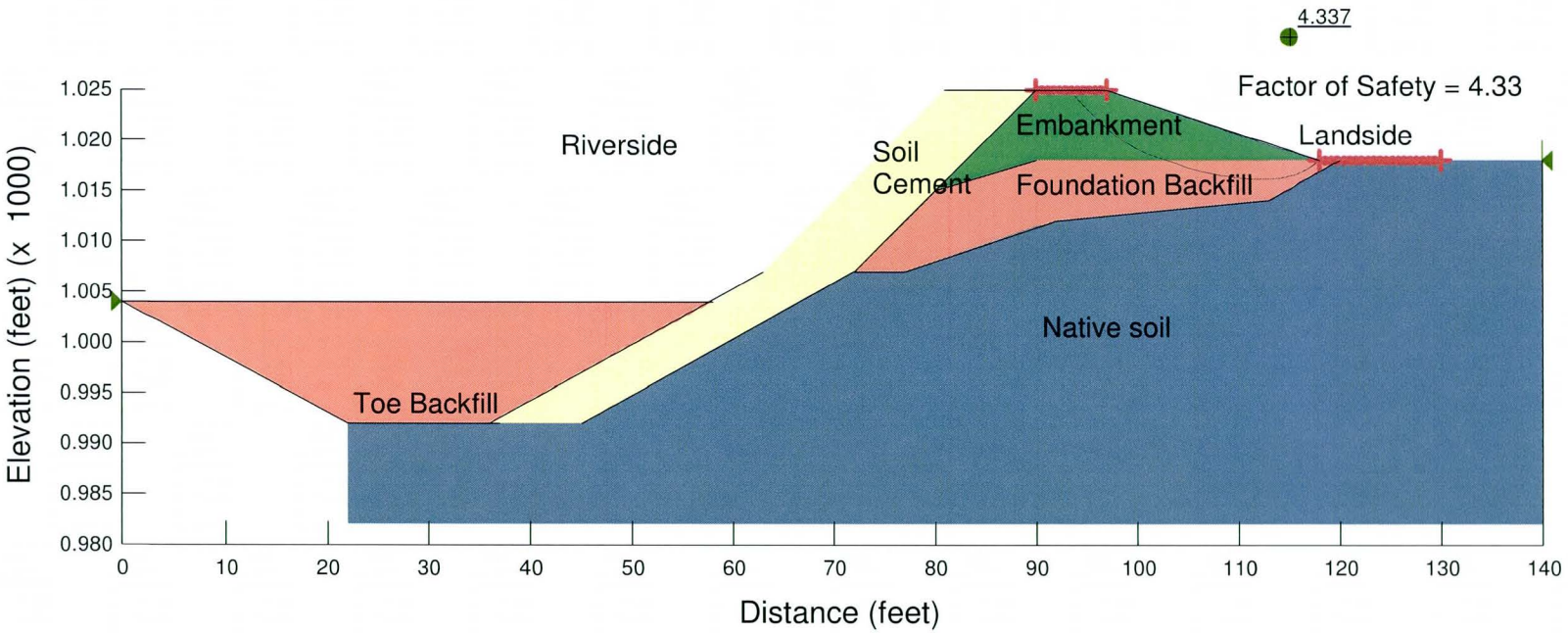
Camelback Ranch Leeve- South
Station 15+00

Case 4 - End of Construction
Riverside (Pseudo-static- Eq=0.08g)



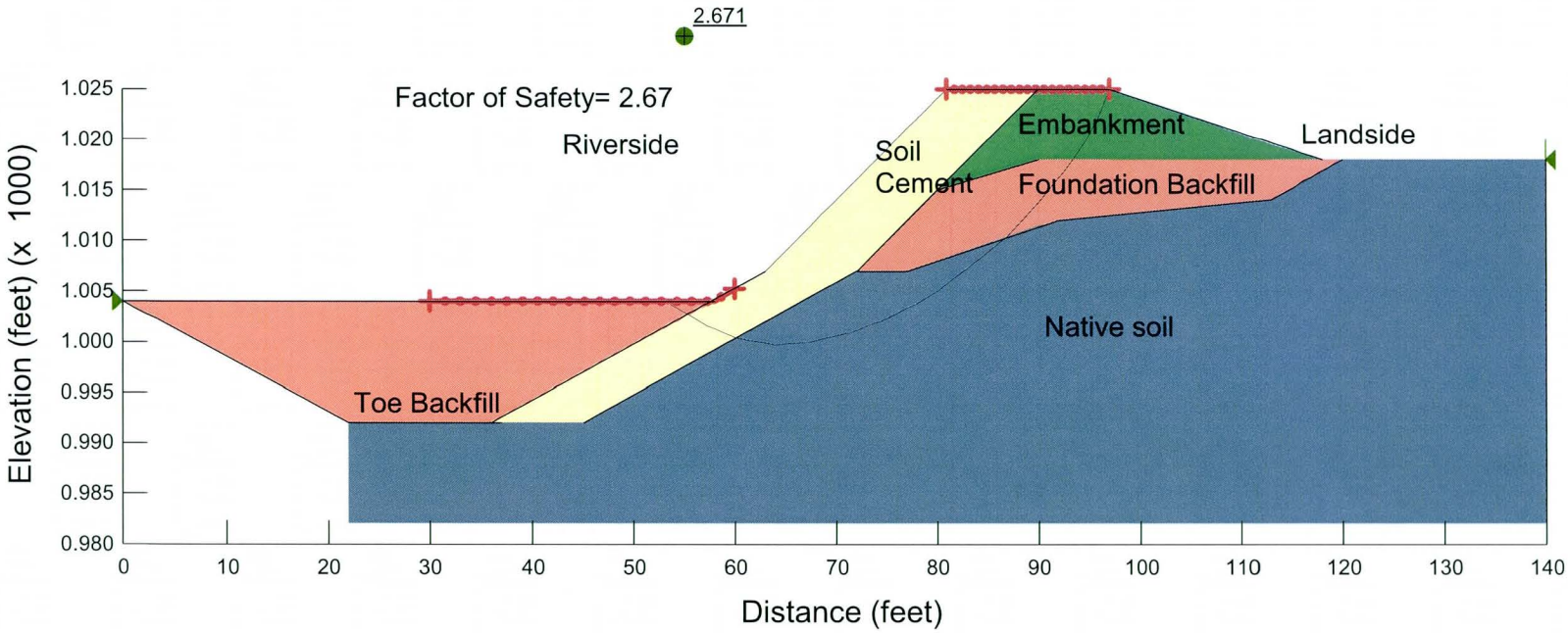
Camelback Ranch Leeve- South
Station 41+40

Case 1 - End of Construction
Landside (static)



