FINAL REPORT

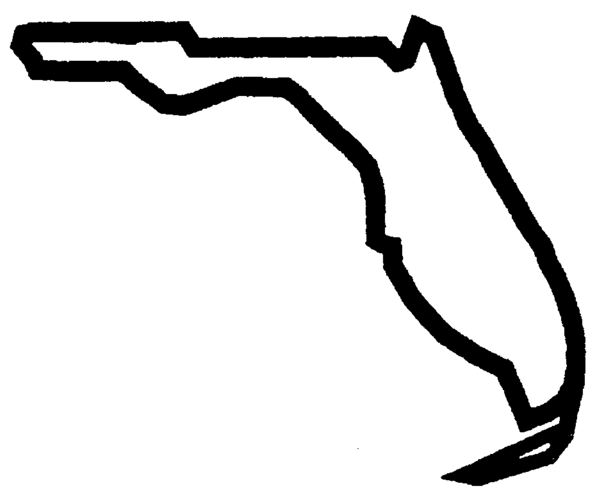
U.F. No. 49104504613-12
State Project No. 99700-3601-119
W.P.I. No. 0510853
Contact No. BB-347

LIFECYCLE COST ANALYSIS OF VARIOUS SLOPE TREATMENT ALTERNATIVES

PB99-160608

Principal Investigator: Ralph Ellis
Principal Investigator: David Bloomquist
Graduate Assistants: Michael A. Coffey
Barry D. Guertin

JUNE 1999



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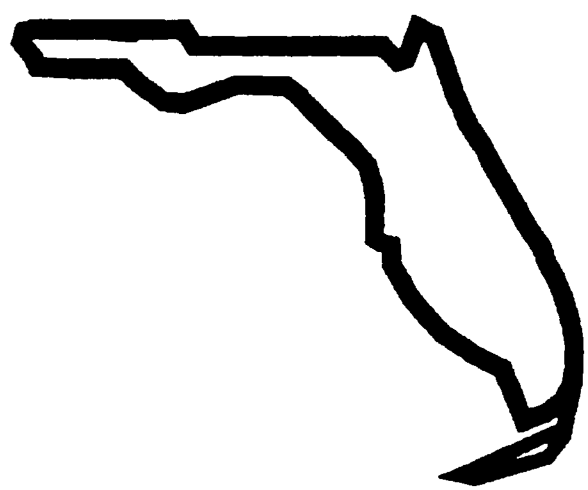

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16. Abstract

The objective of this paper is to compare various slope treatment alternatives based on lifecycle cost analysis. A preliminary database of alternatives, their costs, and a spreadsheet program is used for the analysis. The method of comparison will be based on construction cost, maintenance cost, maintenance schedule, and usable life. Time value of money formulas are used to calculate lifecycle cost. Constructability, soil properties, site characteristics, and aesthetic considerations are additional variables entered into the decision-making process.

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Submitted to
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June 1999

DISCLAIMER

"The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Florida Department of Transportation or the U.S. Department of Transportation.

Prepared in cooperation with the State of Florida Department of Transportation and the U.S. Department of Transportation

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

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ABSTRACT

The objective of this paper is to compare various slope treatment alternatives based on lifecycle cost analysis. A preliminary database of alternatives, their costs, and a spreadsheet program is used for the analysis. The method of comparison will be based on construction cost, maintenance cost, maintenance schedule, and usable life. Time value of money formulas are used to calculate lifecycle cost. Constructability, soil properties, site characteristics, and aesthetic considerations are additional variables entered into the decision-making process.

Keywords: *lifecycle cost analysis, slope treatment alternatives, time value of money.*

I. INTRODUCTION

Slope treatment is required where earth masses will produce shear or slip failure if the soil is untreated. This document contains an examination of the options available to stabilize soil slopes and the cost effectiveness of these options based upon lifecycle cost.

II. DISCUSSION

The Need for Slope Treatment

Slope treatment is necessary where earth masses are unsupported and the desired face-inclination angle of the slope is too steep for the soil to remain stable[1]. The consequences of not treating earth masses, which need stabilization, may be shear failure or slip failure. To increase the stability of slopes requires treatment. Some examples of treatment techniques are growth of vegetation, reinforcement with geosynthetics, and construction of retaining structures.

Structures which Require Stabilization

Although there are many structures which require stabilization for this document discussion will be limited to the following structures.

- Bride Abutments
- Off-ramps
- Right-of-ways

Bridge Abutments.

At each end of a bridge there are abutments. Abutments are earth masses built up in height on either side to create the clear span of the bridge. Drastic slopes are common underneath bridges (steeper than a 1 vertical: 2 horizontal[2].) Slopes can not be stabilized are treated by alternatives such as retaining walls (either cast-in-place (CIP) or mechanically stabilized earth (MSE)) are chosen.

Off-ramps.

Roads mainly intersect highways in the form of an overpass. An overpass occurs when a road passes over a highway by use of a bridge. If exit ramps and on ramps exist, the ramps must incline to meet the grade of the road that is passing over the highway. Slope treatment is necessary in these locations to deter erosion and maintain a safe exit or entrance between the highway and the intersecting road.

Right-of-ways.

As more vehicles use the Florida transportation system, a typical roadway will need to be widened. This expansion can leave little room for gradual slopes (1:3). The slopes must therefore be reduced in length horizontally which increases the ratio of rise to run. This makes the slope steeper, requiring reinforcement or retaining walls.

Methods of Analysis

Lifecycle Cost Analysis.

The treatment options considered in this document have various components in their total cost.

The total cost of an option may include any or all of the following.

- Initial cost of construction.
- Maintenance cost
- Operational cost
- Disposal cost

The component costs of the options are converted to a present value basis. The summations of the present values then are used to compare the lifecycle costs of the different treatment options.

Considerations Other than Cost.

In addition to the cost of an alternative, other variables exist which should be considered. Specifically, some of these considerations are.

- Site location
- Constructability
- Environmental conditions
- Behavior of adjoining structures
- Soil type

Different situations can be distinguished from one another by use of a list of questions. An excellent list of questions was presented by Don Keenan of the FDOT Structures Design Office. The topic of Keenan's discussion was *MSE Retaining Walls*[3]. The following list was taken from Keenan's article because it covered a variety of variables in a well-stated, well-organized manner. Keenan's article served as an excellent stepping stone for a question list addressing slope treatment.

Taken from Page 2 of "Guidelines for Determining Retaining Wall Applications and Types."

1. Are walls necessary?
2. Is the wall in water?
3. If in water, is a hydraulic report available?
4. Is the water corrosive?
5. Is there a fast current?
6. How deep is the water?
7. Is it a cut or fill location?
8. If a cut section, how close to the right-of-way is the wall located?
9. Are nearby buildings going to impact wall selection (based on aesthetics and the need for pile supports)?
10. Is more right-of-way required?
11. Is a MSE wall appropriate for this cut section or would a gravity wall work?
12. If in a fill section, is there room for MSE soil reinforcing?
13. Are steep slopes more appropriate than walls?

After determining that a retaining wall is required, the list continues with geotechnical questions.

1. How much short-term and long-term settlement is anticipated?
1. What is the bearing capacity of the soil?
2. What is the internal friction angle of the soil?
3. Will slip joints be required?
4. Are there any unusual geotechnical problems?

The next set of questions address environmental concerns.

1. 1. Is there corrosive water present? (Consider tidal information and 100-year flood data.)
2. Are there environmental constraints that will affect construction and wall choice (i.e. noise abatement, pile-driving constraints)?
3. What is the electro-chemical analysis of the soil and water?

Constructability is the next issue addressed.

1. Is the project phase construction?

1. Does the wall have acute angles or sharp curves?

2. Is this a widening project?

3. Is there room to install soil reinforcing strips?

4. Are there overhead utilities?

5. Are there buried utilities?

6. How will maintenance or traffic affect construction of a wall?

7. Is temporary shoring required?

8. Do soil conditions require special construction requirements (i.e. wick drains, time dependent fill placement, special equipment)?

Aesthetics are the final concern addressed in the list. Since FDOT is putting emphasis on the aesthetics of retaining wall sections. The wall finish, color, and type should match the project location.

1. Is the wall in a rural or urban site?
2. Has the project manager been contacted about aesthetic requirements?
3. Is the wall type compatible with the site (i.e. steel sheet piles are not compatible with an urban residential site)?
4. Are the surface finishes that are used more expensive than other finishes that appear more attractive, (i.e. raised surface finish is sometimes expensive due to shipping costs)?
5. Does it match other walls in the area?

(Source: Fla. Dept. of Transportation. Structures Design Office, 1995)

III. TREATMENT ALTERNATIVES FOR SLOPES < 50°

Vegetation

Alternatives classified as vegetation are simple solutions to stabilize mild slopes (less than 1:3[4]). Vegetation such as grass or landscaping can involve a number of maintenance activities during its lifecycle. Other alternatives such as wildflowers have little or no maintenance requirements. The design life for Vegetation alternatives was assumed 20 years[5].

Grassing by seeding.

This option is used for slopes with face inclination angles that are less than 18.4 degrees (1:3[6]). Standards are outlined for this option in Section 570 of the Standard Specifications for Road and Bridge Construction 1996[7].

The price for initial construction of this option that was used in all calculations includes the following pay items by number (The price for *Seeding and Mulching* was used in place of *Seeding* when calculating the cost for the Grass Seeding With Mulching option).

2570-1	Seeding (per sq. meter)
2570-2	Seeding and Mulching (per sq. meter)
2570-3	Grass Seed (Permanent Type)
2570-4	Mulching Material
2570-5	Fertilizer
2570-7	Dolomic Limestone
2570-9	Water for Grassing
2570-10	Seed Grass (Quick Grow)
2570-11	Water for Plant Establishment

Sodding.

This option is used for slopes less than 26.5 degrees[8]. Standards for use are outlined in Section 575 of the Standard Specifications for Road and Bridge Construction 1996[9]. A total price for initial construction included the following pay items:

2575- 1-	Sodding (per sq. meter)
2575- 2-	Fertilizer (per metric ton)
2575- 7-	Dolomic Limestone (per metric ton)
2575- 9-	Water for Grassing (per cubic meters)

This option is being used more often due to the poor growth of seed grass in certain areas, mainly in the south districts.[10] Sod takes to the soil better than spread grass seed. Refer to Figure 1 on page 20.

<u>Native Wildflower Establishment.</u>

An aesthetically pleasing options for vegetating slopes is the installation wildflowers, used primarily when slopes are less than 18.4 degrees, this program began (by the State of Florida) in 1963. By 1973, the Federal Highway Administration had established its own program to promote native flowers for all of the States. Donated seed was broadcast in large amounts with limited success between 1973 and 1980. The main emphasis since 1980 has been the preservation of existing wildflowers by altering mowing schedules and setting mowing limits in locations containing flowers[11]. Many native species are available. Some of are some of the most common native species used for vegetating include (Figure 2 page 21).

- Blanket flower (*Gaillardia pulchella*)
- Black-eyed Susan (*Rudbeckia hirta*)
- Lance-leafed Tickseed (*Coreopsis tinctoria*)
- Phlox (*Phlox drummondii*)
- Dune Sunflower (*Helianthus debilis*)

- Leavenworth's Coreopsis (*Coreopsis leavenworthii*)
- Scarlet Flax (*Linum rubrum*)

One of the best arguments for the vegetative option is lower maintenance cost. There is no scheduled mowing required. Another argument is the cost to install wildflowers. The percentage of money spent on wildflowers for an average landscaping project with a total cost of approximately $50,000, is 0.75% or approximately $375[12].

