HARTCROWSER

MEMORANDUM

DATE: January 11, 2002

TO: Jim Thomson, P.E., HNTB Corporation

EXPIRES 12/13/03

FROM: Michael Bailey, P.E., and Barry Chen, P.E., Hart Crowser, Inc.

RE: **Geotechnical Input to MSE Wall Design**
Third Runway Embankment
4978-30

CC: Mr. John Sankey, P.E., RECo
Mr. Rob Millar, P.E., HNTB

This memorandum presents geotechnical design parameters and related information used as the basis for design of the Third Runway MSE walls. The proposed geotechnical basis of design information was originally presented in a Hart Crowser's draft memoranda dated June 22 and August 21, 2000, for discussion with HNTB and RECo. Subsequently the design team decided to adopt the 1996 AASHTO code with interim addenda through 2000 ("the AASHTO code") as the basis for design.

This memorandum retains the organization and much of the information presented in the previous draft versions. Hart Crowser has added information to document changes in geotechnical design parameters that we have adopted based on additional tests, analyses and discussions with the Embankment Technical Review Board (ETRB).

Geotechnical Analysis

Geotechnical design information summarized herein was used as input into RECo's internal reinforcement design analysis, and used by Hart Crowser for external stability analyses. Note that the external stability analyses indicated in some cases that reinforcement strip cross sectional area, length, and/or depth of the reinforced zone (embedment) needed to be increased to meet AASHTO target factor of safety criteria. Recommended changes to satisfy the compound and global slope stability requirements are presented in an accompanying Hart Crowser memorandum dated January [illegible], 2002.

Minimum Factors of Safety

MSE design is based on 1996-2000 AASHTO criteria, as well as any other more stringent requirements based on RECo's experience with wall design and construction. Tables 1 and 2 compare AASHTO and FHWA factors of safety and other criteria to the RECo design manual for static and seismic stability, respectively. (Note that while the FHWA criteria were updated in 2001, Tables 1 and 2 retain the original values used for comparison, in the draft versions of this memo)

Table 1 - Static Stability Analysis

	FHWA, 1997 (Target F.S. or Other)	**AASHTO, 1996-2000 (Target F.S. or Other)**	**RECo Design Manual, 1999 (Target F.S. or Other)**
External Stability			
Sliding	≥1.5 MSEW[1]; ≥1.3 RSS[2]	≥1.5	≥1.5
Overturning	Not explicitly stated (expressed as maximum eccentricity)	≥2.0	≥2.0
Eccentricity at Base	≤B[3]/6	Not specifically stated	Not specifically stated
Bearing Capacity (for sliding and overturning)	≥2.5, ≥1.3 RSS local bearing failure	≥2.0 (if justified by geotech analysis); ≥2.5 otherwise	≥2.0 (if detailed geotech info.); ≥2.5 (if general geotech info.)
Deep-Seated Stability (i.e., Global and Compound Stability)	≥1.3	≥1.3 (if soil param. based on lab tests); ≥1.5 otherwise	Not specifically stated
Internal Stability			
Pullout Resistance	≥1.5 (MSEW and RSS); ≥1.3 (Internal Slope Stability for RSS)	≥1.5, where maximum friction angle of 34 deg. is used to calculate the horizontal force (if without the benefit of triaxial or direct shear testing to provide soil shear strength data)	Defaults to AASHTO, Interim 1998
Pullout Resistance[5]	(Same as AASHTO)	$T_{max} \leq 0.55\ F_y$	$T_{max} \leq 0.55\ F_y$

1. Mechanically Stabilized Earth Wall.
2. Reinforced Soil Slopes.
3. Dimension B equals the reinforced zone length plus the facing panel width.
4. Dimension [illegible] equals the reinforced zone length
5. T equals "tension" and F_y equals "yield strength."

Strength test data obtained for the project were used in the analyses, as discussed later in this memorandum. Hart Crowser used a target factor of safety of 1.3 for end of construction conditions involving undrained or partially consolidated subgrade soil conditions. We used a target of [illegible] for steady state conditions, in part to allow for some variability in the embankment materials (to be selected by the Contractor in accordance with specified criteria) relative to the tested materials.

