

**Section 3-03**  
**Earthwork Design**

**TABLE OF CONTENTS**

INTRODUCTION ..... 4  
    General ..... 4  
    Exhibit 1- Earthwork Cross-Section ..... 4  
    Excavation (cut) ..... 4  
    Embankment (fill) ..... 4  
    Topsoil ..... 4  
    Moisture and Density Control (MDC) ..... 4  
  
EARTHWORK VOLUMES ..... 5  
    General ..... 5  
    End Area Calculations ..... 6  
    Exhibit 2 - Irregular Polygon ..... 6  
    Exhibit 3 - End Area Calculations ..... 6  
    Volume Calculations ..... 7  
    Exhibit 4 - Roadway Cross Sectional End Areas ..... 7  
    Compaction Factors ..... 7  
  
MASS DIAGRAM (MASS CURVE) ..... 8  
    General ..... 8  
    Mass Diagram Calculations ..... 8  
    Exhibit 5 - Mass Diagram Spreadsheet ..... 9  
    Exhibit 6 - Mass Diagram Plot ..... 9  
    Interpretation of the Mass Diagram ..... 10  
  
HAUL ..... 10  
    General ..... 10  
    Haul Defines Work ..... 10  
    Exhibit 7 - Hauling 1 CY of Excavated Material 1 Mile ..... 11  
    Calculating Project Haul ..... 11  
    Exhibit 8 - Calculate Total Haul As Sum Of Individual Rectangles ... 12  
    Haul With Different Soil Types ..... 12  
    Exhibit 9 - Effect of Combining Different Soil Types ..... 13

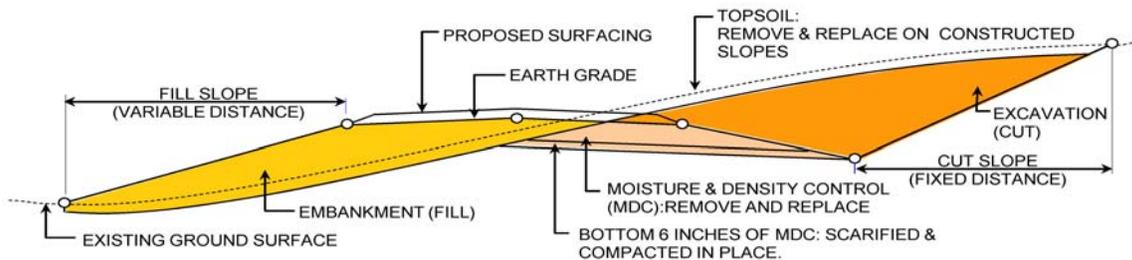
OTHER EARTHWORK CONSIDERATIONS .....	14
Interrelationship of Design Elements .....	14
Borrow Material .....	14
Exhibit 10 - Mass Diagram With Insufficient Excavation .....	14
Exhibit 11 - Mass Diagram With Borrow Material .....	15
Waste Material .....	15
Exhibit 12 - Mass Diagram With Excess Excavated Material .....	15
Exhibit 13 - Mass Diagram With Waste Material .....	15
Point of Economical Haul .....	16
Exhibit 14 - Economical Haul Point .....	16
Special Considerations .....	17
COMPUTER EARTHWORK SOFTWARE .....	18
General .....	18
KEY USER GUIDELINES .....	18
General .....	18
Earthwork Reports .....	18
Exhibit 15 - Grand Summary Earthwork Report .....	18
Exhibit 16 - Mainline Earthwork Report .....	19
Added Quantities in GEOPAK .....	20
Positive Embankment (Fill) .....	21
Exhibit 17 - Added Fill Affect On Mass Curve .....	21
Negative Embankment (Fill) .....	21
Positive and Negative Excavation (Cut) .....	21
Exhibit 18 - Earthwork and Added Quantities .....	22
Using Shrink or Swell Factors in GEOPAK .....	22
Multiple Compaction Factors .....	22
GEOPAK Three-step Process For Multiple Compaction Factors .....	23
Exhibit 19 - GEOPAK Multiple Factor Table .....	23
Exhibit 20 - GEOPAK Multiple Factor Table .....	26
Spreadsheet Process For Multiple Compaction Factors .....	27
Widening for Guardrail .....	28
Exhibit 21- Widening for Guardrail .....	28
Graphically Fixing Slopes .....	29
GUIDELINES FOR SNOW DRIFTING .....	29
General .....	29
Road Surface Elevation .....	29
Barn Roof Section .....	30
Median Section .....	30
Roadway Cuts .....	30

Exhibit 22 - Cross-Section Scenario With Snow Drifting . . . . . 30  
Cut Slope Configuration to Prevent Snow Encroachment . . . . . 31  
Exhibit 23 - Cut Slope Modification For Snow Drift Control . . . . . 31  
Superelevation Drifting Problems . . . . . 32  
Exhibit 24 - Special Configuration That Requires Snow Mitigation . . . 32  
Snow Management For Rock Cuts . . . . . 33  
Exhibit 25 - Cross-Section For Snow Management . . . . . 33

BARRIERS AND SNOW DRIFTING . . . . . 33  
General . . . . . 33

## INTRODUCTION

**General:** One of the major tasks in roadway construction is removing and placing earth materials to achieve the desired earth grade cross section. The design tasks required to define where the roadway material is to be obtained, where it will be placed, the direction in which it will be hauled, the amount of effort required to transport the material to its desired location, the amount of material to be excavated, etc., are collectively known as the earthwork process. The basic elements of the earth grade portion of the roadway cross section are shown in Exhibit 1.



**EXHIBIT 1**  
EARTHWORK CROSS - SECTION

**Excavation (cut):** In-place material that is removed to achieve the desired earth grade cross section. The cut slope catch point for each cut section is normally set at a fixed distance from the bottom of the ditch. The most common WYDOT contract bid item for excavation is Unclassified Excavation.

**Embankment (fill):** Excavated material that is placed and compacted to achieve the desired earth grade cross section. WYDOT considers embankment quantities to be incidental to excavation pay quantities.

**Topsoil:** The top layer of nutrient rich soil that is removed, stored, and eventually placed over the surface of all disturbed areas for revegetation purposes. The topsoil is handled and paid for twice, once for removal and once for placement. WYDOT contract bid items for topsoil are Topsoil Storing and Topsoil Placing.

**Moisture and Density Control (MDC):** It is WYDOT construction practice to excavate additional material beneath the proposed surfacing in cut sections, adjust the moisture content, replace it, and properly compact it to provide a stable roadway foundation. The required MDC depth for a particular project is specified in the Soils Profile. Typically, the bottom 6 in [150 mm] of the specified depth is scarified and compacted in place with added moisture. When necessary, the remaining depth of MDC material is removed and replaced.

Separate quantities for MDC are included in the plans, but MDC quantities are paid for as part of Unclassified Excavation.

## EARTHWORK VOLUMES

**General:** The traditional method used to calculate embankment and excavation volumes is the average end area method. The average end area procedure is as follows:

- Cross sections of the existing terrain are first taken at regular intervals throughout the project as specified by the engineer. For rural projects, the cross section interval is generally 100 ft [30.48 m] in tangent sections and 50 ft [15.24 m] in curved sections. For urban projects, the cross section interval is generally either 50 ft [15.24 m] or 25 ft [7.62 m] depending on the level of detail needed. Additional cross sections are also obtained at “breaks” in the terrain, such as drainage bottoms, ridges lines, etc.

