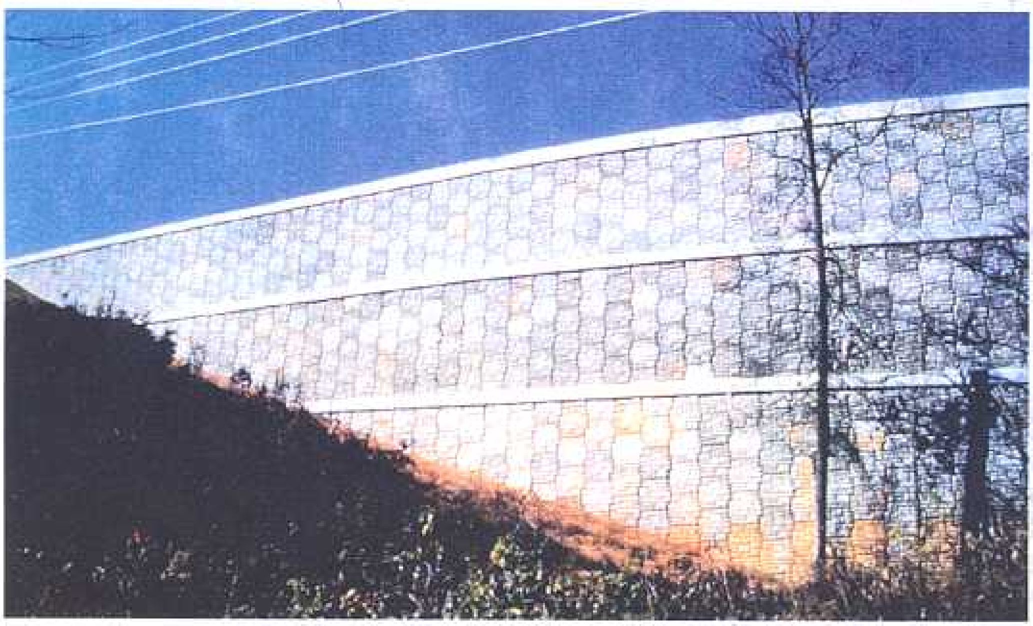
Evaluation of Retaining Wall/Slope Alternatives to Reduce Impacts to Miller Creek Embankment Station 174+00 to 186+00

Third Dependent Runway
Sea-Tac International Airport



Prepared by

HNTB,

Hart Crowser, Inc.

and

Parametrix

AR 042353

Port of Seattle

AVIATION PROGRAM MANAGEMENT GROUP
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TRANSMITTAL RECORD

TO: Tom Walsh

DATE: July 13, 1999

[X] Enclosed please find one copy of the Wall/Slope Evaluation Document.

X	For Review and Approval		Approved as Noted
	Approved		Resubmit for Approval
	Not Approved		Other: (see remarks)

REMARKS: Your review comments are appreciated. Please note that my team and I would be happy to meet with you to discuss specific mitigation elements, comments, and/or issues.

Our goal is to initiate renotice of our permit no later than August 6, 1999.

Thank you for your assistance in this time sensitive issue.

Very Truly yours,

Barbara Hinkle

COPY TO:
Port of Seattle: Michael Cheyne, Traci Goodwin, John Rothnie, Earl Munday, Mary Vigilante, Jim Thomson, Elizabeth Leavitt

Foster, Pepper, & Sheffleman: Tom Walsh

U.S. Army Corps of Engineers: Jonathon Freedman

Department of Ecology: Erik Stockdale, Tom Luster, Ray Helwig, Kevin Fitzpatrick

FAA: Cayla Morgan

USFWS: Nancy Brennan-Dubbs

USDA Wildlife Services: Roger Woodruff

King County: David Masters

WA Dept. of Fish and Wildlife: Phil Schneider

U.S. E.P.A.: Steve Roy

April 1999

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EVALUATION OF RETAINING WALL/SLOPE ALTERNATIVES TO REDUCE IMPACTS TO MILLER CREEK
Embankment Station 174+00 to 186+00

EXECUTIVE SUMMARY

Introduction

The Port of Seattle is proposing to construct a new runway on the west side of Seattle-Tacoma International Airport. The new runway must have a minimum separation of 2,500 feet from the existing Runway 34R/16L as described in the Environmental Impact Statements for the project. The majority of the embankment necessary for the new runway is being designed with a conventional 2:1 slope, which is the most widely accepted approach to embankment design. In certain portions of the proposed embankment, however, preliminary designs anticipated that retaining walls and/or steepened slopes would be constructed to minimize impacts on environmentally sensitive areas.

One location where a retaining wall and/or steepened slope was anticipated is the area between Runway Stations 174+00 and 186+00, where an environmentally valuable section of Miller Creek and an adjoining wetland ecosystem exist. Recently, as the Port acquired the properties necessary for construction of the embankment and completed topographic surveys of the newly-acquired properties, it discovered that the section of Miller Creek in this area is somewhat closer to the proposed embankment than previous aerial mapping had indicated. As a result, the retaining wall assumed in the preliminary designs for this area would have required relocation of this section of Miller Creek and the embankment would have resulted in greater impacts to the wetland ecosystem than previously anticipated.

In an effort to avoid this greater impact, the Port conducted additional studies of various alternative design and layout options for the retaining wall. These studies were conducted to determine whether a practicable alternative exists that would result in less adverse impact on the aquatic ecosystem in this area. Consistent with Section 404 of the Clean Water Act, practicable alternatives are those that achieve the purposes of the project and are logistically, technologically and economically feasible.

The purpose of this document is to describe these additional studies conducted by Port of Seattle staff and consultants. The area discussed in this report is an eastward bow in Miller Creek, in the vicinity of runway stations 174+00 to 186+00. Figure ES.1 shows the project area. In this location, the creek extends within an area that would be filled if conventional embankment construction were used for the Third Runway.

Evaluation of the alternatives and the associated environmental impacts used an organized process to define objectives; identify, screen, and rank alternatives; assess potential risks;

and develop a recommended alternative. This approach is consistent with the standard decision-making process used by Port management. Figure ES.2 is a flow chart depicting the process and inputs used to develop and evaluate the recommended alternative.

Environmental issues affecting the selection and analysis of alternatives included:

- The desirability of avoiding creek relocation;
- The desirability to reduce or avoid impacts to the creek buffer area and adjacent wetlands;
- The need to protect and restore riparian habitat while avoiding creation of wildlife attractants that are inconsistent with airport safety; and
- The need to protect or create flood storage and conveyance features.

The selection and analysis of alternatives required a careful balance between environmental impacts and technical practicability. Avoidance of impacts to this reach of Miller Creek and its adjacent wetland ecosystem was considered a top priority. From a technical perspective, alternatives must satisfy airfield operational needs and provide emergency response access, must be seismically stable and easily constructable, must accommodate differential settlements, and must be maintainable.

Overview of the Evaluation Process

More than 60 embankment slope, retaining wall, and creek relocation configurations were initially screened to identify critical issues. Existing site conditions and four creek relocation alignments were considered during the screening process.

A ratings matrix was used to further evaluate 20 retained wall and slope geometric options. The following criteria were used to compare alternative embankment slope and retaining wall configurations:

- Avoidance or Minimization of Creek Relocation;
- Wetland and Creek Buffer Avoidance;
- Floodplain Avoidance;
- Minimizing the Quantity of Embankment Fill (related to fill transport and other construction impacts);
- Cost;
- Access (the need to provide airport Fire, Police, and maintenance access along the runway embankment);
- Operational Impacts;
- Ease of Maintenance;
- Drainage Adaptability;
- Scheduling Adaptability;
- Wildlife Attractiveness; and

- Aesthetics.

A separate ratings matrix was used to evaluate 13 different types of retaining wall or steepened slope structure systems that could meet geometric and environmental constraints. This matrix considered a range of wall slope technology alternatives, ranging from conventional structures used for highway and marine terminal embankments, dams, and specialized wall structures used in mining operations. The following types of retaining wall and slope technologies were identified for comparative evaluation:

Wall Concepts
- Mechanically Stabilized Earth (MSE) Walls
- Anchored Walls
- Criblock-Type Walls
- Cellular Cofferdams
- Concrete Dam (2 types)
- Conventional Cantilever Wall
- Counterfort Wall
- Cylinder Pile Wall

Steepened Slope Concepts
- Mechanically Stabilized Earth (MSE) Slopes
- Soil Cement Buttress
- Roller-Compacted Concrete

Wall and slope concepts were evaluated using the following criteria:

- Material Design Life;
- Experience/Performance History (i.e., relative number of constructed projects and duration in service);
- Technical Certainty (i.e., established design methods);
- Seismic Performance Characteristics;
- Constructability;
- Cost;
- Surface/Subsurface Drainage;
- Differential Settlement Performance;
- Ease of Maintenance; and
- Aesthetics.

Results from the various evaluation matrices were compiled and four options selected for further risk analysis. Options were selected to represent a range of potential impact scenarios while completely satisfying technical and airport operational requirements (security, emergency and maintenance access.). The intent was to identify risks and assess their manageability for each of the options. The facilitated risk assessment first identified risks common to all options. The following is a summary of the anticipated potential risks:

- **Accidental Encroachment.** Risk of accidental encroachment into wetlands, creek buffer or creek itself.
- **Seismic.** Level of design complexity necessary to ensure a reasonable factor of safety.
- **Aesthetic and Attractive Nuisance.** Relative difficulty in providing an aesthetically pleasing appearance and the potential of becoming an "attractive nuisance" for graffiti, climbing, etc.

A composite alternative was developed based on optimizing the benefits associated with each of the four options as well as input from a risk analysis. The recommended alternative was evaluated by an independent group of peer reviewers, consisting of local geotechnical engineering and environmental consultants specifically retained for this purpose.

Summary of the Recommended Alternative

The recommended alternative consists of a series of mechanically stabilized earth (MSE) retaining walls, in four tiers. This recommended configuration is tiered, rather than a single flat surface, for both aesthetic and technical reasons.

MSE is a method of improving soil strength through incorporation of reinforcing strips or sheets within the embankment during construction. It is economical to construct and highly stable during seismic shaking.

Figures ES.3, ES.4, and ES.5 show the recommended creek and retaining wall configuration in plan, profile, and cross section at the most constrained section of the wall. It should be noted that the maximum wall height occurs in a limited area, approximately 200 feet, in the vicinity nearest to Miller Creek.

The recommended design results in no creek relocation and, following construction, a minimum of 50 feet setback from the existing creek. During embankment construction, temporary impacts may occur within 30 feet of the creek.

Typically, the facings for MSE walls consist of modular concrete panels, which are available in a variety of shapes, textures, and colors. Additional facing alternatives including options for limited planting on wall terraces and/or faces, or use of a rock facing are available, but have significant maintenance drawbacks. Figure ES.6 shows a few examples of alternative MSE wall facings.

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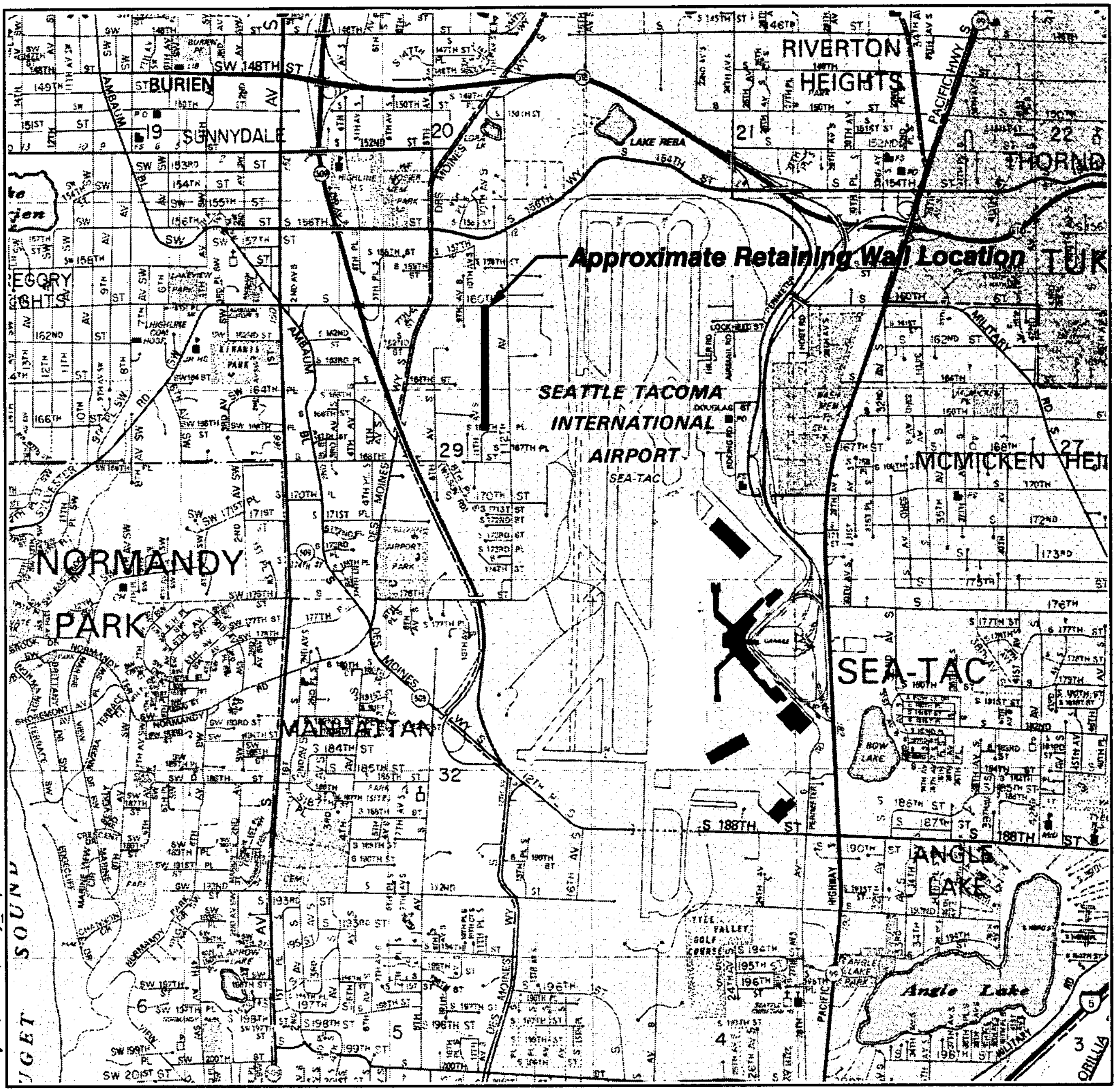
Vicinity Map