Concerns for this option are the amount of turf covering the area and the time of year that planting takes place. Thin turf cover works best because the seeds can be disbursed and then raked or dragged into the soil. Average turf cover requires cutting the turf to a height of one inch (25.4 mm) and then disbursing the seed. Heavy turf cover requires herbicide treatment of the area and a waiting period of two months. Establishment of wildflowers is not recommended for areas with excessive weed infestation[13]. Component costs associated with this option are listed as the following:

2570- 1	Seeding (work cost)
2570- 5	Fertilizer (per metric ton)
2570- 7	Dolomic Limestone (per metric ton)

2570-11 Water for Plant Establishment (per cubic meter)

2570-12 Wildflower Seed (per kg seed)

Calculations of the unit prices begin on page 45. This cost represents one square meter of the slope face.

Landscaping.

Is normally performed on a lump sum basis. A state average was not available. Therefore, a fictitious amount of $50,000/acre ($12.35 per sq. meter) was used[14]. Component costs included in this project included.

- Trees
- Shrubs
- Plants
- Mulch & Bark
- Bed & Mulching Preparation.

This was done in order to provide the particular data needed for a specific work project. This data was not included in the cost analysis program, only in the cost database.

Riprap

Alternatives come in the two forms. This first form includes sand-cement, bedding stone, and rubble. The second form is fabric-formed concrete. Riprap is viable for slopes greater than 1:2 [15]. Section 530 of the Standard Specifications for Road and Bridge Construction 1996 describes requirements for each of the following in detail. A usable life of 30 years was assumed for all riprap options.

Sand-cement.

Sand-cement Bags are filled with a mixture of sand and cement. The bags are stacked against one another and the entire area is watered in order to set the cement. Grouting is then placed in any remaining voids. This alternative can be used for slopes greater than 1:2. Conversion of this value begins on page 45. This option is paid for by the cubic meter, and is pay item number 2530-1.

2530- 1 Riprap (Sand-Cement) (per cubic meter)

Bedding Stone.

This bedding stone consists of stone that is dumped and spread evenly over a surface. The largest sieve size of the stone is 305 mm, with 100% passing. The smallest sieve size of the stone is 25.0 mm, with 15% maximum passing. The conversion to a square-foot value begins on page 45. This option is pay item number 2530-74.

2530- 74 Bedding Stone (per metric ton)

Rubble.

This treatment works very well in water for heavy scour areas. Waterfronts are able to withstand the force of wave actions because rubble absorbs and disburses the energy before it damages the slope. The largest size of the material can be 35 kg. Fifty percent of the material must weigh 15 kg. In addition, the minimum weight is 2 kg. Conversion of this value is shown on Page 48. This option is pay item number 2530-3.

2530 - 3- Riprap (Rubble) (per metric ton)

Fabric-formed Concrete.

Cement and aggregate are poured into bags that are placed into position and hydrated. The bags are a single pay item.

2547-70-1 Riprap (Fabric-Formed) (per sq. meter)

Sloped Concrete

This alternative is used for slopes between 18.4° (1:3) and 26.5° (1:2). It Sloped concrete is chosen over Vegetation for locations under bridge abutments that have poor growth potential due to the limited sunlight.

The requirements for this alternative are outlined in Section 524 of the Standard Specifications for Road and Bridge Construction 1996. It falls under pay item number.

2524- 2-2 Concrete Slope Pavement-100mm thick per sq. meter)

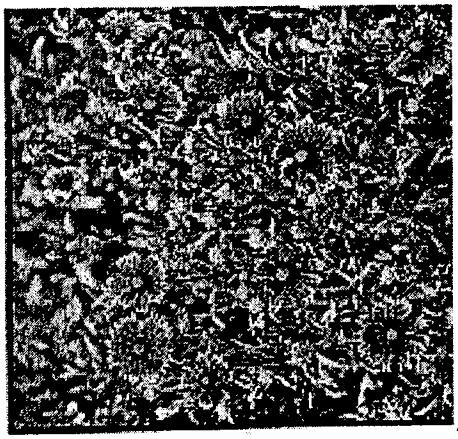
Geosynthetic Reinforced Slopes

- When slope reinforcement is required, the Qualified Products List specifies those companies that are acceptable to FDOT standards. The following are pre-approved for use in construction of slopes and reinforced foundations on soft soil.
- Reinforced Earth Company (Matrix) which produces a polyester Geosynthetic
- Tensar Earth Technologies which offers high-density polyethylene and polypropylene geosynthetic
- Nicolon-Mirafi which is a polyester geosynthetic
- Atlantic Construction Fabrics Inc. (Fortrac, Huesker) which is also polyester in composition[16]

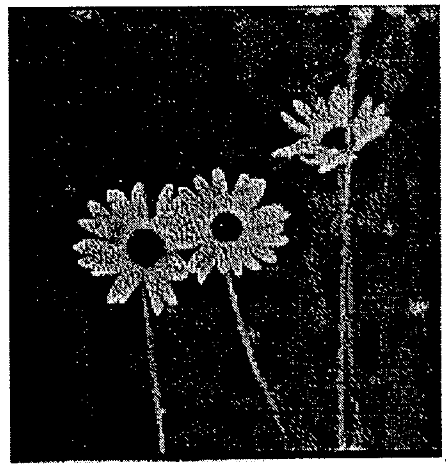
Quantity measurements were based off the slope face surface area in square meters. This quantity includes all geosynthetic and backfill work associated with installation. Requirements and details are in Section 145 of the Standard Specifications for Road and Bridge Construction 1996. This option is pay item:

2145-71-xxa Geosynthetic Reinforced Soil Slopes (per sq. m)

Figure 1 Grassed Slope

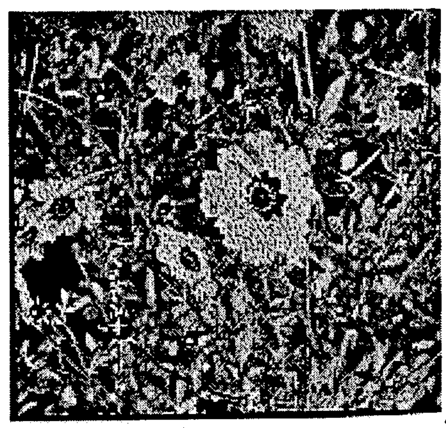


2a



2b

2c



2d

2e

Figure 2 Florida Native Wildflowers

2a Blanket Flower (Gaillardia Pulchella)

2b Black-eyed Susan (Rudbeckia Hutia)

2c Lance-leafed Tickseed (Coreopsis Lanceolata)

2d Tickseed (Coreopsis Tinctoria)

2e Phylox (Phylox Drummondii)

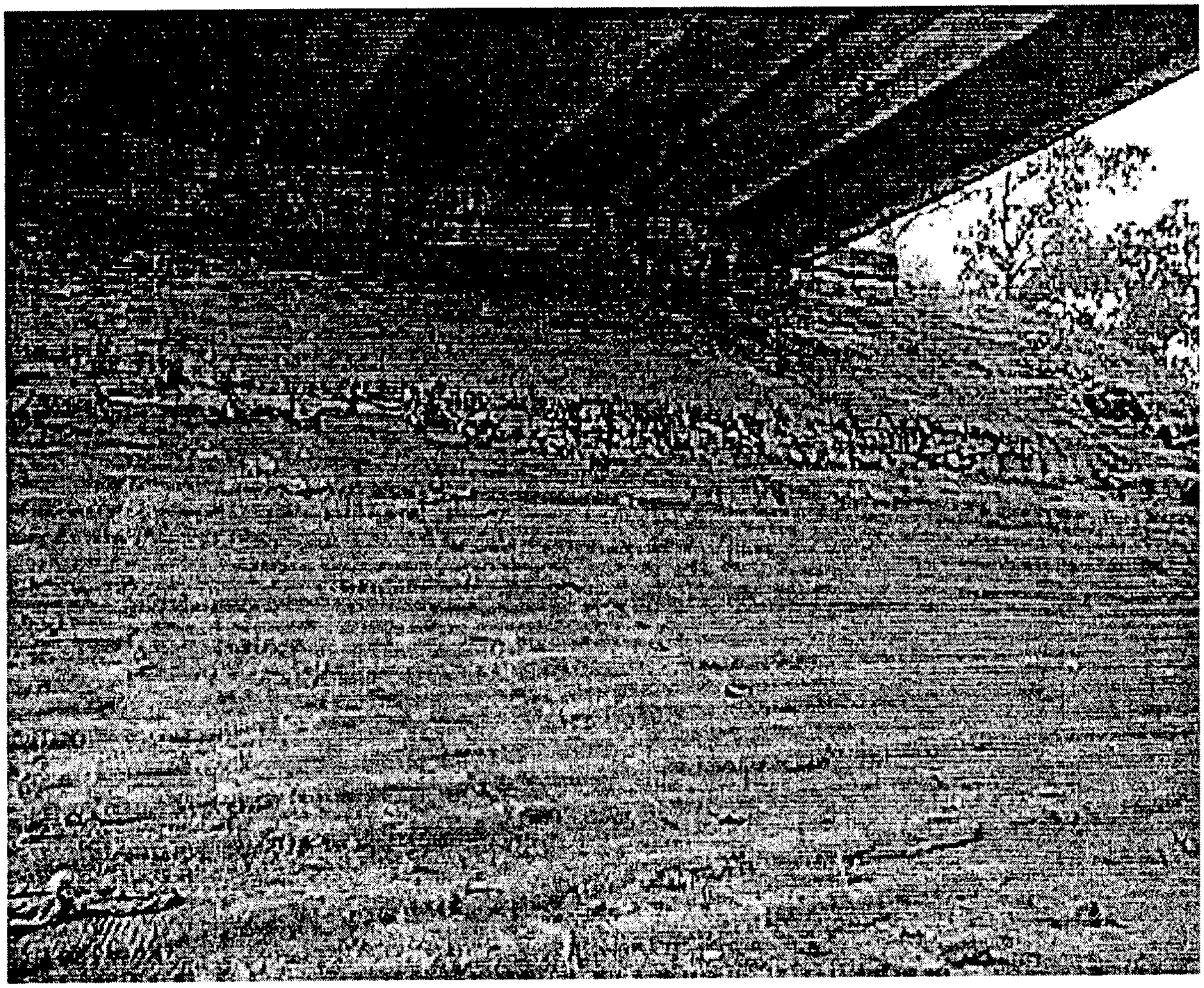


Figure 3 Riprap (Sand Cement)

Figure 4 Riprap (Rubble)