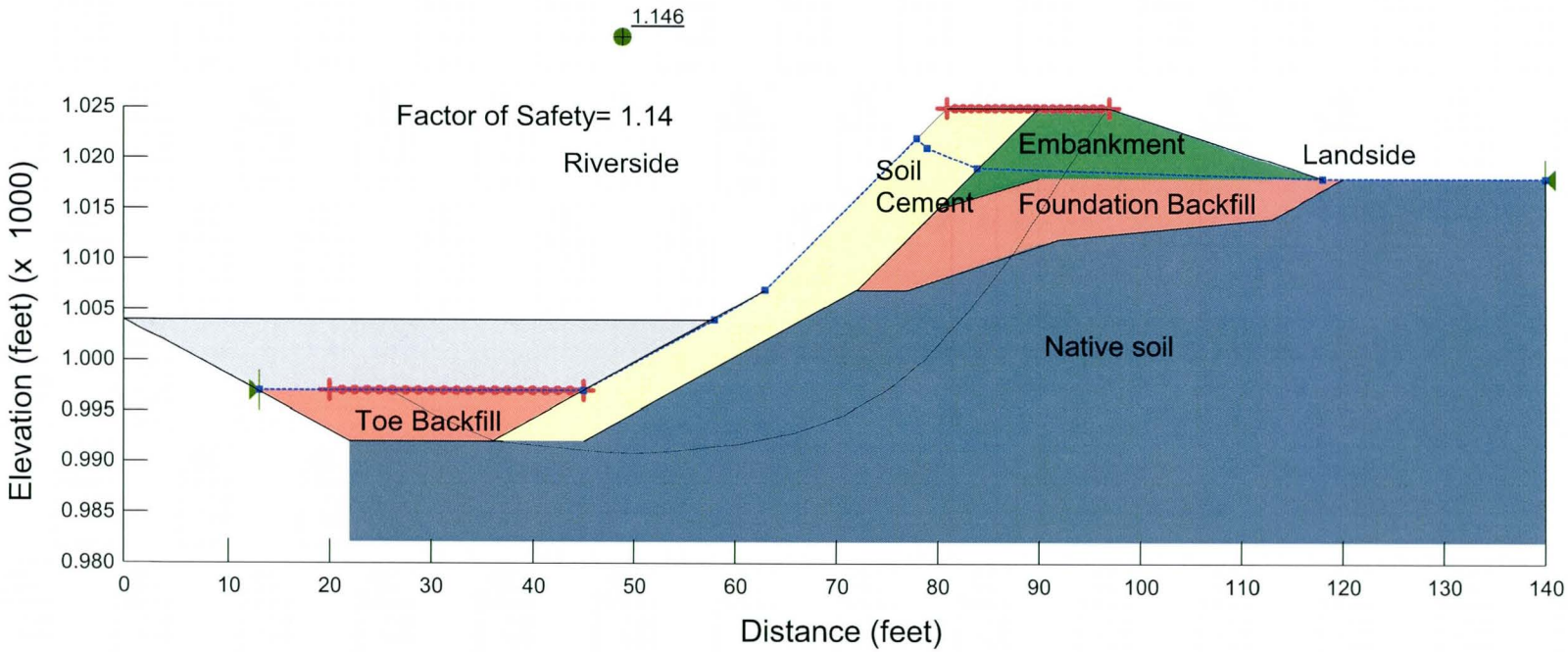
Camelback Ranch Leeve- South
Station 41+40

Case 1 - End of Construction
Riverside (static)



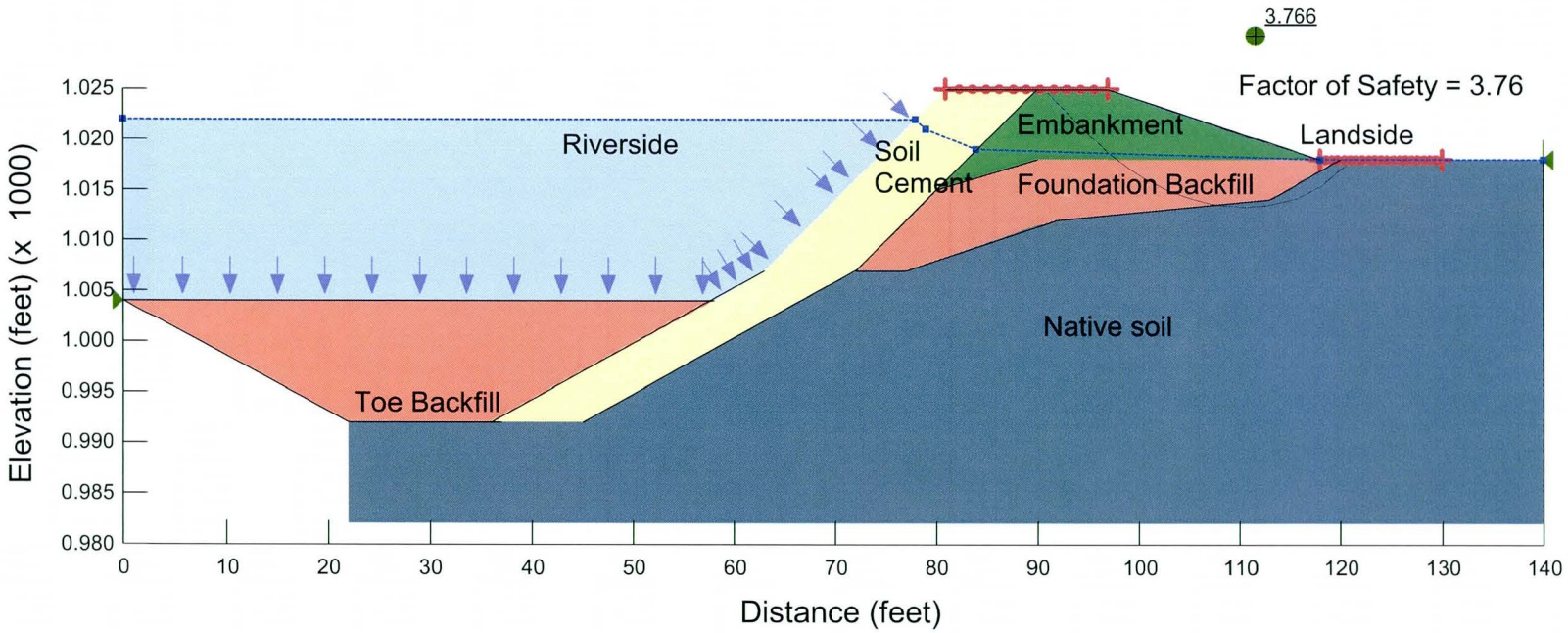
Camelback Ranch Leeve- South
Station 41+40

Case 2 - Sudden Drawdown
Riverside (static)