The cross sections are then plotted, showing the proposed earth grade template superimposed on the existing terrain. The areas of excavation and embankment are then calculated for each cross section.

- The average end area method approximates the volume of excavation or embankment between two cross sections as follows:

$$\text{Volume} = \frac{1}{2} \times (A1 + A2) \times L$$

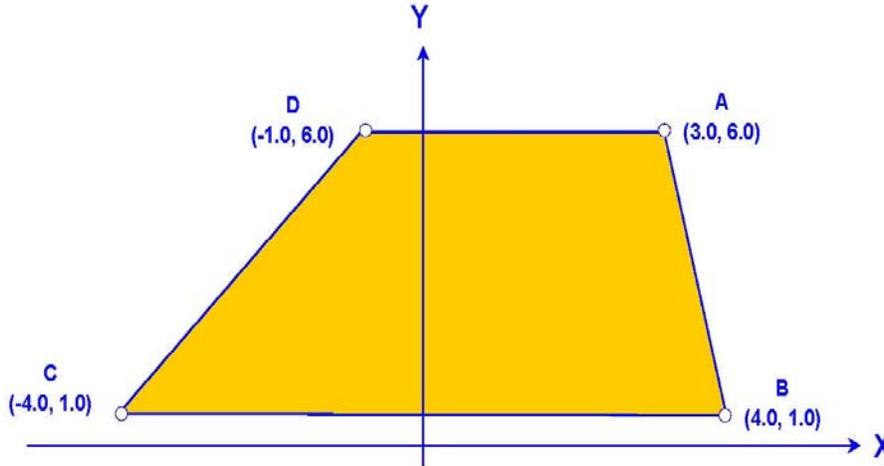
Where: A1 = Area of excavation or embankment of cross section 1  
A2 = Area of excavation or embankment of cross section 2  
L = Distance between cross sections 1 and 2

This method is an approximation in the following respects:

- Any irregularities in the natural terrain between cross sections are not reflected in the calculated earthwork volumes.
- Mathematically, the average end area method is exact only if  $A1 = A2$ . The maximum mathematical error occurs when one of the areas is equal to zero.

Even though some of the terrain irregularities are not accounted for, the average end area method has been found to provide earthwork volumes that are sufficiently accurate for practical engineering purposes. This method’s accuracy can be improved by shortening the cross section interval.

**End Area Calculations:** To use the average end area method, areas must be calculated for irregular polygons whose vertices are defined by their elevations and distances from centerline. One method for determining such areas is the so-called “crisscross” method, which is demonstrated in the following example:



**EXHIBIT 2**  
IRREGULAR POLYGON

Make a list of the x and y coordinates (distance and elevation) at each vertex of the polygon starting at a selected point and proceeding around the enclosed area back to the starting point, as shown in Exhibit 3. The coordinates of the starting point are the first and last entries in the list. Compute cross-products of all coordinates in the list, keeping track of signs, and calculate the sum of these products.

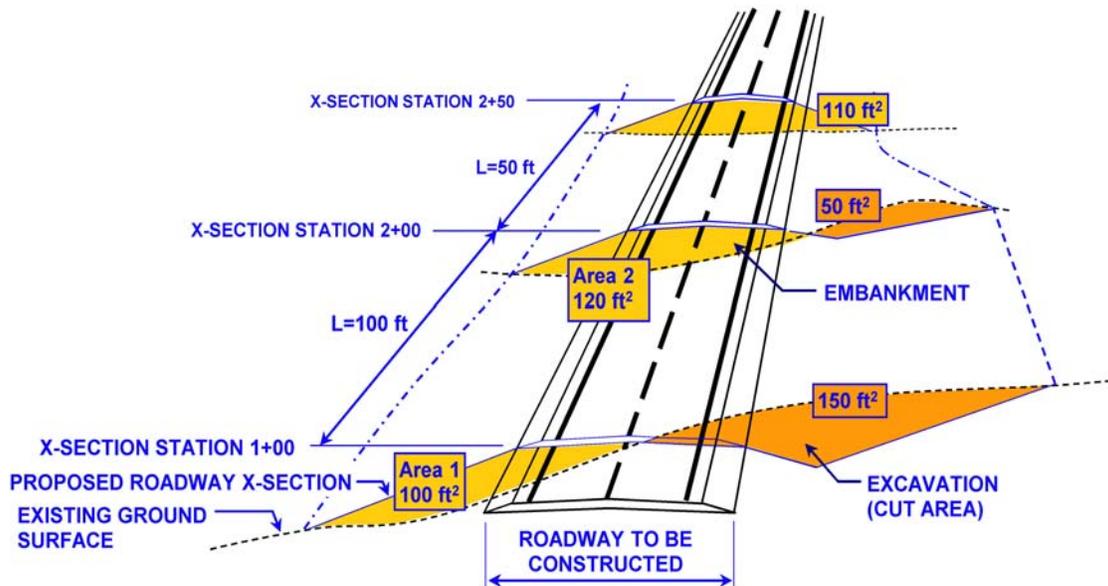
Enclosed area =  $\frac{1}{2} [(\sum y \times x) - (\sum x \times y)]$ . Note that the final area may be positive or negative. The sign is of no consequence. Area =  $\frac{1}{2} [(37) - (-23)] = 30 \text{ ft}^2$

POINT	Y*X	X	Y	X*Y
C		-4.0	1.0	
	-1.0			-24.0
D	18.0	-1.0	6.0	-6.0
A	24.0	3.0	6.0	3.0
B	-4.0	4.0	1.0	4.0
C		-4.0	1.0	
TOTAL	37.0			-23.0

**EXHIBIT 3**  
END AREA CALCULATIONS

**Volume Calculations:** The following pictorial view of a typical roadway and the associated cross sectional end areas illustrates how the earthwork volumes are computed throughout a typical project.

In this example, the end areas provided in Exhibit 4 are used to calculate the cut and fill earthwork volumes between Sta. 1+00 and Sta. 2+00:



**EXHIBIT 4**

ROADWAY CROSS SECTIONAL END AREAS

Example:  $V = [\frac{1}{2} (A1+A2) \times (L)] \div 27$  (Where end areas are in ft<sup>2</sup>)

Where:  $V =$  Volume in CY  
 $A1 =$  End Area in ft<sup>2</sup> at Sta. 1+00  
 $A2 =$  End Area in ft<sup>2</sup> at Sta. 2+00

Fill volumes  $V = [\frac{1}{2} \times (100 + 120) \times (100)] \div 27 = 407$  CY

Cut volumes  $V = [\frac{1}{2} \times (150 + 50) \times (100)] \div 27 = 370$  CY

**Compaction Factors:** The density of embankment material is normally different from the density of the excavated material. This difference is accounted for in the earthwork process by using compaction factors. The compaction factors are provided in the Soils Profile, or the Geology Program/Field Offices can provide them.

Excavated soil-type material (dirt) typically shrinks in volume from its natural state, when compacted during the embankment construction process. For example a soil-type material with a 20 % shrink results in a compaction factor of 1.2 that is applied to the embankment quantities so that the earthwork can be balance.  $\text{Fill Volume} \times 1.2 = \text{Cut Volume}$ .

Excavated rock-type material typically swells in volume from its natural state, when compacted during the embankment construction process. For example a rock-type material with a 10% swell results in a compaction factor of 0.9 that is applied to the embankment quantities.  $\text{Fill Volume} \times 0.9 = \text{Cut Volume}$ .