Table 2 - Seismic Stability Analysis

	FHWA, 1997 (Target F.S. or Other)	AASHTO, 1996-2000 (Target F.S. or Other)	RECo Design Manual, 1999 (Target F.S. or Other)
External Stability			
Sliding	75% of the target static FS or about ≥1.1; (same approach as AASHTO),	75% of the target static FS or about ≥1.1; include 100% of inertial force and 50% of dynamic thrust[1]	≥1.1
Overturning	Not specifically stated	≥1.5; include 100% of inertial force and 50% of dynamic thrust	≥1.5
Eccentricity at Base	≤L/3[4]	Not specifically stated	Not specifically stated
Bearing Capacity (for sliding and overturning)	75% static (i.e., ≥1.87); (same approach as AASHTO)	75% static (i.e., ≥1.5 or ≥1.87 for MSE and RSS, respectively); include 100% inertial force and 50% of dynamic thrust	Not specifically stated
Deep-Seated Stability (i.e., Global and Compound Stability)	≥1.1	≥1.1	Not specifically stated
Internal Stability			
Pullout Resistance	75% static; reduce F*[2] to 80% static value	75% static; reduce F* to 80% static value; include internal inertial force	Not specifically stated
Pullout Resistance	(Same as AASHTO)	$T_{max} \le 0.55$ F	$T_{max} \le 0.55$ F

1. Dynamic thrust determined by the pseudo-static Mononobe-Okabe analysis.
2. F* is the friction factor variable, which is part of the reinforcement pullout analysis.
3. Other parameters as defined for Table 1.
4. We understand the base eccentricity is an alternate approach to "check" overturning resistance, and does not carry over to design requirements for bearing pressure.

Hart Crowser considered seismic global and compound stability to include both pseudo-static analysis, as indicated by AASHTO, and static analysis for post-earthquake conditions using reduced residual strength to account for liquefaction of granular soils and cyclic strength loss for cohesive soils. A target factor of safety of [illegible] was used in both cases.

Other MSE Wall Design and Reinforced Slope Parameters

Table 3 provides a comparison of various aspects of MSE wall design that were identified to resolve potential discrepancies or omissions of specific design information. The design team accepted use of these AASHTO criteria without exception.

Table 3 - Comparison of Other Aspects of MSE Wall and Reinforced Slope Design

	FHWA, 1997 (Target F.S. or Other)	AASHTO, 1996-2000 (Target F.S. or Other)	RECo Design Manual, 1999 (Target F.S. or Other)
MSEW Embedment[1]	H/7 (H same as AASHTO)	H/7 for 2H:1V slope in front of wall, where H is from top of wall at wall face to top of leveling pad	Same as AASHTO
Horizontal Bench in Front of Walls Founded on Slopes	4 feet minimum width	4 feet minimum width	3 feet minimum width
Calculation of Sliding for External Stability	(Same as AASHTO)	Neglect passive resistance; include width and weight of wall facing in calculation of sliding/overturning	Not specifically stated
Leveling Pad Width	Not specifically stated	Designed to meet local bearing capacity needs and differential settlement between wall facing and backfill[2]	Not specifically stated
Maximum particle size for reinforced backfill (see text for detailed discussion)	4 inches	4 inches	6 inches
Friction Factor for Internal Reinforcement Design (backfill on ribbed steel strips)	(Same as AASHTO)	$F^*_{max}<2.0$; $F^*_{max}<1.2 + \log C_u$ where C_u equals backfill uniformity coefficient. $C_u = 4$ for ribbed steel strips if tests are not available	Based on extensive pullout tests, but no values are specifically stated

1. MSEW embedment is not a specific requirement of AASHTO or FHWA, but is provided as guidance for MSEW constructed on fill.
2. Based on discussion with RECo, a non-structural leveling pad shall be used.
3. Other abbreviations and symbols as previously defined.

Embankment Soil Input Parameters

Figure 1 is a "typical" cross section through a MSE wall showing the conceptual fill soil zones within the embankment. As suggested by the figure, each zone has a somewhat different function, which affects the requirements of the engineering properties within a given zone.

For Third Runway embankment construction to date, several fill categories (i.e., soil "Groups") have been defined to meet the needs of various zones, to give the contractor maximum flexibility in selecting fill material, while maintaining the engineer's ability to control performance of the fill. The fill groups are defined by grain size distribution and plasticity, and have distinct placement and compaction criteria.

Table 4 provides soil gradations recommended by FHWA and AASHTO for the reinforced zone. There are examples reported in the literature of walls performing well with less select gradations, and RECo has indicated they can design reinforcement for wall backfill with a much wider gradation range than recommended by AASHTO. However, the design team decided to constrain the wall backfill gradation to specific fill materials that satisfy both AASHTO criteria and the Port's specification for wet weather fill. This approach will provide a high degree of confidence that strength, deformation, and drainage parameters for the compacted backfill will conform to parameters used in the design analyses as well as providing maximum construction schedule flexibility.