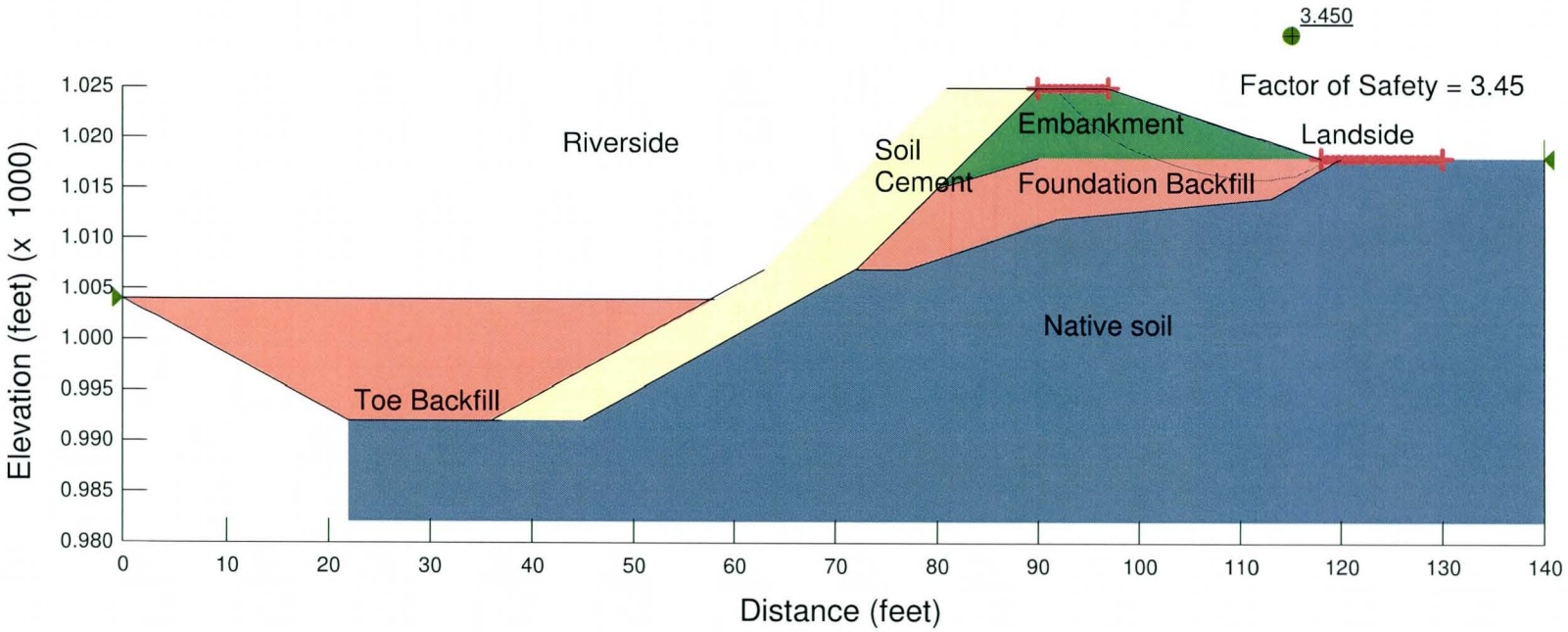
Camelback Ranch Leeve- South
Station 41+40

Case 3 - Steady Seepage from 100-year Flood Level Condition
Landside (static)



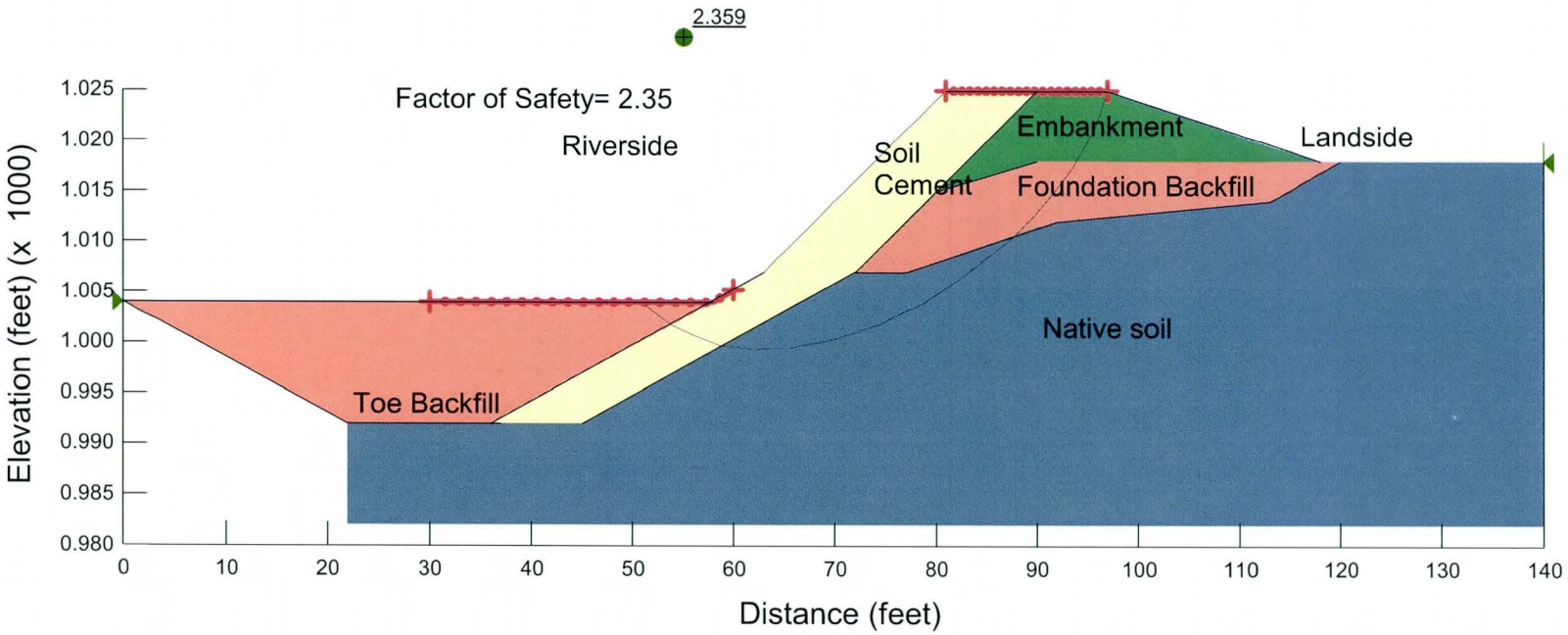
Camelback Ranch Leeve- South
Station 41+40

Case 4 - End of Construction
Landside (Pseudo-static- Eq= 0.08g)