Compaction factors are subjective and factors determined by soil-type will not always provide the best results. Experience has shown that a project with several sliver cuts and fills could require a compaction factor of  $1.5 \pm$  verses a laboratory determined factor of  $1.2 \pm$ . The designer should work with the field offices to make sure that the shrink factor being used is applicable to the project being designed.

## MASS DIAGRAM (MASS CURVE)

**General:** Embankment and excavation volumes for an entire project are summarized in the form of a mass diagram, which is an extremely useful tool in the earthwork design process, to evaluate balance points (zero mass ordinate), to calculate haul, etc.

One way to understand the mass diagram concept is to visualize a truck that travels along the length of the project in the direction of increasing station. As the truck travels between two stations, the excavation quantities between these stations are added to the truck, and the embankment quantities (adjusted for the compaction factor) are removed from the truck. The volume of material in the truck at a particular station is the mass ordinate. Using the truck analogy, positive ordinates are excess material at a particular station. Negative ordinates are the volume of material required for embankment construction. In general, the mass ordinate at any station is given by the following equation:  $M2 = (+ \text{ or } - M1) + (\text{Exc } 1 - 2) - (\text{CF} \times \text{Emb } 1 - 2)$

Where:  $M2$  = The mass ordinate at a particular station

$M1$  = The mass ordinate of the preceding station

$\text{Exc } 1 - 2$  = The volume of excavation between stations 1 and 2

$\text{Emb } 1 - 2$  = The volume of embankment between stations 1 and 2

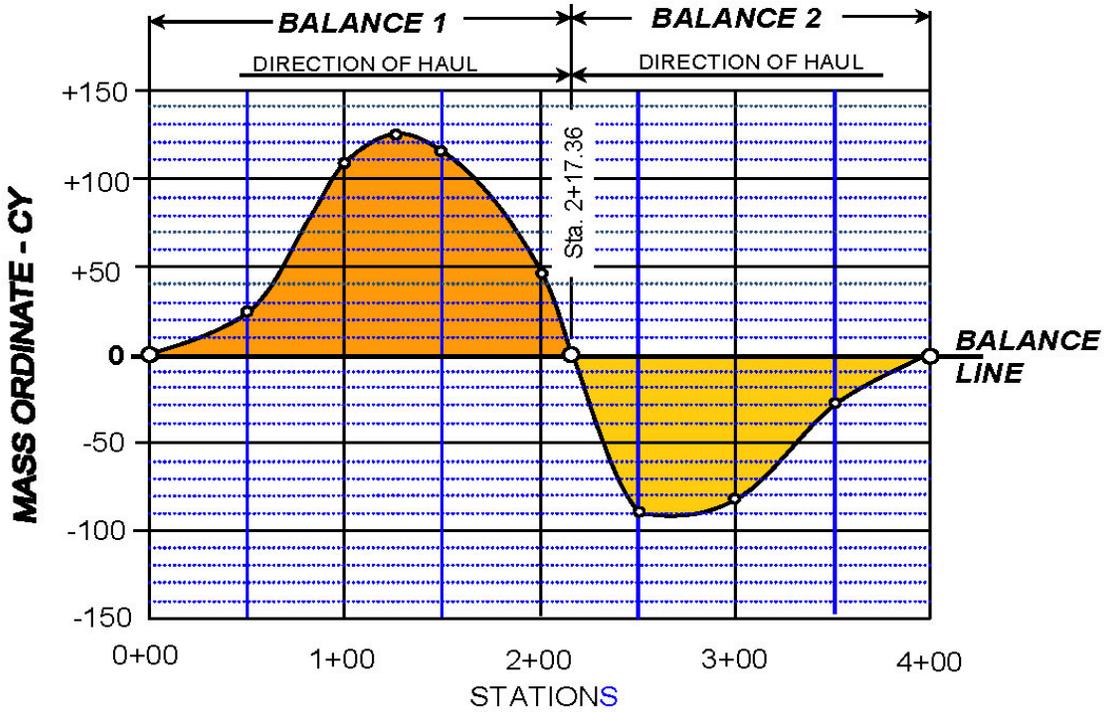
$\text{CF}$  = The compaction (shrink or swell) factor for the material on the project

**Mass Diagram Calculations:** The spreadsheet in Exhibit 5 illustrates how the associated end areas and earthwork volumes are applied to calculate the mass ordinate at each cross station:

STATION	DISTANCE	EXC. AREA	AVG. EXC. AREA	EXC. VOL.	EMB. AREA	AVG. EMB AREA	EMB VOL.	EMB VOL + 20% SHRINK	MASS ORDINATE
	FT	FT <sup>2</sup>	FT <sup>2</sup>	CY	FT <sup>2</sup>	FT <sup>2</sup>	CY	CY	CY
0+00		0.00			0.00				0.0
	50		24.80	45.9		9.00	16.7	20.0	
0+50		49.60		18.00		34.00	63.0	75.6	25.9
	50		85.80	158.9		46.50	43.1	51.7	
1+00		122.00		50.00		28.50	26.4	31.7	109.3
	25		71.00	65.7		45.35	84.0	100.8	
1+25		20.00		43.00		61.40	113.7	136.4	123.3
	25		27.00	25.0		76.70	136.4	166.2	
1+50		34.00		14.00		81.10	166.2	196.0	116.7
	50		17.00	31.5		84.0	196.0	225.8	
2+00		0.00		76.70		84.0	225.8	255.6	47.4
	50		0.00	0.0		61.40	255.6	285.4	
2+50		0.00		46.10		27.55	285.4	315.2	-89.1
	50		37.00	68.5		51.0	315.2	345.0	
3+00		74.00		9.00		33.70	345.0	374.8	-81.8
	50		68.50	126.9		62.4	374.8	404.6	
3+50		63.00		58.40		29.20	404.6	434.4	-29.8
	50		51.20	94.8		54.1	434.4	464.2	
4+00		39.39		0.00			464.2	494.0	0.1

**EXHIBIT 5**  
MASS DIAGRAM SPREADSHEET

Exhibit 6 shows a mass diagram plot of the ordinates calculated in Exhibit 5.



**EXHIBIT 6**  
MASS DIAGRAM PLOT

**Interpretation of the Mass Diagram:** Positive mass ordinates can be considered to be the excess volume of excavated material at a particular station. As material is used for embankment construction, the mass ordinates decrease. Negative mass ordinates can be considered as the volume of material required for embankment construction. As more material is excavated, the shortage of embankment material is lessened and the mass ordinates increase.

Zero mass ordinates are called balance points, and the section of roadway between two consecutive balance points is called a balance. The location of an intermediate balance point is normally determined by linearly interpolating between positive and negative mass ordinates. For example, the sample project has two balances—one between Station 0+00 and Station 2+17.36, and one between Station 2+17.36 and Station 4+00.00. Thus, sufficient material was excavated in each balance to construct the embankment, taking the compaction factor into account. Contractors normally work each balance separately and material usually is not taken from one balance into another.