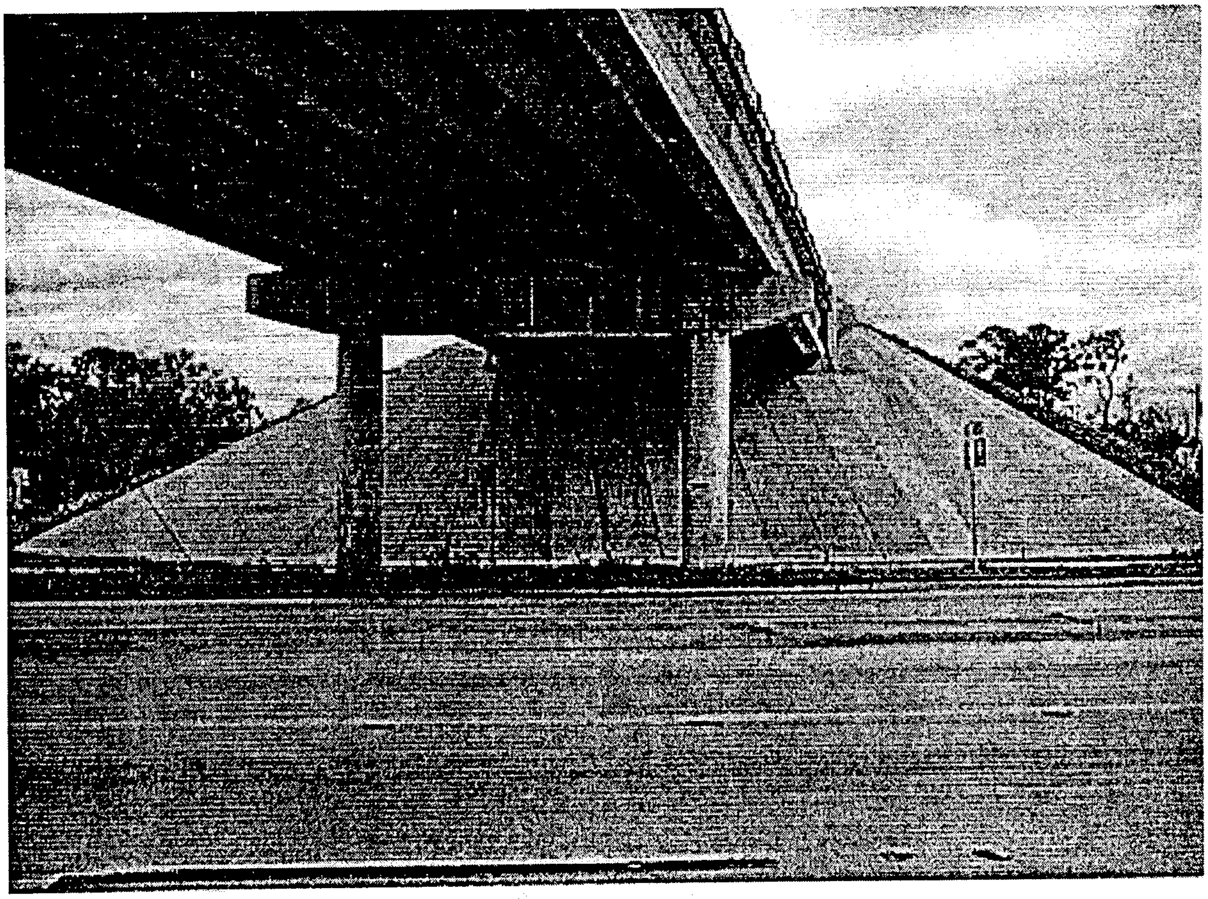


Figure 5 Sloped Concrete

IV. TREATMENT ALTERNATIVES FOR 50° < SLOPES < 90°

Permanent Retaining Wall Structures

Treatment of slopes with face inclinations greater than 50° are limited to six options.

1. Riprap
2. C-I-P Retaining Walls
3. Steel Sheet Piles
4. Gabion Basket
5. Reinforced Earth Structures.

All permanent structures should have a design life of 75 years, unless they are located at bridge abutments. For which the design life is 100 years[18]. For analysis, the usable life for all concrete structures was assumed to be 40 years. The usable life for all other types of permanent structures was assumed to be 30 years.

Riprap.
This choice should be treated as in the previous section for slopes <50°.

Cast-in-place Concrete.

Requirements for construction are in the Structural Design Standards Manual 1997. Detailed design drawings are in Drawing Index Numbers 801 through 821 of the Structural Design Standards 1997. As noted on the drawings, approximate quantities are given in chart form for walls of different heights.

Index Drawings 800 through 821 of the Structural Design Standards 1997 lists the average estimation of quantities for steel and concrete per-8m-section. To get an average cost per square-meter an average height had to be assumed. Index Drawing No. 807 held the highest values for the quantities. An average height of 5.5 meters was used. This value greater than 5.45m which was the average between 1.8m and 9.1m listed. Calculations of the unit prices begin on page 45.

Pay item numbers associated with this type of alternative are.

2400-1-11 CIP Concrete Class I Retaining Walls (per m^3)

2400-2-11 CIP Concrete Class II Retaining Walls (per m^3)

2400-4-39 CIP Concrete Class IV Superstructures (per m^3)

2400-4- 8 CIP Concrete Class IV Bulkhead (per m^3)

Sheet Piles and Panel Walls.

For braced cuts--cantilevered sheet-pile walls are used in granular soil. The sheet-piles are anchored bulkheads used for waterfront construction. Sheet-piles are made of concrete, steel, or timber. Panel walls such as soldier piles are applicable for bulkheads or retaining walls that are located in corrosive environments. Rock should be located relatively close to the surface for this alternative to be used[19]. The different types of anchoring that are employed are the following.

- Deadman anchors (precast or CIP concrete)
- Braced piles
- Tie rod anchors
- Helical anchors[20]

Example figures of sheet piles and panel walls are shown on pages 32 through 44. The pay item numbers associated with these types of alternatives.

2400-101-xxa Precast Concrete Bulkhead Panels (per sq. meter)

2455-14-3 Sheet Piling-Concrete, 255mm x 760mm (per meter)

2455-14-5 Sheet Piling-Concrete, Special (per meter length)

2455-133 Sheet Piling-Steel, Permanent (per sq. meter)

2400-6 Precast Concrete Anchor Beams (measured each)

Gabion Baskets.

This is an alternate type of facing for MSE type structures. Gabion baskets are steel-wire baskets that are filled with stone. The structures are then back-filled. Geosynthetics filter liners are installed at the interface of the wall and the soil to prevent water from removing soil[21]. The pay item numbers associated with this option are.

2530-77-2 Gabion Basket-900mm thick (per sq. meter)

2530-77-4 Gabion Basket-455mm thick (per sq. meter)

Reinforced Earth Walls.

This type of wall incorporates the use of galvanized-steel strips or grids for soil stabilization[22]. When needed, the Qualified Products List specifies those companies that are acceptable to FDOT standards. The following are pre-accepted for use in construction.

- Reinforced Earth Company, which offers strip-type of reinforcement with either cruciform or square panels.
- Techwall, which is a precast counterfort, wall.
- Techwall II is also precast counterfort.
- Retained Earth Company (VSL) which offers grid-type reinforcement with either hexagon or square panels

Temporary Retaining Wall Structures

There are times when soil is retained on a temporary basis, (i.e. construction, settlement). Alternatives of a temporary nature are listed below. The usable life for all temporary structures was assumed to be 3 years[25].

Steel Sheet Piles.

The pay item number associated with this option.

2455-133-1 Sheet Piling-Steel, Temporary (per sq. meter)

Gabion Baskets.

This is the same as the *Gabion* option listed previously.

Geosynthetic.

Tensar's high-density polyethethylene (HDPE) is the only geosynthetic pre-approved for construction of temporary retaining walls[24].

Proprietary Soil Reinforcement.

All available options for temporary treatment are a combination of either geosynthetic or steel reinforcement with a wire face. The Qualified Products List specifies those fabricators and suppliers whose product meets FDOT standards. The following are pre-qualified by FDOT. Reinforced Earth Company (Terratrel)

- Tensar Earth Technologies
- T&B Structural Systems Inc. (Hilfiker)
- Retained Earth Company (VSL Metal Face Wall)
- Nicolon-Mirafi
- Atlantic Construction Fabrics Inc. (Fortrac by Huesker)[26]

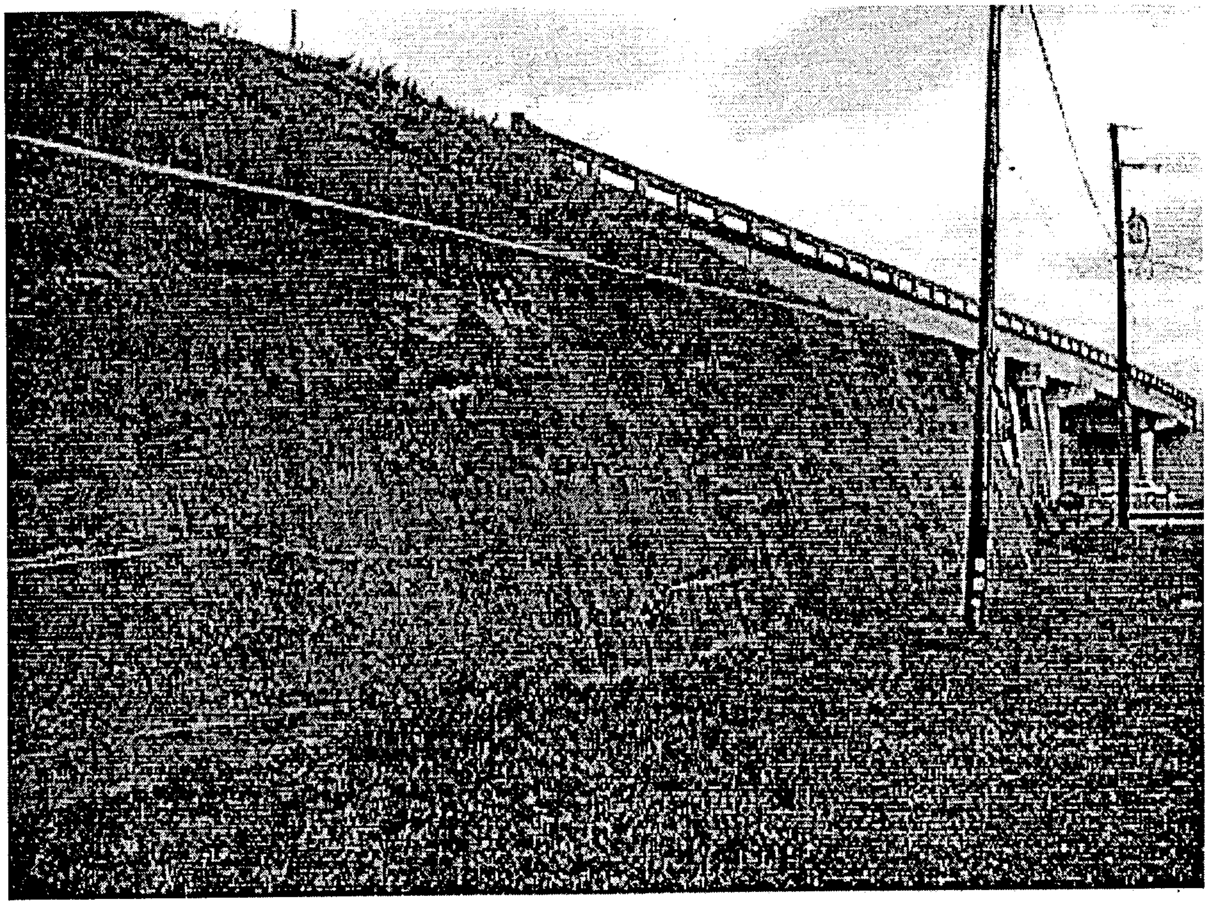
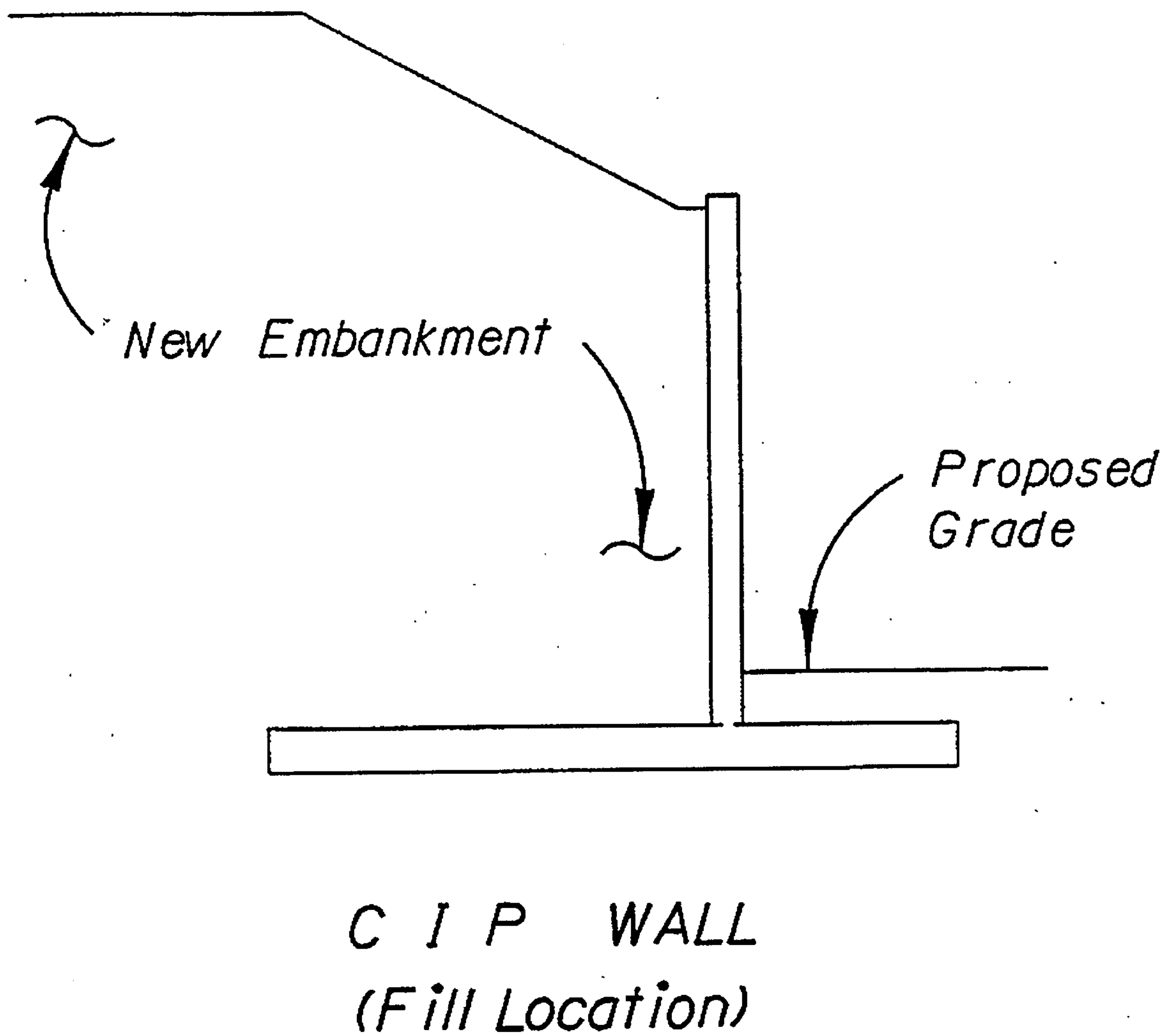