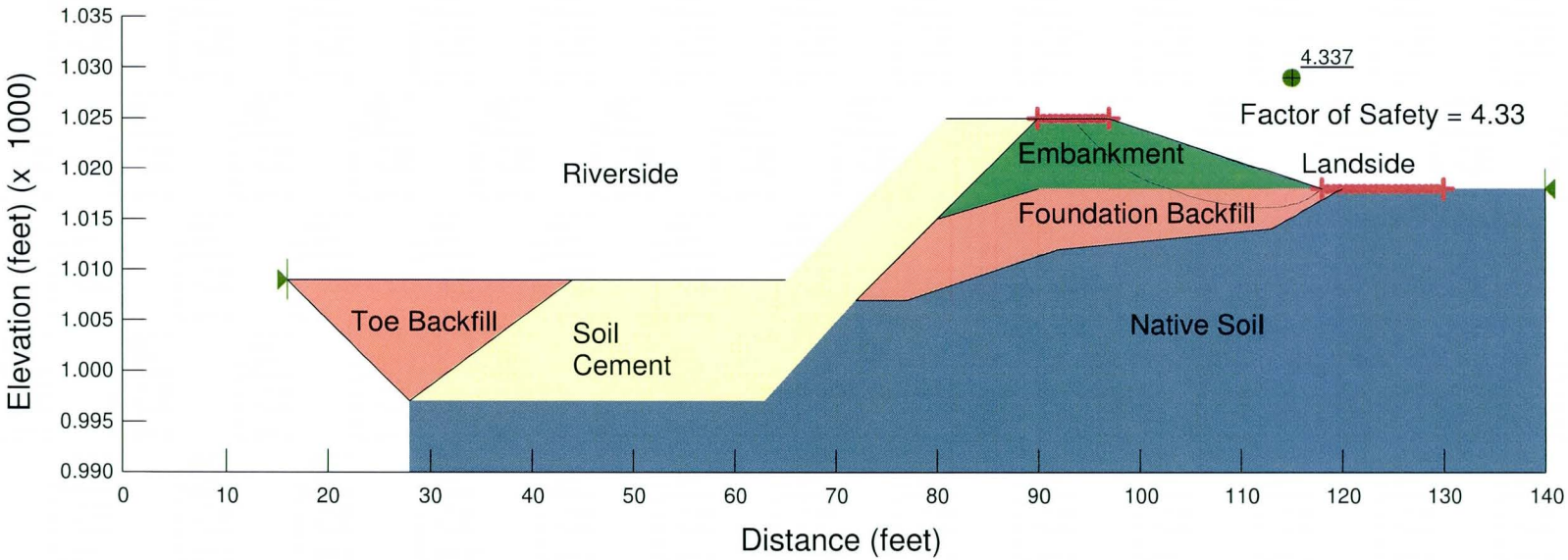
Camelback Ranch Leeve- South
Station 41+40

Case 4 - End of Construction
Riverside (Pseudo-static- Eq= 0.08g)



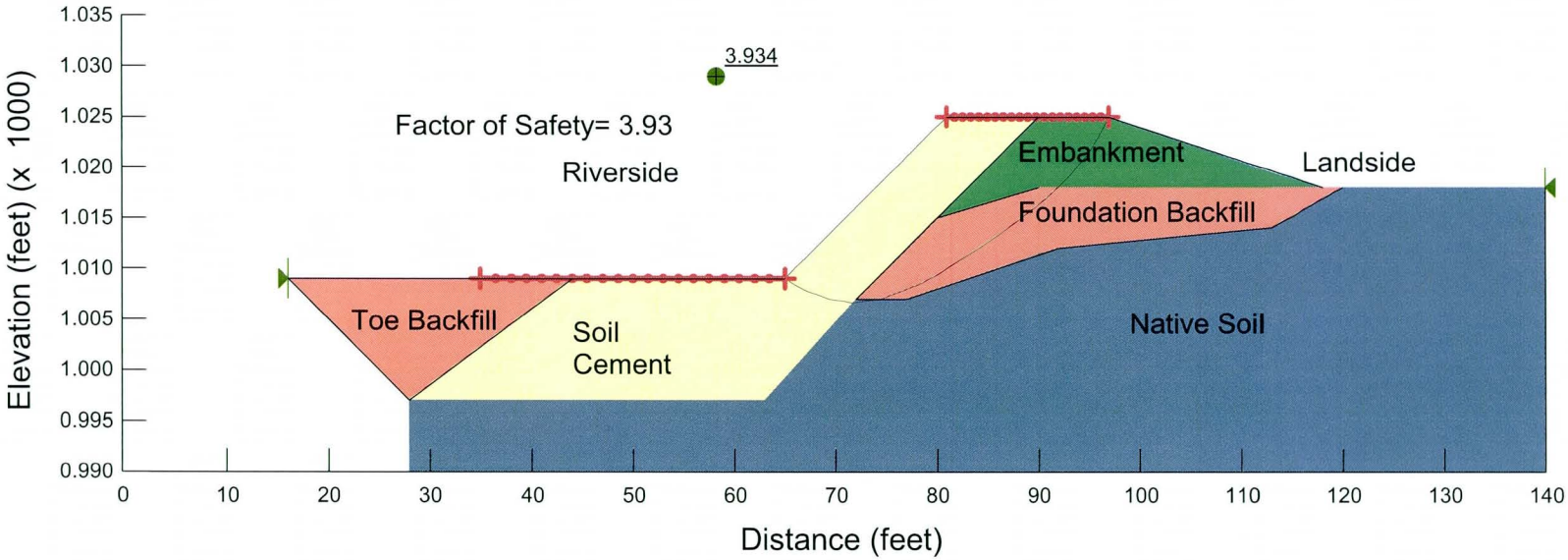
Camelback Ranch Leeve- South
Station 42+00

Case 1 - End of Construction
Landside (static)



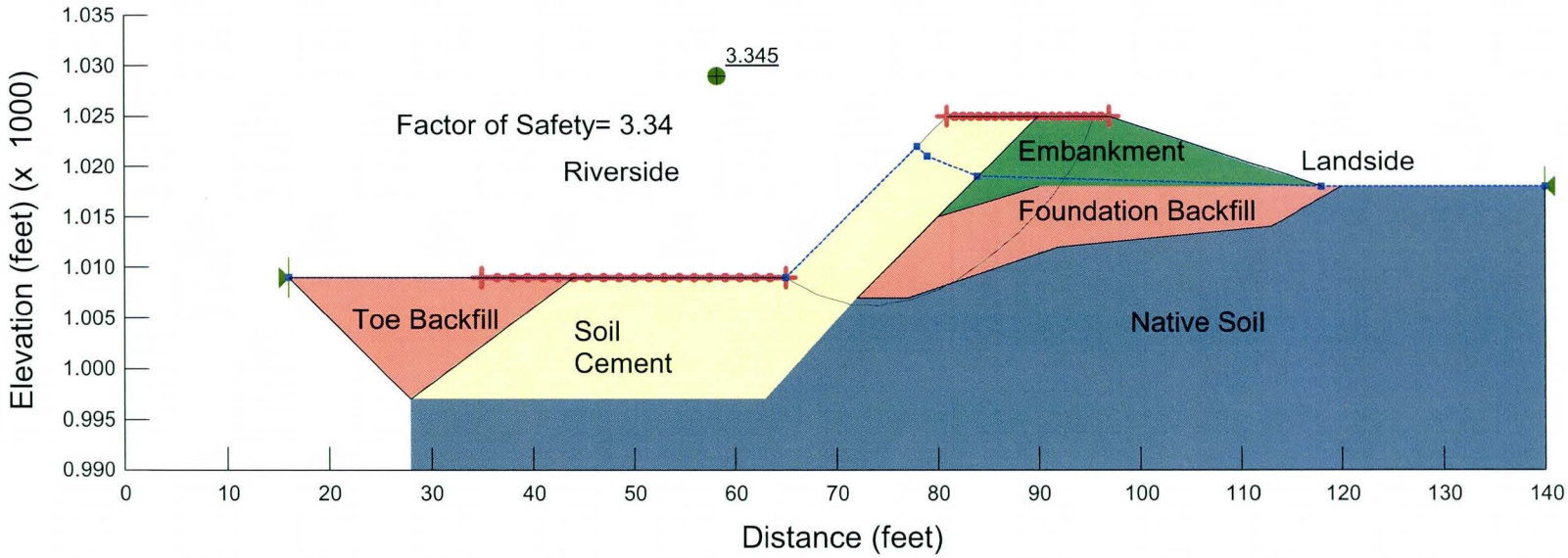
Camelback Ranch Leeve- South
Station 42+00