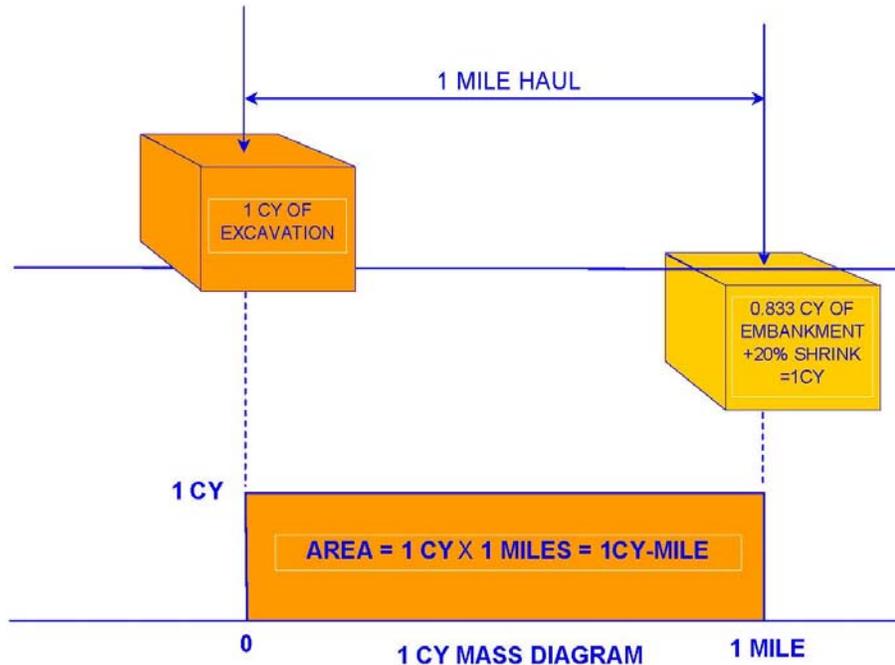
In the example, the mass ordinate at the end of the project is near zero, indicating that sufficient material was excavated to construct all of the embankment, taking into account the compaction factor. Therefore, a separate borrow source is not needed to furnish material necessary for embankment construction, nor is extra material (waste) left over at the end of the project.

Where the mass ordinate is increasing, more material is being excavated than is being used in the embankments. Where mass ordinates are decreasing, embankment predominates. Thus, the direction of haul in a balance where the mass ordinates are positive, is ahead-station, which is from an area of increasing mass ordinates toward an area of decreasing mass ordinates. Similarly, the direction of haul in a balance where mass ordinates are negative, is back-station.

## HAUL

**General:** The amount of work involved in a grading project is not totally reflected by the excavation and embankment quantities alone. Two balanced projects with similar excavation quantities, but significantly different lengths, differ widely in the amount of work required to move the excavated material to its final position in the embankment.

**Haul Defines Work:** The effort required to transport the excavated material is quantified as haul. Haul is measured in units of cubic yards-miles (CY-Miles) [ $\text{m}^3\text{-km}$ ], which is defined as the amount of work required to move 1 CY [ $\text{m}^3$ ] of excavated material a mile [ $\text{km}$ ] as illustrated in Exhibit 7.

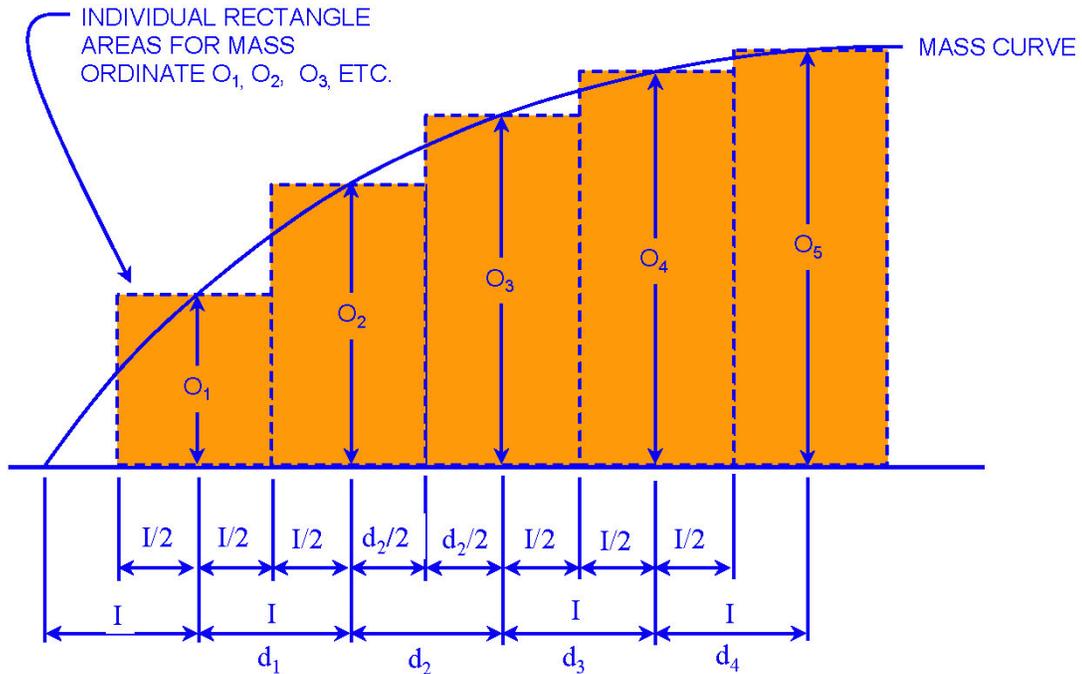
**EXHIBIT 7**

HAULING 1 CY OF EXCAVATED MATERIAL 1 MILE

Exhibit 7 shows a one mile balance with a haul quantity of 1 CY-Mile. Note that the mass diagram is a rectangle enclosing an area of 1 CY-Mile. Therefore, the haul for the project can also be regarded as the area enclosed by the mass diagram (Haul = 1 cubic yard  $\times$  1 mile).

The area under the haul diagram is the minimum amount of work required to transport the excavated material to its final position in the embankment for the balance. It is not a direct measure of the amount of work actually performed by the contractor. The total quantity for haul is the area enclosed by the final mass diagram for the project.

**Calculating Project Haul:** Haul is not a WYDOT pay item, but it's calculated and shown in the plans for estimating purposes. It is customary to calculate haul quantities by approximating the area enclosed by the haul diagram as a series of vertical rectangles as shown in Exhibit 8.



**EXHIBIT 8**

CALCULATE TOTAL HAUL AS SUM OF INDIVIDUAL RECTANGLES

Area  $O_1 = O_1 \times (\frac{1}{2} \text{ distance to previous x-section} + \frac{1}{2} \text{ distance to next x-section})$

For standard interval cross sections, the area for ordinate  $O_1$  is:

$$\text{Area } O_1 = O_1 \times (\frac{1}{2} \times I + \frac{1}{2} \times I) = (O_1 \times I)$$

Total Haul = Area  $O_1$  + Area  $O_2$  + ... etc.

$$= I \times O_1 + [(I+d_2) \div 2] \times O_2 + [(d_2+I) \div 2] \times O_3 + I \times O_4 + \dots \text{ etc.}$$

Where:

$O_1$  = mass ordinate at cross section 1

$O_2$  = mass ordinate at cross section 2, etc.