Table 5 provides soil gradations agreed to by the design team for the various fill categories. Figures 2 and 3 illustrate the grain size distributions for the embankment fill Groups 1A and 1B, which will be limited to a 4-inch maximum size to fall within the AASHTO criteria for wall backfill soils.

Table 6 provides electrochemical soil property limits recommended by FHWA, AASHTO, and RECo for reinforced fill zones. The design team concurred on use of the AASHTO criteria as the basis for design and specifications.

The design team anticipates that fill material for the wall reinforcement zones will be controlled by the constructions specifications, and that the Contractor will need to demonstrate by submittal that proposed fill materials meet design criteria for shear strength gradation, and plasticity. Hart Crowser will verify that RECo's specifications include requirements for submittal of the appropriate test information.

Table 4 - Soil Gradations for Reinforced Walls and Slopes

Sieve Size	Percent Passing
	Steel Strip Reinforced Zones
AASHTO (1996 - 2000)	
4-inch	100
3-inch	-
¾-inch	-
No. 40	0 to 60
No. 200[4]	0 to 15
FHWA (1997)	
4-inch	100
0.8-inch (20 mm.)	-
No. 4	-
No. 40	0 to 60
No. 200	0 to 15
RECo[1]	
6-inch	100-
U.S. No. 200[2]	0 to 15

1. The RECo design manual does not provide a specific backfill gradation; rather, the manual states specific requirements for maximum particle size, fines content, etc.
2. The plasticity index should be less than or equal to 6 for fine-grained fraction.

Table 5 - Soil Gradations for Fill Material "Groups" to be Used for Construction

Sieve Size	Percent Passing	
	Embankment Fill (Not Reinforced)	**MSE Reinforced Zones**
Group 1A		
6-inch	100	-
4-inch	-	100
3-inch	70 to 100	70 to 100
1¼-inch	-	-
¾-inch	50 to 77	50 to 77
U.S. No. 4	30 to 50	30 to 50
U.S. No. 40	3 to 15	3 to 15
U.S. No. 200[1]	0 to 5	0 to 5[2]
Group 1B		
6-inch	100	-
4-inch	-	100
3-inch	70 to 100	70 to 100
1¼-inch	-	-
¾-inch	35 to 80	35 to 80
U.S. No. 4	20 to 55	20 to 55
U.S. No. 40	3 to 30	3 to 30
U.S. No. 200[1]	0 to 8	0 to 8[2]
Group 2		
6-inch	100	
4-inch	-	
3-inch	70 to 100	
1¼-inch	-	
¾-inch	50 to 85	
U.S. No. 4	30 to 65	
U.S. No. 40	5 to 30	
U.S. No. 200[1]	0 to 12	
Group 3		
6-inch	100	-
U.S. No. 4	50 to 100	-
U.S. No. 40	20 to 60	-
U.S. No. 200[1]	0 to 35	-
Group 4		
[illegible]	[illegible]	
¾-inch	75 to 100	-
U.S. No. 4	50 to 100	-
U.S. No. 40	20 to 70	-
U.S. No. 200[1]	0 to 50	-

1. In the original embankment specifications, the fine-grained soil percentage passing the U.S. No. 200 is based on the fraction of the soil passing the ¾-inch sieve. Based on the total sample this will result in a maximum fines content of about 4% for Group 1A and about 6.4% for Group 1B.
2. [illegible] for fine-grained fraction.

Table 6 - Comparison of Recommended Backfill Electrochemical Properties

	FHWA (1997)	AASHTO (1996 - 2000)	RECo Design Manual 1999
Soil pH	5 to 10	5 to 10	5 to 10
Soil resistivity (at 100% saturation)	>3000 ohm-cm	>3000 ohm-cm[1]	>3000 ohm-cm
Water soluble chloride content	<100 ppm	<100 ppm	<100 ppm
Water soluble sulfate content	<200 ppm	<200 ppm	<200 ppm
Organic content	1% max.	1% max. (for material finer than No. 10 sieve)	Free of organics and other deleterious materials

1. If soil resistivity is greater than or equal to 5,000 ohm-cm, the chlorides and sulfates requirement may be waived.

The remainder of this section provides design information for those fill material groups the contractor would use to construct the embankment zones relevant to the MSE and reinforced fill design. Depending on the results of the RECo analysis and input from HNTB, some of the fill material groups may need to be excluded from consideration for specific zones, or need to have strength values modified based on laboratory testing.