Case 1 - End of Construction
Riverside (static)



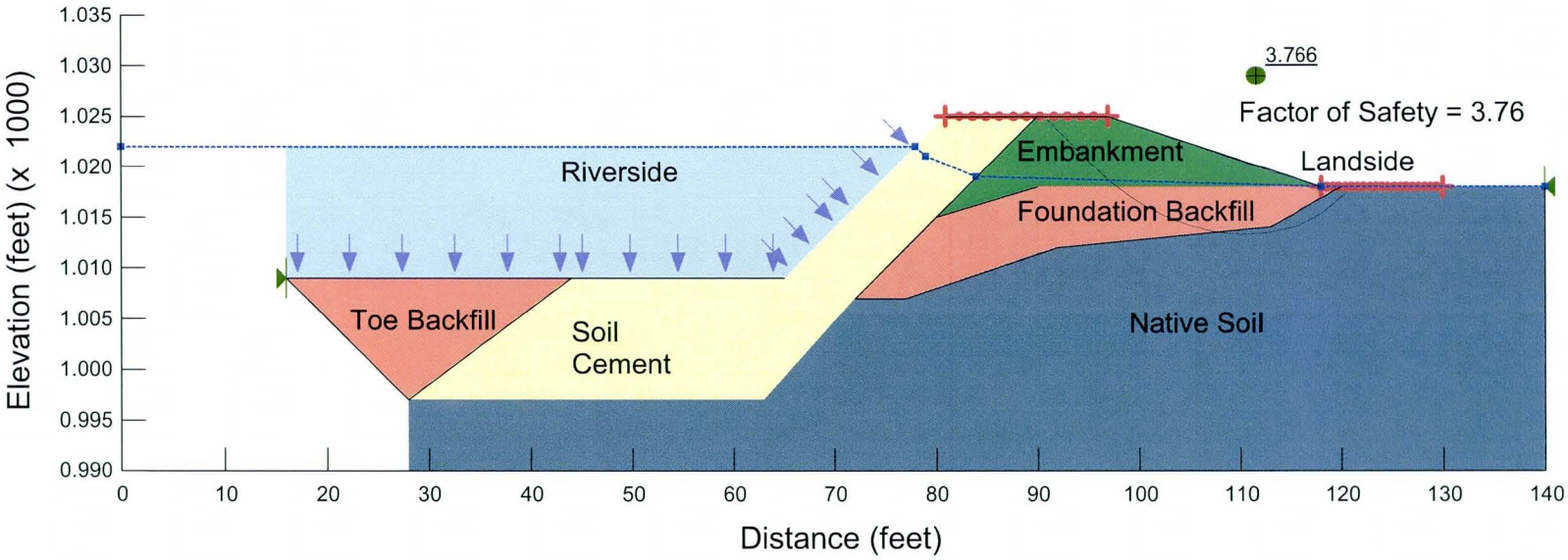
Camelback Ranch Leeve- South
Station 42+00

Case 2 - Sudden Drawdown
Riverside (static)



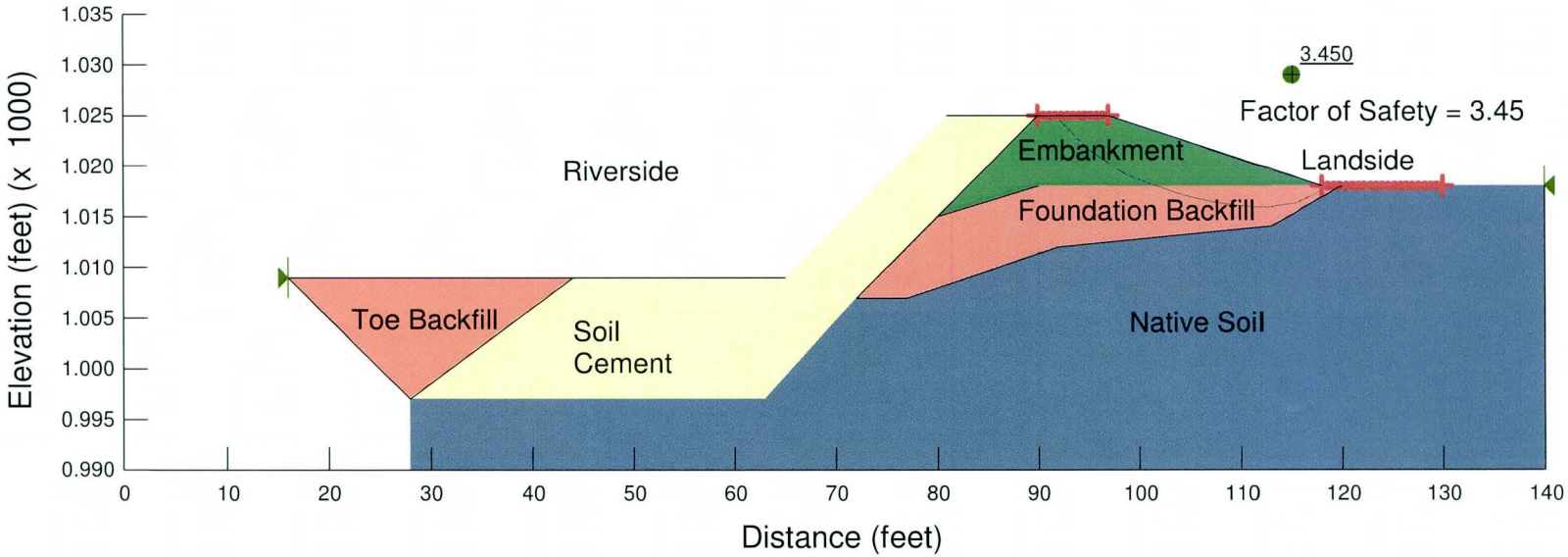
Camelback Ranch Leeve- South
Station 42+00

Case 3 - Steady Seepage from 100-year Flood Level Condition
Downstream (static)