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Scale in Feet

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AR 042364

Vicinity Map

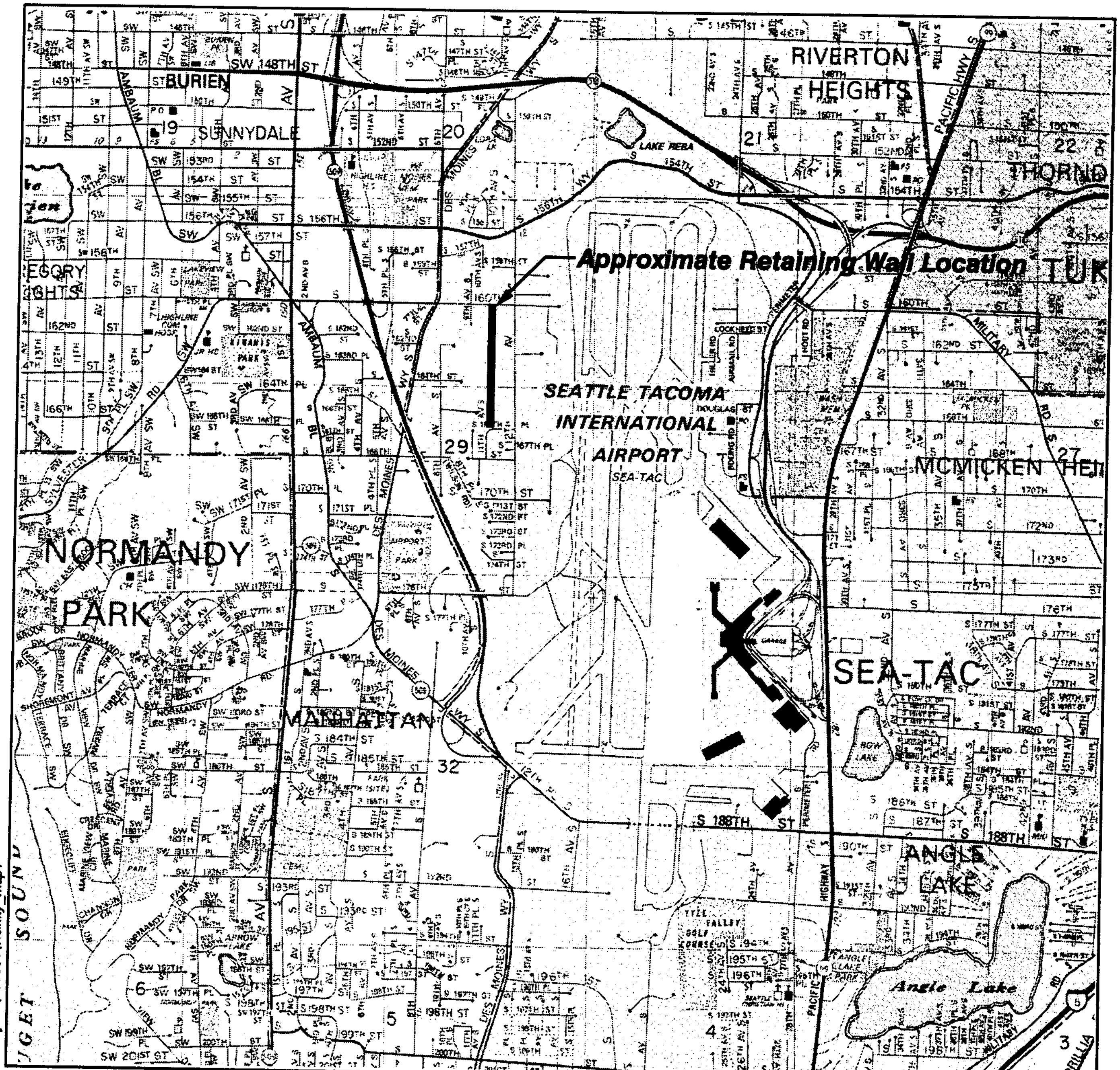

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Figure ES.1

WALL/SLOPE ALTERNATIVES EVALUATION PROCESS

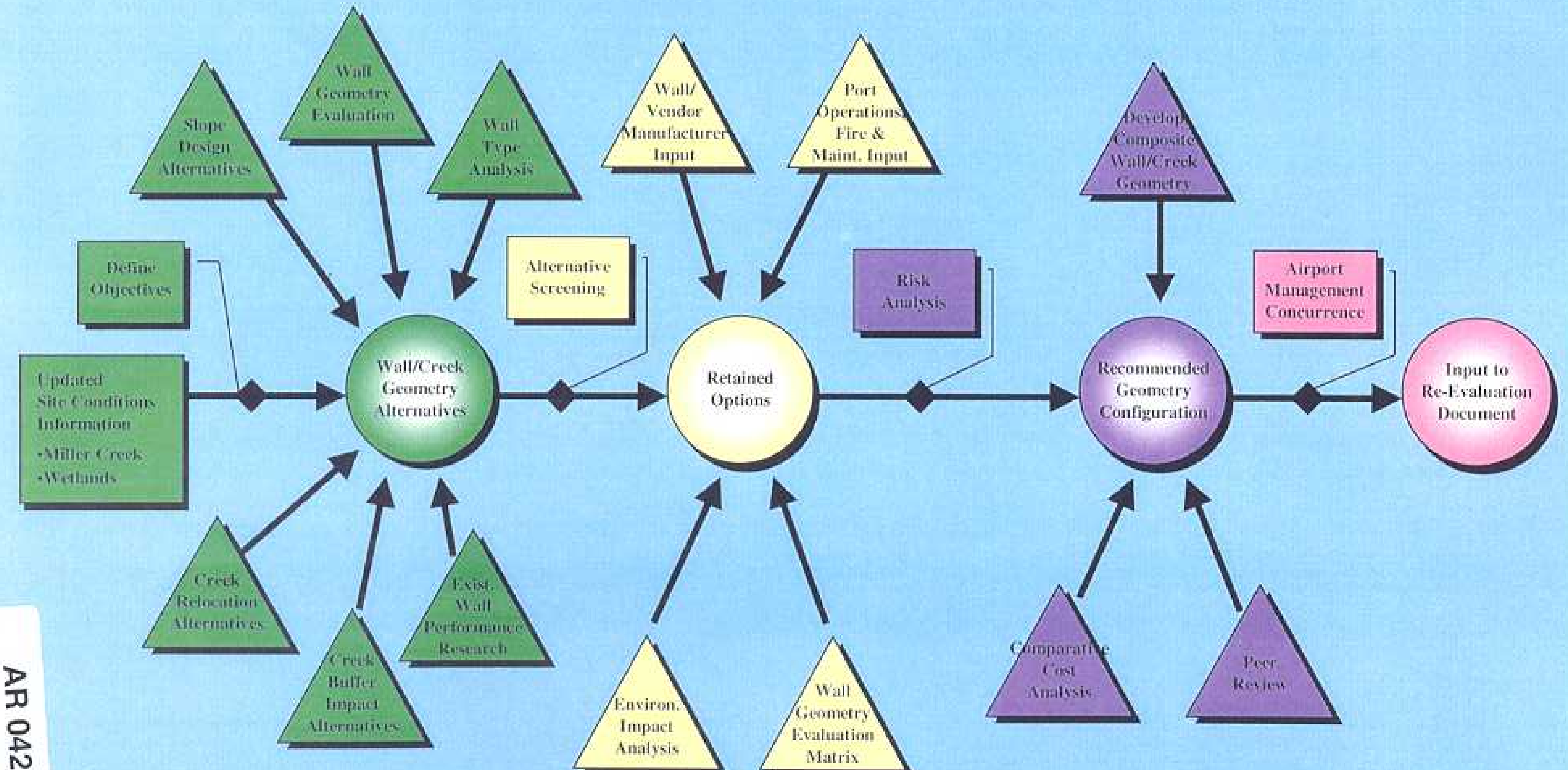


Figure ES.2

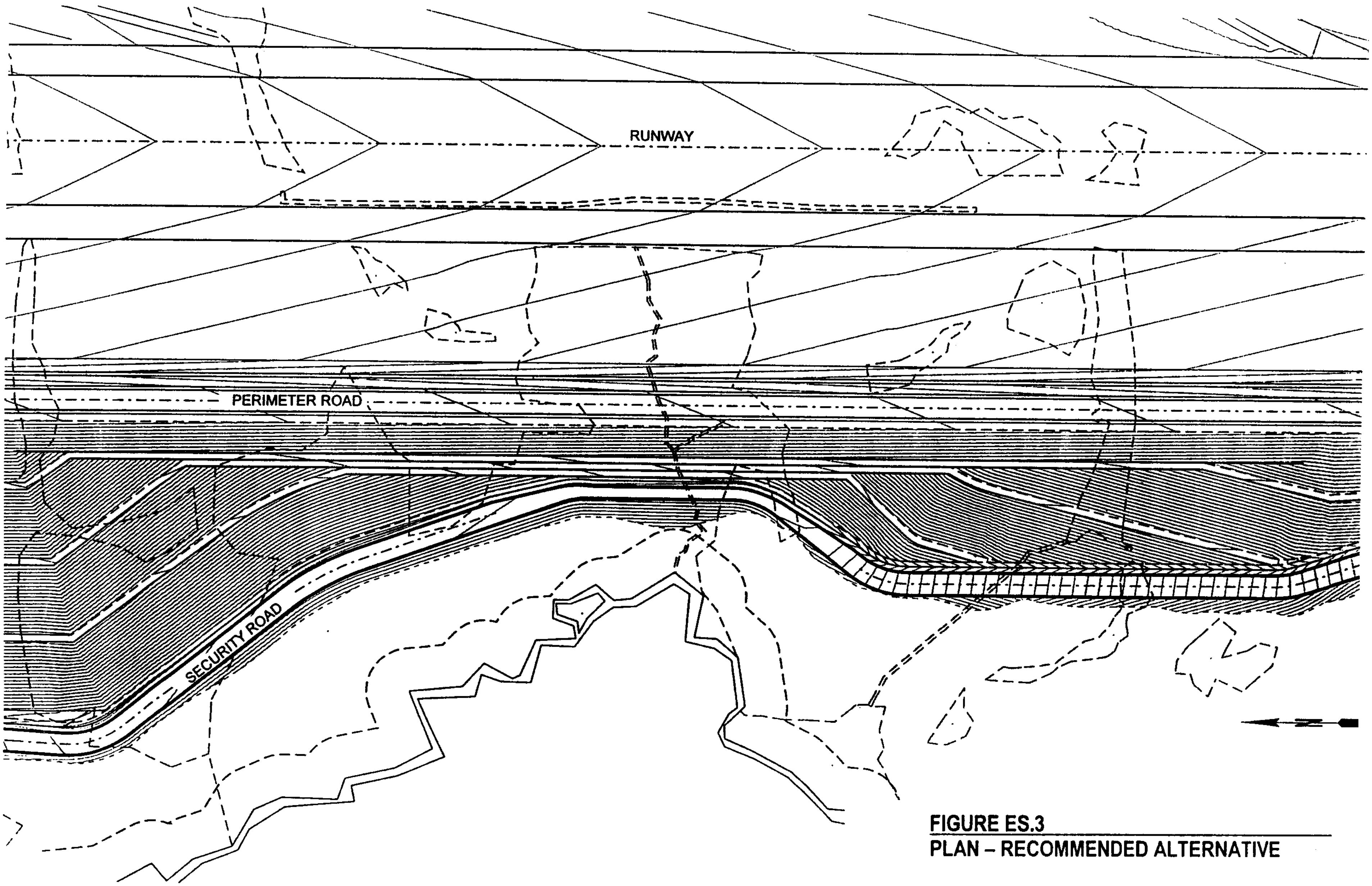
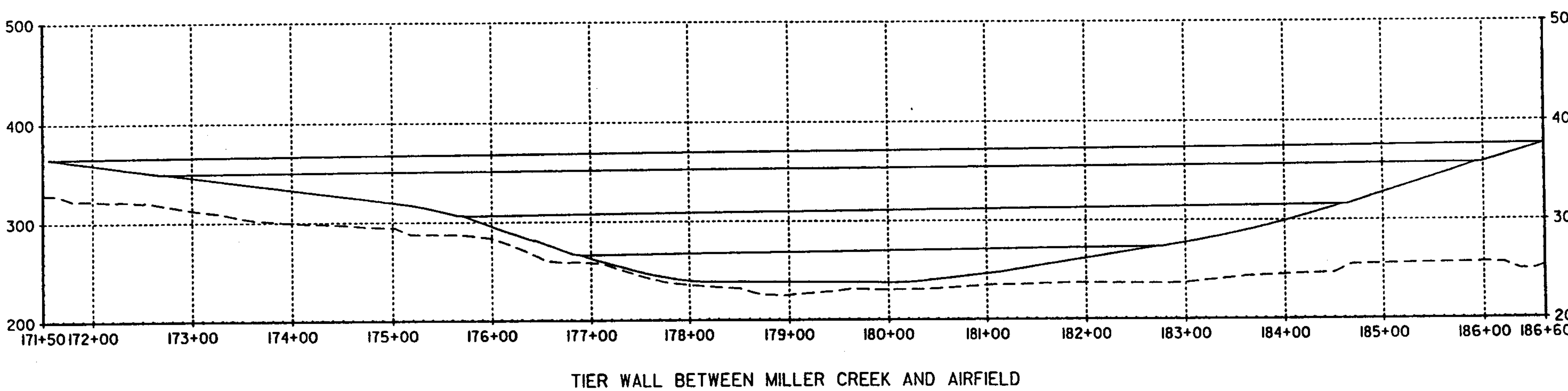


FIGURE ES.3
PLAN – RECOMMENDED ALTERNATIVE



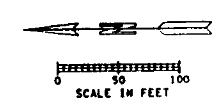
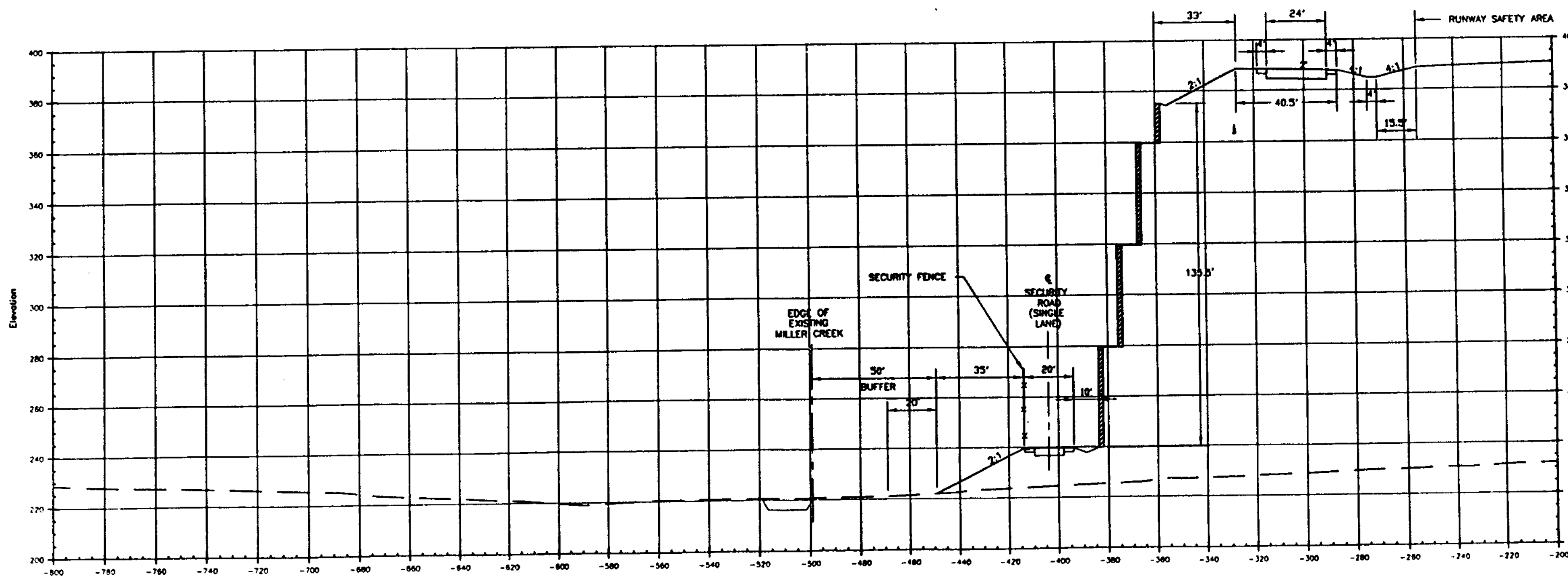


FIGURE ES.4
PROFILE – RECOMMENDED ALTERNATIVE

SUGGESTED WALL/CREEK GEOMETRY

TIERED WALL, NO CREEK RELOCATION, PARTIAL BUFFER IMPACT



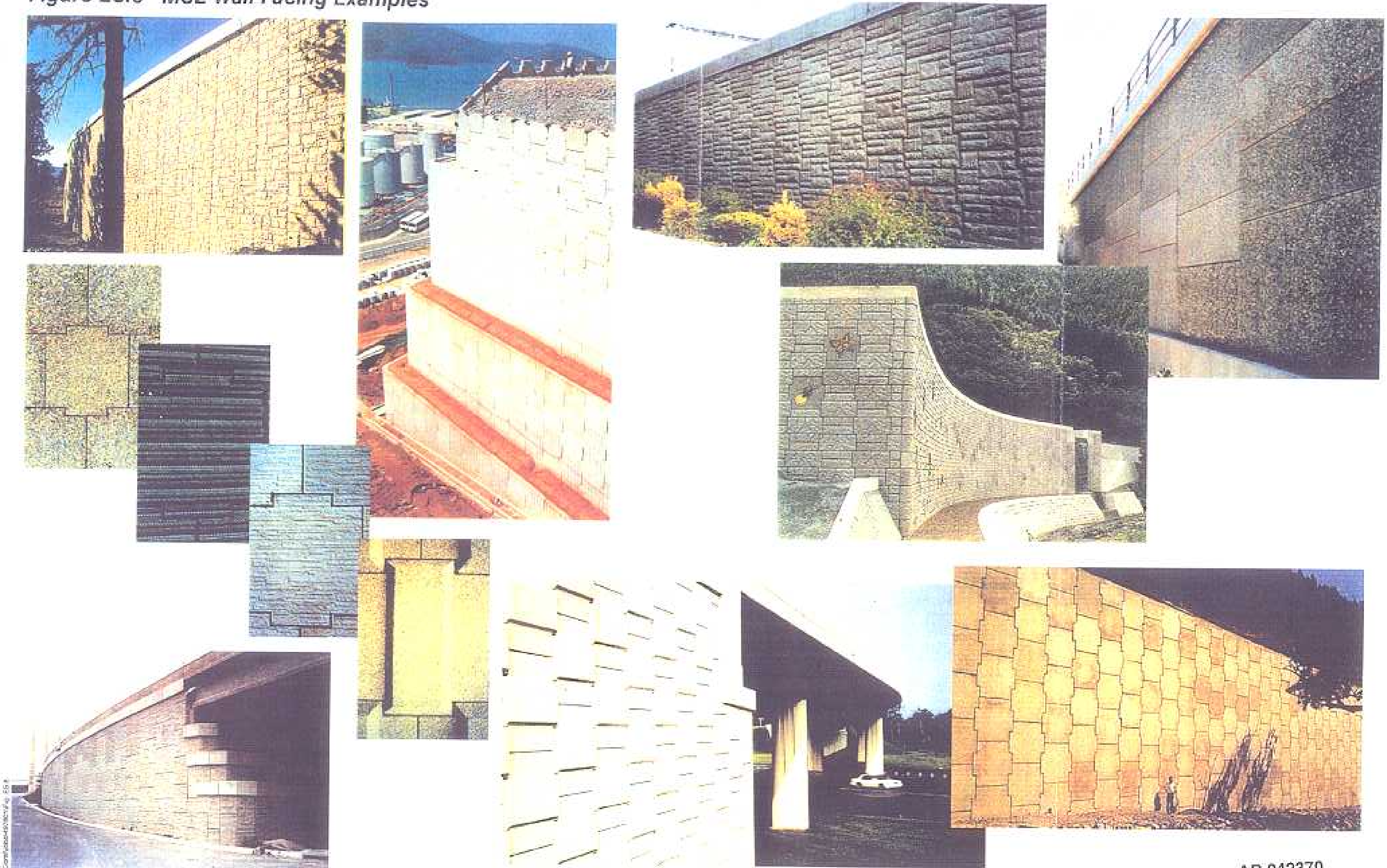
STATION 178+88

1" = 40'

FIGURE ES.5

SECTION – RECOMMENDED ALTERNATIVE

Figure ES.6 MSE Wall Facing Examples



Evaluation of Retaining Wall/Slope Alternatives to Reduce Impacts to Miller Creek

Embankment Station 174+00 to 186+00

Third Dependent Runway
Sea-Tac International Airport

Prepared By: HNTB
Hart Crowser
Parametrix

INTRODUCTION

EVALUATION OF RETAINING WALL/SLOPE ALTERNATIVES TO REDUCE IMPACTS TO MILLER CREEK
Embankment Station 174+00 to 186+00

INTRODUCTION

The main text of this report includes the following sections:

Section	Title	Description
1	Existing Conditions	
2	Evaluation of Geometric Alternatives to Minimize or Avoid Creek Impacts	Summary of the retaining wall/slope layout and geometry evaluation.
3	Evaluation of Alternative Technical Approaches to Retaining Wall Construction	Summary of retaining wall/slope construction materials evaluation.
4	References	

Figures are included at the end of each section, tables are typically included in the text where cited.

This report also includes the following appendices to present more detailed information:

Appendix	Title	Description
A	Miller Creek Relocation Site B	Discusses the four potential creek relocation alternatives that were considered.
B	Supporting Information on Wall/Slope Geometry Variables	Describes the geometrical variables used to develop the wall/slope options.
C	Supporting Information on Wall/Slope Alternatives	Describes wall/slope construction types.
D	Commentary on MSE Wall Design Issues	Summarizes issues specific to MSE retaining wall design.
E	Geotechnical Peer Review Report	

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SECTION 1

EXISTING CONDITIONS

SECTION 1 EXISTING CONDITIONS

Background

Design for the Third Runway embankment considers using a nominal 2H:1V fill slope wherever possible along the length of the runway embankment. Both the 1994 Preliminary Engineering Report and the Final Environmental Impact Statement indicated a retaining wall would likely be constructed in the vicinity of runway Station 174+00 to 186+00, to avoid impacts to Miller Creek.

As site access was obtained in the vicinity of the proposed embankment, existing ground-feature mapping was updated with more accurate information. Between stations 174+00 and 186+00, the location of Miller Creek based on ground survey information is approximately 80 feet east of the location that had been determined based on photographic mapping at it easternmost point. This information led to a re-evaluation of the conceptual embankment design in this area. This report documents the detailed process used to evaluate embankment construction alternatives to reduce undesirable impacts to Miller Creek and associated wetlands.

Site Description

The area addressed in this report is between runway stations 174+00 and 186+00. The area just north of the new runway's midpoint, at approximately runway station 178+88, is adjacent to Miller Creek's easternmost point before it turns west towards Puget Sound. At this point Miller Creek is closest to the proposed runway alignment.

The existing ground surface across the project site typically slopes down to the west from the existing airfield embankment toward Miller Creek at 10 to 15 percent. The area west of 12th Avenue includes Class II riparian wetland that is vegetated with forest shrubs and emergent plant communities.

Subsurface soils in the project area range from relatively soft, wet, organic soils in the wetlands, to medium dense mostly sandy soils in adjacent uplands, both overlying very dense glacially overridden soils at depths on the order of 10 to 30 feet. Construction considerations for these soils include the need to provide an adequate foundation for the embankment and to maintain shallow groundwater "base-flow" to support Miller Creek and adjacent wetlands.

Because of the existing topography, this area of the project requires the greatest height of embankment necessary for the Third Runway construction. East of the project area, the horizontal and vertical positions for the new third runway safety area and perimeter road have been established and are fixed based on other aspects of the project. North and south of the project area, the runway embankment will typically slope down to the existing ground at a nominal slope of 2H:1V for most of the embankment length. Drainage collection benches will typically be located approximately every 40 vertical feet along the length of the embankment.

2H:1V Fill Slope Not a Viable Option for This Area

Construction of a conventional earth embankment with nominal 2H:1V slopes through the central embankment area would require extensive relocation of Miller Creek and loss of Class II wetlands. Substantial disturbance beyond the embankment would be necessary to provide a suitable channel for the relocated creek. To avoid these impacts, options to the 2H:1V fill slope were identified and evaluated for application in the central embankment area.

SECTION 2

EVALUATION OF GEOMETRIC ALTERNATIVES TO MINIMIZE OR AVOID CREEK IMPACTS

SECTION 2 EVALUATION OF GEOMETRIC ALTERNATIVES TO MINIMIZE OR AVOID CREEK IMPACTS

Introduction

This section describes the evaluation process to develop a preferred geometrical configuration of the retaining wall and the surrounding slopes. The selected geometrical layout will determine the impacts to the creek and wetlands. The evaluation process follows the Army Corps of Engineers 404-b1 guidelines relating to alternatives analysis. The result of the evaluation is selection of the most practical geometrical layout with the least impacts to the creek and adjacent wetlands.

Design Criteria

Design criteria were developed to aid in development of the goemetric options. The design criteria are intended to enable construction of an embankment that will support on operational runway, and they are intended to define security, safety, and engineering constraints. Table 2.1 summarizes the design criteria used to develop the wall/slope embankment options evaluated.

Table 2.1 - Geometry Design Criteria

Description	Design Standard	Rational
Perimeter Road Width	32 feet (24 feet road with 4-foot-wide shoulders)	To allow passage of two emergency and/or construction vehicles.
Perimeter Road location and Elevation	As set by Third Runway Elevation and runway safety area	Must meet FAA runway safety area grading standards and allow airfield access.
Security Road Width	28 feet (24 feet with 2-foot-wide shoulders)	To allow passage of one security vehicle and one emergency vehicle.
Single Lane Security Road	16 feet (12 feet with 2-foot-wide shoulders, 200 feet maximum distance)	To allow passage of one emergency vehicle.
Maximum Horizontal Distance from Edge of Road to Adjacent Retaining Structure	50 feet	Maximum distance emergency rescue equipment can reach.
Maximum Perimeter/Security Road Grade	15 percent	Maximum grade for emergency vehicles.
Maximum Conventional Embankment Slope	2H:1V with 8-foot-wide drainage benches every 40 vertical feet	Maximum unreinforced slope to meet stability requirements

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Description	Design Standard	Rational
Security Fence Location	Western edge of Security Road	As required to meet FAA security and patrol requirements.
Width of Maintenance Strip Outside Security Fence	5 feet (on 2H:1V slope)	As required to meet FAA security requirements.
Construction Impact Distance from Toe of Slope	20 feet	Estimated minimum distance to provide construction drainage collection at toe of slope.
Creek Buffer Width	Optimal: 50 feet on east side, 100 feet on west side	As presented to federal and state resource agencies during permit negotiations.
Wetlands	Avoid wetland and aquatic resource impacts to the maximum extent practicable.	As required by the Army Corps of Engineers and Environmental Protection Agency.

Wall/Slope Geometry Options

Various retaining wall and slope geometry options were identified to reduce impacts to Miller Creek while maintaining the Port's access, maintenance, and serviceability requirements. Potential wall/slope geometric options were considered in combination with different design concepts involving alignment of Miller Creek and potential impact to the creek buffer area. These three design variations are described in Table 2.2.

Table 2.2 - Design Variables

Variable	Description	Identifier
Wall Configuration (five total)	Single Wall	A
	Double Wall	B
	Single Wall with Bridge	C
	Double Wall with Bridge	D
	Over-steepened Slope	S
Creek Alignment (five total)	Existing Alignment	Exist
	Creek Relocation, Alignment 1A	1A
	Creek Relocation, Alignment 1B	1B
	Creek Relocation, Alignment 2	2
	Creek Relocation, Alignment 3	3
Creek Buffer Impact (two total)	Construction Impact inside Buffer	B
	No Construction Impact inside Buffer	NB

There are a total of 50 potential wall/slope geometry options based on the above variables.

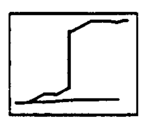
Descriptions of the three design variables associated with the wall/slope geometry options (wall configuration, creek alignment, creek buffer impact) are briefly described below. The identifying number or letters for each variable are used later in this report to identify each option. Each of the options assumes that the security road at the base of the wall or the over-steepened slope will be reduced from two lanes to one lane for approximately 200 feet in the most critical section of the alignment to help reduce wetland impacts.

More detailed discussion of the creek alignment alternatives is presented in Appendix A. More detail on the wall/slope design variables is presented in Appendix B of this report.

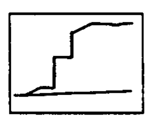
Wall Configuration Variables

Four potential retaining wall configurations plus an over-steepened slope configuration were identified and are described as follows:

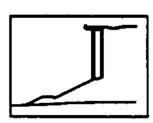
Configuration A Single Retaining Wall



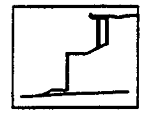
Configuration B Double Retaining Wall



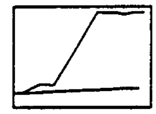
Configuration C Single Wall with Bridge (Elevated Perimeter Road)



Configuration D   Double Wall with Bridge (Elevated Perimeter Road)



Configuration S   Over-steepened Slope



As noted, two of the alternatives considered potential use of an elevated bridge structure constructed on the runway embankment to accommodate the perimeter road within the minimum possible embankment-impact to the adjacent creek and wetlands. The wall and bridge configuration variables are shown on Figure 2.1.

Creek Alignment Variables

The evaluation included a base case of leaving Miller Creek in its existing alignment, along with four potential creek relocation alignments developed by Port environmental consultants. The potential creek alignments are shown on Figure 2.2. The potential creek relocation alignments were evaluated as a means to provide additional flexibility to the retaining wall options while making best use of the topography in the vicinity of the existing creek. The four potential creek relocation alignments, as well as the existing creek alignment, are identified as follows:

Exist	Existing Creek Alignment
1A	Creek Relocation Alignment 1A
1B	Creek Relocation Alignment 1B
2	Creek Relocation Alignment 2
3	Creek Relocation Alignment 3

Buffer Impact Variables

The third variable associated with the Geometry Options is the impact to the creek buffer. For design options that require creek relocation, a new 50-foot buffer between the project footprint and the creek was included in the design. The evaluation considered the potential need for and consequences of construction within the 50-foot creek buffer in limited areas. The potential buffer impact would be mitigated by re-establishing the creek buffer area at the completion of construction. This results in two buffer impact variations identified as follows:

B	Buffer Impact
NB	No Buffer Impact

Initial Evaluation of Geometry Options

An initial screening was conducted to reduce the 50 possible wall/slope geometry options to a smaller number that represented the range of configurations available that could be permitted and built. Reducing the options by eliminating overlap and unrealistic configurations simplified comparison of the options and facilitated the decision-making process. The initial screening was completed in meetings involving staff and consultants representing the Third Runway engineering and environmental permitting effort (Port, HNTB, Parametrix, and Hart Crowser). Through this process the following reductions in combinations of potential alternatives were made:

- Since Creek Relocation Alignments 1A and 1B are variations of a similar creek relocation, it was determined that evaluating only Creek Relocation Alignment 1A would provide the information necessary for a wall/slope geometry decision. The exact location of the creek alignment, if relocated, would be finalized during design.

- Creek Relocation Alignments 2 and 3 are also similar alignments; therefore, only Creek Relocation Alignment 3 (the alignment with the more severe environmental impact) was included for this analysis.

- Because Creek Relocation Alignment 3 involves significant earthwork to create a new channel, there would be impacts to the 50-foot creek buffer if this creek alignment were selected. Therefore, the No Buffer Impact variable was not included for those options involving Creek Relocation Alignment 3.

- The Single Wall with Bridge, No Buffer Impact Option was eliminated because of the high road support structure that would be necessary. The Double Wall with Bridge options involving Creek Relocation Alignments 1A and 3 were eliminated due the high estimated costs associated with relatively high creek and buffer impacts.