Zone B_2. Zone B_2 soils refer to the reinforced fill zone behind the MSE face panels. Table 7 presents proposed specification requirements and recommended design parameters for Zone B_2 fill.

Table 7 - Zone B_2 Fill

Zone B_2	Proposed Specification Requirements			Recommended Design Parameters[1]		
	Minimum % Compaction ASTM D 1557[2]	**Moisture Range Relative to** OMC[3]	**Maximum Loose Lift Thickness in** inches	**γ in pcf**	**c' in psf**	**φ' in deg.**
Group 1A	92	±3	12	140	0	37
Group 1B	92	±3	12	140	0	37

1. The soil shear strength values shown do not consider any contribution of the reinforcing elements.
2. Somewhat less than 92 percent compaction is acceptable in the reinforced zone, within 3 feet of wall, to control panel displacement during construction.
3. Moisture content for compaction may be reduced to [illegible] OMC per RECo recommendation.
4. Maximum [illegible] compacted fill thickness.

For compaction immediately adjacent to the MSE wall facing panels, only hand compaction equipment can be used to avoid the risk of damaging or causing deflection of the panels, which may result in a somewhat lower level of compaction being achieved in this zone. The distance affected is typically about 5 feet, but this would need to be confirmed based on the compaction equipment being used by the contractor.

Zone B_3. This is the high strength embankment fill zone that provides a foundation for the MSE wall. Table 8 presents proposed specification requirements and recommended design parameters for Zone B_3 fill.

It is important that the Zone B_3 soils not impeded drainage from the overlying Zone B_2 soils, which could result in build-up of pore pressures and affect stability of the wall. Accordingly, Hart Crowser recommends that Type 1B soil not be used in Zone B_3 unless the overlying Zone B_2 is also Type 1B. (However, Type 1A soil could be used below either Type 1A or Type 1B).

Table 8 - Zone B_3 Fill

Zone B_3	Proposed Specification Requirements			Recommended Design Parameters		
	Minimum % Compaction ASTM D 1557[1]	Moisture Range Relative to OMC	Maximum Loose Lift Thickness in Inches[2]	γ in pcf	c' in psf	ϕ' in deg.
Group 1A	92	±3	12	140	0	37
Group 1B	92	±3	12	140	0	37

1. Minimum percent compaction may be increased pending further analysis of potential settlements under wall load.
2. Maximum 10-inch compacted lift thickness.

Compaction of Zone B_3 fill to 95 percent of maximum density is required within the depth of the subgrade improvement backfill that may be subject to liquefaction.

Zone C_1. This is the common embankment fill outside the MSE wall reinforced and support zones. Zone C_1 is similar to the "random fill" designation in the RECo design manual for the fill behind the MSE wall reinforced zone. Here, the contractor will have the most flexibility in the fill material groups. Zone C_1 fill may contain fill material within some or all of the groups indicated below in no particular sequence or relative thickness. Table 9 presents proposed specification requirements and recommended design parameters for zone C_1 fill.

Table 10 - Zone A_2 Fill

Zone A_2	Proposed Specification Requirements			Recommended Design Parameters		
	Minimum % Compaction ASTM D 1557	Moisture Range Relative to OMC	Maximum Loose Lift Thickness in Inches	γ in pcf	c' in psf	ϕ' in deg.
Group 1A	90	±3	12	140	0	37

Notes on Soil Fill Strength Values. Hart Crowser accomplished global and compound stability analyses using a frictional strength value of $\phi' = 37$ degrees for Zones B_2, B_3 and C_2 and $\phi' = 35$ degrees for the Zone C_1 embankment fill. These values were based on a combination of laboratory tests, experience and published information results for comparable embankment fills that are well-compacted and constructed of relatively well-graded soils.

Foundation Soil Input Parameters

The foundation soils vary significantly from one wall location to another, as well as below the footprint of a given wall. The values used in preliminary global stability analysis, (Hart Crowser 2000b) have been adjusted slightly for use in the final stability analyses, as shown in Table 11.