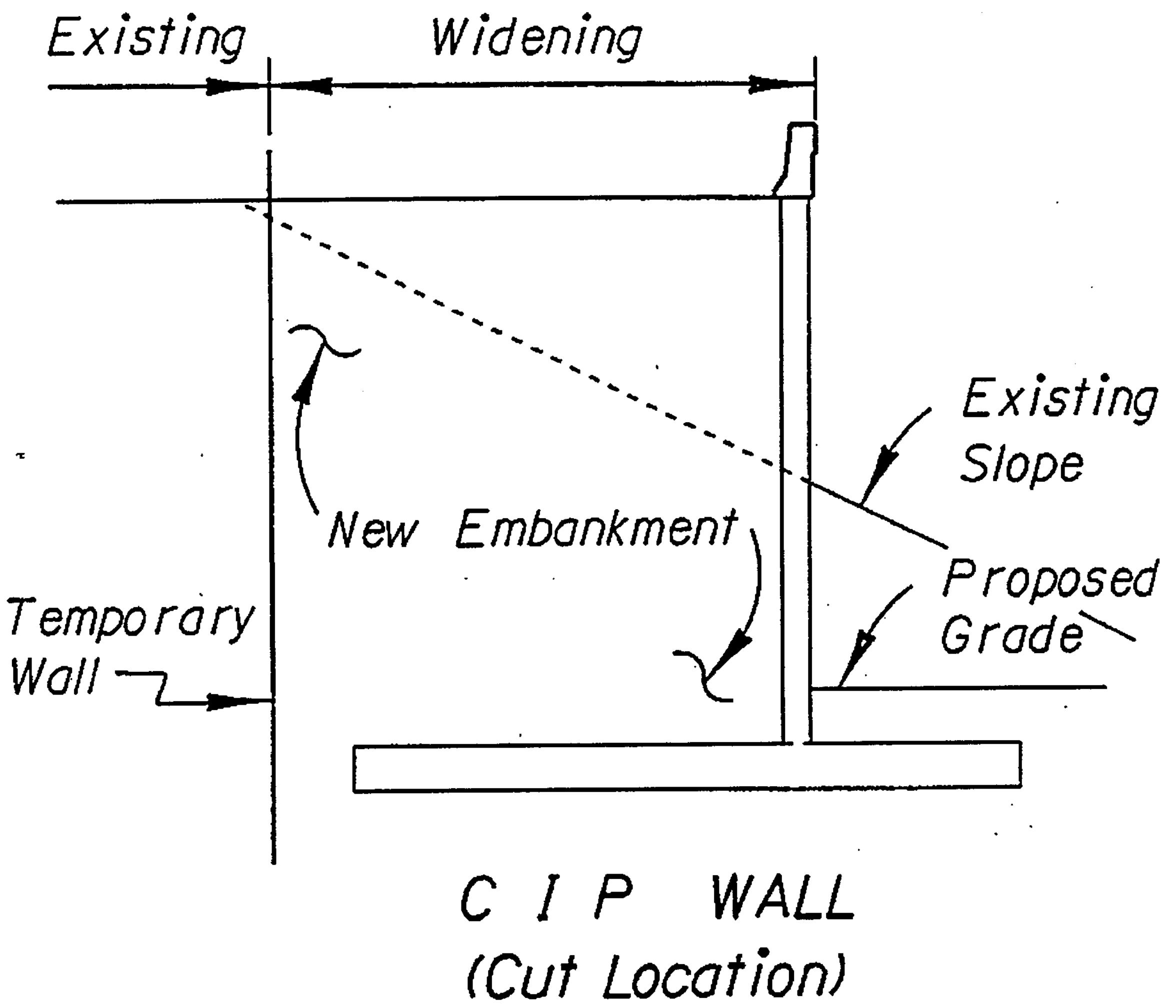
Figure 6 Cast-in- Place Concrete Retaining Wall