- The over-steepened slope option is not viable with the creek in the existing alignment without impacting the buffer due to inadequate horizontal separation. Therefore the No Buffer Impact variable was eliminated for this option.

After the initial screening, the total options retained was reduced to 20. A summary of the geometry data for each of the retained options is presented in Appendix B.

Ranking of Options

An evaluation matrix was prepared to identify and quantify the issues associated with each of these 20 retained wall/slope geometry options. The matrix facilitates selection of preferred wall/slope geometry by ranking each option with a numerical value. The matrix was developed and completed by Port staff and consultants, including HNTB, Parametrix, and Hart Crowser, with input from Port Environmental, Airport Maintenance, Airport Operations, and Airport Fire Department staff. The options with the highest ranked scores were selected for detailed analysis and risk assessment.

The issues that were included in the evaluation matrix used to rank the 20 options included:

- Creek and Wetland Avoidance;
- Buffer Avoidance;
- Floodplain Avoidance;
- Access;
- Operational Impacts;
- Ease of Maintenance;
- Drainage Adaptability;
- Scheduling Adaptability;
- Wildlife Attractiveness;
- Aesthetics;
- Cost; and
- Fill Quantity Minimization.

(Order does not indicate priority or ranking.)

Each of these issues was weighted from 1 to 10, with 10 assigned to the issue(s) determined to be the most important by the evaluation group. A detailed discussion of each of the evaluation issues and the associated weighting factor is presented in Appendix B of this document. Based on the outcome of the matrix scoring and detailed discussions, four options were selected for further investigation and detailed analysis.

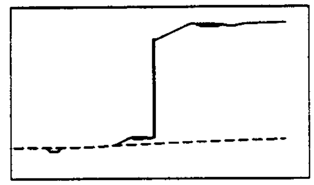
Four Selected Options Subjected to Risk Assessment

Based on review of the results of the wall/slope geometry matrix evaluation, four options were selected for further detailed evaluation and risk assessment. The selected options included two with the highest overall ranking scores as well as two with lower ranking scores, which were retained to further assess the remaining creek relocation alternatives.

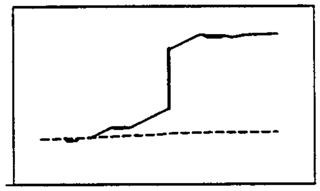
During the evaluation, input from Port Fire and maintenance staff enabled refinement of some of the ranked options. The refined geometric considerations included: eliminating the intermediate access road, which had initially been included in the central embankment area to provide access to the bench between the double wall alternatives); and reducing the width of the lower perimeter road over a short length.

The four options selected from the original 20 retained options for the detailed risk analysis are:

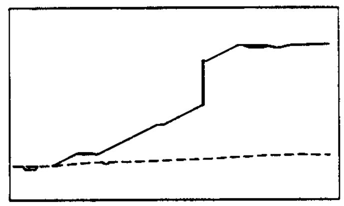
- **Option 1—Configuration A with Existing Creek and No Buffer Impacts.** A single high wall with no creek relocation and no buffer impacts. This option involves a vertical, single face wall and avoids all environmental impacts to Miller Creek.



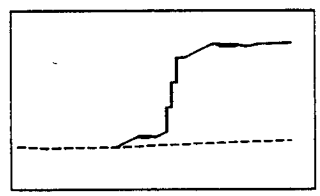
- **Option 4—Configuration A with Creek Relocation 1A and Temporary Buffer Impacts.** A single wall, with creek relocation alignment 1A and temporary construction impacts within the creek buffer. This option involves relocating approximately 145 lineal feet of the creek and temporarily impacting the creek buffer during construction.



- **Option 5—Configuration A with Creek Relocation 3 and Temporary Buffer Impacts.** A single wall, with creek relocation alignment 3, and temporary construction impacts within the creek buffer. This option involves relocating approximately 504 lineal feet of the creek as well as temporarily impacting the creek buffer.



- **Option 7(M)—Configuration B with Existing Creek and Temporary Buffer Impacts.** A tiered wall, with no creek relocation but requiring some temporary construction impacts to the creek buffer area. Option 7 is a double wall configuration option. The modified option 7(M) was selected over the original option 7 based on input from the Port Fire Department to eliminate large horizontal separation between the tiered wall segments[1]. The addition of more tiers eliminates the need for a limited access road between the upper and lower wall faces.



Plan and cross section views for each of the selected options are presented on Figures 2.3 through 2.6. Table 2.3 summarizes some of the geometrical data associated with each of the four recommended options.

[1] Excessive horizontal separation between tiers was determined undesirable due to the "shadows" the tiers would create. The shadows would prevent fire-fighting agent from reaching portions of the tier surface from the Perimeter or Service roads.

Table 2.3 – Geometry Characteristics of Recommended Options

Option	Estimated Maximum Height (Feet)	Estimated Wall Area (SF)	Length of Creek Relocation (Feet)	Buffer Impact	Wetland Impact [1] (Acres)
1	132	116,000	None	No	3.01
4	98	92,000	140	Yes	3.65
5	62	71,000	480	Yes	4.39
7(M)	127 (tiered)	130,000	None	Yes	3.54

[1] Reported impacts are permanent fill of wetlands in the vicinity of station 174+00 to 186+00 (Wetland 37).

Risk Analysis

The potential risks associated with the four selected options were evaluated and ranked as part of the engineering evaluation. Potential risks associated with the selected alternatives were identified and then ranked relative to each other.

The potential risks can be divided into two groups. The first group includes potential risks that all the selected option share. Those potential risks common to the options were identified as seismic risks, aesthetic and attractive nuisance risks, and accidental wetland encroachment risks. The second group includes potential risks that are specific to a certain option. The risks and associated ranking results are described below.

Seismic Risk

The structural components of a wall must be designed to withstand the forces of shock waves traveling through the retaining structure backfill during a seismic event. The ability of the wall facing to accommodate differential movement during a seismic event increases in complexity with wall height.

Tiered walls, in general, allow the wall segments to move independent of each other so that the overall structure can better accommodate differential movement. The tiered walls therefore result in reduced potential for damage to the wall facing and the connection between the facing and reinforcing elements during a seismic event compared to a flat, vertical face wall.

The risk analysis review indicated that each of the selected options have somewhat different seismic performance issues. Assessment of the seismic risk involved an estimate of the level of design complexity necessary to provide a reasonable safety factor for a particular seismic event. The seismic risk of each of the four options was ranked as follows:

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Option	Seismic Rank	Rationale
1	4	High, flat-face vertical walls perform poorly during seismic events. Seismic movement is likely to damage the wall facing.
4	3	High, flat-face vertical walls perform poorly during seismic events. Seismic movement is likely to damage the wall facing.
5	2	Flat-face vertical walls perform poorly during seismic events. Seismic movement is likely to damage the wall facing.
7(M)	1	Tiered wall allows independent deformation of wall segments between tiers. They can withstand greater amounts of seismic movement without damage to the wall facing.

Rank 1 represents the option with the lowest relative seismic complexity and rank 4 four represents the option with the highest relative complexity.

Aesthetic and Attractive Nuisance Risk

The relative difficulty in providing an aesthetically pleasing appearance was ranked for each alternative. Each of the options also has the potential of becoming an "attractive nuisance" for graffiti or climbing which was found to correspond to the ranking of the aesthetic risks.

Option	Aesthetic/ Nuisance Risk Rank	Rationale
1	4	Large vertical-face walls are generally unattractive.
4	3	Large vertical-face walls are generally unattractive.
5	2	Steep slopes at base of wall could be planted, however, vertical face still relatively large.
7(M)	1	Tiers provide vertical separation and opportunity for planting.

Rank 1 represents the option with the least challenges in providing an aesthetically pleasing appearance and the least relative risk for creating an attractive nuisance. Rank 4 represents the option with the highest relative risks.

Accidental Wetland Encroachment Risk

Construction will involve the risk of accidental encroachment in wetlands, creek buffer, or the creek itself. The closer the toe of the wall is to the creek, the higher the risk of accidental encroachment and the higher the potential for water quality violations.

Option	Encroachment Risk Rank	Rationale
1	1	Construction takes place completely outside creek buffer.
4	4	Construction inside buffer with high wall construction adjacent to creek buffer.
5	3	Construction inside buffer with wall construction adjacent to creek buffer.
7(M)	4	Construction inside buffer with high wall construction adjacent to creek buffer.

Rank 1 represents the lowest accidental encroachment potential, and rank 4 represents the highest accidental encroachment potential.

Option-Specific Risks

After identifying and ranking the risks common to the selected options, the risks specific to each option were listed. Those were identified as follows:

- Option 1
  No additional risks were identified specific to this option.

- Option 4
  1. Option requires a small creek relocation that could delay the permitting process for the project.
  2. Other practicable alternatives with less wetland fill may prevent receiving a permit for this option.

- Option 5
  1. The larger scope of creek relocation will cause a greater likelihood of permitting delays and complications noted above for Option 4.
  2. Other practicable alternatives with less wetland fill may prevent receiving a permit for this option.

- Option 7(M)
  1. If regulatory agencies do not allow temporary construction impacts inside the 50-foot creek buffer, the wall height will need to be increased.
  2. The tiered wall design may provide areas for undesirable vegetative growth that could require periodic maintenance.
  3. The tiered wall design and any vegetation that it supports may provide habitat that is a potential bird attractant that is difficult to manage.

Summary

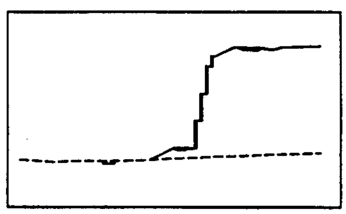
The following observations were formulated based on the results of the risk analysis.

1. Options 1 and 7(M) have the least impact on Miller Creek and its adjacent wetland ecosystem. Therefore, these options are preferred over Options 4 and 5 on this basis.
2. Tiered wall configurations significantly improve the seismic performance of the wall, and thus reduce risk.
3. Tiered wall configurations present the least difficulty in creating an aesthetically pleasing appearance; however, they may create undesirable wildlife or vegetative habitat.
4. Construction within the buffer [Options 4, 5, and 7(M)] increases the risk of accidental wetland encroachments.

The proposed recommended alternative discussed below includes features of more than one option to best meet the needs of the project.

Recommended Wall/Creek Configuration

Option 7(M) (the tiered wall alternative) is recommended over Option 1 (a single high wall). Although Option 1 has slightly less wetland impact than Option 7(M), it is not as practicable an alternative compared to Option 7(M). The estimated cost of Option 7(M) is $2.5 million less than Option 1 but adds only 0.5 acre of wetland impact. Also, a single high wall has substantial disadvantages compared to a tiered wall configuration with regard to seismic stability, settlement tolerance, and aesthetics. The tiered wall's significant seismic performance advantage, by itself, constitutes a sufficient reason to recommend the tiered wall alternative. Also, the undesirable effects of a tiered wall can be managed with appropriate treatments along the tier sections. Therefore, a tiered wall configuration is recommended.



Option 7(M) has a somewhat higher risk associated with potential accidental wetland or creek encroachment. Moving the proposed toe of embankment away from the existing creek is the best way to reduce the likelihood of potential encroachment. Therefore, the proposed, recommended wall alternative involves a slight realignment of Option 7(M). In order to better protect the creek, the recommended alignment

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through this area calls for the toe of the embankment to be moved to the 50-foot buffer edge, rather than 30 feet inside the buffer as shown in Option 7(M). This will improve the level of safety and confidence in being able to avoid potential wetland or creek encroachment during construction. The final recommended alternative is depicted in plan, profile, and section views on Figures 2.7, 2.8, and 2.9.

Construction of the proposed, recommended alternative enables Miller Creek to remain in its current channel with construction completely outside of the minimum 50-foot creek buffer. Approximately 20 feet of the creek buffer may be temporarily impacted during construction for erosion control facilities. Temporary construction impacts to wetlands are discussed in detail the report titled "Wetland Impact and Functional Analysis" (Parametrix, Inc. April 1999). The temporary impacts are anticipated to include installation of silt fencing, drainage swales, or sedimentation ponds. These facilities will removed and the area restored after they are no longer necessary for construction.

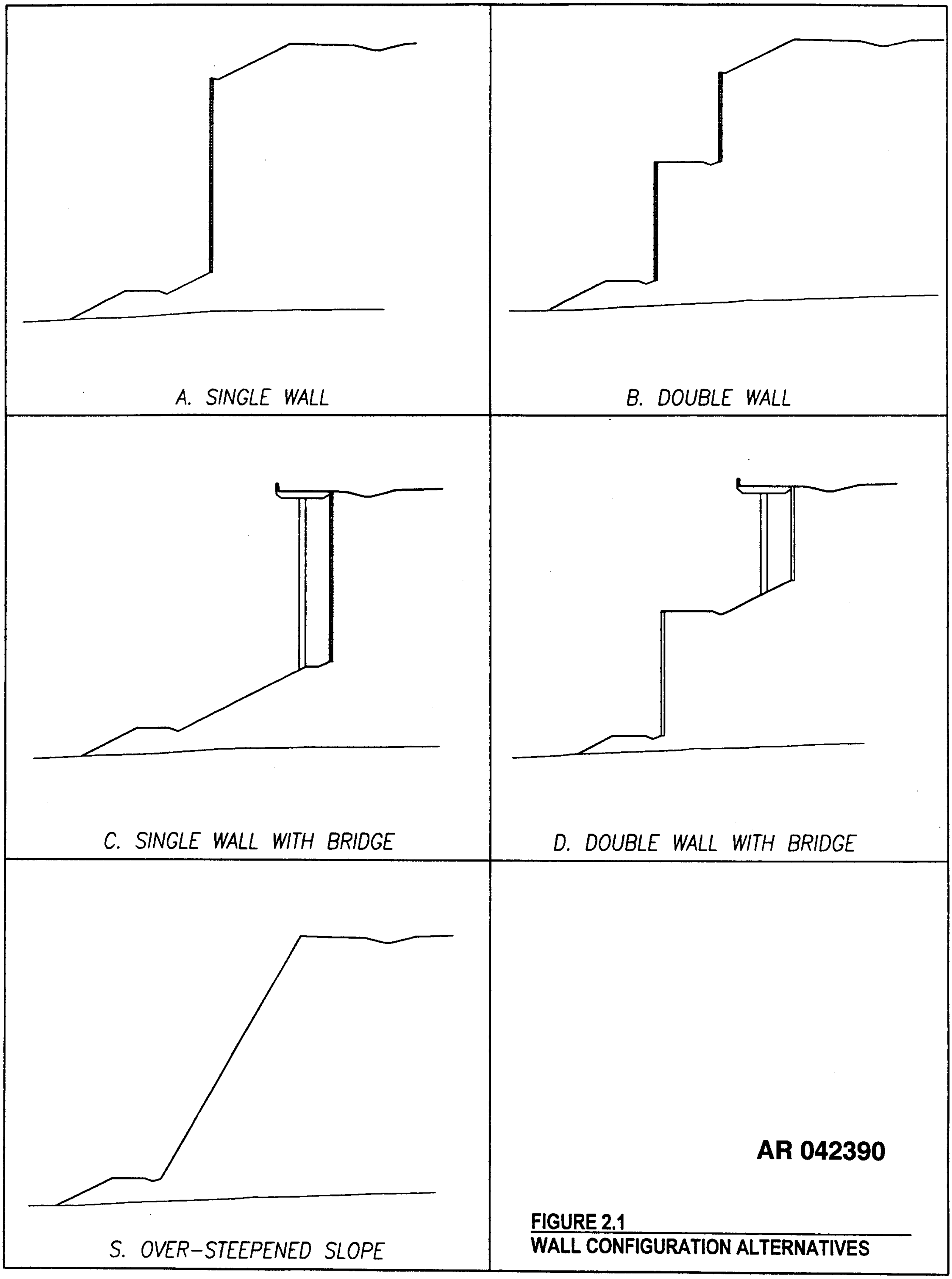

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FIGURE 2.1
WALL CONFIGURATION ALTERNATIVES

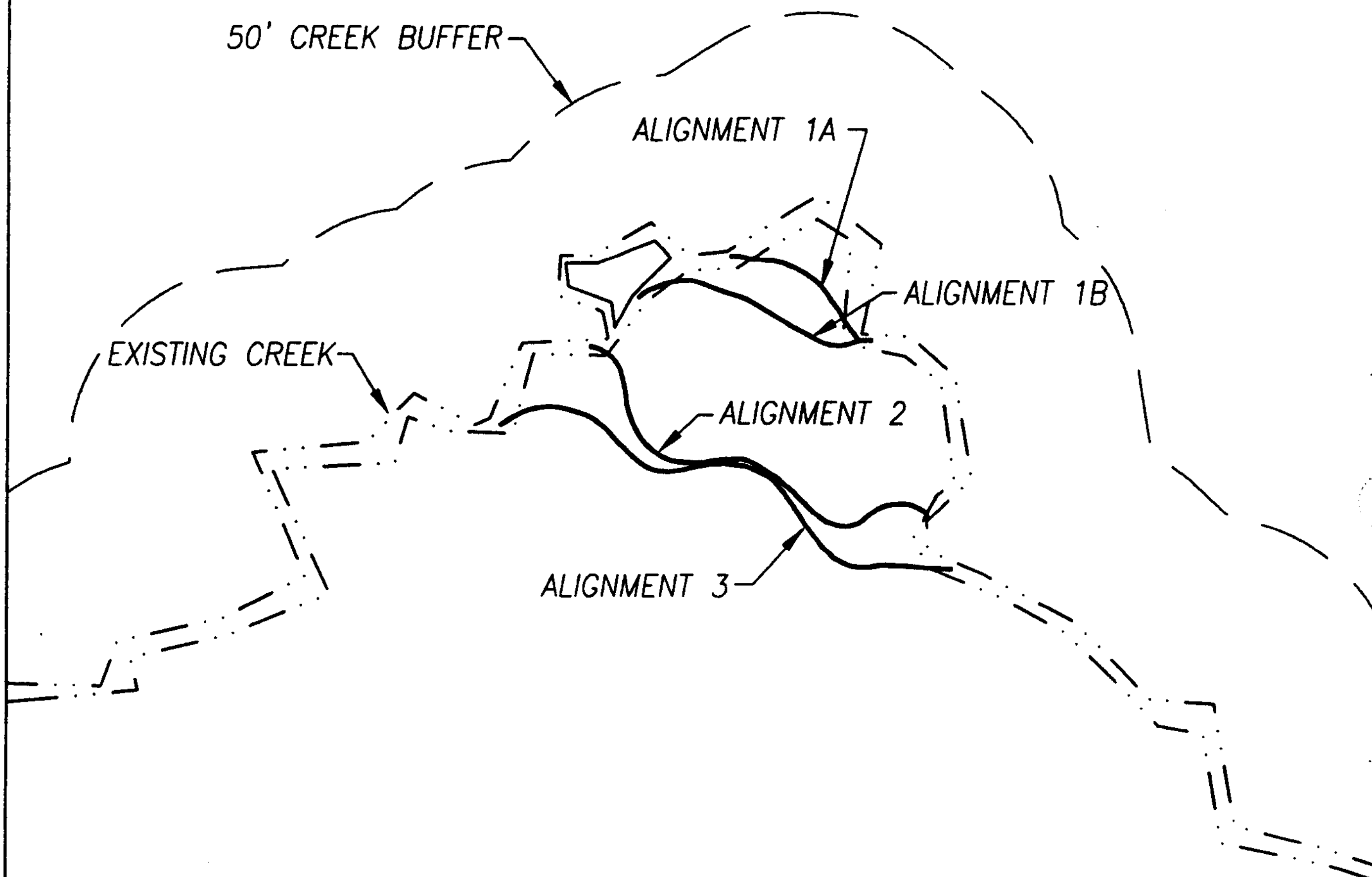
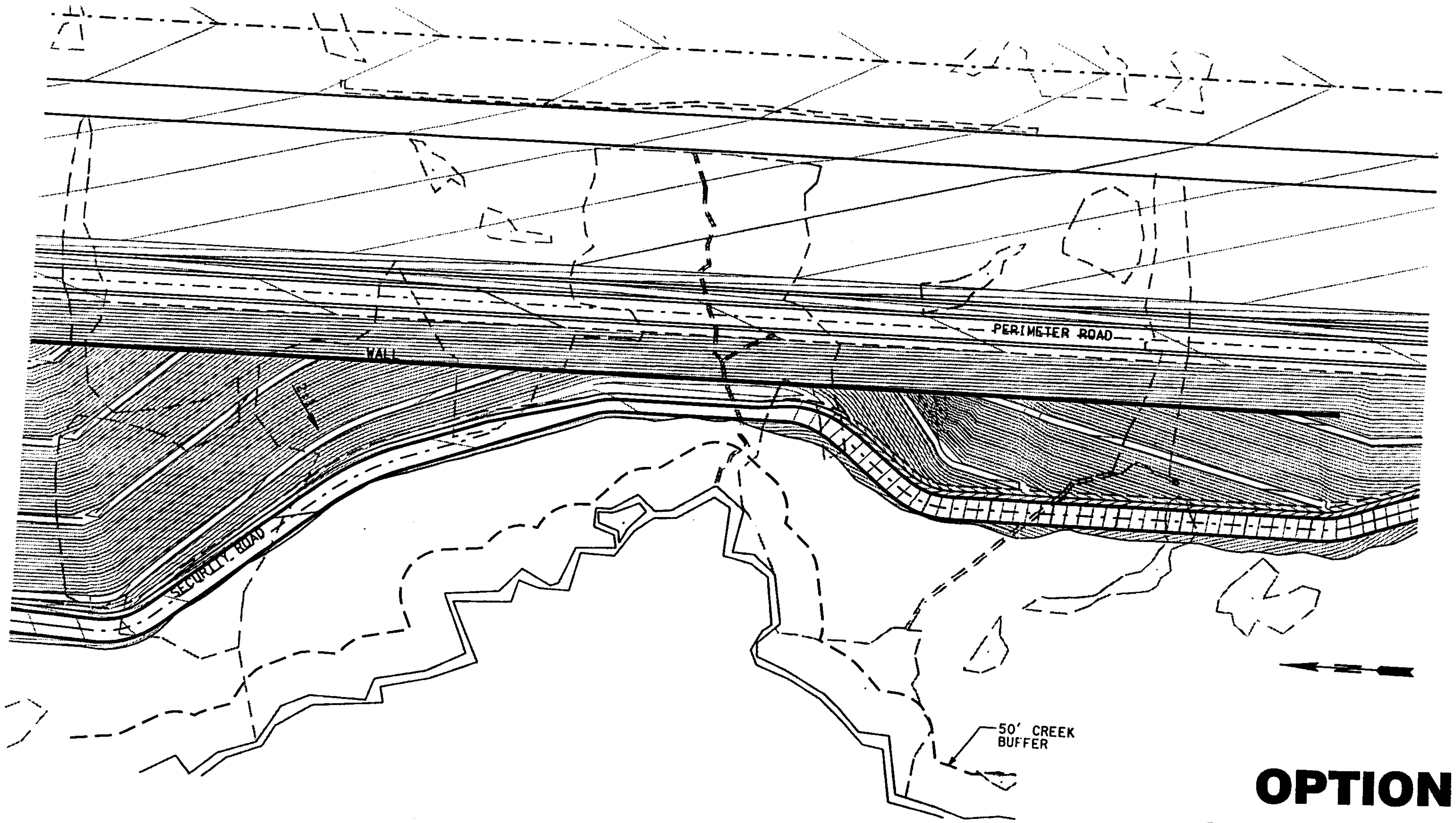
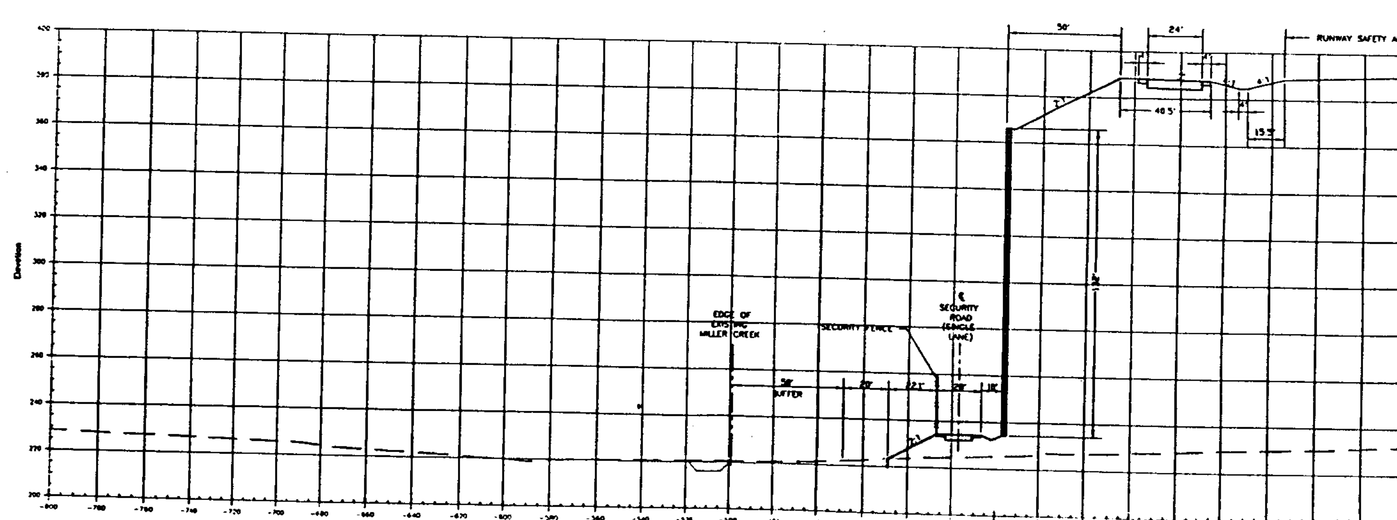