Subgrade improvements are needed in some areas to improve shear strength and/or where mitigation of settlement and/or soil liquefaction are required. Based on evaluation of alternatives, including field tests of stone columns at the Third Runway site, Hart Crowser recommended and HNTB concurred to use overexcavation and replacement with densely compacted fill for subgrade improvements.

Seismic Stability Input Parameters

The 475-year return period seismic event has been selected for MSE wall design. For pseudo-static analysis in accordance with AASHTO criteria, this event would produce a horizontal peak ground acceleration (PGA) of about 0.36 g based on Hart Crowser's previous site-specific evaluation (see Hart Crowser's memoranda dated October 8, 1999, and April 10, 2000). Based on comments from the ETRB, Hart Crowser has accomplished additional analyses to address a potential deterministic seismic hazard with the same return period, and used the results for more detailed analyses. The results have been used in

Table 9 - Zone C_1 Fill

Zone C_1	Proposed Specification Requirements			Recommended Design Parameters		
	Minimum % Compaction ASTM D 1557	Moisture Range Relative to OMC	Maximum Loose Lift Thickness in Inches	γ in pcf	c' in psf	ϕ' in deg.
Group 1A	90	±3	12	135	0	35
Group 1B	90	±3	12	135	0	35
Group 2	90	±2	12	135	0	35
Group 3	92	−2→+3	8	135	0	35
Group 4	92	−2→+1	8	130	0	35

Soil strength for some Group 4 soils have been verified in the laboratory, and this value was used in Hart Crowser's stability analyses. However, we do not recommend that RECo modify their design to use this value (rather than ϕ' = 34 degrees) because of results of the global and compound stability analyses that required increasing the amount of reinforcement in some areas.

The current embankment specifications also allow a Group 5 soil that has essentially no gradation limits below a maximum 6-inch size, but allows no more than 50 percent fines, provided the Contractor demonstrates a minimum friction value (based on specified tests and oversize correction) of at least 35 degrees.

Zone C_2. Zone C_2 represents a select zone used along the face of the embankment for control of seepage and to enhance stability. Zone C_2 is limited to Type 1B fill, within the same specification limits used for Zone C_1.

Zone A_2. This is the free-draining soil used in the embankment underdrain layer (i.e., nominally 3 feet thick). Table 10 presents the proposed specification requirements and recommended design parameters for Zone A_2 fill.

additional analyses, including trigger liquefaction, deformation and stability as discussed in Hart Crowser's Seismic Design Summary Report (draft in progress).

Other Geotechnical Input Parameters

Coefficient of Friction for Sliding Analysis. For the reinforced zone and the interface below the reinforced zone (i.e., top of Zone B_3), use tan 37 degrees = 0.75.

This is an ultimate value of friction, and allowable resistance to sliding should be based on a minimum Factor of Safety as noted in Tables 1 and 2.

Soil Allowable Bearing Capacity. Hart Crowser's analyses confirm that no deep-seated bearing capacity failures below the extent of ground improvement would occur due to the presence of dense, glacial soils. For local punching shear analysis below the leveling pad, Hart Crowser recommended assuming an allowable bearing capacity of 6 ksf with a minimum of 2 feet of embedment and a 1-foot-wide bearing surface.

Differential Settlement. The design team anticipates that the wall facing panels can tolerate the differential settlements that Hart Crowser initially estimated for the MSE wall foundation soils including subgrade improvements (up to 1/100). We understand that additional slip joints were proposed at the ends of tiers for multi-tier wall sections, and elsewhere based on aesthetic criteria and engineering judgment.

Groundwater Conditions. Groundwater generally occurs at relatively shallow depth in the foundation soils. MSE wall backfill will need to be hydraulically connected to the embankment drainage layer (Zone A_2). Hart Crowser's analyses were based on the maximum groundwater levels in each wall area. The design stability analyses rely on comparison of these levels (obtained during a relatively wet period) with local precipitation data, and the presence of the underdrain, to assure protection of the wall from potential instability associated with higher groundwater levels (ref. Appendix C, Hart Crowser 2000).

REFERENCES

AASHTO 1996-2000. "Standard Specifications for Highway Bridges." 16th Edition. 1996, with current interim addenda through 2000. American Association of State Highway and Transportation Officials.

FHWA 1997. Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines, SA-96-071. Federal Highway Administration.

FHWA 2001. Mechanically Stabilized Earth Walls and Reinforced Slopes, Design and Construction Guidelines, FHWA NHI-00-043. March 2001.