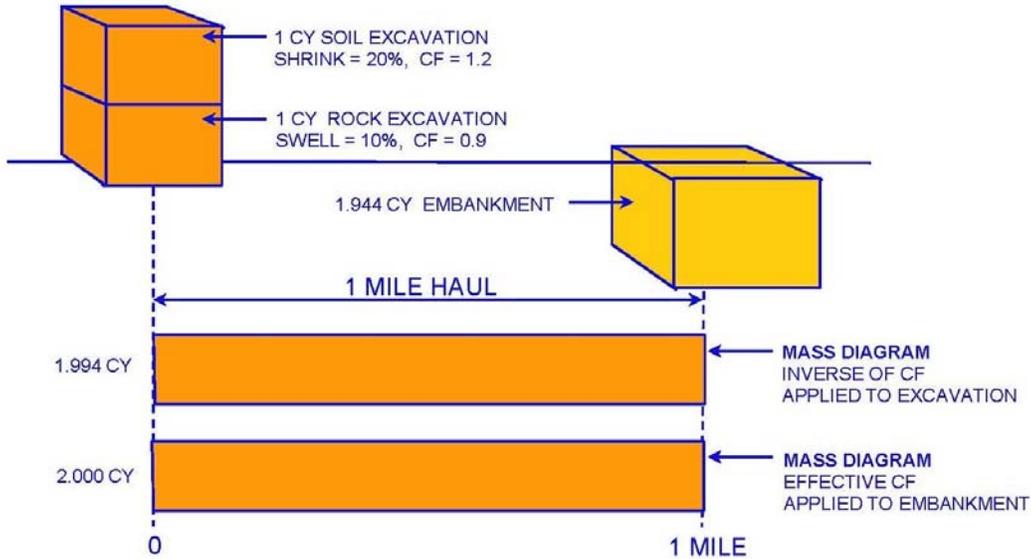
$d_1$  = distance between cross section 1 and cross section 2 = I

$d_2$  = distance between cross section 2 and cross section 3  $\neq$  I

I = standard cross section interval.

**Haul With Different Soil Types:** Even though compaction factors are applied to embankment volumes, the amount of material required to construct a cubic yard of embankment is a function of the type of excavated material used in the embankment.

On projects where embankment is constructed with differing soil types that have different compaction factors, a two-step earthwork process is required to determine the balance points and the associated amount of haul. This process is illustrated in Exhibit 9:



**EXHIBIT 9**  
EFFECT OF COMBINING DIFFERENT SOIL TYPES

To determine the balance points, the inverse of the compaction factor is applied to the excavation volumes, and 1 cubic yard of excavation is used to construct each cubic yard of embankment. Using the truck analogy from earlier in this chapter, the excavated material is compacted as it is loaded into the truck rather than being compacted when it is being placed in the embankment.

$$\text{Adjusted Excavation} = (1 \div 1.2) + (1 \div 0.9) = 1.944 \text{ CY}$$

Since the adjusted excavation is equal to the embankment, the project is self balancing. The mass diagram for this step incorrectly indicates that the haul is 1.944 CY-Miles. Obviously, the haul should be 2.0 CY-Miles.

To maintain the balance points determined in step one and to correct the haul, the effective compaction factor is calculated for each balance and applied to the embankment. Using the truck analogy, the different types of materials are excavated, blended, placed in the truck, and compacted as the embankment is constructed.

$$\begin{aligned} \text{Effective Compaction Factor} &= \text{total exc. vol.} / \text{total emb. vol.} \\ \text{vol.} &= (2.0 \div 1.944) = 1.0288 \end{aligned}$$

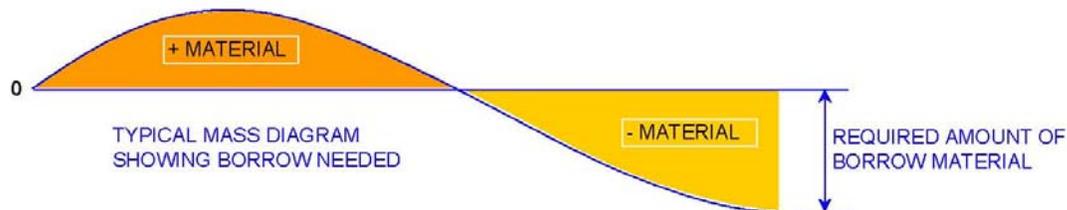
$$\begin{aligned}\text{Adjusted Embankment Volume} &= (\text{Embankment Volume}) (\text{Effective CF}) \\ &= (1.944) \times (1.0288) = 2.0 \text{ CY}\end{aligned}$$

Since the adjusted embankment is equal to the excavation, the project is still self balancing. However, the mass diagram for this step now indicates the correct haul of 2.0 CY-Miles.

## OTHER EARTHWORK CONSIDERATIONS

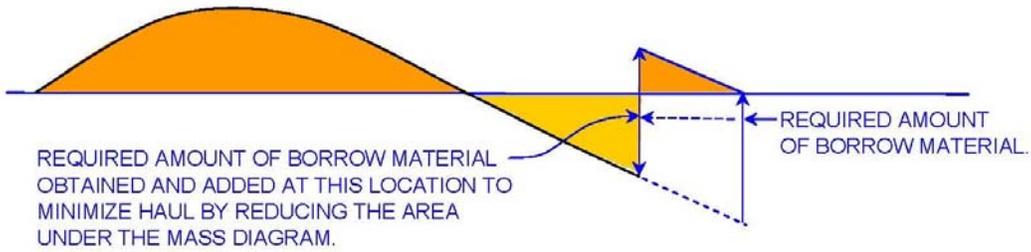
**Interrelationship of Design Elements:** The earthwork design is dependent on all the other roadway design elements, such as horizontal alignment, vertical alignment, roadway cross section, etc. The designer must use good engineering judgment to achieve an appropriate balance between all these elements to provide a final roadway design that meets all the constraints for a particular project. For example, utility conflicts may occur on a particular project, or additional right of way may be required. The designer can choose to accept such encroachments or minimize them by shifting the horizontal alignment, by revising the vertical alignment, by modifying the embankment slopes, or by combining these techniques.

**Borrow Material:** On widen and overlay projects, the existing profile grade cannot be adjusted, and there may be insufficient excavation material available adjacent to the roadway to balance the earthwork. Consequently, borrow areas must be obtained to furnish the required amount of excavation. A typical mass diagram for such a project is shown in Exhibit 10.



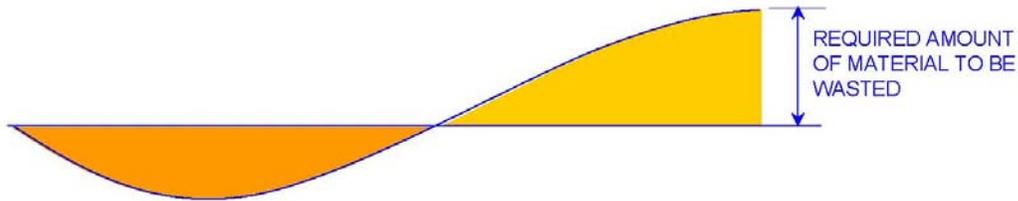
**EXHIBIT 10**  
MASS DIAGRAM WITH INSUFFICIENT EXCAVATION

Adding borrow material causes an immediate increase in the mass ordinate at the location where the borrow material is brought onto the project. Although it is not always possible to obtain borrow areas in optimal locations, borrow areas should be located in the vicinity of the shortage of material. If possible, borrow areas should be located to minimize haul by reducing the area under the mass diagram. A reasonable location for a borrow area on the above noted project is shown in Exhibit 11.