FIGURE 2.2
CREEK RELOCATION ALTERNATIVES



OPTION 1 A - EXIST - NB

SINGLE WALL, NO CREEK RELOCATION, NO BUFFER IMPACT



STATION 178+88

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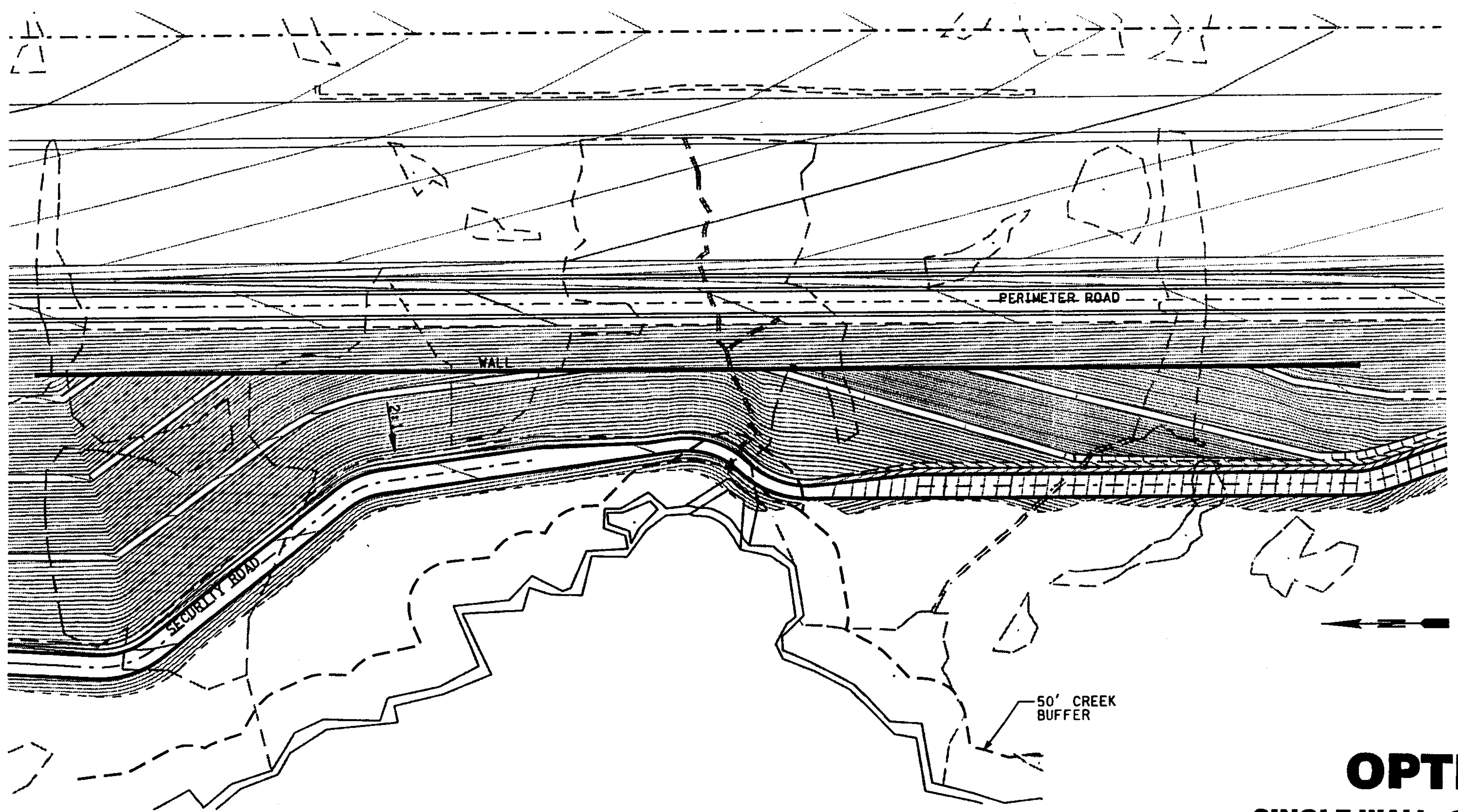
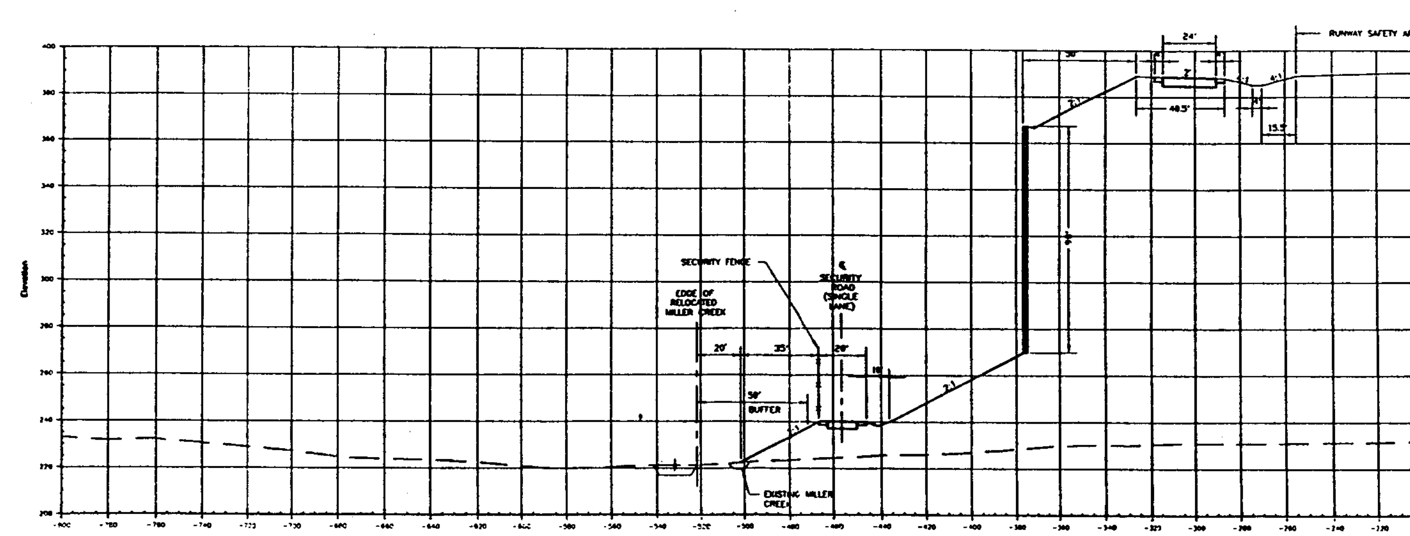
FIGURE 2.3
OPTION 1 – PLAN AND SECTION



OPTION 4 A - 1A - B

SINGLE WALL, CREEK RELOCATION 1A, BUFFER IMPACT



STATION 179+33

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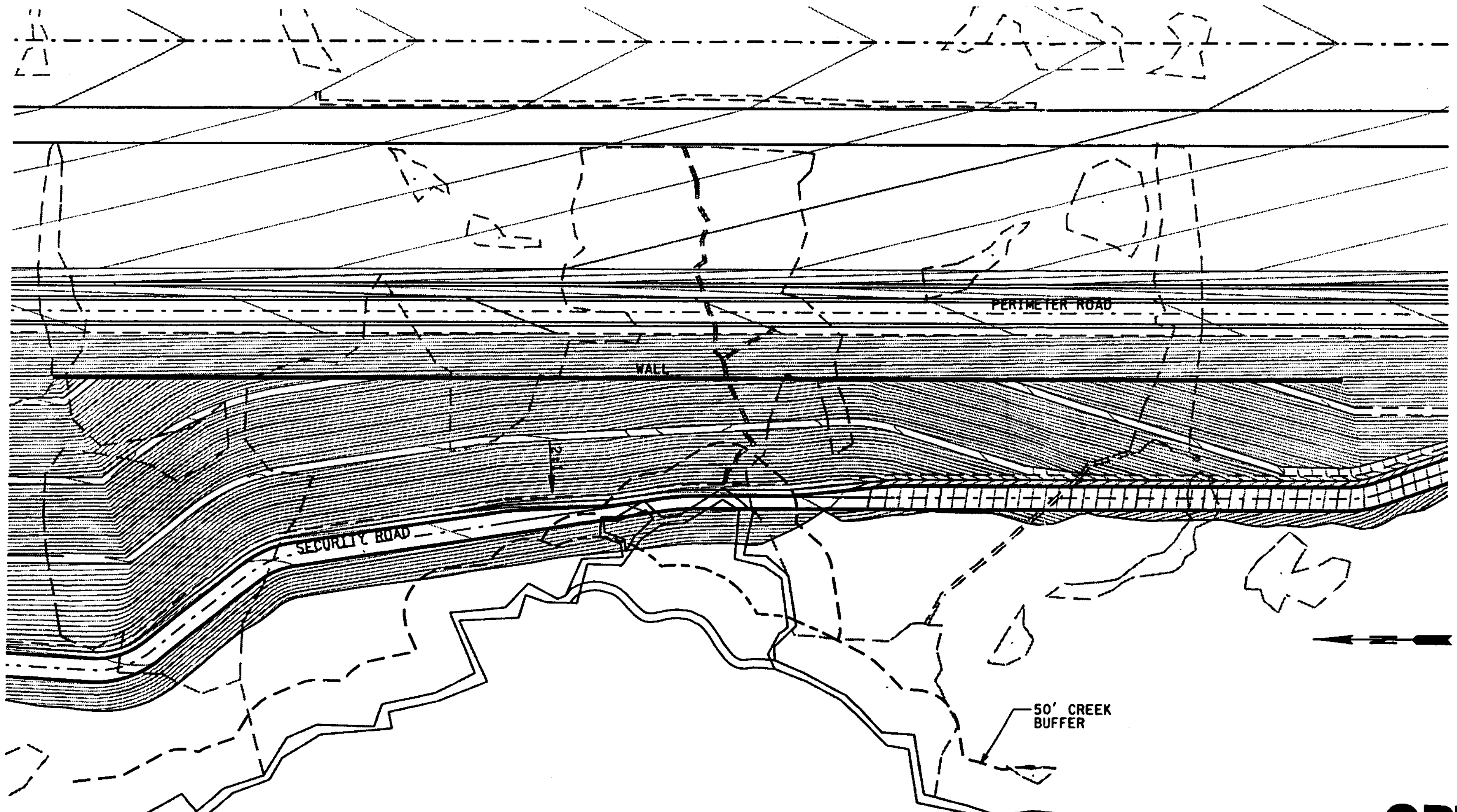
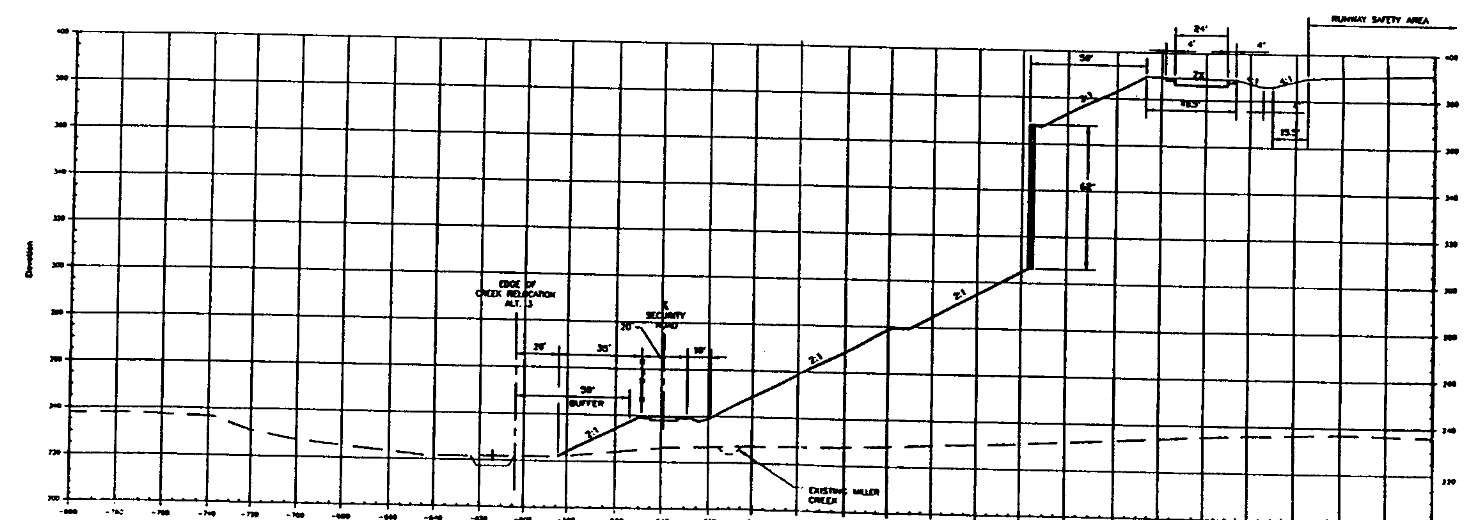
FIGURE 2.4
OPTION 4 – PLAN AND SECTION



OPTION 5 A - 3 - B

SINGLE WALL, CREEK RELOCATION 3, BUFFER IMPACT



STATION 180+29

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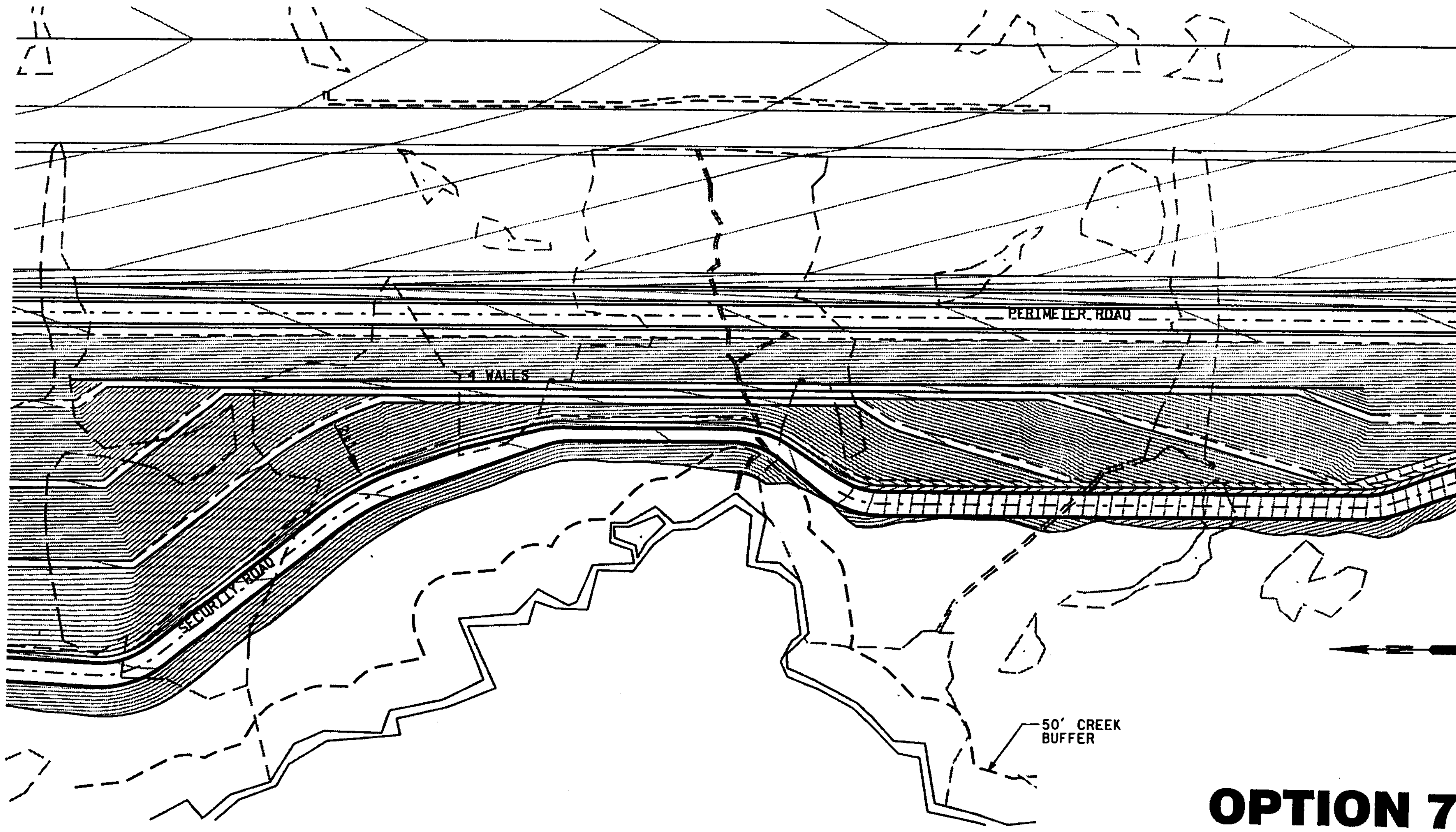
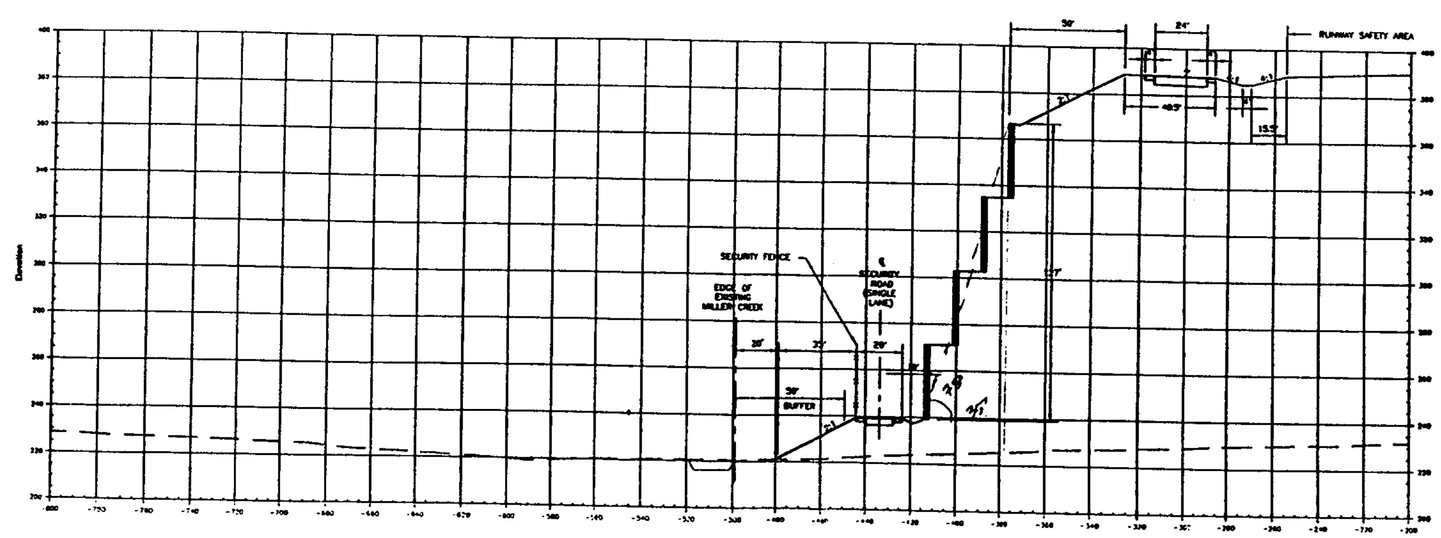
FIGURE 2.5
OPTION 5 – PLAN AND SECTION



OPTION 7(M) B - EXIST - B

TIERED WALL, NO CREEK RELOCATION, BUFFER IMPACT



STATION 178+88

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FIGURE 2.6
OPTION 7(M) – PLAN AND SECTION