Hart Crowser 1999d. Sea-Tac Airport Third Runway, Probabilistic Seismic Hazard Analysis Results, Memorandum to Jim Thomson, HNTB, October 8, 1999.

Hart Crowser 2000a. DRAFT Memorandum: Seismic Basis of Design, Third Runway. April 10, 2000.

Hart Crowser 2000b. Preliminary Stability and Settlement Analyses, Subgrade Improvements, MSE Wall Support, Third Runway Project, June 2000.

Hart Crowser 2000c. DRAFT Memorandum: Geotechnical Input to MSE Wall and Reinforced Slope Design, Third Runway Embankment. June 22, 2000, revised August 21, 2000.

Hart Crowser 2000d. DRAFT Geotechnical Engineering Report, Phase 4 Fill, Third Runway Embankment, Sea-Tac International Airport. December 4, 2000.

Attachments:

Table 11 – Foundation Soil Parameters
Figure 1 - Diagram of Zoned Embankment Cross Section for MSE Wall
Figure 2 - Original Group 1A Fill Specification Modified to Meet AASHTO Criteria for Wall Backfill
Figure 3 - Original Group 1B Fill Specification Modified to Meet AASHTO Criteria for Wall Backfill

[illegible]

Table 11 - Foundation Soil Parameters

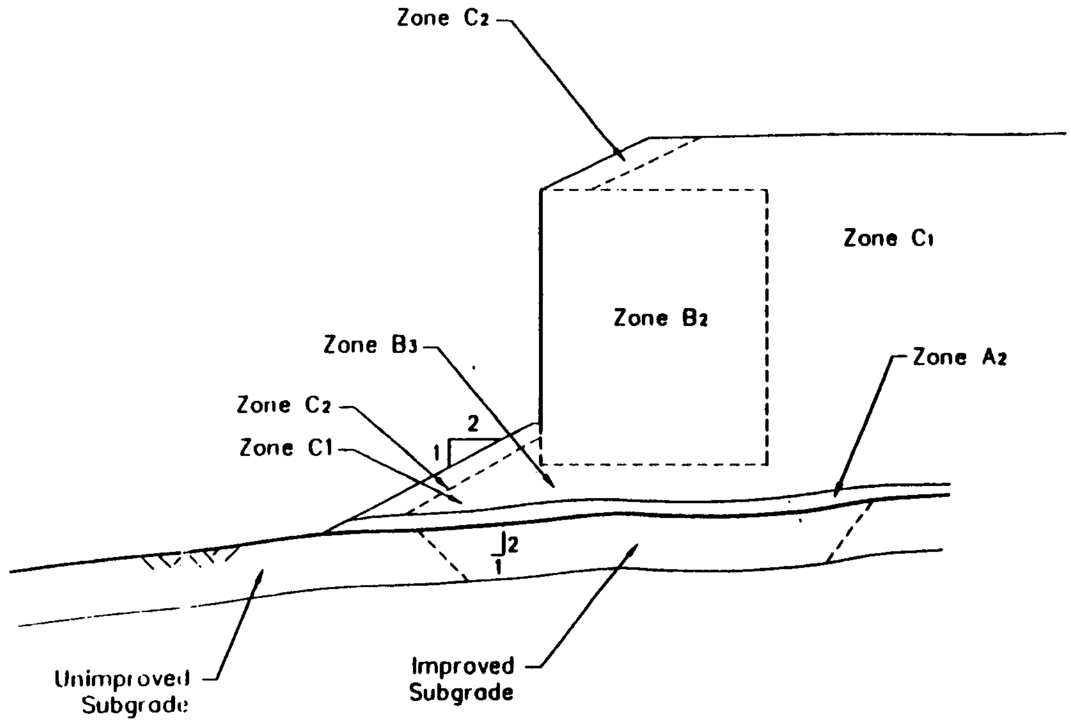
Soil Units	Unit wt in pcf	ϕ' in degrees	c' in psf [1]	S_u or S_r in psf
1 Embankment Fill	135	35	0	-
2 Reinforced fill	140	37	0	-
3- Drainage blanket	140	37	0	-
4- Ground Improvement	140	37	0	-
5 Loose to medium dense silty sand				
static				-
seismic	125	32	0	
post earthquake - No liq				
post-earthquake - liq.				S_r Based on Liq. Analysis [1]
6- Medium dense to dense sand	130	35	0	presents proposed specification requirements and recommended design parameters for Zone B_2 fill.
7- Dense to very dense silty sand	135	37	0	-
8- Till	140	40	250	-
9- Very stiff to hard silt				
static	120	32	0	-
seismic		-	-	4,000
post earthquake		-	-	3,200
10 - Normally to slightly consolidated silt & clay				
static	115	32	0	
seismic		-	-	$0.23\sigma'_v$ (min.1000 psf)
post earthquake - No liq		-	-	$0.8 * su$ (seismic case)
post-earthquake - liq.		0	0	$0.11 * \sigma_v'$
11- Peat				
static	110	15	0	-
seismic		0	0	$0.23\sigma'_v$ (min. site specific)
post-earthquake		0	0	$0.8 * su$ (seismic case)