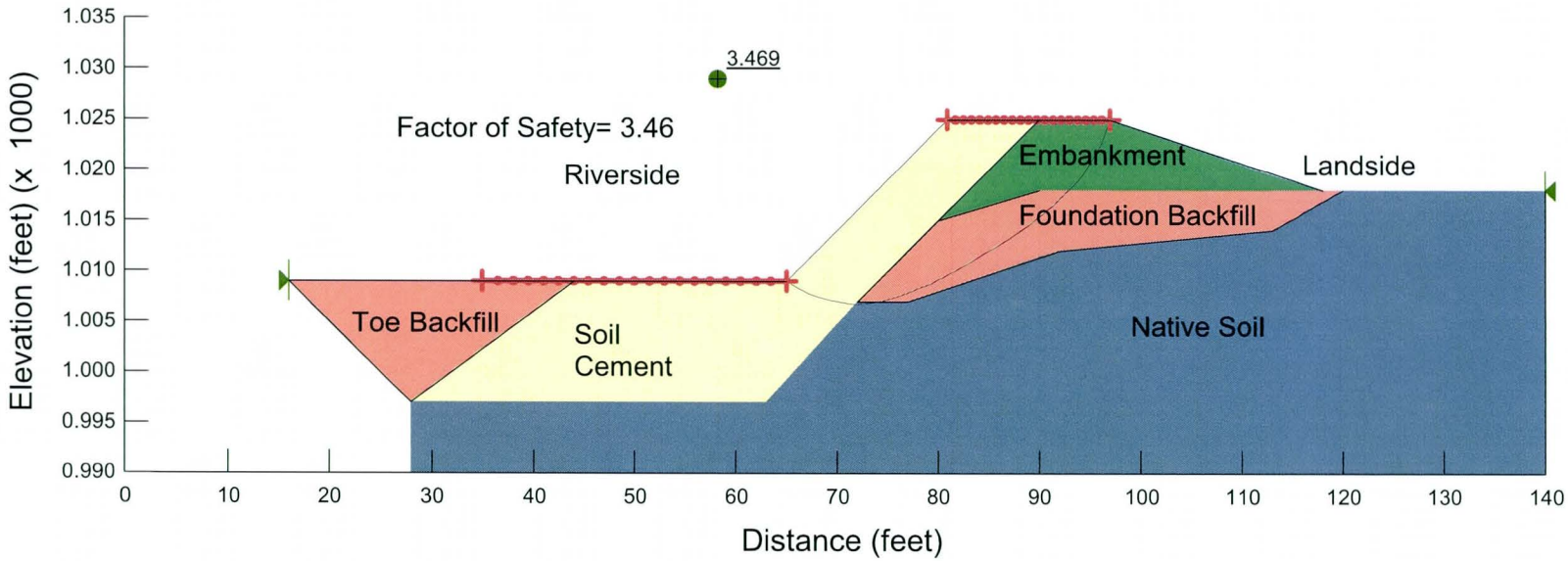
Camelback Ranch Leeve- South
Station 42+00

Case 4 - End of Construction
Landside (Pseudo-static- Eq= 0.08g)



Camelback Ranch Leeve- South
Station 42+00

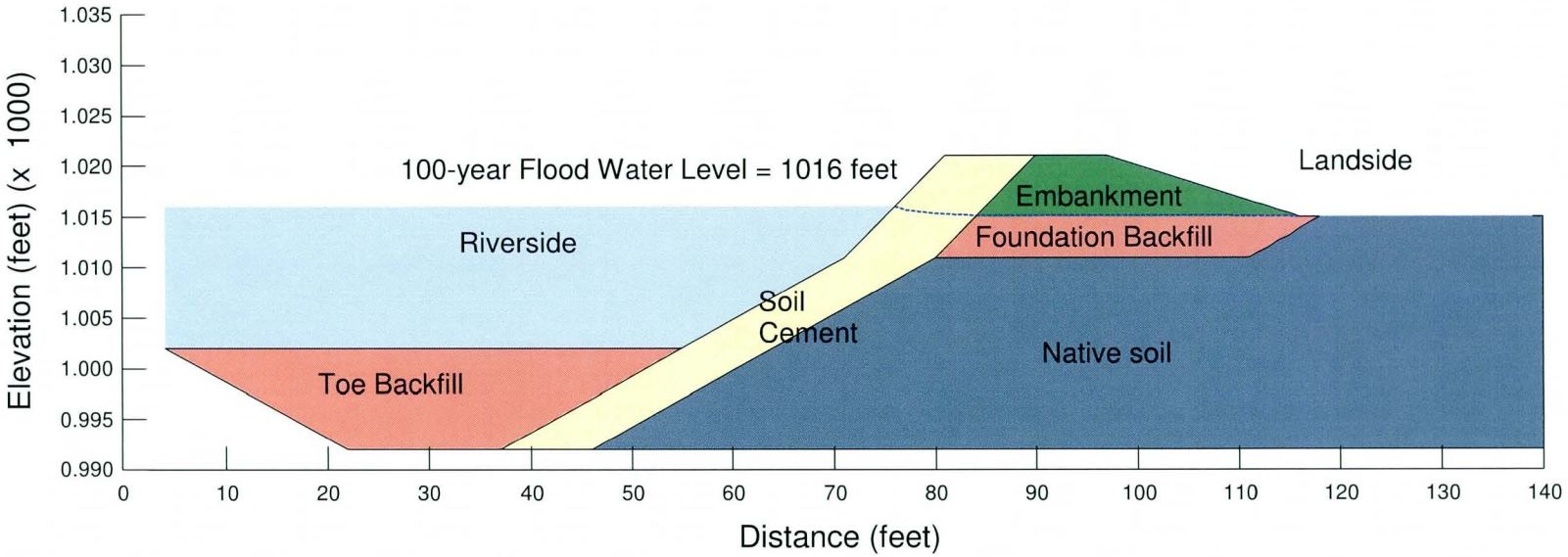
Case 4 - End of Construction
Riverside (Pseudo-static- Eq= 0.08g)



SEEPAGE ANALYSES

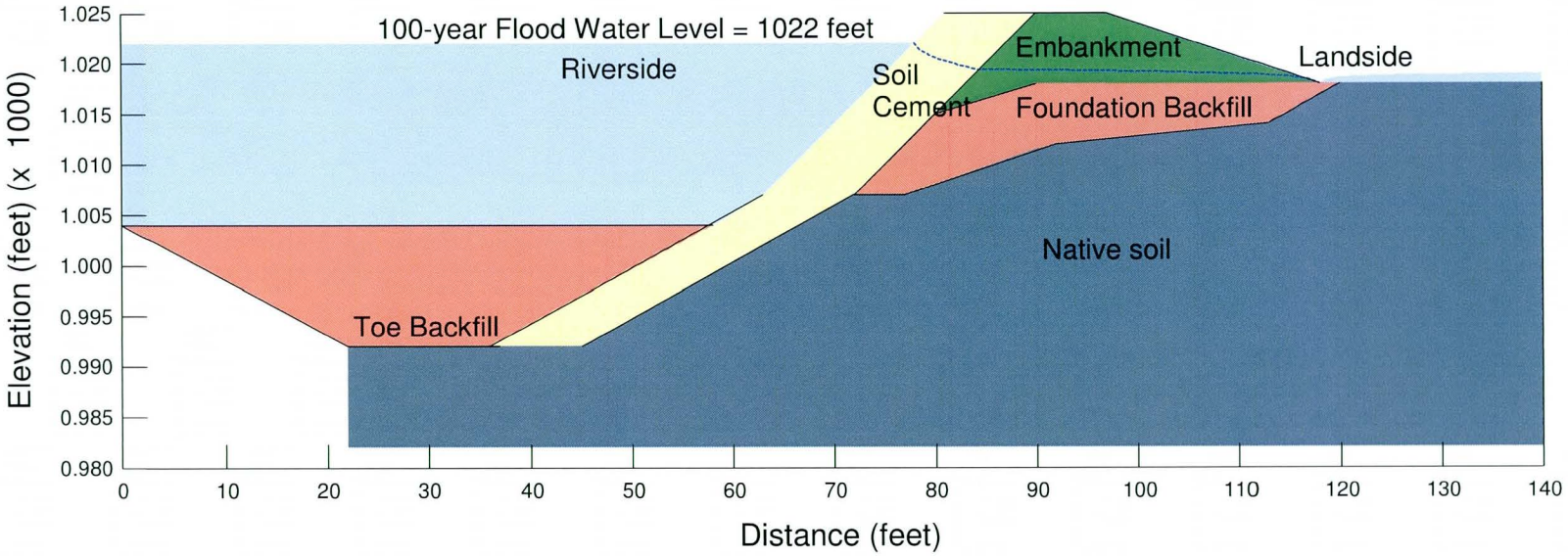
Camelback Ranch Leeve- South
Station 15+00