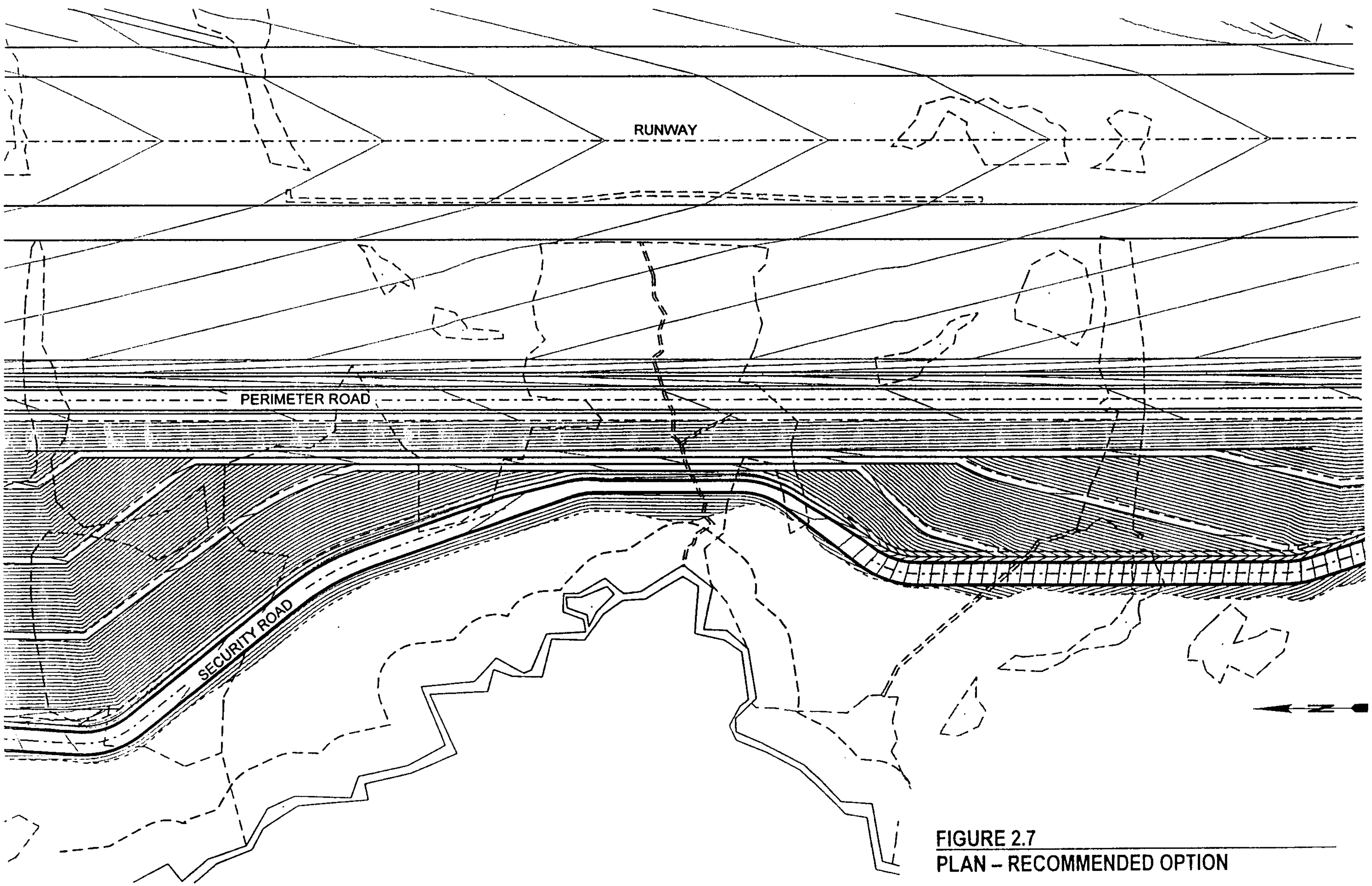
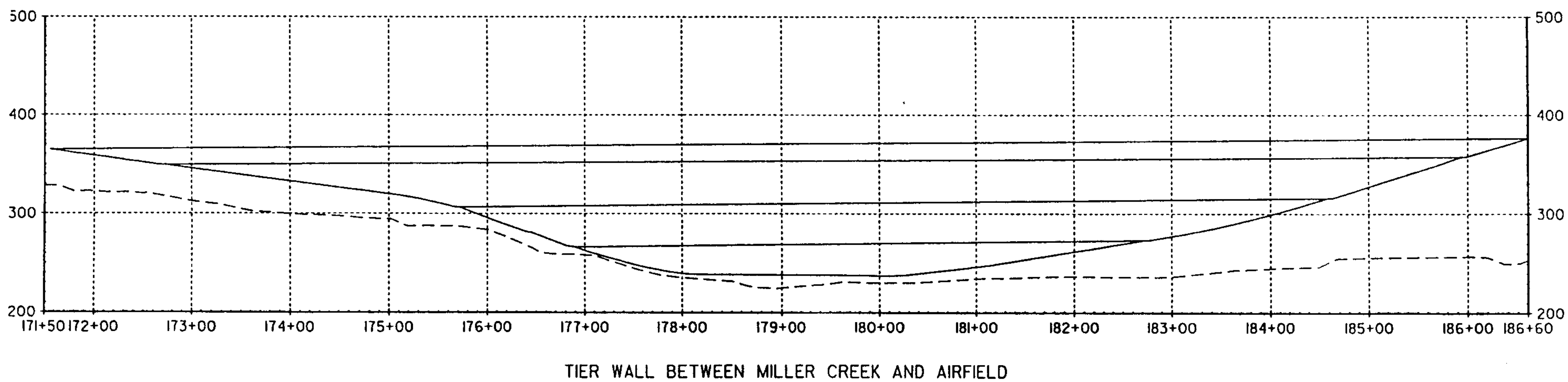


FIGURE 2.7
PLAN – RECOMMENDED OPTION



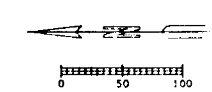


FIGURE 2.8
PROFILE – RECOMMENDED OPTION

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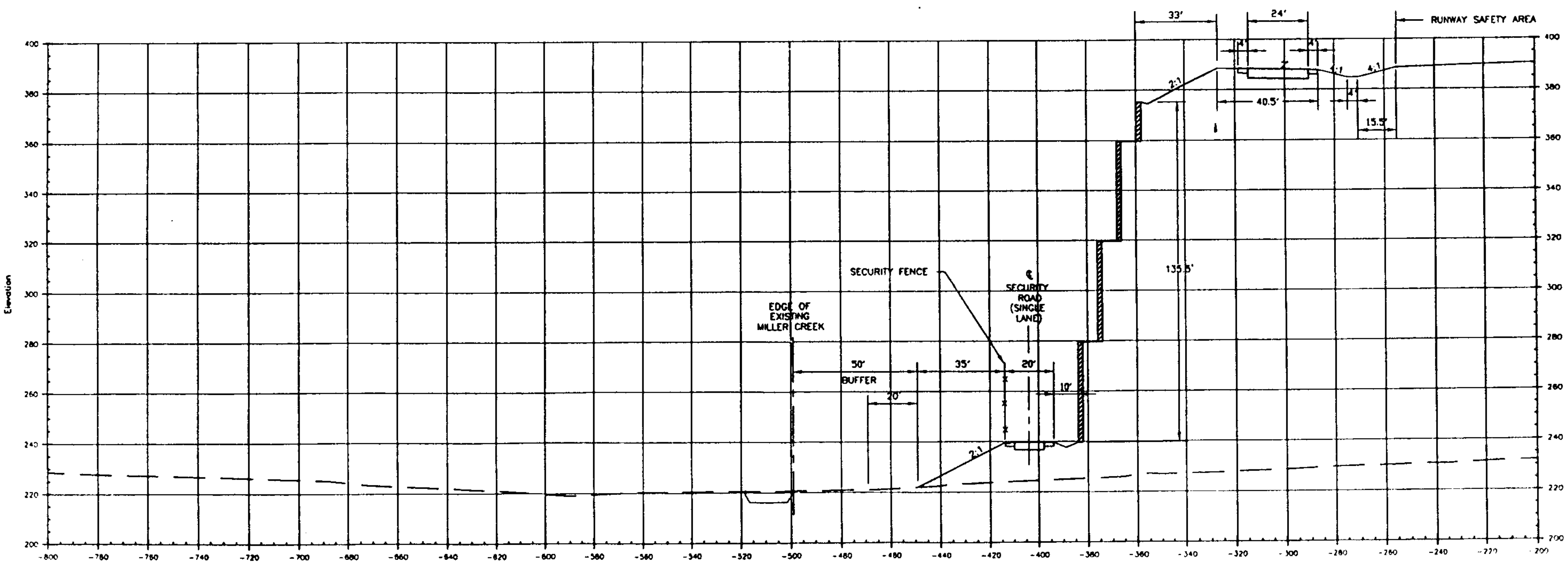
SUGGESTED WALL/CREEK GEOMETRY

TIERED WALL, NO CREEK RELOCATION, PARTIAL BUFFER IMPACT



STATION 178+88

1" = 40'

FIGURE 2.9
SECTION – RECOMMENDED OPTION

SECTION 3

EVALUATION OF ALTERNATIVE TECHNICAL APPROACHES FOR RETAINING WALL CONSTRUCTION

SECTION 3 EVALUATION OF ALTERNATIVE TECHNICAL APPROACHES FOR RETAINING WALL CONSTRUCTION

Introduction

Given a preferred geometric design (Section 2) a variety of wall or slope treatments are available to meet the design criteria. This section describe the evaluation process used to select preferred wall structure type from a broad list of retaining structures used in this type of application.

Identification and Evaluation of Alternatives

Alternatives were identified from staff experience (over 90 years of combined engineering experience for the six staff who compiled the list of alternatives); reported experience of engineering organizations (i.e., Washington and California State Departments of Transportation, US Army Corps of Engineers, etc.); and various technical publications.

At various times during the review process, additional information was obtained from contacts with other consultants, construction representatives, and vendors who provide proprietary retaining wall components.

Alternatives to a conventional 2H:1V embankment included a range of options to increase the slope of the embankment to 70 degrees or more, as well as different types of retaining wall structures, as follows:

Slopes

- Mechanically Stabilized Earth (MSE) Slope;
- Soil Cement Buttress; and
- Roller-Compacted Concrete Buttress.

Walls

- Mechanically Stabilized Earth (MSE) Wall;
- Anchored Wall;
- Crib Wall;
- Cellular Cofferdam;
- Concrete Dam;
- Cantilever Wall;
- Counterfort Wall; and
- Cylinder Pile Wall.

Summary Descriptions of Alternatives Considered

Base Case

The base case considered for the embankment was a conventional compacted soil fill, constructed with nominal 2H:1V side slopes. Final average slope of the fill would be somewhat flatter than 2H:1V because of the need to include runoff control berms and roads for safety and operational access.

Conventional embankment slopes consist of unreinforced soil and/or rock fill. The fill is placed in successive lifts and compacted to provide strength and uniformity. Conventional soil slopes are typically around 2H:1V, which is considered a practical limit for maintaining vegetation used for surface erosion control. Some highway embankment slopes are constructed at 1-1/2H:1V, and rock fill slopes ranging up to 45 degrees have been successfully used for both dams and highway embankments. Rock fill slopes can reduce or eliminate the need for post-construction surface erosion control.

Over-steepened Slopes

Several techniques were identified to increase embankment slopes beyond the conventional values noted above.

Mechanically Stabilized Earth (MSE) Reinforced Slopes. MSE slopes are composite slopes of compacted soil and layers of steel or polymer (i.e., geosynthetic) reinforcement. These slopes can be built in excess of 70 degrees with the proper combination of backfill material and reinforcement strength and spacing. Figure 3.1 shows the range in reported slope heights and inclinations for a number of MSE slopes constructed around the world.

MSE slopes that exceed 70 degrees in inclination are regarded by the Federal Highway Administration (FHWA) and others as "walls" and are discussed later in this report.

Geotextiles used for MSE slope reinforcement can be wrapped at the slope face and planted with a variety of plant materials (referred to as greenscaping). Alternatives include coarse stone retained by mesh, left unplanted, or use of concrete facings (which may be either pre-cast units, pneumatically applied shotcrete, or possibly cast-in-place).

Soil Cement and Roller Compacted Concrete (RCC). Soil cement and RCC can be used to construct slopes greater than conventional compacted soil or rock embankments due to the strength increase resulting from the mixture.

- Soil cement consists of soil amended with Portland cement (fly ash or lime are possible substitutes). For soil cement, the additive is generally 4 to 8 percent of the mix by mass.

Soil cement is mixed in the field by blending the soil and additive in lifts by harrowing prior to compaction.

- RCC is predominantly gravel- and cobble-sized material, blended with sand and Portland cement. Cement content varies depending on strength requirements but is typically greater than used for soil cement. RCC is mixed in a batch plant under controlled conditions, then spread in lifts and compacted after delivery in transit mix trucks. RCC can achieve a "natural angle of repose" between 40 and 45 degrees at edges where compaction is avoided (Corps, 1992); however, no information was available on maximum attainable slopes for RCC when edge compaction is performed.

Retaining Wall Alternatives

The following retaining wall structure types were evaluated for application in this project:

- Mechanically Stabilized Earth
- Anchored Walls
- Crib Walls
- Cellular Cofferdam
- Concrete "Dam"
- Cantilever Walls
- Counterfort Walls
- Cylinder Pile Walls
- Concrete Arch Walls
- Other Proprietary Walls

Mechanically Stabilized Earth (MSE) Walls

MSE walls are a composite system of compacted soil and reinforcing elements, which may have a prefabricated concrete facing, or be faced with geotextiles as described above for MSE slopes. In some applications, the concrete facing is applied after the end of construction, especially in areas where settlement is a concern. The reinforcing elements are typically wire mesh, metal strips, and polymer (plastic) sheets (geotextiles) or grids, collectively referred to as geosynthetics. There are a number of examples of these walls (or combinations of these walls) constructed in excess of 100 feet in height, see Figure 3.2.

Anchored Walls

Anchored walls consist of wall and anchor components.

The walls may be pre-cast modular units, cast-in-place concrete panels, cylinder piles, or soldier piles (typically wide flange steel sections) with lagging. The anchors are typically cables or steel rods attached to an anchor or to rows of anchors, behind the wall. For retaining a soil fill, the anchor typically would consist of a massive concrete block, referred to as a "deadman," that is buried within the backfill as construction proceeds. Typically, the anchor is pre-stressed during construction to limit deformations.

Anchored walls have commonly been constructed in excess of 80 feet; however, these are typically for excavations (i.e., to retain the cut face). Limited information was available for heights of fill retaining walls, maximum heights of less than 40 feet are typical.

Crib Walls

Crib walls are a type of gravity wall typically constructed of shop-fabricated cellular units that are field assembled and filled with soil or rock for stability. The actual cribbing which forms the individual cells can be metal, precast reinforced concrete, or timber. These walls are generally less than 30 feet when used to retain conventional compacted earth fill, but can be much higher (up to around 50 feet) when the backfill is MSE reinforced.

Cellular Cofferdam

Cofferdams are a type of gravity buttress that consists of a series of sheet pile (or equivalent) circular cells that interlock to form a wall.

Individual cells are filled with granular material to provided added support. Cofferdams have been constructed with over 75 feet of exposed height, typically in marine terminal applications.

Concrete "Dam"

Concrete dams are massive concrete gravity buttresses. A concrete dam can be constructed using cast-in-place concrete with adjustable forms or by using RCC. A large number of dams have been constructed in excess of 100 feet, typically for impounding water.

Cantilever Walls

Cantilever walls generally consist of a vertical reinforced concrete slab structurally connected to a base slab, which provides resistance to overturning. Conventional cantilever walls are typically used to retain fill slopes in most situations up to about 35 feet (WSDOT, 1990).

Counterfort Walls

Counterfort walls are a specialized type of cantilever wall which has vertical stiffening ribs on the back or front sides to strengthen the connection between the vertical wall slab and the base slab. These walls can be up to about 50 feet in height (WSDOT, 1990).

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Cylinder Pile Walls

Cylinder pile walls consist of a series of individual piles placed side by side forming a continuous wall. These walls are typically used to retain excavations, where the cylinder piles are concrete cast in shafts drilled into the soil. Typically the piles are in close contact or overlapping (tangent piles) for stiffness and to eliminate the need for lagging.

Individual piles may be 6 to 12 feet in diameter depending on the required wall height. Anchors grouted into the soil behind the wall are sometimes used to reduce wall movements at increased heights. Facing is typically used to improve aesthetics. Reported experience for cylinder pile walls is around 20 to 40 feet in height without anchorage, to more than 100 feet with tieback anchors.

Concrete Arch Wall

Concrete arch dams are shaped to impound water by load transfer into the adjacent ground. These structures typically rely on favorably located massive rock abutments, but possibly could be founded on very dense glacially overridden soil and transfer load with ground anchors.

To our knowledge, these walls have not been used in soil retention applications, but for water storage they have been used to heights of exceeding 250 feet.

Other Proprietary Walls

V.E.R.T. walls consist of a series of piles spaced in rows, which provides stability through earth arching between the piles. Each pile row is offset from the adjacent row to contribute to the "arching effect" that enables this wall system to retain soil. This proprietary system is used to retain soil excavations; no experience was reported for application to embankments.

Modular block walls, or segment retaining walls, consist of interlocking elements that are connected to form a gravity buttress. Reinforcement of backfill using geosynthetics is typically used for this type of walls at heights greater than 10 feet.

Combined Alternatives

The wall alternatives discussed above may be combined alone or in combination with one another. For example, various crib and vendor-proprietary walls are often combined with MSE reinforced backfill to achieve greater heights.

Other combinations could be developed by using one or more wall types in tiers. On the Seattle I-90 project for example, cantilever walls were located both upslope and downslope of cylinder pile walls to increase overall height of a retained cut.

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Composite Slopes and Structures

We also considered combinations of conventional embankment slopes with over-steepened slopes and retaining walls. This would be typically involve MSE-type systems, where the distinction between an over-steepened slope and a wall is conventionally based on inclination less than or greater than 70 degrees, respectively.

Ranking of Alternatives

Initial Evaluation Criteria

An initial evaluation of the various retaining wall and over-steepened slope alternatives was performed using a weighted ranking matrix. The goal of the ranking was to identify preferred wall/slope alternatives for further, more detailed consideration of design and construction issues and performance in applications similar to the project conditions.

The initial evaluation criteria included:

- Relative Cost;
- Material Design Life;
- Experience/Performance History (i.e., relative number of constructed projects and duration in service);
- Technical Certainty (i.e., established design methods);
- Seismic Performance Characteristics;
- Constructability;
- Surface/Subsurface Drainage;
- Differential Settlement Performance;
- Ease of Maintenance; and
- Aesthetics.

To provide a means of effectively screening the alternatives, each of the key factors was assigned a weighting value from 1 to 3 based on relative importance (e.g., aesthetics = 1, technical certainty = 3).

This analysis was repeated considering three different wall height ranges (i.e., 0 to 40 feet, 40 to 80 feet, and greater than 80 feet) to address wall height limitations for some of the wall alternatives.

Initial Evaluation Ranking Factors

Ranking of the alternatives was typically accomplished by assigning a value of 1 to 3 (i.e., low, medium, or high, respectively), to the performance rating for each of the evaluation criteria named above. A value of 0 was used in the scoring if the wall/slope alternative was not applicable for the given height range. The weighting was incorporated into the matrix by multiplying the weighting value times the performance rating. A "Total Ranked Score" for each wall/slope alternative was then determined by summing the weighted values for all the variables.

Initial Ranking of Alternatives

The results of the initial ranking process are shown in Table 3.1

- MSE walls and MSE slopes had the highest Total Ranked Score for each of the height ranges.

- The concrete dam, roller compacted concrete, and soil cement over-steepened slopes also scored relatively well for all height ranges.

The selected wall/slope height and configuration depends on the outcome of the evaluation of preferred project geometry, which was discussed earlier in this report.

Horizontal constraints for the overall slope (based on creek and wetland environmental values, and access requirements) were considered in the final evaluation process to help narrow the number of wall alternatives based on performance within a particular height range.

- If the tiered wall geometry is acceptable, the 0- to 40-foot-high category would be appropriate;

- If a vertical wall is needed, the >80-foot category would be appropriate; and

- If slopes can fit within the geometric constraints, these alternatives may be preferable to walls in some regards.

Based on the wall alternative matrix evaluation and geometric limits determined as discussed previously, the MSE walls, MSE slopes, and RCC slopes were retained for the final selection process.

Table 3.1 - Results of Initial Ranking of Wall/Slope Alternatives

	Wall Height in Feet		
	0 to 40	40 to 80	> 80
	Total Ranked Score		
MECHANICALLY STABILIZED EARTH WALL	50	45	39
ANCHORED WALL (e.g., Deadman, Bulkhead, or Other Anchorage System)	38	28	21
CRIB WALL	41	0	0
CELLULAR COFFERDAM	37	28	2
CONCRETE DAM	32	34	32
CANTILEVER WALL	42	6	6
COUNTERFORT WALL	42	25	6
CYLINDER PILE WALL (i.e., with or without anchorage)	39	28	12
CONCRETE ARCH WALL	25	3	3
OTHER VENDOR WALL (i.e., "V.E.R.T." wall)	34	22	6
REINFORCED SOIL (MSE)	51	49	51
SOIL CEMENT	38	33	23
ROLLER COMPACTED CONCRETE	41	40	38

The matrix evaluation for all the criteria, all the wall/slope types, and the 0- to 40-foot, 40- to 80-foot, and >80-foot height ranges are included in Appendix C.

Geotechnical Issues Relative to Wall/Slope Stability

Existing subsurface information obtained from review of existing geotechnical mapping and anger borings where possible generally indicates there are relatively good foundation conditions along most of the proposed embankment. Very dense soils with high shear resistance and high bearing capacity have typically been encountered within about 15 feet of the ground surface. Local areas, including wetlands and existing fills, may occasionally have compressible soils to depths approaching 30 feet or more.

Soil conditions over most of the site will provide good embankment support. Foundations for retaining walls and over-steepened slopes will locally require subgrade improvements. There are a number of alternatives for improving the compressible soils to provide good foundation support. Hart Crowser reviewed alternatives for constructing wall/slope foundation improvements with HNTB and Port staff in November 1998, for a range of soil and groundwater conditions. From that analysis, it was concluded that foundation improvements could be accomplished within a limited distance (40 feet or less) outside the footprint of the various wall alternatives, to limit impacts to wetlands.

Hart Crowser accomplished preliminary analyses of subgrade settlement below the embankment. The analyses indicated little potential impact on base flow to wetlands and Miller Creek due to settlement under the embankment (Hart Crowser, 1999). The proposed wall/slope alternatives are anticipated to require foundation improvements and produce settlements and base flow impacts over more or less comparable areas.

Fourteen exploratory borings were accomplished in February 1999 to support ongoing design efforts, in three representative areas, including the area discussed in this report. Borings in wetlands were accomplished under the "Nationwide 6" permit process, along with borings adjacent to wetlands. The borings included collection of soil samples and *in situ* tests to provide information on strength and water transmission characteristics of the soils. Results will be used for design and construction planning to avoid and/or mitigate impacts to wetlands.

As part of the geotechnical collection of information and analysis of site conditions and wall/slope alternatives, Hart Crowser consulted with University of Washington Professors Robert Holtz, PhD, P.E., and Steve Kramer, PhD, P.E., who are recognized experts in MSE and seismic engineering, respectively.

Initial stability analyses for both static and seismic conditions indicate the proposed recommended alternative, the tiered MSE wall, is well suited for conditions at the site.