Sketch 1

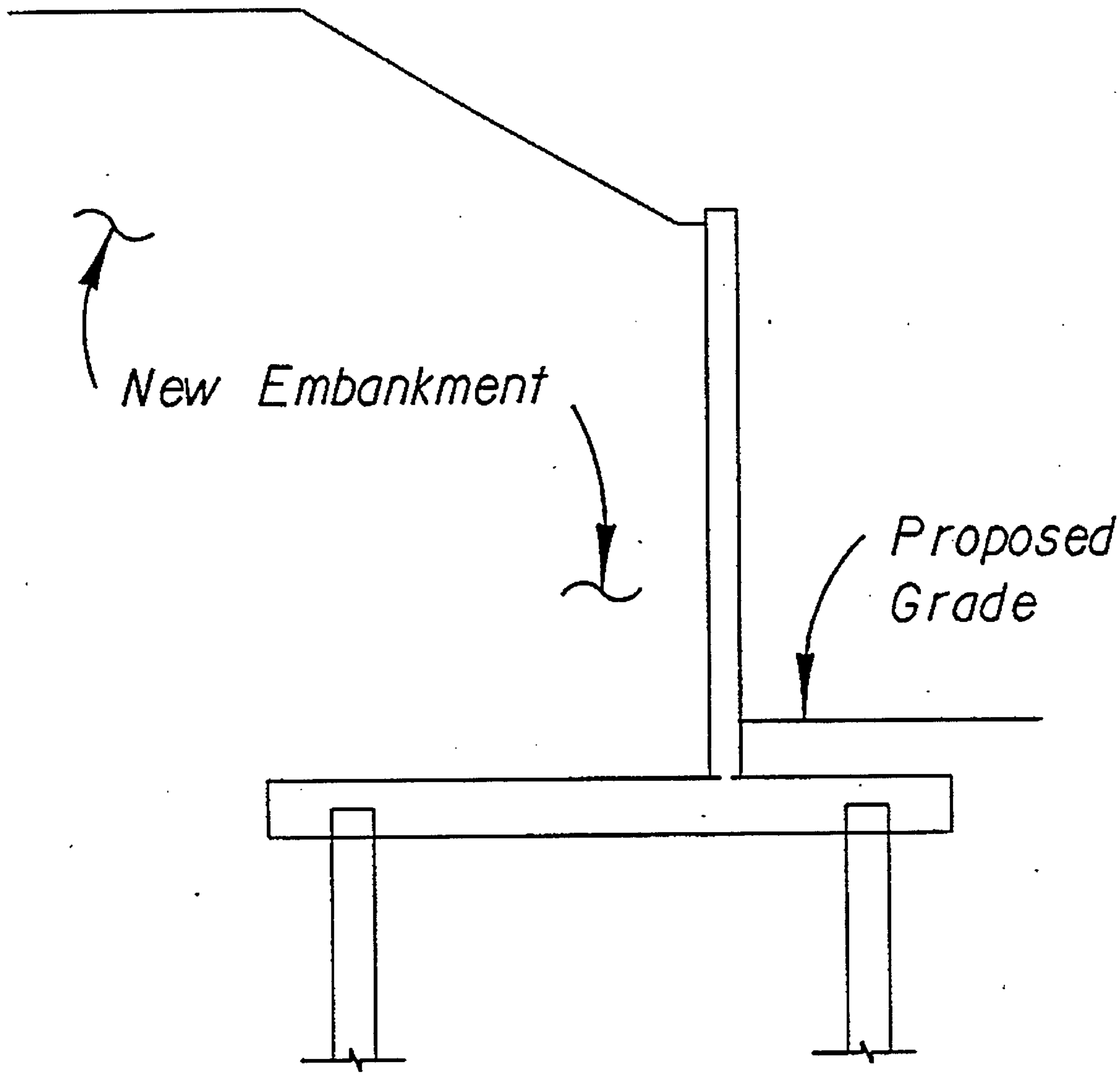


Sketch 1 Source Structures Design Guideline, FDOT 1997

Sketch 2

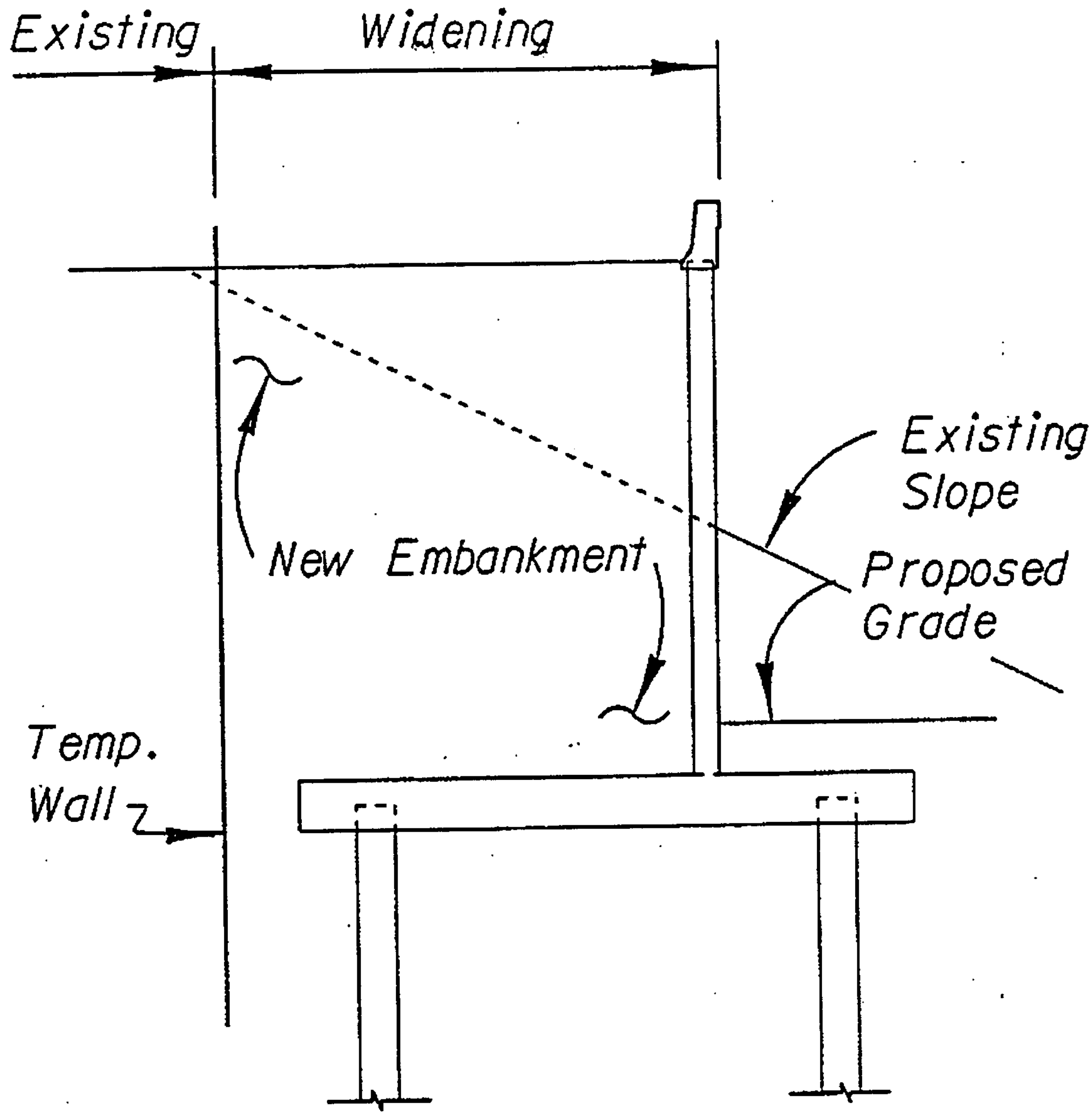


Sketch 2 Source <u>Structures Design Guideline</u>, FDOT 1997



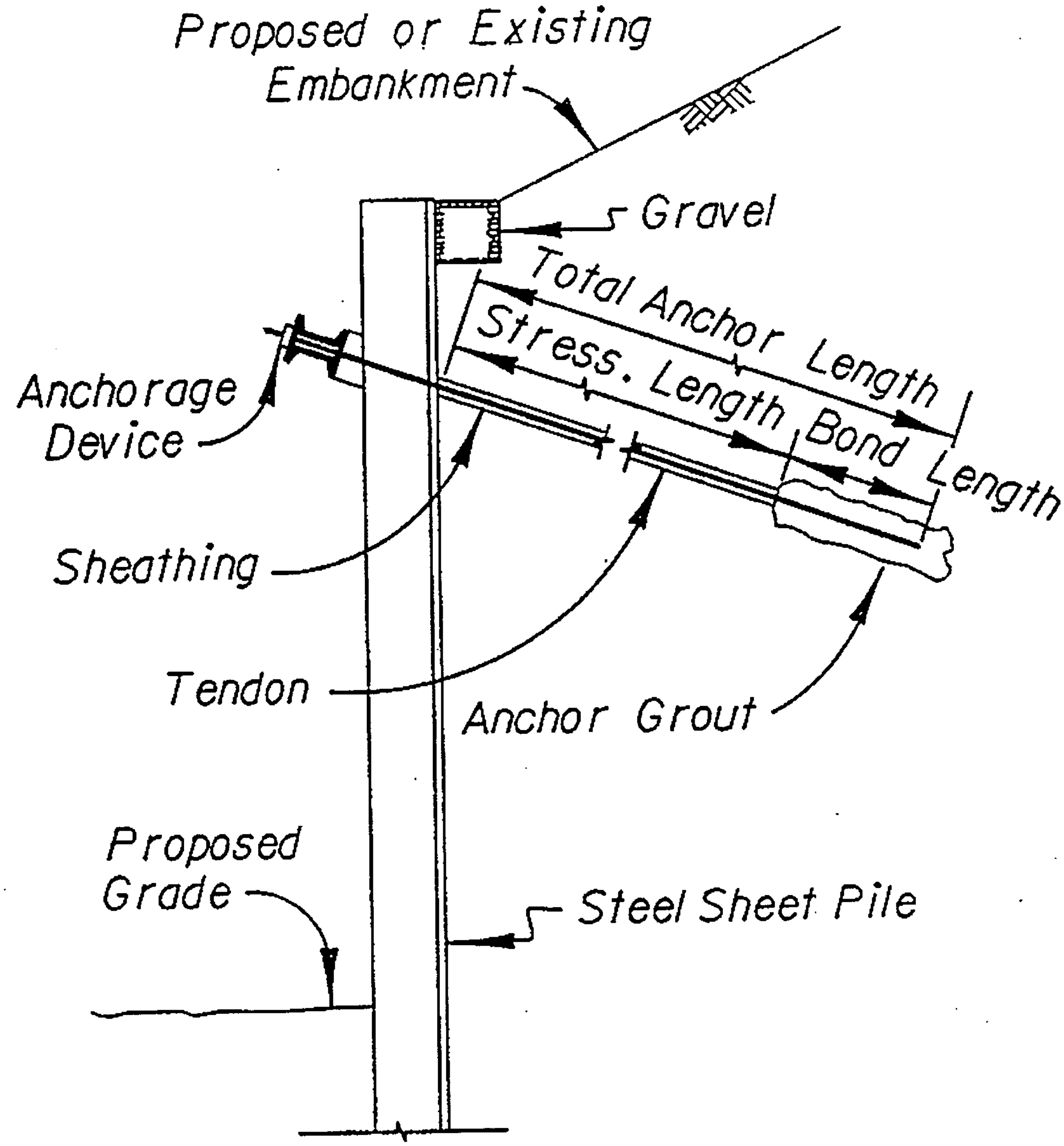
C I P WALL - PILE SUPPORTED
(Fill Location)

Sketch 3 Source Structures Design Guideline, FDOT 1997



C I P WALL - PILE SUPPORTED
(Cut Location)

Sketch 4 Source Structures Design Guideline, FDOT 1997



TIEBACK COMPONENTS
(Steel Sheet Piles)