Notes

[1] Use drained strength if it is less than residual strength

AR 053248

Diagram of Zoned Embankment Cross Section for MSE Wall



NOT TO SCALE

EMBANKMENT ZONES

A_2 DRAINAGE LAYER

B_2 MSE REINFORCED ZONE

B_3 MSE SUPPORT ZONE

C_1 COMMON EMBANKMENT

C_2 COMMON EMBANKMENT, SLOPES

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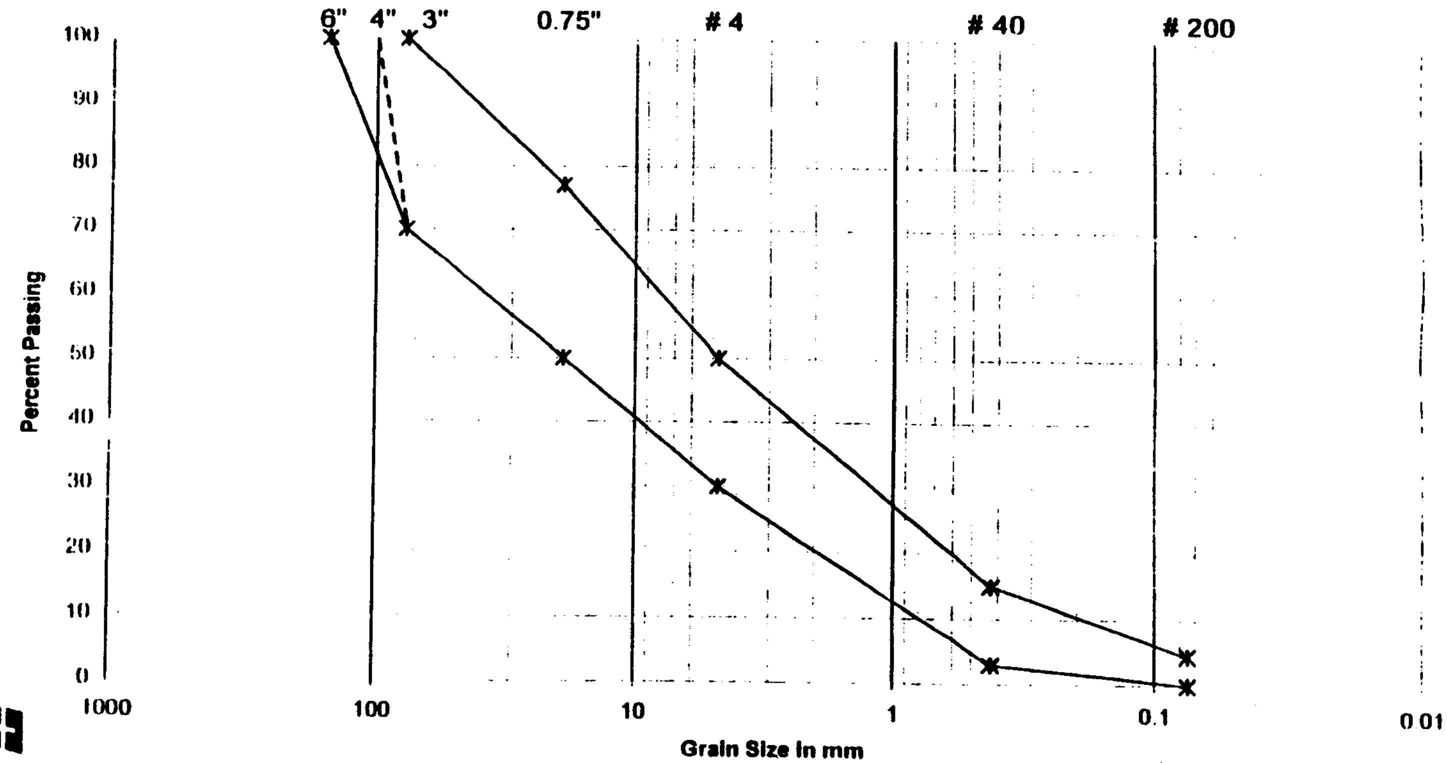
J-4978-30 1/02

Figure 1

Original Group 1A Fill Specification Modified to Meet AASHTO Criteria for Wall Backfill



Note: Specification for maximum Group 1A fines content is 5 percent based on P¾ or about 4 percent for the total sample.