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Representative MSE Slope Experience

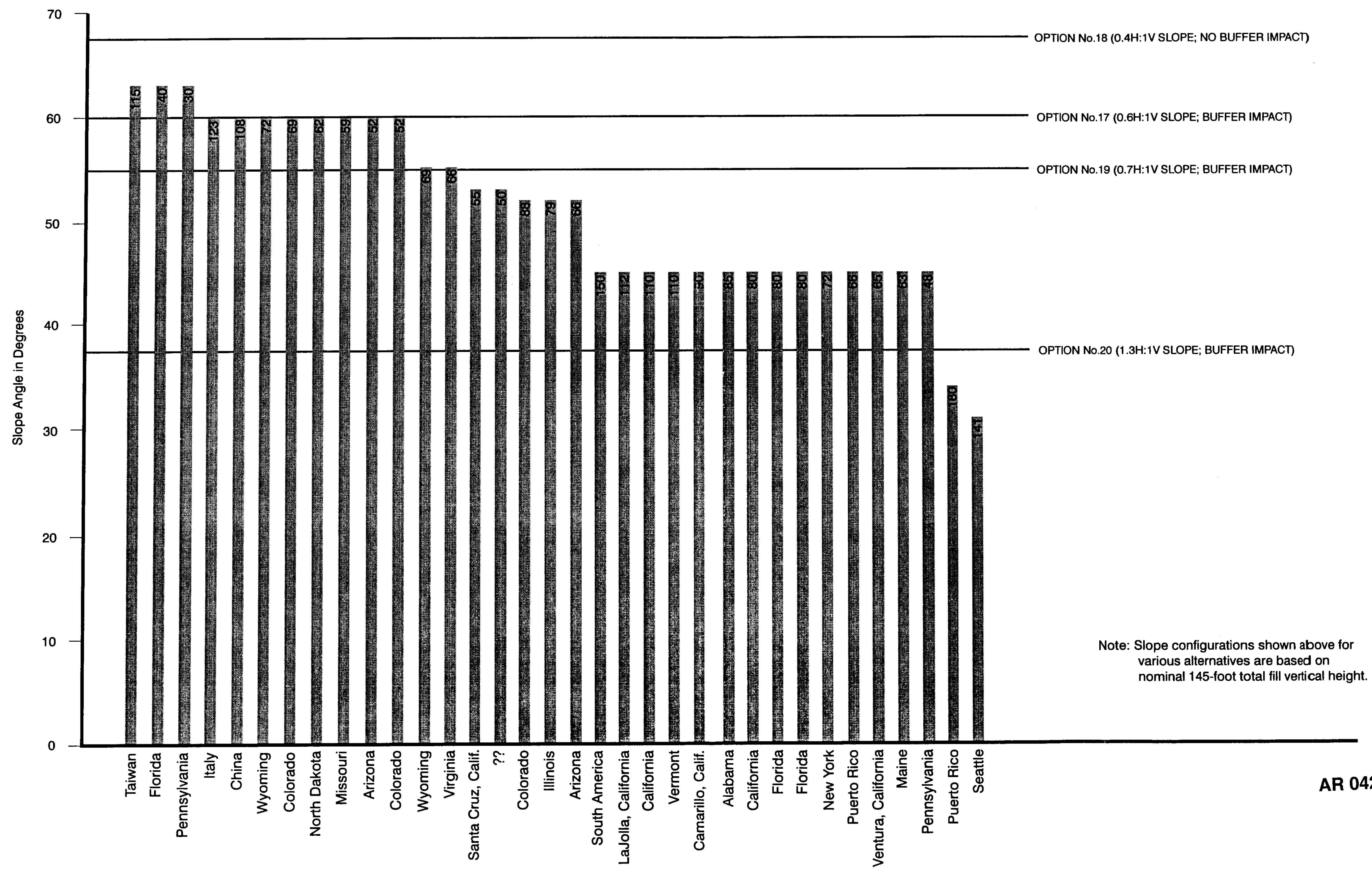

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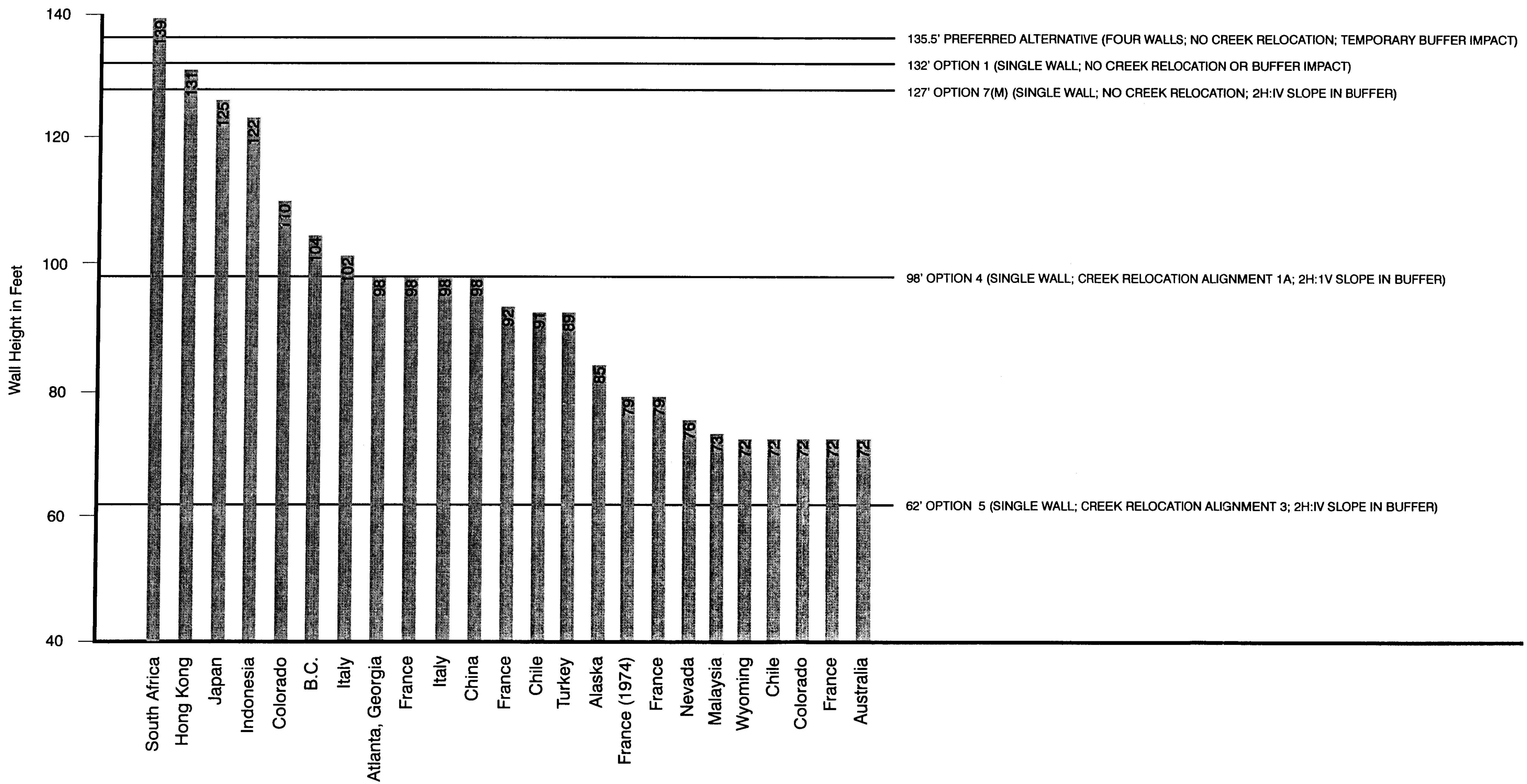
Figure 3.1

Representative MSE Wall Experience



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Corel\jobs\497801\WallExperience

Figure 3.2

SECTION 4

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SECTION 4 REFERENCES

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APPENDIX A
MILLER CREEK RELOCATION SITE B
NEAR EMBANKMENT STATIONS 174+00 TO 186+00

AR 042416

APPENDIX A MILLER CREEK RELOCATION SITE B NEAR EMBANKMENT STATIONS 174+00 TO 186+00

Introduction

The third runway embankment includes fill activities and construction of a retaining wall that could impact Miller Creek south of South 160th Street. Depending on the specific project design, a portion of the creek may need to be relocated. The proposed relocation project would:

1. Move the creek west to an area outside the impact area associated with construction of the retaining wall;
2. Provide mitigation for lost floodplain area and storage volume;
3. Reduce long-term impacts to aquatic habitat by constructing in-stream habitat features and creek hydraulics that provide fish habitat; and
4. Protect a new stream with 50-foot buffers on the east side and 100-foot buffers on the west side.

The preferred alternative for the relocation project would meet the following criteria:

- Relocate Miller Creek away from the impact area associated with construction and long-term maintenance of the retaining wall;
- Minimize impacts to wetlands, riparian vegetation, and the stream bank;
- Minimize the area of land disturbance;
- Provide mitigation for lost flood storage and conveyance; and
- Minimize amount of permanent in-channel habitat loss and replace lost habitat through mitigation.

Four potential creek relocation alignments are evaluated. Alignments 1A and 1B would divert the creek where the existing channel splits into two separate channels as it flows around in-channel woody debris. The new channel would follow the west edge of the existing floodplain. Alignments 2 and 3 would divert flow upstream of the point where the existing channel splits and would be relocated to a depression that is separated from the existing creek by a small hill. Each of the proposed alignments are discussed in more detail below. Floodplain impacts cannot be determined until the preferred wall alternative is selected; therefore, mitigation for floodplain impacts is not evaluated.

Dominant vegetation in the proposed relocation area includes red alder *(Alnus rubra)*, willow *(Salix* sp.), Himalayan blackberry *(Rublis discolor)*, and reed canary grass *(Phalaris* *arlindinacea).* A stand of black cottonwood *(Populus balsamifera)* and a stand of western red cedar *(Thuja plicata)* occur on a small hill located west of the potentially relocated channel segment.

Alignment 1A

Alignment 1A would cause the least impacts to Miller Creek. The proposed channel would be located approximately 40 feet west of its present location (at its easternmost point). The new channel would be 100 feet long, replacing 140 feet of existing channel. Construction of this alignment would disturb approximately 0.2 acre and remove approximately 240 cubic yards of earth.

Adverse impacts to vegetation and existing habitat associated with this alignment are expected to be minimal. Vegetation removed would include red alder saplings and small willow shrubs, blackberry, and reed canary grass. This alignment would not disturb the western red cedar or black cottonwood trees located to the west, and it would provide opportunities to re-establish native vegetation in the riparian zone. The required excavation (width and depth) is minor, thereby reducing impacts to existing stream-side vegetation.

Alignment 1B

Alignment 1B would have more impact on Miller Creek than Alignment 1A. The constructed channel would be located approximately 55 feet west of its present location. The proposed channel would be 140 feet long replacing 200 feet of existing channel. One log weir would be used to match existing channel slopes, and to maintain in-channel velocities equal to or below existing conditions. Constructing this alignment would disturb approximately 0.5 acre and remove approximately 1,300 cubic yards of earth.

Alignment 1B would disturb less land area than Alignments 2 and 3, but cause more disturbance than Alignment 1A. This alignment would also have more impacts to existing vegetation. The proposed route follows the edge of the existing floodplain where vegetation is predominantly alder, willow, Himalayan blackberry, and reed canary grass. This alignment may require a relatively steep slope along its west edge, and may require removal of a western red cedar tree. Alignment 1B would provide opportunities to re-establish native vegetation in the riparian emergent zone; however, more of the existing riparian vegetation and stream shading may be temporarily lost (than Alignment 1A).

Alignment 2

Alignment 2 would have intermediate level impacts on Miller Creek. The constructed channel would be located approximately 85 feet west of its present position. The proposed channel would be 240 feet long, replacing 370 feet of existing channel. This alignment would require three weirs to match existing channel slopes to keep in-channel velocities equal to or below existing conditions. Construction of this alignment would disturb approximately 0.6 acre of land and remove approximately 2,400 cubic yards of earth.

Alignment 2 would disturb more area than Alignments 1A and 1B; it would also impact the stand of western red cedar and may require removal of several of the larger trees. Most likely it would not impact the large stand of black cottonwood located at the downstream end of the project. The area disturbed by this project is predominantly covered by Himalayan blackberry and reed canary grass, so disturbance would provide an opportunity to replace these non-native species with native vegetation. Where the existing creek channel was not filled, it could provide additional flood storage and backwater habitat. This alignment would require significant excavation and replanting of riparian vegetation. Stream shading from existing red cedar would be temporarily lost until the vegetation matured.

A wetland located near the downstream end of the new channel may be impacted. This wetland has not been surveyed due to access restrictions, but impacts could include conversion of forest and shrub wetland to channel habitat.

Alignment 3

Alignment 3 would have the greatest impacts on Miller Creek. The constructed channel would be located approximately 110 feet west of its present position. The proposed channel, which would be 280 feet long, would replace 480 feet of existing channel. This alignment would require five log weirs to match existing channel slopes to keep in-channel velocities equal to or below existing conditions. Construction of this alignment would disturb approximately 0.7 acre of land and remove approximately 2,700 cubic yards of earth.

Alignment 3 would cause the largest area of vegetation disturbance; however, this alignment would not impact the stand of western red cedar or the grove of black cottonwood. Construction would provide opportunities to replace Himalayan blackberry with native vegetation. Some removal of native species would be required, but these species could be replaced. Where the existing creek channel was not filled, it could provide additional flood storage and backwater habitat. This alignment would require significant excavation and replanting of the riparian vegetation. Stream shading would be lost until the vegetation matured.

A wetland located near the downstream end of the new channel may be impacted. This wetland has not been surveyed due to access restrictions, but impacts could include conversion of forest and shrub wetland to channel habitat.

APPENDIX B
SUPPORTING INFORMATION ON WALL/SLOPE GEOMETRY VARIABLES

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APPENDIX B SUPPORTING INFORMATION ON WALL/SLOPE GEOMETRY VARIABLES

Introduction

To determine the potential wall/creek options available, three general design variables were identified. The wall/creek options were developed using various combinations of the three variables. The three design variables identified are:

1. Wall Configuration;
2. Creek Location; and
3. Creek Buffer Impact.

Wall Configuration Variables

Four potential retaining wall configurations plus one over-steepened slope configuration were identified and are described as follows:

A. Configuration A – Single Wall. Configuration A involves construction of a single wall parallel to the third runway centerline. The top elevation of the wall is determined by the perimeter road elevation and does not vary between creek relocation alternatives. The bottom of the wall is determined by the location of the existing or relocated creek edge.

B. Configuration B – Double Wall. This configuration is similar to the single wall configuration except where horizontal separation is adequate the single wall is split into two walls of lesser height. Like the single wall configuration, the top of the double wall configuration is again set by the perimeter road alignment and the bottom elevation is determined by the location of the creek edge.

While the double wall configuration reduces the wall height of the individual tiers, it does not reduce the overall wall height. The separation between the wall tiers could also necessitate an intermediate maintenance and emergency road between the two tiers, depending on the horizontal separation of the tiers. Introduction of an intermediate access road would increase the fill quantities north and south of the critical area or increase the length of the lower retaining wall necessary until the road ties in with either the Perimeter Road or Security Road.

C. Configuration C – Single Wall with Elevated Perimeter Road. Configuration C is a departure from the constraints of Configurations A and B which provide grading and fill to allow the perimeter road to be constructed at grade on the runway embankment. By constructing the roadway on a supporting structure (piers, cantilevers, etc.) the embankment can be reduced by moving the top catch line further east. This allows additional horizontal distance between the top of the fill and the realigned creek for the 2H:1V fill and reduces the maximum required wall height accordingly.

D. Configuration D – Double Wall with Elevated Perimeter Road. Configuration D combines the characteristics of both Configuration B and Configuration C and provides a double retaining wall with an elevated Perimeter Road structure through the critical area.

S. Configuration S – Over-steepened Slope. A fifth alternative involves construction of a slope steeper than 2H:1V. This would be accomplished by installing soil reinforcement at intervals while the fill is being placed. The slope facing can be a variety of treatments.

Creek Alignment Variables

In addition to leaving Miller Creek in its existing alignment, four potential creek relocation alignments were developed by the Third Runway Project Team Environmental Support Group. The potential creek relocation alignments attempt to provide additional flexibility to the retaining wall options while making best use of the existing topography in the vicinity of the existing creek. The four potential creek relocation alignments, as well as the existing creek alignment, are as follows:

Exist— Existing Creek Alignment. Miller Creek flows from north to south roughly parallel to the proposed Third Runway. Before turning west and crossing under the Highway 509, the creek meanders to its closest horizontal position to the proposed runway. The existing creek alignment comes with 180 feet (horizontally) of the proposed perimeter road surrounding the runway.

1A— Creek Relocation Alignment 1A. This creek relocation alignment calls for the least lineal footage of creek relocation. Approximately 145 linear feet (LF) of creek alignment would be lost while approximately 95 LF of creek would be reestablished slightly west of the current creek alignment. This creek alignment allows 210 feet of separation horizontally between the perimeter road and the proposed creek edge.

1B— Creek Relocation Alignment 1B. This creek relocation is a variation of Relocation Alignment 1A with a slightly greater lineal footage of existing creek being lost (195 LF) and a corresponding increase in the lineal footage of reestablished creek bed (130 LF). This creek alignment allows 215 feet of separation horizontally between the perimeter road and the proposed creek edge.

2— Creek Relocation Alignment 2. Creek relocation alignment 2 moves the creek further from the new runway than alignments 1A and 1B. Approximately 384 LF of the existing creek bed would be lost and approximately 250 LF of reestablished creek would be constructed roughly 100 feet west of the existing alignment. This creek alignment allows 260 feet of horizontal separation between the perimeter road and the proposed creek edge.

3— Creek Relocation Alignment 3. Creek relocation alignment 3 is similar to alignment 2 but the realigned creek bed is moved slightly further west. This alignment results in approximately 500 LF of lost creek bed and approximately 285 LF of reestablished creek bed. This alignment allows 290 feet of horizontal separation between the perimeter road and the proposed creek edge.

Buffer Impact Variables

The third variable associated with the Geometry Options is the impact to the creek buffer. Either construction will be allowed to take place within the 50-foot creek buffer and the buffer-area will be reestablished at the completion of construction, or no construction activity will occur inside the 50-foot buffer. This results in two buffer impact variations within the Intermediate Options.

B— Buffer Impact. The buffer impact variation allows construction access, TESC, and placement of embankment within the 50-foot creek buffer. At the completion of construction the embankment inside the buffer would be planted with suitable buffer plant materials and access would be restricted.

NB— No Buffer Impact. This variation provides for an un-impacted creek buffer during construction. No construction activity would be allowed within 50-feet of the existing or relocated creek.

Retained Options

Based on the above-described design variable, 50 different wall/creek configuration options are available. Twenty of the options were retained for evaluation after an initial screening by Port staff and consultants. Table B.1 summarizes the geometrical data associated with each of the 20 retained options.

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Table B.1 – Summary of Geometrical Data for Retained Options

Option	Wall Configuration		Creek Relocation Alignment		Buffer Impact	Max. Wall Height (or Slope)	Face Area	Fill Quantity Reduction	Additional Wetland Disturbance
			Channel	LF	Y or N	FT	SF	CY	Acre
1	A	Single Wall	Exist	0	N	132	116,000	723,000	0
2	A		Exist	0	Y	110	97,000	655,000	0.54
3	A		1A	140	N	120	101,000	675,000	0.27
4	A		1A	140	Y	98	92,000	664,000	0.65
5	A		3	480	N	62	71,000	552,000	1.39
6	B	Double Wall	Exist	0	N	2 x 75	140,000	764,000	0
7	B		Exist	0	Y	2 x 65	128,000	633,000	0.54
8	B		1A	140	N	2 x 70	133,000	652,000	0.27
9	B		1A	140	Y	2 x 59	121,000	641,000	0.65
10	B		3	480	Y	2 x 41	101,000	582,000	1.39
11	C	Single Wall/Bridge	Exist	0	Y	94	104,000	768,000	0.54
12	C		1A	140	N	105	109,000	791,000	0.27
13	C		1A	140	Y	82	97,000	773,000	0.65
14	C		3	480	Y	46	73,000	644,000	1.39
15	D	Double Wall & Bridge	Exist	0	N	2 x 67	144,000	550,000	0
16	D		Exist	0	Y	2 x 56	123,000	498,000	0.54
17	S	Over-Steepened Slope	Exist	0	Y	0.58:1	313,000	611,000	0.54
18	S		1A	140	N	0.41:1	312,000	649,000	0.27
19	S		1A	140	Y	0.73:1	340,000	583,000	0.65
20	S		3	480	Y	1.28:1	339,000	448,000	1.39

Matrix Evaluation

A matrix was developed to aid in evaluating the advantages and disadvantages of the 20 retained options. Based on discussions and input from staff and consultants representing the Third Runway engineering and environmental permitting effort (Port, HNTB, Parametrix, and Hart Crowser) as well as input from the Airport Operations, Maintenance, and Fire Departments, it was determined that the following issues will influence the wall/slope geometry selection. Each of the issues was weighted and incorporated into the evaluation matrix. The final evaluation matrix is shown on Figure B.1. The scoring of each issue is described below.

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Cost. The options with the least estimated initial construction cost of the retaining wall or slope were scored higher than those with higher construction costs. Unit costs were based on an average cost per square foot for MSE walls or slopes. The unit costs were increased as the height of the wall increased based on the graph shown on Figure B.2. The total relative costs of each option are shown on Figure B.3.

Fill Quantity Minimization. The 2H:1V fill slope option discussed earlier would result in the greatest quantity of fill material necessary for the third runway embankment. Each of the retained options will result in a reduction of fill quantity based on the quantity necessary for a 2H:1V slope. The options resulting in a greater reduction in fill quantity necessary were given higher scores.

Creek Relocation and Wetland Avoidance. Between runway stations 174+00 and 186+00, the west-side embankment is typically located in or adjacent to wetlands. Design options (steeper slopes or increased wall heights) that reduce the western limit of the embankment will also reduce the impact to wetlands.

The recommended wall/creek alternative must be consistent with Section 404 regulatory requirements to avoid and minimize wetland impacts. To achieve this, the evaluation matrix considered the potential wetland impacts as well as the feasibility and the practicability (cost, logistics, etc.) of each retained option. These factors were evaluated to determine the least environmentally damaging, practical alternative.

Those options resulting in the least lineal footage of creek relocation and the least impact to existing wetlands were scored higher than those options requiring a longer creek relocation and larger square footage of wetland impacts.

Buffer Avoidance. The options resulting in the least impact to the existing creek buffer were given the higher relative scores. The ranking criteria consisted of:

- Acreage of existing creek buffer impacted; and
- Avoiding the existing buffer completely is preferable to re-planting the buffer.

Floodplain Avoidance. All of the options will impact the existing Miller Creek floodplain. However, those options that minimize the volume of lost floodplain were scored higher than those resulting in a greater volume of lost floodplain.

Access. Although each of the options will accommodate the need for maintenance, security, and emergency access, some of the options result in fewer access concerns. It was determined that the most critical access requirement is the ability of the Airport Fire Department to provide fire suppressant coverage with their existing equipment. Therefore, those options that result in "shadows" or have large horizontal separation where fire suppressant will not reach were scored lower than those options that allow unrestricted fire suppressant placement.

Operational Impacts. A high retaining wall or slope will require some maintenance efforts and specific fire and rescue procedures. Discussions were held with representatives from the airport maintenance department and fire department to quantify those impacts. Harder to quantify, however, are the impacts of a high wall, slope, or bridge on airside operations, such are potential radar reflection and wind shear impacts.

There are few existing examples of high retaining walls constructed near runways. There are a few airports constructed on bluffs that approximate the conditions of a retaining wall. In some cases, the cliffs, bluffs, or walls near a runway do create turbulence during certain wind conditions; however, the effects are generally manageable.

Construction of the wall is not anticipated to create undesirable radar reflection because of the walls location west of and below the runway grade. Those facilities that are to be placed further west of the wall (the ASR) are also not anticipated to be detrimentally effected by the wall or slope.

The operational impacts of the wall to windshear and radar reflection were determined to be negligible for each of the wall/slope options and the evaluation issue was not included in the final evaluation matrix.