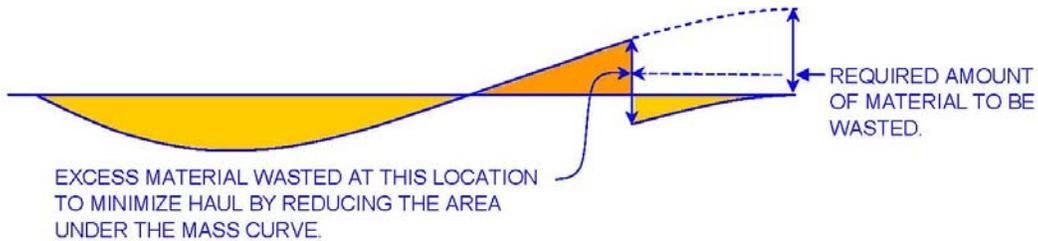
**EXHIBIT 11**  
MASS DIAGRAM WITH BORROW MATERIAL

**Waste Material:** Occasionally, excess excavated material not necessary to construct the roadway embankment is obtained. For example, sight distance considerations may necessitate a deeper cut at the crest of a hill than is necessary to balance the earthwork. A typical mass diagram with waste material is shown in Exhibit 12. Consequently, waste areas must be obtained or embankment slopes must be flattened, etc., to dispose of the excess material.



**EXHIBIT 12**  
MASS DIAGRAM WITH EXCESS EXCAVATED MATERIAL

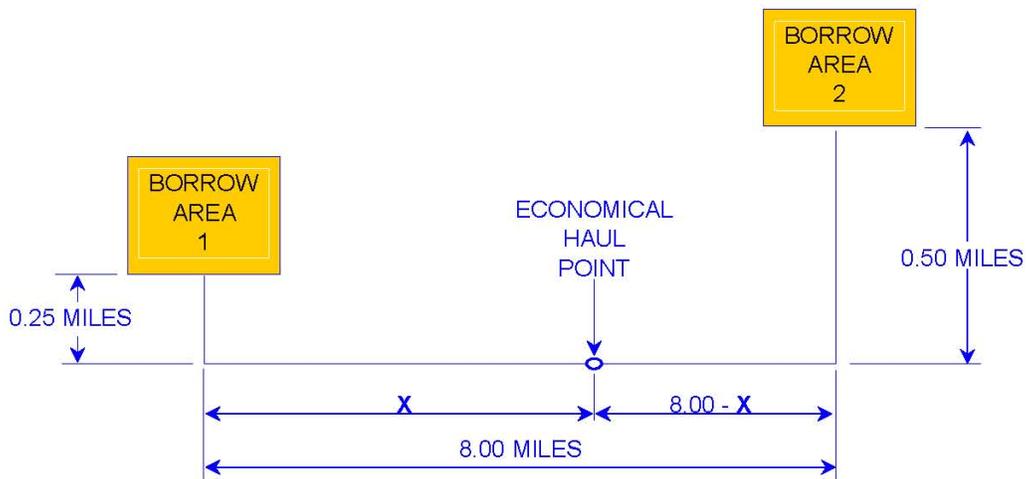
If a waste area is used, waste material causes an immediate decrease in the mass ordinate at the station added. If possible, material should be wasted without hauling it a significant distance. A reasonable location for waste material is shown in Exhibit 13.



**EXHIBIT 13**  
MASS DIAGRAM WITH WASTE MATERIAL

In rare instances, it may be necessary to haul large amounts of excavated material long distances before using it in the embankment. Depending on excavation costs, haul costs, etc., it may be more economical to waste or flatten slopes with the excavated material and then borrow other material necessary to construct the embankment at a location closer to the embankment.

**Point of Economical Haul:** Where two or more borrow areas are used on a single project, a decision must be made as to where to stop using the material from the first borrow area and to begin using the material from the next borrow area. This is known as the point of economical haul, as illustrated in Exhibit 14.



**EXHIBIT 14**  
ECONOMICAL HAUL POINT

The point of economical haul occurs at the location where the total cost of excavating and hauling a cubic yard of material from Borrow Area 1 is equal to the total cost of excavating and hauling a cubic yard of material from Borrow Area 2. The example assumes that sufficient borrow material is available in both borrow areas.

Example Problem:

Borrow Area 1: Royalty = \$0.50 per CY and Excavation cost = \$1.10 per CY  
 Borrow Area 2: Royalty = \$0.60 per CY and Excavation cost = \$1.50 per CY  
 Haul = \$0.10 Per CY-Mile for both borrow areas

$$\begin{aligned} C_1 &= \text{The cost to move 1 CY of excavation from Borrow Area 1:} \\ C_1 &= \text{Excavation} + \text{Royalty} + \text{Haul} \\ &= 1.10 + 0.50 + [0.10 \times (.25\text{Mi} + X)] = 1.625 + .10X \end{aligned}$$

$$\begin{aligned} C_2 &= \text{The cost to move 1 CY of excavation from Borrow Area 2:} \\ C_2 &= \text{Excavation} + \text{Royalty} + \text{Haul} \\ &= 1.50 + 0.60 + [0.10 \times (8.0\text{Mi} - X + 0.5\text{Mi})] = 2.950 - 0.1X \end{aligned}$$

$$\begin{aligned} C_1 &= C_2 \text{ or } 1.625 + 0.1X = 2.950 - 0.1X \\ &\text{Therefore } 0.2X = 1.325 \end{aligned}$$

$$X = \mathbf{6.63 \text{ Miles}}$$

The economical haul distance from Borrow Area 1 =  $X + 0.25 = \mathbf{6.88 \text{ Miles}}$  and the economical haul distance from Borrow Area 2 =  $(8 - X) + .5 = \mathbf{1.87 \text{ Miles}}$ . Where royalty and haul costs are not known as is often the case, the point of economical haul is based on distances only.

**Special Considerations:** Where applicable, take the following into account during the earthwork process:

- Avoid uphill haul of large amounts of excavated material.
- Ensure balance points are located in the vicinity of bridges to avoid hauling large amounts of excavated material across structures. It may be necessary to waste or borrow material to force a balance at a structure.
- It may be necessary to balance each side of a two lane roadway, or both sides and the median of an interstate roadway separately, to minimize conflicts between traffic and earthmoving equipment.
- Typically, scrapers are used for hauling earthwork material distances less than one mile. If haul distances become longer, the earthwork may require a more expensive truck haul.
- Before the final earthwork is accepted, check the drainage for adequacy and modify to remove small “sliver” fills or shallow drainage ditches, etc.

## COMPUTER EARTHWORK SOFTWARE

**General:** There are basically two types of computer methods available that compute earthwork. One method uses a surface to surface volume calculation, and the other method calculates volumes using cross sections. The surface to surface type of programs are not used for roadway earthwork design because they do not calculate earthwork volumes between cross sections, mass curves, haul quantities, etc.

WYDOT uses GEOPAK computer software for roadway earthwork design, and GEOPAK uses the same basic concepts as presented in this chapter. Note that this chapter only provides the reader with a basic understanding of the earthwork process. The designer should refer to the GEOPAK manual for guidance in coding and running the earthwork program.

## KEY USER GUIDELINES

**General:** This section provides the earthwork user with additional information that is applicable to added quantities, compaction factors, GEOPAK output reports, etc.