Steady State Seepage under 100-year Flood level Condition



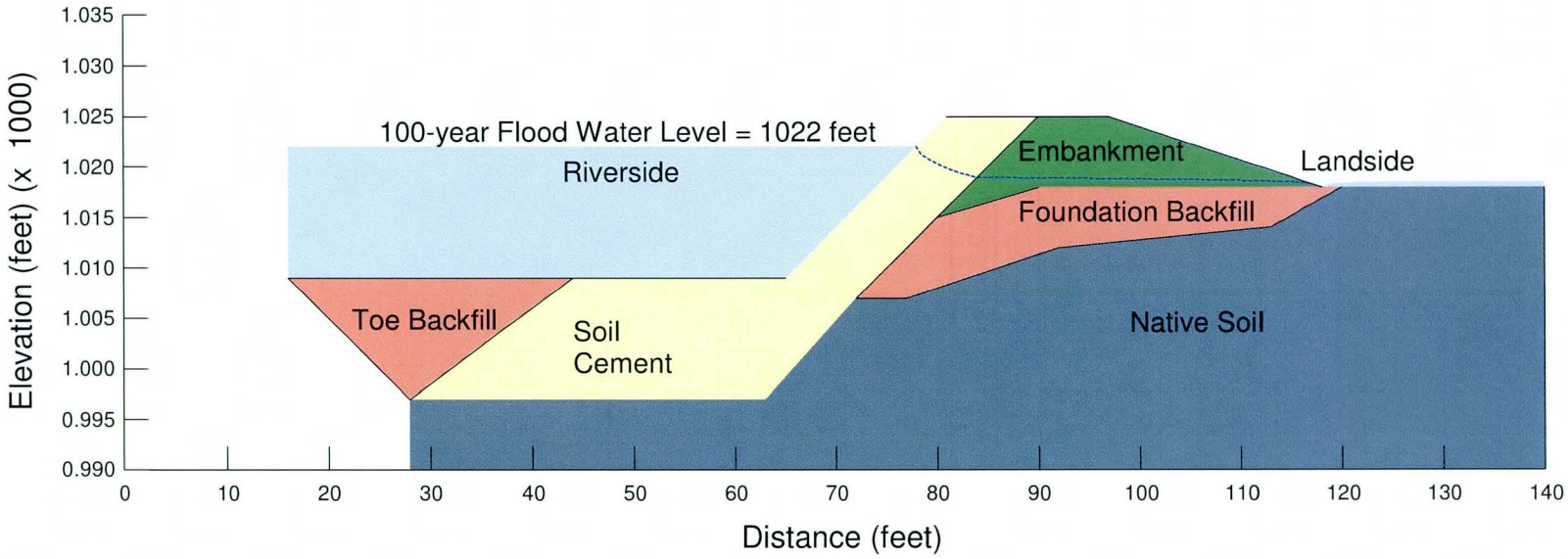
Camelback Ranch Leeve- South
Station 41+40