Ease of Maintenance. Each of the retained options will require periodic inspection and maintenance. Some options, however, are expected to require less routine maintenance than others. Those options with fewer maintenance requirements were scored higher than those that will require greater maintenance efforts. The assumptions that impacted the ranking included:

- Roads at both the top and the bottom of a structure are anticipated to be preferable to a single road;
- Access roads closer to proposed structures are preferable to roads that a further away; and
- Over-steepened slopes can better accommodate facing repair or replacement in needed.

Drainage Adaptability. Each of the wall/slope options can be tailored to meet the requirements associated with collection, storage, and treatment of surface water runoff. However, those options that more easily accommodate the anticipated storm drainage features were given a higher relative score. The assumption that effected the ranking include:

- Double walls will require an intermediate collection system;
- Steep slopes will require benches or intermediate collection system;
- Bridges will require special runoff collection at the abutments;

- Walls will require foundation drainage, over-steepened slopes will not;
- Greater horizontal surface area will result in a higher volume of storm water runoff; and
- Wall/slope configuration will not significantly impact conveyance from the airfield.

Scheduling Adaptability. Phasing and construction sequencing will be an important component to the runway embankment program. Those options that can be more easily adapted to construction over multiple years were given a higher relative score. The assumptions that impacted the ranking are as follows:

- MSE walls can be constructed to any height in a given construction season;
- Sloped benches between wall segments or tiers increase the scheduling complexity;
- Bridge construction adds scheduling complexity; and
- Over-steepened slopes have seasonal constraints for TESC measures.

Wildlife Attractant Avoidance. The options present a variety of concerns regarding potential habitat creation for wildlife unsuitable in an airport environment. The Airport Environmental Group was consulted to quantify the potential for creation of undesirable wildlife habitat that could be provided within each of the geometrical options. Those options with less potential for creating wildlife habitat were given higher relative scores. The assumptions used for the ranking process are as follows:

- The greater the quantity of vegetated slope, the greater the potential for habitat creation;
- There is no significant difference between the each of the wall/slope options for raptor attractiveness; and
- The bridge, if selected, would be constructed to eliminate potential bird roosting and nesting areas.

Aesthetics. Opinions on the aesthetic value of each of the geometrical options can vary widely. However, it was generally assumed that those options resulting in less square footage of wall surface would be more aesthetically pleasing as would options that provide a greater area of planted material. Those options therefore were given a higher relative score. Other assumptions effecting the ranking are as follows:

- Single walls over 100 feet high have low visual attractiveness;
- Vegetated slopes have high visual attractiveness;
- Mixed structure types result in less attractiveness;
- Reduced wall mass is more desirable; and
- Greater wall separation is visually more attractive.

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CREEK/EMBANKMENT CONFIGURATION MATRIX

Opt. #	Wall/Slope Configurations / Ranking Factor --> (1 to 10)	Cost	Fill Quantity Minimization (E)	Creek Relocation & Wetland Avoidance (E)	Buffer Avoidance (E)	Floodplain Avoidance (E)	Access (security, maintenance, emergency)	Operational Impacts (maint., ops., fire & rescue/windshear, radar)	Ease of Maintenance	Drainage Adaptability	Scheduling Adaptability	Wildlife Attractant Avoidance	Aesthetics (E)	Total Ranked Score	Overall Rank
		9	1	10	7	5	7	7	5	2	2	1	4		
A. Single Wall Options:															
1	A-Exist-NB (132')	3	9	10	10	10	10		8	10	10	10	1	420	1
2	A-Exist-B (110')	7	7	8	6	4	10		7	8	10	10	1	367	3
3	A-1A-NB (120')	5	7	6	8	5	10		7	9	10	10	1	350	4
4	A-1A-B (98')	8	7	4	4	1	10		4	7	10	10	1	290	9
5	A-3-B (62')	10	6	1	1	6	4		1	2	10	5	6	229	17
B. Double Wall Options															
6	B-Exist-NB (2x75')	3	10	10	10	10	4		10	6	8	10	4	389	2
7	B-Exist-B (2x65')	5	6	8	6	4	4		8	4	8	10	4	311	7
8	B-1A-NB (2x70')	3	6	6	8	5	3		8	5	8	10	4	287	10
9	B-1A-B (2x59')	7	6	4	4	1	6		7	4	8	10	6	277	13
10	B-3-B (2x41')	8	2	1	1	6	1		1	2	8	5	6	182	20
C. Single Wall w/ Bridge Options															
11	C-Exist-B (94')	6	10	8	6	4	4		2	6	6	7	1	279	12
12	C-1A-NB (105')	5	10	6	8	5	6		2	6	6	7	1	283	11
13	C-1A-B (82')	8	10	4	4	1	3		3	5	6	5	3	230	16
14	C-3-B (46')	9	6	1	1	6	1		4	1	6	5	3	192	19
D. Double Wall w/ Bridge Options															
15	D-Exist-NB (2x67')	1	3	10	10	10	4		3	3	3	10	3	309	8
16	D-Exist-B (2x56')	4	2	8	6	4	4		3	3	3	7	3	254	15
S. Steepened Slope Options															
17	S-Exist-B (145'V @ .58:1)	5	5	8	6	4	8		8	8	1	1	10	347	5
18	S-1A-NB (145'V @ .41:1)	4	6	6	8	5	8		4	6	1	1	10	314	6
19	S-1A-B (145'V @ .73:1)	5	4	4	4	1	8		5	6	1	1	10	258	14
20	S-3-B (145'V @ 1.28:1)	5	1	1	1	6	6		6	3	1	1	10	214	18

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FIGURE B.1
WALL/CREEK EVALUATION MATRIX

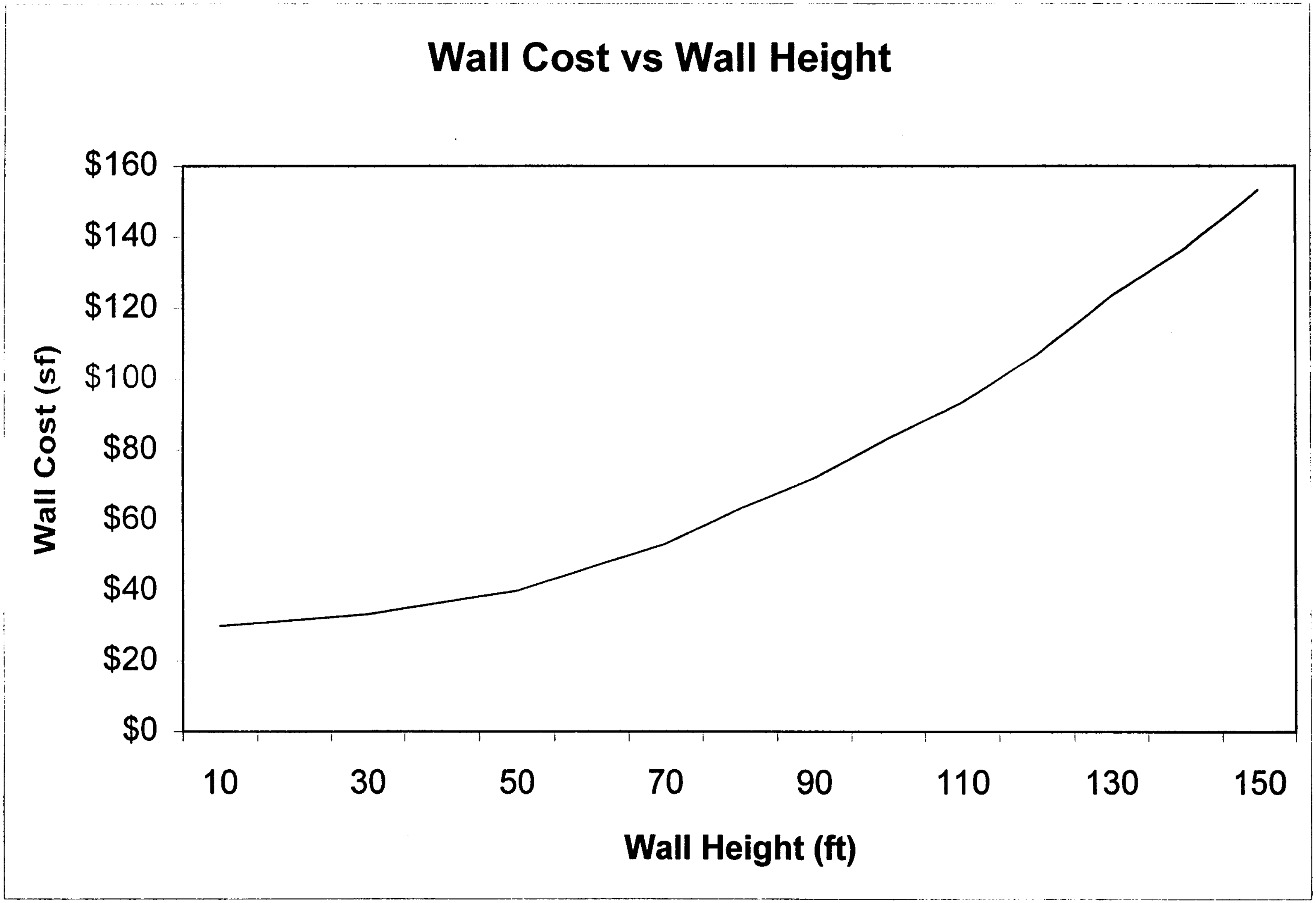

FIGURE B.2
MSE WALL COST CURVE

Estimated Cost

Option Desc	Wall Height	Unit Cost $/SF	Wall Area (SF)	Wall Cost	Bridge Area (SF)	Unit Cost ($/SF)	Bridge Cost	Additional Fill Qty* (CY)	Unit Cost ($/CY)	Fill Quantity Cost	Total Relative Cost	Ranking (20-1)
1 A-Ex-NB	132	$126	116,000	$14,616,000				68000	$13	$884,000	$15,500,000	2
2 A-EX-B	110	$92	97,000	$8,924,000				136000	$13	$1,768,000	$10,692,000	15
3 A-1A-NB	120	$108	101,000	$10,908,000				116000	$13	$1,508,000	$12,416,000	10
4 A-1A-B	98	$80	92,000	$7,360,000				127000	$13	$1,651,000	$9,011,000	18
5 A-3-B	62	$50	71,000	$3,550,000				239000	$13	$3,107,000	$6,657,000	20
6 B-EX-NB	75	$60	70,000	$4,200,000				27000	$13	$351,000	$15,051,000	3
	75	$150	70,000	$10,500,000								
7 B-EX-B	65	$50	64,000	$3,200,000				158000	$13	$2,054,000	$12,934,000	7
	65	$120	64,000	$7,680,000								
8 B-1A-NB	70	$55	66,500	$3,657,500				139000	$13	$1,807,000	$14,641,500	4
	70	$138	66,500	$9,177,000								
9 B-1A-B	59	$46	60,500	$2,783,000				150000	$13	$1,950,000	$10,904,000	14
	59	$102	60,500	$6,171,000								
10 B-3-B	41	$40	50,500	$2,020,000				308000	$13	$4,004,000	$9,306,500	17
	41	$65	50,500	$3,282,500								
11 C-EX-B	94	$76	104,000	$7,904,000	40600	$85	$3,451,000	23000	$13	$299,000	$11,654,000	13
12 C-1A-NB	105	$86	109,000	$9,374,000	40600	$85	$3,451,000	0	$13	$0	$12,825,000	8
13 C-1A-B	82	$65	97,000	$6,305,000	40600	$85	$3,451,000	18000	$13	$234,000	$9,990,000	16
14 C-3-B	46	$40	73,000	$2,920,000	42000	$85	$3,570,000	147000	$13	$1,911,000	$8,401,000	19
15 D-EX-NB	67	$52	72,000	$3,744,000	16800	$85	$1,428,000	241000	$13	$3,133,000	$17,665,000	1
	67	$130	72,000	$9,360,000								
16 D-EX-B	56	$45	61,500	$2,767,500	16800	$85	$1,428,000	293000	$13	$3,809,000	$13,847,000	6
	56	$95	61,500	$5,842,500								
17 S-EX-B	.58:1	$32	313,000	$10,016,000				180000	$13	$2,340,000	$12,356,000	11
18 S-1A-NB	.41:1	$39	312,000	$12,168,000				142000	$13	$1,846,000	$14,014,000	5
19 S-1A-B	.73:1	$29	340,000	$9,860,000				208000	$13	$2,704,000	$12,564,000	9
20 S-3-B	1.28:1	$23	339,000	$7,797,000				343000	$13	$4,459,000	$12,256,000	12

*Option 12 = Basis of Fill 791000
= interpolated

FIGURE B.3
RELATIVE WALL COSTS SUMMARY

AR 042430

APPENDIX C
SUPPORTING INFORMATION ON WALL/SLOPE ALTERNATIVES

AR 042431

Typical Heights

Table C.1 - MSE Walls > 90 Feet in Height.

Vendor	Height in Feet	Notes
TAI	131	Tsing Yi, Hong Kong (6 tiers)
TAI	125	Tokushima, Japan (3 tiers)
TAI	122	Freeport, Indonesia (Full Vertical Wall)
Hilfiker	104	Royal Oak Mines, BC
TAI	98	Kennedy Pkwy, Atlanta, GA
TAI	98	Coccau, Italy (4 tiers)
TAI	92	Les Roches, France
Hilfiker	91	Minera Escondida, Chile

Table C.2 - MSE Walls 70 to 90 Feet in Height.

Vendor	Height in Feet	Notes
TAI	89	Izmir, Turkey (+69-foot surcharge)
TAI	79	Nice, France (built 1978)
TAI	79	Nice, France (built 1974)
Hilfiker	76	Round Mountain, NV
Hilfiker	72	Kennecott Energy, WY
Hilfiker	72	Santa Barabara, Chile
Hilfiker	72	Cripple Creek, CO
TAI	72	Menton, France (built 1968)
TAI	72	Adelaide, South Australia

Anchored Walls

Advantages

- Anchors can be prestressed to limit movements due to lateral earth pressure of fill behind the wall.
- Readily designed to prevent deep-seated failures.
- Narrow base width.

Disadvantages

- Limited cases of high walls >40 feet.
- May be relatively expensive.

- High wall examples are for cut-type situations.

Unknowns

- High wall examples for fill-type situations.

Typical Wall Heights

- Limited information suggests walls on the order of 30 ft. have been constructed and are performing satisfactorily in the Seattle area.

High Wall Examples

- 25-foot anchored cylinder piles (WSDOT Manual).
- Military Handbook 1025/4 shows many marine bulkhead designs 40 to 53 feet tall.
- 55-foot wall with base anchors, Chuckanut Drive, north of Seattle.

Crib Walls

Advantages

- Relatively low cost.
- Can tolerate moderate settlement.
- Base width (50 to 60 percent of wall height).

Disadvantages

- Crib walls usually economical for wall heights < 30 feet.

Unknowns

- High wall examples.

Typical Wall Heights

- 15 to 35 feet, depending on crib material. MSE reinforcement of the backfill enables wall heights greater than 50 feet.

High Wall Examples

- Caltrans Highway manual allows concrete crib walls up to 50 feet tall.

AR 042433

Cellular Cofferdams

Advantages

- Will generally fail as interlocks yield under shear stress before undergoing catastrophic failure by sliding or overturning.
- Can tolerate relatively large movements without damage.
- Good seismic stability.
- Lateral deflections up to 13 percent of exposed height have been reported.

Disadvantages

- Typically designed for marine applications.
- Stability can require deep embedment and wide cells.
- Maximum interlock tension on unloaded side of cofferdam becomes critical for taller structures.
- No accepted analytical method for computing maximum interlock tension on the unloaded side of the cofferdam.
- Extremely difficult to drive long sheets for land installation.

Unknowns

- Method of installing long sheets on land
- Accepted methodology for analyzing interlock tension in sheet piles.
- Accepted seismic analysis methods.

Typical Wall Heights

- 40- to 80-foot-high walls are documented for marine applications. Smaller walls may be more typical of cellular cofferdam construction.

High Wall Examples

- 80 feet exposed height cofferdam at Trident submarine drydock.
- 57 feet exposed height cellular cofferdam at Portland, OR, ship repair facility.
- 40 to 50 feet exposed height cofferdam, Williamson, WV, river embankment.
- 47 feet double-walled reinforced earth cofferdam used in lieu of RCC to reduce costs.

Concrete Dam/Concrete Gravity Walls

Advantages

- Do not require high-quality backfill.
- All-weather construction.

- Proven technology.

Disadvantages

- Relatively high cost.
- Relatively wide base width (60 to 70 percent of wall height).
- Not settlement tolerant.
- Dense soil or rock required for foundation material.

Unknowns

- Recent examples of tall gravity walls for retaining soil.

Typical Wall Heights

- Wall heights in excess of 100 feet are typical for this type of construction.

High Wall Examples

- Mil Handbook 1025/4 shows many mass concrete marine quay walls from 40 to 50 feet tall.
- 150 feet mass concrete wall at the Comerford Dam, Connecticut River.
- 110 feet unreinforced concrete walls at Eisenhower and Snell Locks on the St. Lawrence Seaway.

Cantilever Walls

Advantages

- Relatively narrow base width (50 to 60 percent of wall height).
- Experience with tiers applicable for large fill construction.

Disadvantages

- Relatively high cost; but, generally economical for heights < 20 feet.
- Cannot tolerate appreciable settlement
- Seismic stability may be an issue for high walls.

Unknowns

- Wall examples in excess of 35 feet.

Typical Wall Heights

- 20 to 35 feet wall height is range listed by WSDOT and Caltrans manuals.

High Wall Examples

- Not available.

Counterfort Walls

Advantages

- Relatively narrow base width (50 to 60 percent of wall height).
- Applicable for large fill construction.
- Wall deflection can be minimized.

Disadvantages

- Relatively high cost.
- Not settlement tolerant

Unknowns

- Examples of walls over 50 feet tall.

Typical Heights

- Reportedly are routinely designed to 50 foot heights (Military Handbook 1025/40.

High Wall Examples

- Military Handbook 1025/4 shows counterfort marine quay wall 50 feet tall

Cylinder Pile Walls

Advantages

- Deep embedment will limit deep-seated failures.
- Relatively narrow base width.

Disadvantages

- Deep embedment needed for stability
- Relatively high cost.
- Typically reserved for cut situations in construction.
- Large diameter cylinder piles would be required to limit deflections for high wall sections.

Unknowns

- Cylinder pile walls used in fill-type situations.

Typical Wall Heights

- 20 to 25 feet of exposed height is typical.

High Wall Examples

- 20 to 40 feet exposed height cylinder pile wall for I-5 Seattle used in cut-type construction.
- 41 feet exposed height, anchored cylinder pile wall for highway in Cincinnati (cut-type construction).

Concrete Arch Walls

Advantages

- Design and construction are well-documented.
- High wall examples exist worldwide.
- Longevity has been demonstrated.
- Seismic performance is well understood.
- Narrow base width for thin arch construction (< 20% of structural height)

Disadvantages

- High Cost.
- Typically rock foundation required, suitability of dense soil foundation unknown.
- Typically keyed into rock abutments.

Unknowns

- Examples of concrete arch walls supporting soil.

Typical Wall Heights

- Concrete arch dams have a height that typically ranges from 50 to 300 feet.

High Wall Examples

- More than 24 examples of U.S. concrete arch dams greater than 100 feet high were identified in a cursory review.

Other Proprietary Walls

Advantages

- Modular block retaining walls can be very economical.
- Assembly of modular block retaining walls readily accomplished by inexperienced contractors.

Disadvantages

- Proprietary design systems may not have been subjected to extensive peer review.
- Relatively small differential settlements can cause modular block walls to fail.
- Failures of modular systems have been reported for relatively limited wall heights.

Unknowns

- Validity of vendor performance claims.
- Seismic performance characteristics.

Typical Wall Heights

- Most examples from vendors show walls less than 20 feet tall.

High Wall Examples

- 45 feet high Lock+Load wall in Surrey, BC, with 1H:10V batter.

MSE (Reinforced) Slope

Advantages

- Relatively low cost.
- Can tolerate large settlements.
- High-quality fill is not a requirement.
- Landform contouring, using variable slope angles and native vegetation, simulates natural slope.
- Can tolerate large horizontal and vertical strain.

Disadvantages

- Generally requires more space than a wall.

Typical Slope Heights

- Variable up to at least 150 feet; typically based on geometric constraints.

High MSE Slope Examples

- 150 feet high 1H:1V slope in South America by Tensar (G. Sander).
- 141 feet high slope for Helsell Residence landslide repair (composite slope of 1.6H:1V and 1.8H:1V).
- 115 feet high 1H:1V slope (Holtz, et al, *Geosynthetic Engineering*).
- 85 feet high 0.2H:1V slope with wire mesh/concrete aggregate facing by Hilfiker (E. Aziz).
- 80 feet high 1H:1V slope in Southern California using an 80 ft. deep "shear key".
- 65 feet high 1H:1V slope for Spanish Hills Country Club, Ventura, CA.
- 55 feet high 0.5H:1V slope for Rt. 236, Santa Cruz Mountains.
- 50 feet high 0.75H:1V slope (53°) for developer in Pittsburgh (J. Paulson).
- 36 feet high 0.2H:1V slope (80°) retaining parking lot in Leeds, U.K. (TAI).
- 30 feet high 0.5H:1V slope (63°) with vegetated facing in Pittsburgh.

Soil Cement

Advantages

- May be used to improve strength over conventional embankment materials.

Disadvantages

- Thorough mixing is critical to achieve uniform soil properties throughout the fill.
- Weather limited construction.
- Binders may interfere with surface vegetation.
- Construction rate may be limited by time required for curing the mix.

Unknowns

- Seismic performance characteristics.

Typical Wall Heights

- Not available.

High Wall Examples

- 82 feet, 30 degree slope above a 35-foot crib wall, using quicklime and filter fabric.

Roller Compacted Concrete

Advantages

- Higher strengths compared to soil cement.

- About 25 to 50 percent cheaper than conventionally placed concrete.
- Rapid construction but may be weather constrained.

Disadvantages

- Relatively new technology - oldest RCC gravity dam dates to 1980.

Unknowns

- RCC used in soil retention structures.

Typical Wall Heights

- RCC dams range from 50 to over 300 feet in height.

High Wall Examples

- More than 25 examples of RCC gravity dams over 100 feet in height were identified during a cursory review.