Sketch 5 Source Structures Design Guideline, FDOT 1997

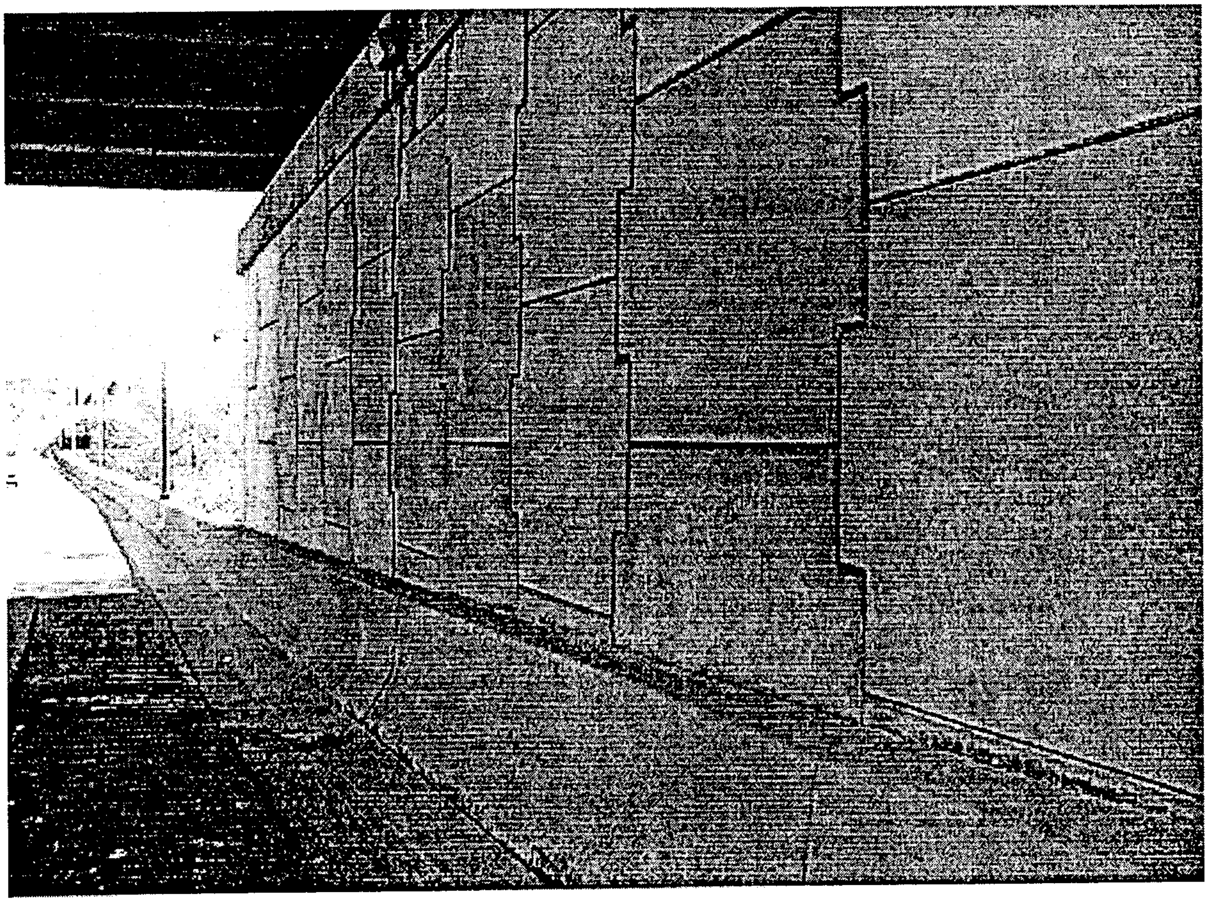


Figure 7 Mechanically Stabilized Earth Wall

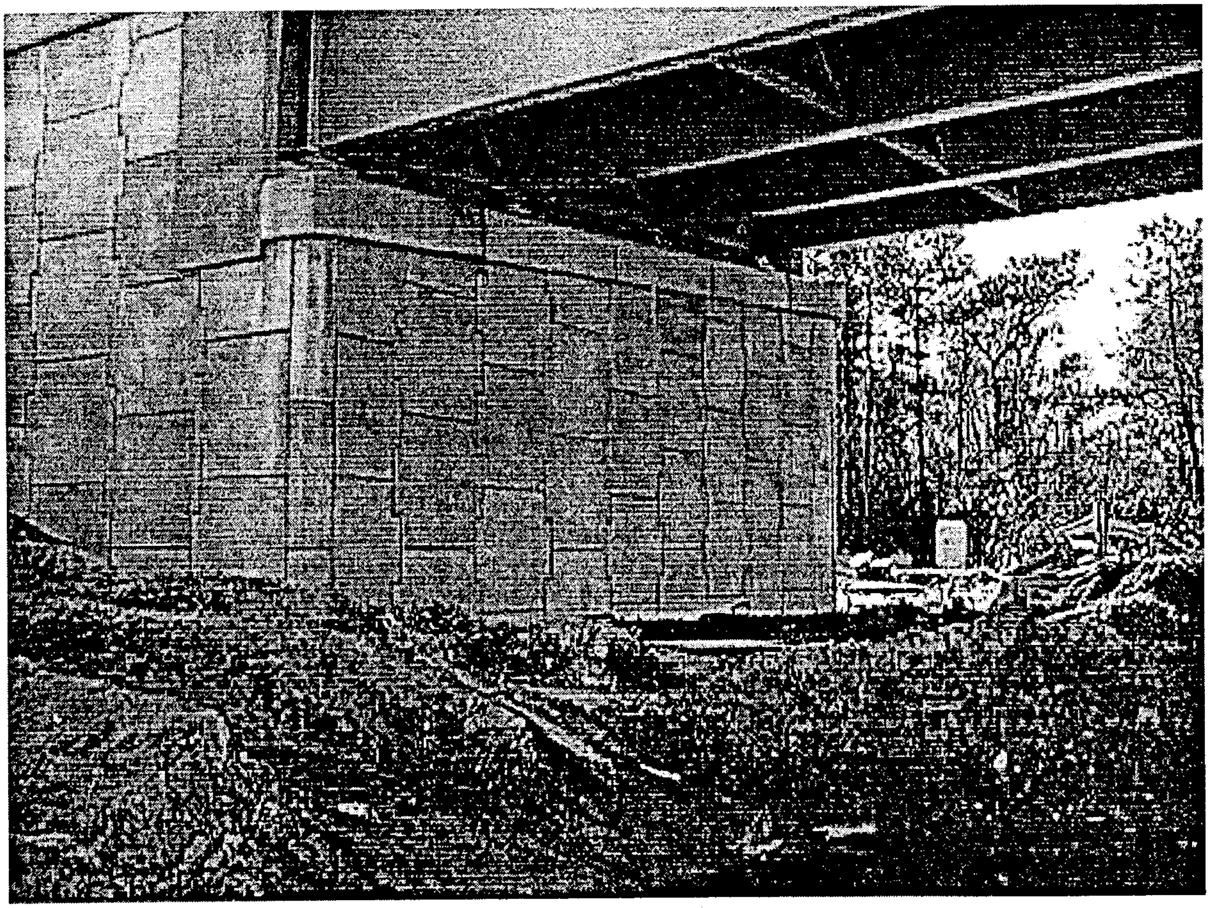


Figure 8 Mechanically Stabilized Earth Wall

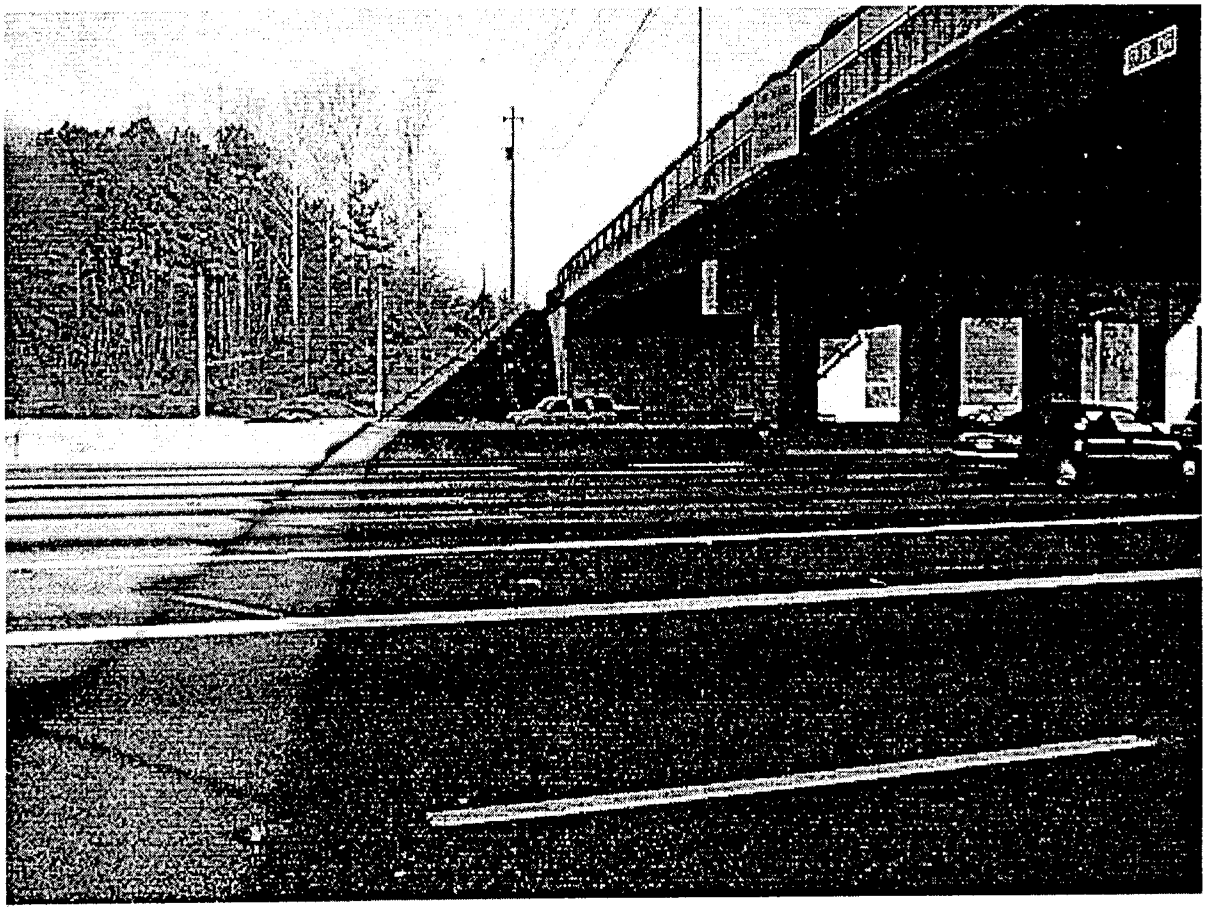
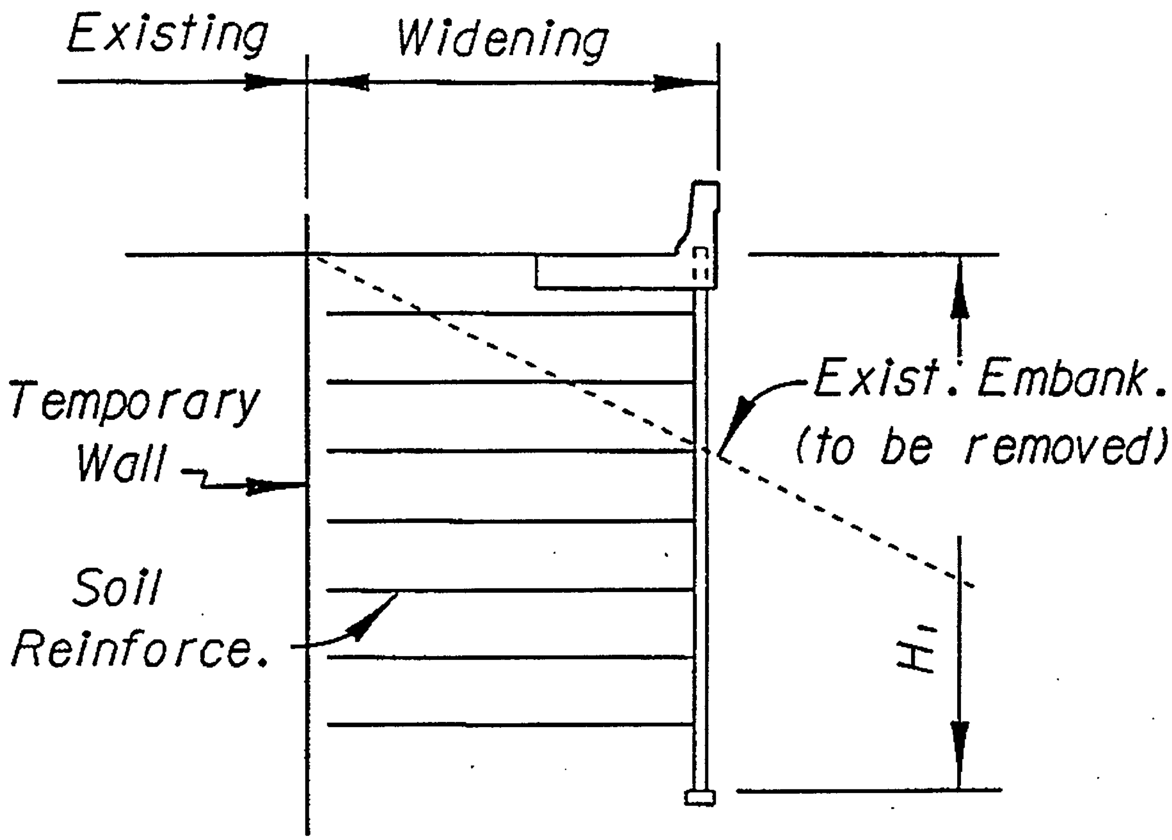