**Earthwork Reports:** Exhibits 15 and 16 are sample earthwork reports with key elements noted.

STATE ROAD 372 GREEN RIVER-FONTENELLE (FONTENELLE EAST) MAINLINE EARTHWORK RUN GRAND SUMMARY TOTAL				
Material Name		Unadjusted Volumes (cu. yd.)	Adjusted Volumes (cu. yd.)	Mult Factor
-----				
<b>SUIT_ GRADING</b>				
	Common Exc	1- 238902	238902	1.00
	Subgrade Exc	2- 20551	20551	1.00
	Subsoil Exc	0	0	1.00
	Fill	3- 216204	4- 259453	1.20
<b>TOPSOIL</b>				
	Common Exc	23305	23305	1.00
	Subgrade Exc	5- 2922	2922	1.00
	Subsoil Exc	25160	25160	1.00
	Fill	0	0	1.00

**NOTES;**

- 1- TOTAL ROADWAY EXCAVATION VOLUME, CY
- 2- TOTAL MOISTURE DENSITY CONTROL (MDC) VOLUME, CY  
1 + 2(ROADWAY EXC + MDC) = TOTAL PROJECT EXCAVATION, CY
- 3- TOTAL EMBANKMENT VOLUME, CY
- 4- TOTAL VOLUME OF FILL MATERIAL X SHRINK FACTOR = TOTAL FILL, CY  
REQUIRED TO CONSTRUCT EMBANKMENT
- 5- TOTAL TOPSOIL STRIPPING QUANTITY = 23305+2922+25160=51387, CY

### EXHIBIT 15

#### GRAND SUMMARY EARTHWORK REPORT

STATE ROAD 372  
GREEN RIVER-FONTENELLE (FONTENELLE EAST)  
MAINLINE EARTHWORK RUN  
BALANCE POINT SUMMARY

Material Name	Cumulative		Incremental		Mult Factor	
	Unadjusted Volumes (cu. Yd.)	Adjusted Volumes (cu. Yd.)	Unadjusted Volumes (cu. Yd.)	Adjusted Volumes (cu. Yd.)		
<b>Station = 1838+74.45 Region 1</b>						
SUIT_GRADING						
EARTHWORK BALANCE RANGE	Common Exc	4946	4946	4964	4946	1.00
	Subgrade Exc	2678	2678	2678	2678	1.00
	Subsoil Exc	0	0	0	0	1.00
	Fill	6354	7624	6354	7624	1.20
TOPSOIL						
BALANCE POINT	Common Exc	1616	1616	1616	1616	1.00
	Subgrade Exc	237	237	237	237	1.00
	Subsoil Exc	642	642	642	642	1.00
	Fill	0	0	0	0	1.00
<b>Station = 1839+00.56 Region 1</b>						
SUIT_GRADING						
EARTHWORK BALANCE RANGE	Common Exc	5261	5216	270	270	1.00
	Subgrade Exc	2729	2729	51	51	1.00
	Subsoil Exc	0	0	0	0	1.00
	Fill	6621	7945	267	321	1.20
TOPSOIL						
BALANCE POINT	Common Exc	1658	1658	42	42	1.00
	Subgrade Exc	239	239	2	2	1.00
	Subsoil Exc	662	662	20	20	1.00
	Fill	0	0	0	0	1.00
<b>Station = 2007+28.34 Region 1</b>						
SUIT_GRADING						
EARTHWORK BALANCE RANGE	Common Exc	109744	109744	104528	104528	1.00
	Subgrade Exc	9709	9709	6980	6980	1.00
	Subsoil Exc	0	0	0	0	1.00
	Fill	99544	119453	92923	111508	1.20
TOPSOIL						
BALANCE POINT	Common Exc	11177	11177	9519	9519	1.00
	Subgrade Exc	1724	1724	1485	1485	1.00
	Subsoil Exc	13991	13991	13329	13329	1.00
	Fill	0	0	0	0	1.00
<b>Station = 2011+36.98 Region 1</b>						
SUIT_GRADING						
EARTHWORK BALANCE RANGE	Common Exc	111235	111235	1491	1491	1.00
	Subgrade Exc	9750	9750	41	41	1.00
	Subsoil Exc	0	0	0	0	1.00
	Fill	100821	120985	1277	1532	1.20
TOPSOIL						
BALANCE POINT	Common Exc	11558	11558	381	381	1.00
	Subgrade Exc	1758	1758	34	34	1.00
	Subsoil Exc	14300	14300	309	309	1.00
	Fill	0	0	0	0	1.00
<b>Station = 2015+30.05 Region 1</b>						
SUIT_GRADING						
EARTHWORK BALANCE RANGE	Common Exc	112873	112873	1638	1638	1.00
	Subgrade Exc	9799	9799	49	49	1.00
	Subsoil Exc	0	0	0	0	1.00
	Fill	102227	122673	1406	1688	1.20
TOPSOIL						
BALANCE POINT	Common Exc	12002	12002	444	444	1.00
	Subgrade Exc	1798	1798	40	40	1.00
	Subsoil Exc	14587	14587	287	287	1.00
	Fill	0	0	0	0	1.00

CUMULATIVE EMB. VOLUME  
CUMULATIVE EMB. INCLUDING SHRINK

EMB. VOLUME INCLUDING SHRINK  
EMB. VOLUME WITHIN BALANCE

**EXHIBIT 16**  
MAINLINE EARTHWORK REPORT

**Added Quantities in GEOPAK:** Quantity adjustments to the earthwork can be coded as plus or minus cut or fill quantities at specified point locations. The added quantity directly adjusts the mass curve from the point of entry forward to the end of the project. This also changes all the balance points and haul calculations from the point entered forward to the end of project. It is common practice to add quantities to the mass curve to construct additional roadway features such as approaches, parking areas, guardrail widening, median cross-overs, earthwork for special message signs, adding borrow, wasting fill, etc. The computer program considers the excavation as a positive number and fill as a negative number.

***Not understanding how added quantities affect the earthwork can result in a costly mistake.*** For example, if the project earthwork shows 10,000 CY of extra excavation and the designer coded in an added quantity of -10,000 CY of excavation, the computer would adjust quantities and the designer may think that the earthwork is now balanced and the associated quantities list is correct. The next logical step would be for the designer to use these quantities to create an earthwork summary and pay quantity for the bid item Unclassified Excavation. However, the Unclassified Excavation pay item would be short by 10,000 CY because the computer program would also deduct the negative added quantity from the accumulated earthwork total. The contractor still needs to move this material, but there is no pay quantity for the work being performed. If the designer would have coded this as an added fill quantity to waste the material, the project would still balance, and the 10,000 CY would have been included in the excavation pay item.

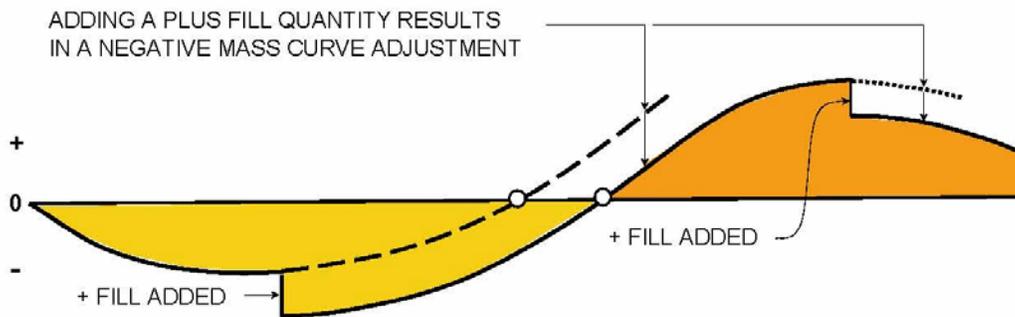
WYDOT Standard Specifications (effective at the time of this chapter's publication) call for general earthwork quantities on road construction projects to be measured and paid for as the volume of Unclassified Excavation removed from its original place. Other earthwork quantities that are incidental to the pay item Unclassified Excavation, such as placing embankment, haul, etc., are included in the plans for bid estimating purposes only.