RETAINING WALL AND OVER-STEEPENED SLOPE ALTERNATIVES

0 to 40 FOOT WALL HEIGHTS	Cost	Material Design Life	Experience/Performance History (Relative Number of Constructed Projects and Duration in Service)	Technical Certainty (Established Design Method)	Seismic Performance Characteristics	Constructability (Seasonal Issues, Schedule Impacts, and Access)	Surface/Subsurface Drainage	Differential Settlement Performance	Ease of Maintenance	Aesthetics	Total Ranked Score
Ranking Factor	1	2	3	3	2	1	2	2	2	1	
MECHANICALLY STABILIZED EARTH WALL	3	2	3	3	3	3	3	3	1	2	50
ANCHORED WALL (e.g., Deadman, Bulkhead, or Other Anchorage System)	3	1	2	3	1	2	3	2	1	2	38
"Criblock" TYPE WALL	3	2	3	2	1	3	3	1	2	2	41
CELLULAR COFFERDAM	1	2	3	2	2	2	1	2	2	1	37
CONCRETE DAM	1	3	0	3	2	1	0	2	3	1	32
CANTILEVER WALL	2	3	3	3	2	1	1	1	2	3	42
COUNTERFORT WALL	2	3	3	3	2	1	1	1	2	3	42
CYLINDER PILE WALL (i.e., with or without anchorage)	1	3	1	3	2	2	2	2	2	2	39
CONCRETE ARCH WALL	1	1	3	1	1	1	1	0	2	1	25
OTHER VENDOR WALL (i.e., "V.E.R.T." wall)	2	3	1	1	2	2	2	2	2	2	34
REINFORCED SOIL (MSE)	3	2	3	3	3	3	3	3	1	3	51
SOIL CEMENT	2	3	1	3	3	1	1	2	2	1	38
ROLLER COMPACTED CONCRETE	2	3	1	3	3	2	1	2	3	1	41

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FIGURE C.1
EVALUATION MATRIX - 0 TO 40 FOOT WALL HEIGHTS

RETAINING WALL AND OVER-STEEPENED SLOPE ALTERNATIVES

40 to 80 FOOT WALL HEIGHTS	Cost	Material Design Life	Experience/Performance History (Relative Number of Constructed Projects and Duration in Service)	Technical Certainty (Established Design Method)	Seismic Performance Characteristics	Constructability (Seasonal Issues, Schedule Impacts, and Access)	Surface/Subsurface Drainage	Differential Settlement Performance	Ease of Maintenance	Aesthetics	Total Ranked Score
Ranking Factor →	1	2	3	3	2	1	2	2	2	1	
MECHANICALLY STABILIZED EARTH WALL	3	2	3	3	2	3	3	2	1	1	45
ANCHORED WALL (e.g., Deadman, Bulkhead, or Other Anchorage System)	2	1	1	2	1	2	3	1	1	1	28
"Criblock" TYPE WALL	0	0	0	0	0	0	0	0	0	0	0
CELLULAR COFFERDAM	0	2	2	1	2	1	1	1	2	2	28
CONCRETE DAM	1	3	0	3	2	1	0	2	3	3	34
CANTILEVER WALL	0	3	0	0	0	0	0	0	0	0	6
COUNTERFORT WALL	0	3	1	1	1	1	1	1	2	2	25
CYLINDER PILE WALL (i.e., with or without anchorage)	1	3	0	2	1	1	1	2	2	2	28
CONCRETE ARCH WALL	1	1	0	0	0	0	0	0	0	0	3
OTHER VENDOR WALL (i.e., "V.E.R.T." wall)	2	3	0	1	1	1	1		2	2	22
REINFORCED SOIL (MSE)	3	2	3	3	3	3	3	3	1	1	49
SOIL CEMENT	2	3	0	2	3	1	1	2	2	2	33
ROLLER COMPACTED CONCRETE	2	3	0	3	3	2	1	2	3	3	40

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FIGURE C.2
EVALUATION MATRIX - 40 TO 80 FOOT WALL HEIGHTS

RETAINING WALL AND OVER-STEEPENED SLOPE ALTERNATIVES

> 80 FOOT WALL HEIGHTS	Cost	Material Design Life	Experience/Performance History (Relative Number of Constructed Projects and Duration in Service)	Technical Certainty (Established Design Method)	Seismic Performance Characteristics	Constructability (Seasonal Issues, Schedule Impacts, and Access)	Surface/Subsurface Drainage	Differential Settlement Performance	Ease of Maintenance	Aesthetics	Total Rated Score
Ranking Factor -->	1	2	3	3	2	1	2	2	2	1	
MECHANICALLY STABILIZED EARTH WALL	2	2	2	2	2	3	3	2	1	2	39
ANCHORED WALL (e.g., Deadman, Bulkhead, or Other Anchorage System)	1	1	0	1	1	1	3	1	1	2	21
"Criblock" TYPE WALL	0	0	0	0	0	0	0	0	0	0	0
CELLULAR COFFERDAM	0	1	0	0	0	0	0	0	0	0	2
CONCRETE DAM	1	3	0	3	2	1	0	2	3	1	32
CANTILEVER WALL	0	3	0	0	0	0	0	0	0	0	6
COUNTERFORT WALL	0	3	0	0	0	0	0	0	0	0	6
CYLINDER PILE WALL (i.e., with or without anchorage)	1	3	0	0	0	1	1	0	0	2	12
CONCRETE ARCH WALL	1	1	0	0	0	0	0	0	0	0	3
OTHER VENDOR WALL (i.e., "V.E.R.T." wall)		3	0	0	0	0	0		0	0	6
REINFORCED SOIL (MSE)	3	2	3	3	3	3	3	3	1	3	61
SOIL CEMENT	2	3	0	1		1	1	2	2	1	23
ROLLER COMPACTED CONCRETE	2	3	0	3	3	2	1	2	3	1	38

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FIGURE C.3
EVALUATION MATRIX - > 80 FOOT WALL HEIGHTS

APPENDIX D
COMMENTARY ON MSE WALL DESIGN ISSUES

APPENDIX D COMMENTARY ON MSE WALL DESIGN ISSUES

This appendix summarizes MSE wall design issues in the areas of: global stability, reinforcing materials, facing materials, contracting issues and special geometric considerations.

Global Stability

1. Does a higher wall change the nature of the global stability problem or will conventional analyses work with appropriate geometric considerations?

   Several sources (Holtz, Aziz, McIntosh, Paulson) indicated conventional analysis for global stability is unchanged with wall height. Typical practice for MSE walls has the owner assure global (external) stability, and the vendor often taking responsibility for internal stability. According to the Corps of Engineers, conventional stability analyses (similar to a gravity retaining wall) can be used, and for MSE walls > 30 feet high, the Corps states that sliding failure of the reinforced mass may be the main design issue.

2. For sloping ground (upward behind the wall) is it feasible to bench the slope behind the wall and increase length of the reinforced zone with height, or does the conventional practice of having all the reinforcement the same length need to be followed?

   Early FHWA guidance had all the reinforcement the same length, but this is not strictly necessary and variable lengths are shown in some articles. Load on toe and base sliding resistance require good foundation materials.

3. For sloping ground along the face of the wall, can reinforcement length vary with different "H"?

   Yes, need to set reinforcing vertical spacing the same along the back of the wall, and survey during construction so backfill of adjacent sections can be continuous.

4. Where unsuitable subgrade exists below the wall or the reinforced fill, can it be improved solely below the wall/fill or is it ever necessary to improve the ground in front of the wall?

   No examples were found of toe berms being required and at least two sources (Holtz and Paulson) indicated reinforcement beyond the toe was not conventional. Preference was for overex and replace soft soils with reinforced fill, Paulson raised question about shear strength of stone columns, HC possible concern with different seismic response for improved foundation relative to adjacent glacially overridden material.

AR 042445

Reinforcing Materials - Are there reinforcing material property issues that may limit wall height?

1. Stiffness of reinforcing elements (yield strength over time or creep).

   Holtz and the polymer vendors say creep is a manageable problem, but McIntosh and Aziz are very specific that only steel provides necessary creep resistance for walls above 60 feet. Polymer product creep test data readily available for 10,000 to 15,000 hours, (some longer ?) design guidance suggests limits on extrapolation.

2. Strength of reinforcing elements.

   Aziz said that overstressing of lower levels of polymer reinforcing has been a problem and that he has a general problem with conventional "batch" QA for polymer products. Paulson cites composite polymer products have higher tensile strength than single polymer type (PEC). Typically specified strength of material and layer spacing are varied by the designer for overall cost effectiveness.

3. Strength of reinforced soil composite.

   Quality of backfill (compacted soil) typically controls strength. Length of reinforcing zone varied to increase total strength where low unit shear values are a concern, ranging 0.65 H to 1.2 H; typical vendor quote is 0.7 H

   Installation damage risk is quantified in design process.

4. Corrosion or degradation of reinforcing over time.

   Widely acknowledged to be a serious issue for steel. Can be approached by oversizing section, special metals and coatings, galvanizing. Backfill soil needs QA/QC for corrosion inducing products, also need to consider long term infiltration.

   Polymer products generally regarded as being susceptible to sunlight UV but very durable once installed. Reaction to fuel spills reportedly not a problem.

   Many of Hilfiker high walls are special use structures on private land with fixed design life specified (e.g., "20-year design life based on normal corrosion criteria").

AR 042446

Facing Materials - Are there facing materials or detailing issues that may limit wall height? Such as:

1. Horizontal load (over-stressing due to compaction).

   Problem identified by Azziz, not identified in initial literature review. Requires further evaluation.

2. Vertical Load (crushing of bearing pads).

   According to TXDOT, compressed cork bearing pads have not performed adequately for tall walls. Neoprene works well but is relatively expensive. On one tall wall, injection molded pads were used that crushed under the weight of the facing; however, no serious consequences were noted. (McClelland)

3. Stiffness (seismic P wave flex).

   The predominant failure mode seems to be toppling at the top of the wall under seismic loading. To minimize this potential, reinforcement layers should be used close to the crest, with adequate connection capacity and anchorage length. In the Northridge quake, two walls did not develop this failure, likely the result of good reinforcement at the crest. (Bathurst et al., 1997)

   A RECO study of walls in the Northridge quake showed that stiff facing elements could be damaged by movements of flexible elements nearby. Facing panels that were embedded at the ground surface suffered some minor concrete spalling at the interface with flexible panels above them. This damage did not affect the structural integrity of the wall, which was estimated to have experienced accelerations of 0.63 to 0.91g horizontal, and 0.35 to 0.62g vertical. (Frankenberger et al., 1996)

   Shaking table tests by Matsuo et al., showed that a wall with continuous facing experienced a larger displacement than a wall with discrete panels, an "unexpected" result. Horizontal displacement at the top of the wall was about 3 times greater for the continuous facing wall. (Matsuo et al., 1998)

4. Stiffness (differential settlement).

   RECO built an MSE wall for the northern I-5/I-405 interchange in WA in a peat bog that was overexcavated and filled with quarry spalls. Even so, the wall experienced settlements up to 3 inches, but was flexible enough to accommodate this. (Grabner, 1999)

5. Ease of installation/replacement (panel size, connection detail).

   Wide range of details indicates need to consult with vendors to address this.

6. Do we need a stiff facing? If so what are the effects of installing facing as wall construction proceeds vs. applying a facade later?

A numerical study by Rowe and Ho found that facing stiffness has a much less significant effect on horizontal displacement than the reinforcement stiffness and backfill friction angle. They found that reducing facing stiffness will induce a larger total force on the reinforcement layers, but a smaller force at the connection between the facing and the reinforcement. Furthermore, a decrease in facing stiffness will decrease the force in the top reinforcement layers, thus decreasing strain at the top of the wall (forces lower down are increased, leading to larger strains in the lower part of the wall). (Rowe and Ho, 1998)

Bathurst and Hatami summarize previous numerical modeling showing that stiff walls tend to maximize the forces at the interface between the facing and the reinforcement, while segmental walls attenuated the forces between the reinforcement and facing under seismic loading. (Bathurst and Hatami, 1998)

7. Potential decoupling (differential horizontal movement related to seismic P wave).

Shaking table tests by Ramakrishnan, et al., showed no decoupling (neither failure in the keys, nor over-riding of the keys) for a segmental concrete block wall. The block faced wall moved laterally after a seismic force of 0.45g's was applied, compared to the wrapped faced wall, which moved after a seismic input of 0.25g. The author compared the response of the segmental wall to a cantilever beam supported by the geotextiles. (Ramakrishnan, 1998)

Bathurst and Alfaro showed, with shaking table tests, that segmental walls with "fixed-face construction" (i.e., connected with keys or pins) sustained the largest acceleration before significant displacement occurred, in comparison to segmental walls with frictional interface shear properties. (Ramakrishnan, 1998)

8. How beneficial or detrimental is vegetation?

Subject to further study, vegetation does not appear to have any detrimental impact on stability or structural life.

AR 042448

Contracting Issues - What is typical industry practice or preference with respect to contracting?

1. Typical practices are:

   Owner specs goal: type, size and location, and sometimes performance criteria (deflection, installation tolerances) and contractors shop for competitive design & supply bids from manufacturers;

   Most systems are patented and therefore designed by the vendor. There are several specialty consultants (Aziz, Christopher, Holtz, MacIntosh) who work for vendors and/or owners.

   or

   Owner specs detailed design with option for contractor to provide alternate proposal, and contractors shop for alternate design and supply bids materials to see if they can find anything cheaper to build than the speced design.

   This may produce marginal proposals for cheaper components based on limited analysis, and related problems of review and appeal.

   Caltrans Highway Design Manual, Chapter 200. Caltrans has pre-approved a number of proprietary systems. In their scheme, Caltrans provides one fully-detailed "State designed" system as a basis for payment, and some alternatives (which include the pre-approved proprietary systems) as part of the contract bid package. Contractors & vendors are free to propose alternative systems, which allows vendors to introduce new systems that may not already be pre-approved. (WSDOT ?).

   Problem with review time for vendor or contractor proposals, "new"/proprietary design methods,

2. Recommended approach: Owner pre-qualify vendor(s) and complete specific designs, and specs require contractor to build as speced with support of the pre-qualified manufacturer during construction.

   This provides time for detailed design interaction between Owner's engineers and vendor(s) and enables all the attorneys and insurance companies to sort out real product liability issues with the Owner and the vendor(s). Involvement of with more than one vendor provides price competition.

3. Should Owner pre-qualify specialty wall construction contractors?

   Mixed responses, typically steel - no, polymer - yes

Are there special geometric considerations for "walls" in the 70 to 150 foot height range?

1. How much horizontal offset does it take for the retained fill to act as a series of low walls rather than a single high wall?

   Global stability (probably seismic) typically controls effect of upper wall on lower wall related to setback distance. Superposition of surcharge loads is applicable for internal stability within 0.5 H : 1.0 V zone below upper reinforced mass.

   Aesthetics improves with setbacks. One system in Hong Kong used offsets of 1.5m for 4.5 to 6.5m sections, on a 24m project. A 30m wall for a National Park Service Project in Atlanta used 2m setback for 10m sections, for aesthetics only. The design was analyzed as a vertical wall.

   Tiers can be vegetated for appearance, use of a special consultant on wall vegetation was mentioned by Paulson.

   Also, using tiers of limited height reduces load and contact stress problems on the lower courses of masonry facing blocks or panels.

2. What are the relative effects of putting the toe of the wall at the top of a slope vs. the toe of a slope at the top of the wall?

   Both a question of global stability, and internal stability (due to the superimposed load). Generally slope above wall is part of design height.

3. Does wall batter matter much?

   Some facing panel installation systems require some batter. For instance, the bottom row is battered 5/8 inch per 5 feet, allowing for some lateral displacement to mobilize the resistance of the reinforcement (Foster). Not clear if this batter is maintained for all subsequent rows.

   Batter reduces theoretical load on face but conventional practice (FHWA) is to design reinforced fill slopes steeper than 70 degrees as vertical walls.

   Shaking table tests by Matsuo et al., showed that a battered wall experienced larger horizontal movements mid-height, and smaller horizontal movements at the top of the wall, compared to a vertical wall. (Matsuo et al., 1998)

AR 042450

APPENDIX E
GEOTECHNICAL PEER REVIEW REPORT

AR 042451

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

March 27, 1999

HNTB
600 – 108th Avenue NE, Suite 400
Bellevue, WA 98004

Attn: Mr. Robert T. Maruska

RE: PEER REVIEW, SEATTLE-TACOMA INTERNATIONAL AIRPORT THIRD RUNWAY, WASHINGTON

As part of the Third Runway Construction Project at SeaTac Airport, a 135-foot-tall retaining wall would be required near Station 179+00. At this location, Miller Creek is at its furthest eastern limit. At HNTB's request, we have completed a peer review of this proposed retaining wall. In the process, we have attended two meetings (March 16 and 22, 1999) and reviewed plans, elevations, boring logs, test pit logs, Generalized Geologic Cross Section B-B, and Draft Document "Evaluation of Wall/Slope Alternatives to Reduce Impacts to Miller Creek, Embankment Station 174+00 to 186+00." The above documents were prepared by HNTB and/or Hart Crowser, Inc.

The design team reviewed and evaluated several alternative wall types. Based on the results of the review and evaluation, a Mechanically Stabilized Earth (MSE) retaining wall appears to be the most appropriate for this site. We concur with this assessment. Both tiered walls and single face walls have been proposed. The former would be more appropriate in our view, particularly if a precast concrete facing is to be attached to the wall. Shorter panels (say, 35 to 40 feet in height) would be lighter, easier to handle or lift to respective tier levels, and could accommodate more differential settlement than longer, heavier, single-wall panels. The following presents a discussion about design and contract issues, instrumentation, and construction considerations, among others.

Design Issues

Base Stability

Preliminary subsurface explorations indicate that there is a potential presence of soft soils and excess hydrostatic pressure at the base of the wall. These conditions could have an adverse impact on base stability and settlements of the proposed wall. Additional explorations would be completed to better define subsurface conditions; a test trench is recommended. Mitigation measures could include removal of soft soils and structural fill replacement, or soil improvement (such as soil-cement treatment and vibro replacement). To maintain base stability, the removal of soft soils and replacement with structural fill would be more effective. Settlements and slope stability, including both global and local, would require detailed analyses.

MSE Wall Reinforcement

Welded wire (steel) or polymers are typically used as reinforcement within the wall backfill. Polymers have the potential to creep under high stress levels, which is a distinct possibility for this high wall. A thorough evaluation of various polymer creep potential (percent strain with time) would be necessary in conjunction with a reasonable design factor of safety. Wrapped-face construction procedures and inspection would be critical for a polymer-reinforced MSE wall. Permanent walls similar in height to that being proposed reinforced with polymers have yet to be constructed, whereas MSE walls reinforced with welded wire have been constructed to heights of greater than 135 feet.

The concern with welded wire is corrosion potential. A detailed analysis of corrosion potential is described in FHWA Demonstration Project 82 Ground Improvement (Working Draft – June 1996). We recommend that this information be reviewed and incorporated into the design. Based on our experience, a non-corrosive type backfill (high resistivity and pH between 5 and 8) would not have a significant impact on the long-term performance of a welded wire reinforced MSE wall. Our preference would be to construct an MSE wall reinforced with welded wire rather than polymers at this site.

Wall Facing

Various types of facings could be used, such as exposed welded wire, shotcrete, or precast concrete panels or blocks in various shapes. (We understand that an exposed face is unacceptable.) Concrete blocks attached to the reinforcing would be placed in lifts as the wall is being constructed. Detailed settlement analyses would be required to estimate the magnitudes of the total and differential settlements. The amount of settlements should meet established criteria so that high stress concentrations where successive blocks are in contact would not occur.

Stresses would be significant for the blocks installed in the lower portion of the wall. Elastic spacers may be required at these contact points. Vertical precast concrete panels, on the other hand, would be attached to the walls after they have settled, decreasing the potential of overstressing.

The panel-to-wall connection details would require a thorough evaluation. In addition, the behavior of panel wall connections during a strong ground motion event are not well understood. We suggest reviewing the recent work of R.J. Bathurst (Royal Military College, Kingston, Ontario), or retaining him as a consultant.

Drainage

Adequate drainage would be key to the long-term performance of this retaining wall. The Draft Document referred to earlier recommended subdrains behind the base of each bench or wall tier. We agree with this recommendation. Consideration should also be given to a vertical drainage layer located beyond the reinforced zone if the backfill used in this zone is rather impervious.

Seismic Design

We understand that seismic design would be based on various earthquake (EQ) levels, and that a site-specific ground response analysis would be completed by Professor Steve Kramer of the University of Washington. The earthquake levels would be: (1) probability of an EQ being exceeded during design life of the wall, (2) low probability of exceedance during design life, and (3) a rare EQ. The analysis would include a pseudostatic analysis for the internal and external stability of the wall under seismic loading conditions, and a displacement analysis using Newmark's Method. A Fast Lagrangian Analysis of Continua (FLAC) method of analysis is also proposed to evaluate static and seismic performance of the MSE wall. Site-specific time histories would be required for the FLAC seismic study. This latter approach would also provide some insight into the behavior of the wall panel connection during a strong ground motion event. We concur and support the proposed seismic design approach.

Contract Issues

Considering the sensitivity and height of the proposed MSE wall, it is our opinion that a pre-qualified list of MSE wall vendors should be included in the bid documents. The HNTB design team should complete the majority of the design, including reinforcement width-to-height ratios, subgrade bearing capacity, sliding resistance, earth pressures, estimated total and differential settlements and wall lateral displacement, and structural fill and drainage material properties. The design criteria should be incorporated into the plans and specifications for the vendors to complete their design. The Design Team and Owner should interview prospective vendors prior to the selection of the prequalified vendors. The vendors should probably complete a preliminary wall design (preferably for a small fee) as part of the interview prequalification process.

Hart Crowser should be involved with developing the plans and specifications and in the prequalification process. Based on our experience, this would ensure that the desired materials and gradations for drainage and reinforcing backfill, degree of compaction, compaction testing and frequency requirements, and edge or facing construction are included in the documents.

Instrumentation

As a minimum, we recommend that a row of permanent inclinometer casings be installed behind each wall tier. The bottom of each inclinometer casing should be embedded at least 10 feet below the top of each successive wall. The inclinometer casing for the lowest wall should be installed at least 10 feet into the underlying undisturbed bearing soil layer. The purpose of the inclinometers would be to accurately document and record wall deflections during construction, including rate of movement and long-term performance. Rate of movement could be used to evaluate whether potential wall deflection has stabilized in order to proceed with construction or to access the need for mitigation measures. Two separate rows of inclinometers should be considered for redundancy. Additional instrumentation could include extensometers to measure lateral movement within and beyond the reinforced zone.

Survey points should be established on the walls (tops and sides) to monitor and record movements. Readings should be taken on a regular basis and be made available to the Owner and Design Team the next day.

Construction

An experienced representative from the MSE vendor should be onsite full-time during wall construction. In addition, a full-time, experienced representative from Hart Crowser, preferably an engineer, should also be onsite during construction. The purpose of this level of construction observation is to evaluate and document that wall construction is being completed in full accordance with the plans, specifications, and intent of the geotechnical report(s).

Partnering should be considered prior to construction. Based on our experience, this is an effective method of developing team relationships, cooperation, and mutual respect between owner, designer, and contractor to achieve a successful project for all. Team goals could be developed, such as open communication, good-faith negotiations, a quality project within budget, and a profitable and successful project, to name a few.

Test Wall

Constructing a test wall is being considered for this project. In our opinion, design and construction of a stable 135-foot MSE wall could be achieved with current engineering state-of-practice and available technology. A test wall should be used to better understand specific aspects of wall design, such as reinforcement strength, spacing, and length through a detailed instrumentation program. Test wall results would be used to confirm design criteria or assumptions and for economizing the actual wall design. The costs to build and instrument a test wall may not result in a significant cost savings for the actual wall. Additional effort in designing this critical MSE wall would probably be more cost-effective, in our opinion.

Mitigation

Consideration should be given to developing mitigation measures in case wall deflections become excessive. Adequate instrumentation would be key in determining whether mitigation measures are warranted. Mitigation could include additional precast panels and/or tieback anchors to reduce bulging of the reinforced wall.

We appreciate the opportunity to participate in this unique and challenging project. If you have any questions, or if we can be of further service, please do not hesitate to call me at (206) 695-6801.

Sincerely,

SHANNON & WILSON, INC.

Thomas M. Gurtowski, P.E.
Vice President

TMG:JW/tmg

cc: Peter M. Douglass, Inc.
Hart Crowser, Inc., Michael J. Bailey