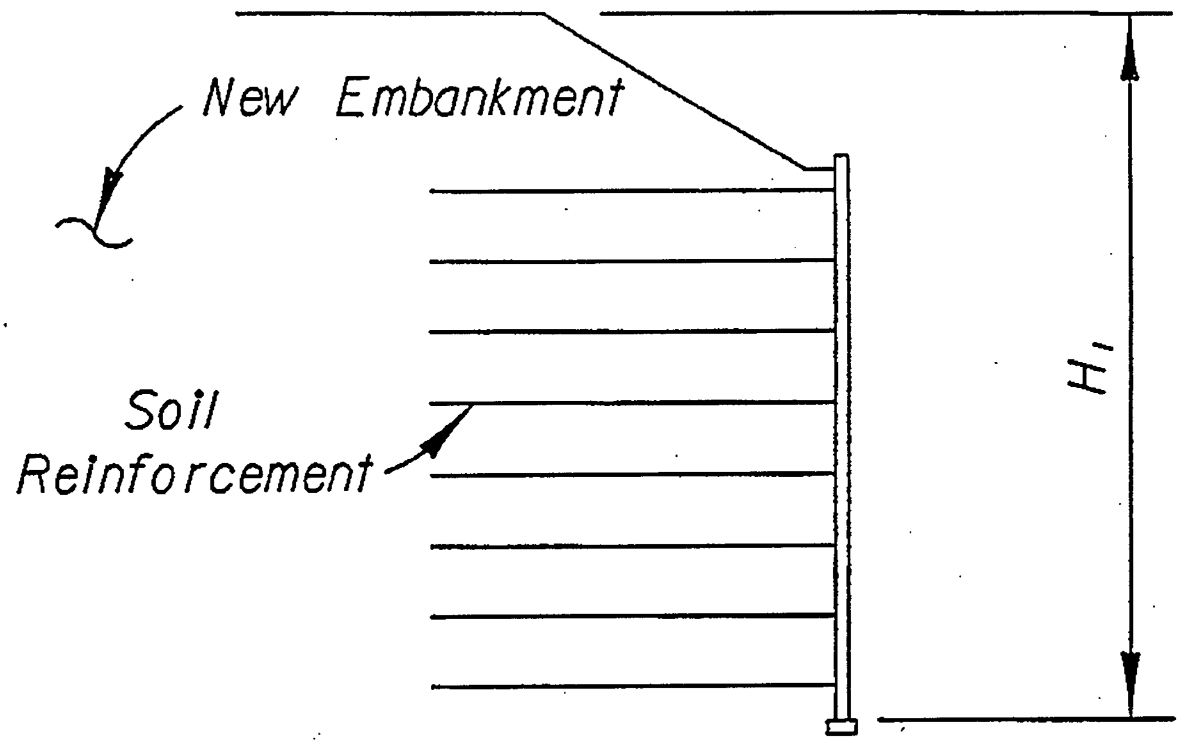
Figure 9 Mechanically Stabilized Earth Wall (Hexagonal Face)



H_1 = Mechanical Height of Wall

MSE WALL
(Cut Location)

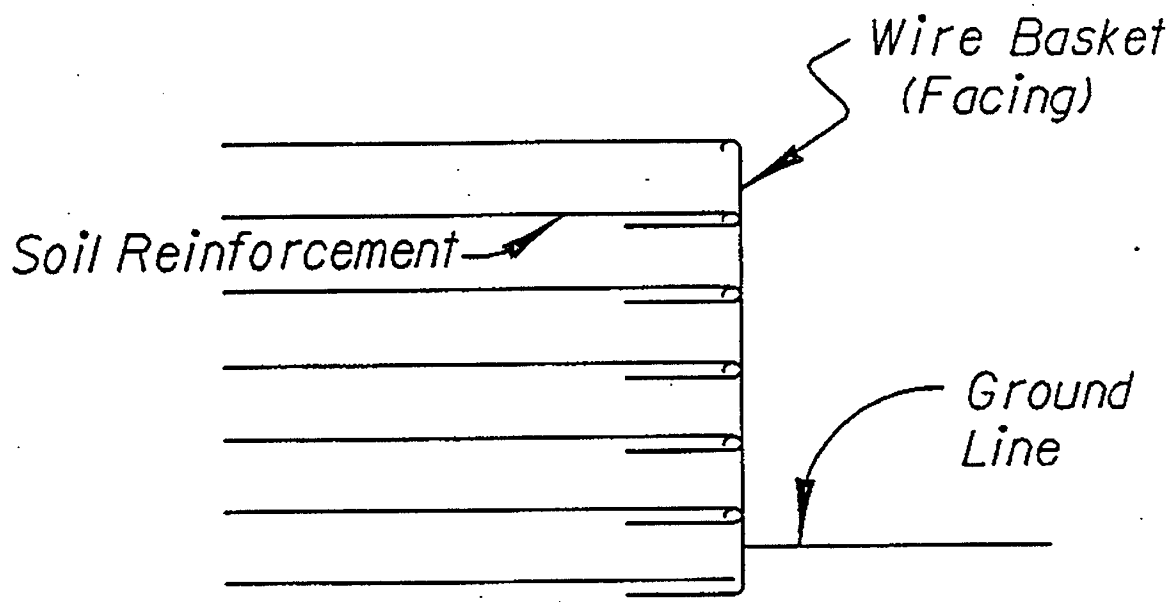
Sketch 10 Source Structures Design Guideline, FDOT 1997



H_1 = Mechanical Height of Wall

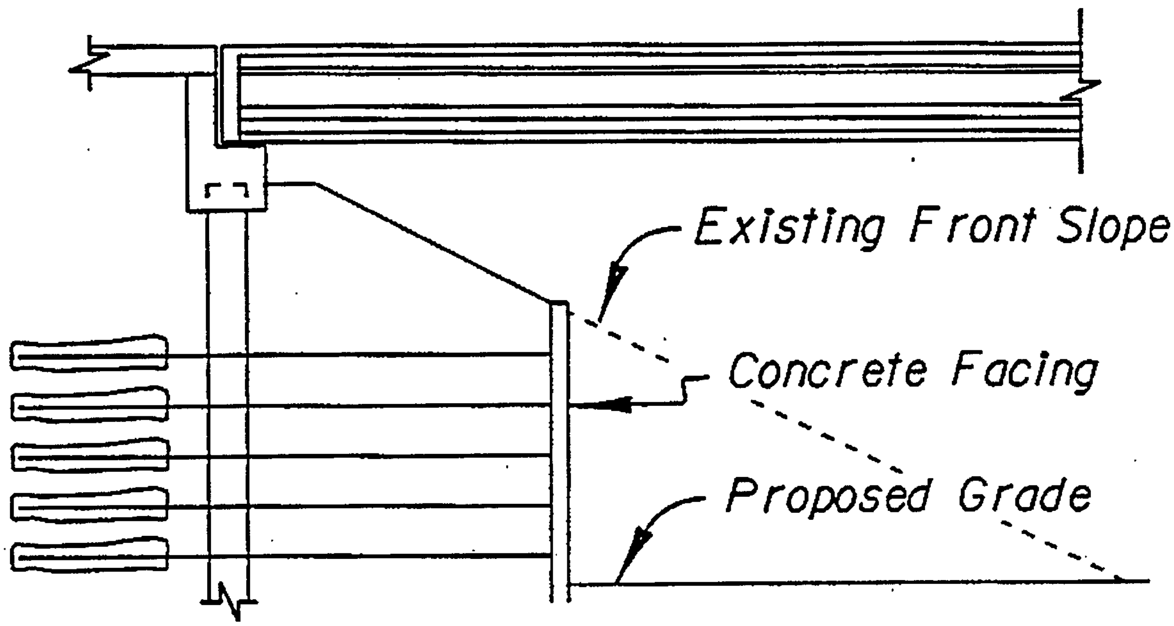
MSE WALL
(Fill Location)
Sketch 12

Sketch 11 Source Structures Design Guideline, FDOT 1997



WIRE FACED - MSE WALL
(For Temporary Wall Only)

Sketch 12 Source Structures Design Guideline, FDOT 1997



SOIL NAIL WALL
(Temporary Wall)

Sketch 13 Source Structures Design Guideline, FDOT 1997

V. Cost Analysis Method

Methods of Analysis

Comparison of alternatives was based on the present value of the *total* cost of each alternative during its life. The total included initial construction cost, the cost of regular maintenance and operation, and the cost of disposal. After the total cost was calculated, each treatment option was compared.

The first step was the gathering of initial construction cost data through use of the University of Florida's NERDC system. The price for each alternative was converted to a square-meter unit cost. Conversions are exemplified in the following section.

The second step was to identify the maintenance activities associated with each alternative. The data on maintenance included the frequency of the activity performed and a unit cost per square meter. Information on frequency of maintenance was obtained from the Gainesville office of FDOT Maintenance Division[27]. Information on average costs was obtained from the Maintenance Office in Tallahassee[28]. The third step was to determine the usable life of each option. Different departments were contacted to find determine this information. As previously mentioned, all vegetation was assumed to have a design life of 20 years on roadways. The design life for all roadway structures was 75 years. Except when the components are part of a bridge abutment, this had a life of 100 years. The usable life for permanent concrete structures was 40 years. For all other permanent types of structures 30 years, and all temporary structures 3 years.

Calculations, Conversions and Assumptions

Grass Seed(78+140+78+140)/4kg/ha/year = .0109 kg/m^2/year, *$2.55 Ave/kg = $.27795/$m^2$

Seeding = $.09000/$m^2$

Fertilizer 500 kg/ha *1ha/10000m^2 * $75.45 /kg = $.03772/$m^2$

Limestone 1000kg/ha*1ha/10000m^2 * $350.00/1000kg = $.35000/$m^2$

Water (assume 1 inch cover) = .0245m * $2.22 /$m^3$ = $.05439/$m^2$

Approximate Total Cost of Grass By Seeding = $.81006/$m^2$

(Refer to Sect. 570-4 of the Standard Specifications for Road and Bridge Construction 1996).

Sodding Average $2.0286/m^2$

Fertilizer 500 kg/ha *1ha/10000m² * $75.45 /kg = $.04 /m²

Limestone 1000kg/ha*1ha/10000m² * $350.00/1000kg = $.35 /m²

Water (assume 1 inch cover) = .0245m*$2.22/m³ = $.05 /m²

Approximate Total Cost of Grass By Sodding = $2.47 /m²

(Refer to Sect. 575-3 of the Standard Specifications for Road and Bridge Construction 1996).

Seeding = $.09 /m²

Fertilizer 500 kg/ha *1ha/10000m² * $75.45 /kg = $.04 /m²

Wildflower Seed 32.625kg/10000m² * $69.74 /kg = $.23 /m²

Water (assume 1 inch cover) = .0245m * $2.22/m³ = $.05 /m²

Approx. Total Cost of Native Wildflower Est. = $.41 /m²

(Used seeding cost from grass option. Seed was converted from an average value).

Concrete Slope Pavement-non-reinforced (State average)= **$29.90 /m²**

Concrete Slope Pavement-reinforced (State average) =

$50.00 /m²

Sand-Cement Riprap (Assumed 150 mm thickness__) =

$37.66 /m² .150 m * $251.05 /m³

Bedding Stone (Sp. gravity of 1.9 void factor

.4)*1000kg/m³*$44.49

/1000kg*.3m = **$10.68 /m²**

Rubble (Specific gravity of 2.5 void factor .9) * 1000kg/m³ *

$44.49 /1000kg * .750m

= **$ 8.34 /m²**

Fabric-Formed Concrete = **$30.00 /m²**

C-I-P Concrete Retaining Walls (Class I) Converted vol. CC for

Ave. thickness = .624m, $658.00/ m³ * .624 m =

$410.59/m²

Add reinforcing bar cost $1.00/kg * 47.16kg/m² =

$47.16 /m²

Approx. Total Cost of C-I-P Concrete Retaining Walls (Class I)

= **$457.75/m²**

C-I-P Concrete Retaining Walls (Class II) Converted Vol. CC for Ave. thickness = .624m.