Steady State Seepage under 100-year Flood Level Condition



Camelback Ranch Leeve- South
Station 42+00

Steady State Seepage under 100-year Flood Level Condition

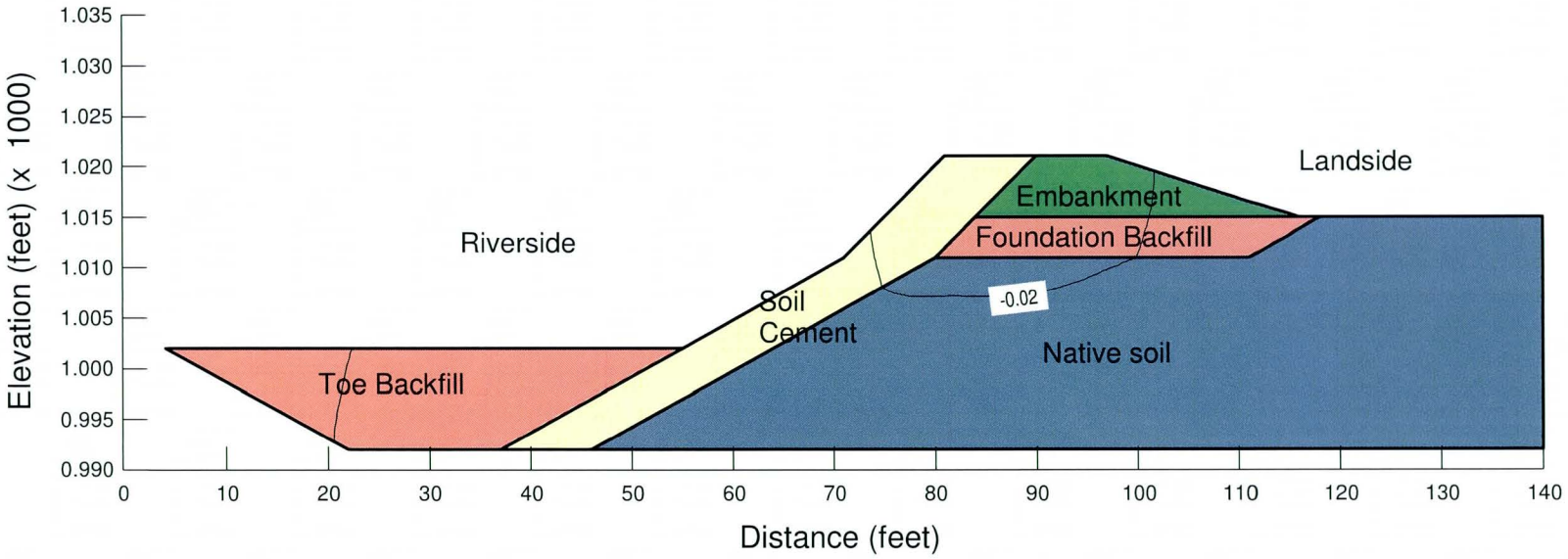


SETTLEMENT ANALYSES

Camelback Ranch Leeve- South
Station 15+00

Settlement Analysis

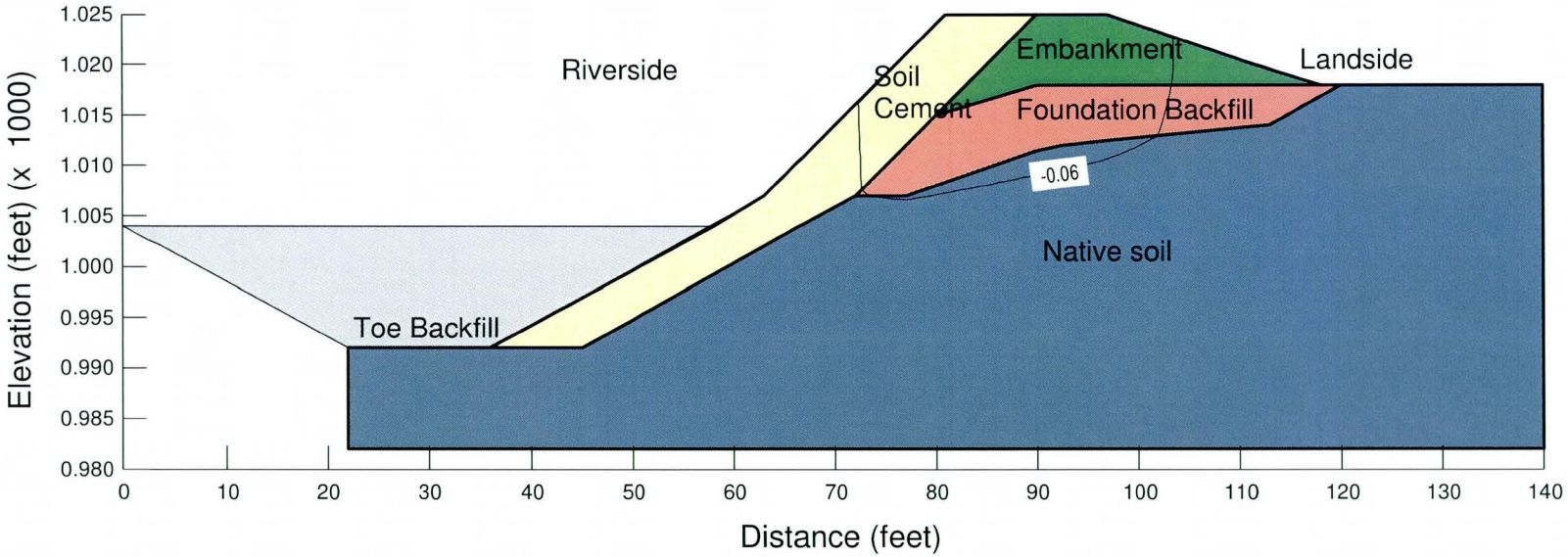
Maximum Vertical Settlement Contour in Feet



Camelback Ranch Leeve- South
Station 41+40

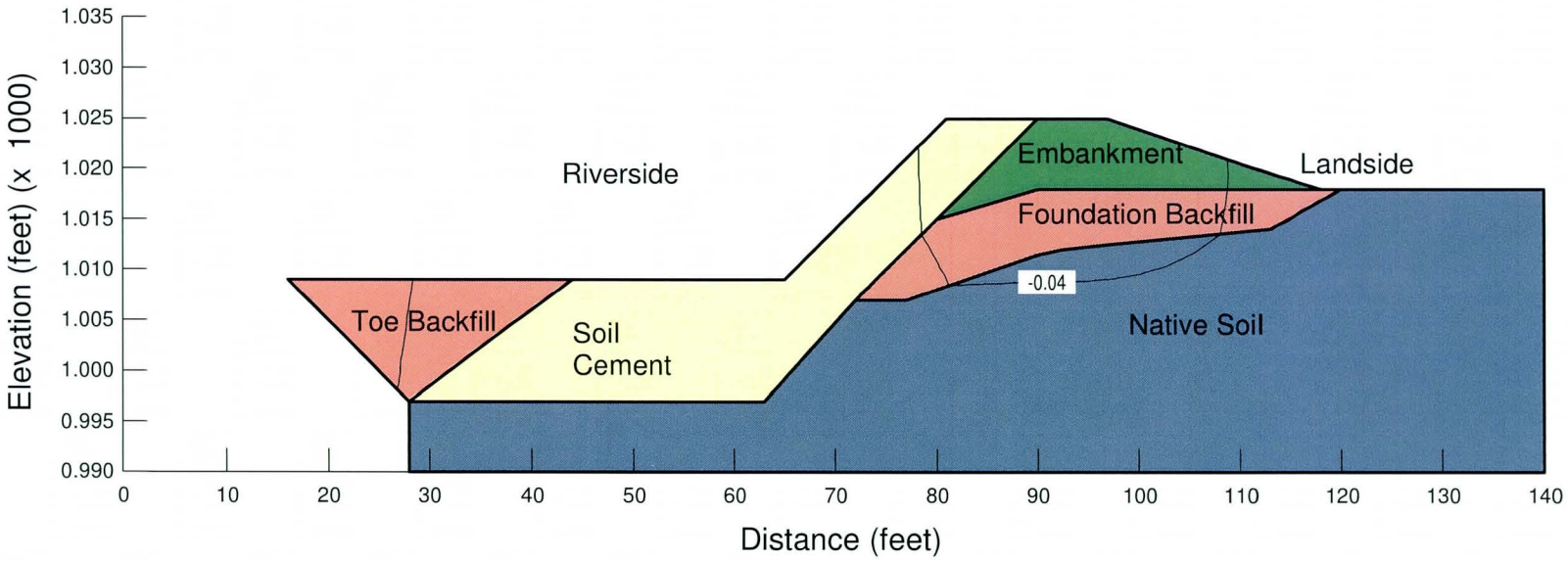
Settlement Analysis

Maximum Vertical Settlement Contour in feet



Camelback Ranch Leeve- South
Station 42+00
Settlement Analysis

Maximum Vertical Settlement Contour in feet



APPENDIX B
PHOTOGRAPHS

PHOTOGRAPH LOG

Photograph No. 1
Erosion of soil cement bank stabilization Sta. 38+25 to 41+60 (looking south) June 29, 2010.

Photograph No. 2
Erosion of soil cement bank stabilization Sta. 38+20 to 41+60 (looking north) June 29, 2010.

Photograph No. 3
Approach of Agua Fria River to eroded portion of Levee. Camelback Road Bridge in Background.

Photograph No. 4
Segment of Levee reconstructed for storm drain construction. Sta 41+85, June 29, 2010.

APPENDIX C
PARTIAL CERTIFICATION LETTER

March 18, 2011

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 & Settlement
Camelback Ranch Levee South
Phoenix, Arizona
AMEC Project Number 17-2010-4016

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 NFIP regulations [44 CFR 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.

Tony J. Freiman, PE
Senior Engineer

Registered Professional Engineer (Civil) CERTIFICATE NO. 23982 TONY J. FREIMAN Date Signed 3/18/2011 ARIZONA, U.S.A. Expires 12/31/2011

Reviewed by:

Brett A. Howey, PE
Unit Manager – Geotechnical Services

Registered Professional Engineer (Civil) CERTIFICATE NO. 40209 BRETT A. HOWEY Date Signed 3/18/11 ARIZONA, U.S.A. Expires 12/31/12

AMEC Earth & Environmental
1405 West Auto Drive
Tempe, Arizona 85284-1016
Tel (480) 940-2320
Fax (480) 785-0970