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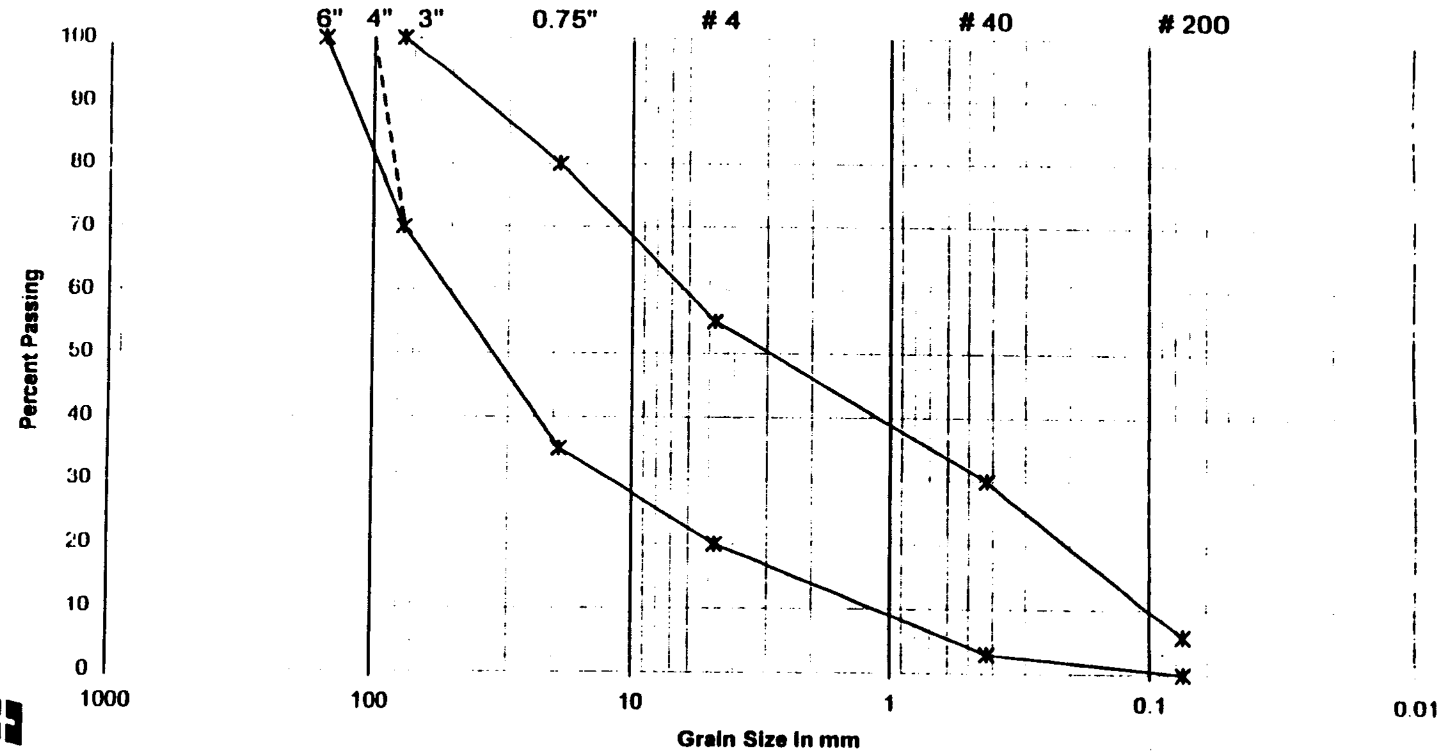
J-4978-30 1/02

Figure 2

Original Group 1B Fill Specification Modified to Meet AASHTO Criteria for Wall Backfill



Note: Specification for maximum Group 1B fines content is 8 percent based on P¾ or about 6.4 percent for the total sample.

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J-4978-30 1/02
Figure 3