$440/ m^3 * .624m =

$274.56/m^2

Add reinforcing bar cost $1.00/kg * 47.16kg/m^2 =

$47.16 /m^2

Approx. Total Cost of C-I-P Concrete Retaining Walls (Class II)

= **$321.72/m^2**

C-I-P Concrete Retaining Walls (Class IV) Converted vol. CC for Ave. thickness = .624m. $571.16/ m^3 * .624m =

$356.40/m^2

Add reinforcing bar cost $1.00/kg * 47.16kg/m^2 =

$47.16 /m^2

Approx. Total Cost of C-I-P Concrete Retaining Walls (Class IV)

$403.56/m^2

C-I-P Concrete Bulkhead Walls (Class IV) Converted vol. CC for Ave. thickness = .624m. $379.45/ m^3 * .624m =

$236.78/m^2

Add reinforcing bar cost $1.00/kg * 47.16kg/m^2 =

$47.16 /m^2

Approx. Total Cost of C-I-P Concrete Bulkhead Walls (Class IV)

$283.94/m^2

Precast Segmental Panels (Class IV) Converted vol. CC for Ave. thickness = .624m. $500/ m^3 * .624m

= $312.00/$m^2$

Add reinforcing bar cost $1.00/kg * 47.16kg/$m^2$ = $47.16 /$m^2$

Approximate Total Cost of Precast Segmental Panels (Class IV)

$358.16/$m^2$

VI. SPREADSHEET OPERATION

This is a guide to the Excel spreadsheet formulas in a file called "Slope.xls." The first part of this section will cover the "input" cells. The second part will cover how to manipulate information contained in the "operation" cells.

INPUT Cells

Only Three pieces of information are needed to compare the costs of slope treatment alternatives for a given situation.

1. Desired Useful Life to be analyzed in decimal years cell B-3.
2. Interest rate in entered into cell B-2 as a percentage (The interest rate automatically changes due to different frequencies of payment schedule.)
3. Square footage of slope face into cell B-5.

The Slope angle is also entered, but is not required for computation

OPERATION Cells

Maintenance frequency cells.

Values within the spreadsheet can be changed if necessary. On the "Operational sheet," cell F-10 begins the maintenance frequency information, filled to Z-42. This group of cells contains the frequency-per-year of each maintenance activity. For instance, view the Overhaul frequency for Seed Grass in cell F-10. The value .05 means 1/.05, or every 20 years.

Cost per Area Cells.

The cost per square-meter for each maintenance activity starts with G-8 and ends in cell Z-8.

Logic Cells.

The remaining cells should not be altered until the logic is well understood. Making a mistake in this area would yield poor results. Cells beginning with C-56 and filling to AB-88 should not be altered.

VII. CONCLUSION

Conclusion

Based upon the Lifecycle cost research conducted, The conclusion is the same for all years and interest rates analyzed.

1. Bedding stone was the most affordable option for slopes less than 18.4 degrees.
2. Bedding stone was also the most affordable option for the second category of angle between 18.4 and 26.5 degrees.
3. Geosynthetic Reinforced Soil Slope represented the most affordable option between 26.5 and 50 degrees.
4. For slopes between 50 degrees and 90 degrees, the Gabion Basket was the most affordable option. It presented the least cost for both construction and maintenance.

The analysis developed in this report had the purpose of comparing slope treatment alternatives based on lifecycle cost. Data of initial costs, project characteristics, site conditions, environmental concerns, maintenance frequencies, and maintenance cost should be updated in order to increase the effectiveness and accuracy of the analysis.

However, it is important to remember that lifecycle cost is only one criterion by which to select a design. Other criteria exist and should be considered when making a design selection.

Figure 10 Lifecycle Cost Comparison

10 Years of Treatment	COMPARISON OF PV TOTAL FOR 1 SQ METER									
40 degree slope										
TREATMENT	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Less than 18.4o										
GRASS BY SEEDING	$29.67	$28.26	$26.94	$25.72	$24.57	$23.50	$22.49	$21.55	$20.67	$19.84
GRASS SEEDING WITH MULCHING	$29.70	$28.29	$26.97	$25.75	$24.60	$23.53	$22.52	$21.58	$20.70	$19.87
GRASS BY SODDING	$34.55	$32.87	$31.33	$29.90	$28.59	$27.37	$26.24	$25.18	$24.19	$23.27
WILDFLOWER SEEDING AND MULCHING	$0.26	$0.26	$0.26	$0.26	$0.26	$0.26	$0.26	$0.26	$0.26	$0.26
LANDSCAPING	$2,483.64	$2,363.54	$2,251.40	$2,146.60	$2,048.60	$1,956.88	$1,870.97	$1,790.46	$1,714.93	$1,644.03
RIPRAP (SAND-CEMENT)	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65
BEDDING STONE	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
RIPRAP (RUBBLE) (BANK AND SHORE)	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72
RIPRAP FABRIC-FORMED CONCRETE (100MM	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00
18.4o < Q < 26.5o										
GRASS BY SODDING	$34.55	$32.87	$31.33	$29.90	$28.59	$27.37	$26.24	$25.18	$24.19	$23.27
RIPRAP (SAND-CEMENT)	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65	$37.65
BEDDING STONE	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
RIPRAP (RUBBLE) (BANK AND SHORE)	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72	$0.72
RIPRAP FABRIC-FORMED CONCRETE (100MM	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00	$30.00
26.5o < Q < 50o										
CLASS I CONCRETE (SLOPE CONCRETE)	$418.64	$418.53	$418.43	$418.34	$418.25	$418.18	$418.11	$418.04	$417.99	$417.93
GEOSYNTHETIC REINFORCED SOIL SLOPES (	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00	$40.00
GEOSYNTHETIC REINFORCED SOIL SLOPES (	$50.27	$50.27	$50.27	$50.27	$50.27	$50.27	$50.27	$50.27	$50.27	$50.27
GEOSYNTHETICREINFORCED SOIL SLOPES (	$28.96	$28.96	$28.96	$28.96	$28.96	$28.96	$28.96	$28.96	$28.96	$28.96
50o < Q < 90o										
CLASS I CONCRETE (RETAINING WALLS)	$278.43	$278.43	$278.43	$278.43	$278.43	$278.43	$278.43	$278.43	$278.43	$278.43
CLASS II CONCRETE (RETAINING WALLS) W/	$482.13	$482.13	$482.13	$482.13	$482.13	$482.13	$482.13	$482.13	$482.13	$482.13
CLASS III CONCRETE (RETAINING WALLS) W/	$474.11	$474.11	$474.11	$474.11	$474.11	$474.11	$474.11	$474.11	$474.11	$474.11
CLASS IV CONCRETE (RETAINING WALLS) W/	$403.56	$403.56	$403.56	$403.56	$403.56	$403.56	$403.56	$403.56	$403.56	$403.56
CLASS IV CONCRETE (BULKHEAD) W/REINF.	$283.94	$283.94	$283.94	$283.94	$283.94	$283.94	$283.94	$283.94	$283.94	$283.94
STEEL SHEET PILE (PERMANENT)	$340.00	$340.00	$340.00	$340.00	$340.00	$340.00	$340.00	$340.00	$340.00	$340.00
CLASS IV PRECAST CC SEGMENTAL PANELS	$1,371.26	$1,315.53	$1,264.77	$1,218.40	$1,175.92	$1,136.90	$1,100.96	$1,067.78	$1,037.09	$1,008.62
GABION BASKET (915MM THICK)	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00
GABION BASKET (455MM THICK)	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00	$150.00
REINFORCED EARTH WALL (MSE BY RECO)	$211.38	$211.38	$211.38	$211.38	$211.38	$211.38	$211.38	$211.38	$211.38	$211.38
RETAINING WALL (PERMANENT-HAYWARD B	$1,399.35	$1,399.35	$1,399.35	$1,399.35	$1,399.35	$1,399.35	$1,399.35	$1,399.35	$1,399.35	$1,399.35
RETAINING WALL (PERMANENT-SCHNABEL)	$753.50	$753.50	$753.50	$753.50	$753.50	$753.50	$753.50	$753.50	$753.50	$753.50
RETAINING WALL (PERMANENT-TENSAR)	$330.00	$330.00	$330.00	$330.00	$330.00	$330.00	$330.00	$330.00	$330.00	$330.00
TENSAR RETAINING WALL (ADD PERMANEN	$470.00	$470.00	$470.00	$470.00	$470.00	$470.00	$470.00	$470.00	$470.00	$470.00
TEMPORARY										
TENSAR RETAINING WALL (WITH TEMP FACE	$957.15	$918.25	$882.82	$850.46	$820.81	$793.57	$768.48	$745.33	$723.90	$704.03
RETAINED EARTH WALL (BY VSL) TEMPORA	$1,167.73	$1,120.27	$1,077.04	$1,037.56	$1,001.38	$968.15	$937.55	$909.30	$883.16	$858.91
RETAINING WALL (TEMPORARY-HILFIKER)	$349.90	$335.68	$322.73	$310.89	$300.05	$290.10	$280.93	$272.46	$264.63	$257.36
RETAINING WALL (TEMPORARY-TENSAR)	$561.43	$538.61	$517.83	$498.84	$481.45	$465.48	$450.76	$437.18	$424.61	$412.95
RETAINING WALL (TEMPORARY-TERRATREL	$497.72	$477.49	$459.07	$442.24	$426.82	$412.66	$399.61	$387.57	$376.43	$366.09
STEEL SHEET PILE (TEMPORARY)	$241.20	$231.40	$222.47	$214.32	$206.84	$199.98	$193.66	$187.82	$182.42	$177.42

VIII. IMPLEMENTATION REPORT

Technical Summary

This section summarizes the background, approach and findings of this report

Background.

Investigation was conducted in to the alternatives currently used by FDOT for slope stabilization, and their lifecycle costs.

Approach.

Data on the initial cost of alternatives was obtained from FDOT and other sources. Additional data was gathered on continuing expenses such as, maintenance, overhaul, repair and mowing. This data was then used to compute lifecycle costs for the alternatives currently in use by FDOT.

Findings.

It was determined that the most cost effective treatments were.

1. Bedding stone was the most affordable option for slopes less than 18.4 degrees.
2. Bedding stone was also the most affordable option for the second category of angle between 18.4 and 26.5 degrees.

3. Geosynthetic Reinforced Soil Slope represented the most affordable option between 26.5 and 50 degrees.
4. For slopes between 50 degrees and 90 degrees, the Gabion Basket was the most affordable option. It presented the least cost for both construction and maintenance.

Benefits.

It is expected that through use of the materials contained in this report and the companion Excel spreadsheet that FDOT will have an additional tool to aid in the design selection and evaluation process.

Technology Transfer Plan

This portion of the implementation report will discuss who is expected to benefit from this research (coverage) and how to transfer this information to them (transfer).

Coverage.

It is expected that FDOT, other state and Federal transportation agencies will find the information in this report useful when selecting design alternative based upon lifecycle cost. This report may also benefit consultants who are working for these same agencies.

Transfer.

Three steps should be implemented to ensure that the results of this report are transferred to those whom may benefit from it.

1. Make this report and spreadsheet available to FDOT designers
2. Make report and spreadsheet available to interested consultants
3. Consider inclusion of portions of this report and the companion Excel spreadsheet in future design manuals

Implementation Test

After review and implementation, the best criteria for evaluating the success of this research would be to interview FDOT design officials to determine if design procedures have been altered by this research. At the current time lifecycle cost is not the criteria by which slope stabilization designs are evaluated. With this research available to the design professional it is expected that lifecycle cost will be one of the factors used in determining the best design.

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