Follow these general rules when added quantities are used:

- Use positive cut and fill added quantities as needed to adjust the earthwork and associated pay item Unclassified Excavation.
- Negative added cut and fill quantities should not be used unless the removed quantity is paid for by some other means.

The following is an example of how the added quantities affect the mass curve, balance points, haul, and summary totals:

**Positive Embankment (Fill):** Adding a positive embankment (fill) quantity will result in adjusting the mass ordinate in a negative direction. If the mass ordinate is a negative -1500 CY and 300 CY of approach fill material is added, GEOPAK will adjust the mass ordinate to -1800 CY, and if the mass ordinate is a positive +1500 CY, then the mass ordinate is adjusted to +1200 CY. Note that in both cases the mass curve adjustment is in the negative direction and the balance point is adjusted as shown in Exhibit 17.

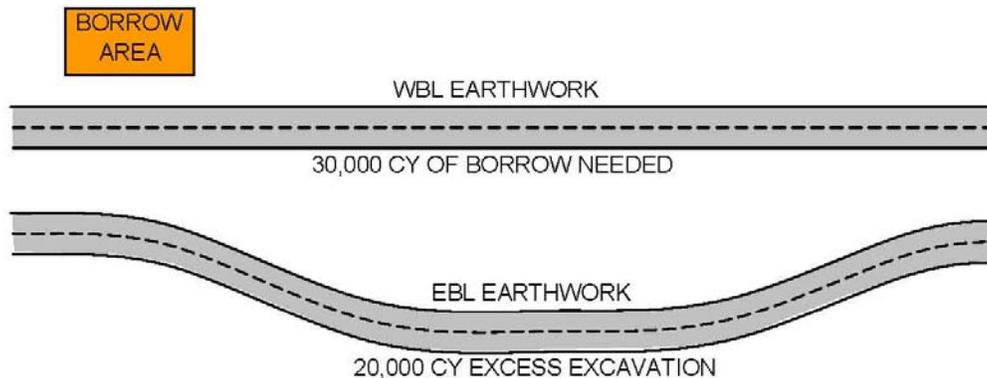


**EXHIBIT 17**  
ADDED FILL AFFECT ON MASS CURVE

**Negative Embankment (Fill):** Adding a negative fill quantity adjusts the mass ordinate in the positive direction. This option is generally used only in special cases to void a specific area so that it can be filled using a different pay item such as Drain Rock, etc.

**Positive and Negative Excavation (Cut):** Adding a positive cut quantity adjusts the mass ordinate in a positive direction, and adding a negative cut will adjust the mass ordinate in a negative direction. Positive added quantities generally include quantities for approaches, ponds, parking areas, borrow areas, etc. However, a negative added cut quantity should be used with caution because excavation is a pay quantity, and the earthwork program will subtract a negative added quantity from the total project excavation. There are special circumstances when the designer would use a negative added cut quantity to remove material that would be paid for under a different bid item or as an added quantity in a separate earthwork.

Assume a scenario where the designer is working on an interstate project with separated earthwork runs on the EBL and WBL. Also, assume the EBL has 20,000 CY of excess cut and the WBL requires 30,000 CY of borrow material as shown in Exhibit 18:



**EXHIBIT 18**  
EARTHWORK AND ADDED QUANTITIES

In this case, the designer wants to use the excess excavation from the EBL as borrow material for the WBL. This would be a special circumstance where the designer would use a negative added cut quantity of 20,000 CY to remove material from the EBL earthwork and use a positive added cut quantity of 20,000 CY to add the material to the WBL earthwork. The borrow material needed for the WBL has now been reduced to 10,000 CY, which will come from a borrow area and be added to the WBL earthwork by coding a positive added cut quantity of 10,000 CY.

The total pay item for Unclassified Excavation is correct because the WBL earthwork accounts for the 20,000 CY of cut material removed from the EBL earthwork.

**Using Shrink or Swell Factors in GEOPAK:** As stated in the EARTHWORK VOLUMES section of this chapter, the density of compacted embankment is different than the density of excavated material. This difference is accounted for in the earthwork process by the use of shrink and swell factors applied to the embankment.

GEOPAK's initial process allows only one compaction factor to be used for each soil type represented by the cross-section graphics, which works for the majority of projects.

**Multiple Compaction Factors:** Projects that include multiple compaction factors can be handled as a Three-step GEOPAK Process or as a Spreadsheet Process that require the GEOPAK quantities to be copied into an Excel spreadsheet so that the different shrink factors can be applied. The following outlines the GEOPAK and spreadsheet method of earthwork manipulation necessary to apply multiple compaction factors:

**GEOPAK Three-step Process For Multiple Compaction Factors:** This example project begins at Station 76+50 and ends at Station 123+00. The Geology Program provides the compaction factors and the station ranges where excavated material with those factors are expected to be found. For example, the Soils Profile indicates that any cut that occurs from Stations 82+00-96+00 and 103+00-123+00 will primarily consist of rock materials and will swell 10 percent (**embankment** compaction factor = 0.90). The remaining material will have a shrink factor of 20% (**embankment** compaction factor = 1.20).

**Step 1** The earthwork is processed in the normal manner through GEOPAK with no compaction factors applied to either excavation or embankment. Once the log file has been created through this process, the Earthwork Tools can be used to include multiple compaction factors in the earthwork computations.

**Step 2** Load the log file created in Step 1, and choose the Multi-factor table option. At this point there are different types of material being excavated at each cross-section location. This means that the inverses of the shrink and swell factors are applied to the **excavation** quantity rather than the embankment. For the materials described above, the factors applied to **excavation** volumes will be  $1/1.2 = 0.83$  for soil and  $1/0.9 = 1.11$  for rock. The resulting **excavation** compaction factor table for this project is shown in Exhibit 19.

Begin Station	End Station	Common	Excavation	Subsoil	Subgrade	Fill
76+50.00 R 1	81+50.00 R 1	0.00	0.83	0.00	0.83	1.00
82+00.00 R 1	96+00.00 R 1	0.00	1.11	0.00	1.11	1.00
96+50.00 R 1	102+50.00 R 1	0.00	0.83	0.00	0.83	1.00
103+00.00 R 1	123+00.00 R 1	0.00	1.11	0.00	1.11	1.00

Soil: SUIT\_GRADING    Begin Station: 96+50.00 R 1    End Station: 102+50.00 R 1

Common: 0.00    Excavation: 0.83    Subsoil: 0.00    Subgrade: 0.83    Fill: 1.00

Apply

**EXHIBIT 19**  
GEOPAK MULTIPLE FACTOR TABLE

Once the compaction factor table is completed, the Apply and Calculate Volumes buttons can be selected, and a new log file can be created (i.e., Ewexcfact.log).

The resulting Grand Summary Totals and Balance Point Summary output tables are given below. From the quantities shown below, the final mass ordinate is +306 CY (a balanced project, for practical purposes).

G R A N D S U M M A R Y T O T A L S				
Material Name	Unadjusted Volumes (cu. ft.)	Adjusted Volumes (cu. ft.)	Multi Factor	
-----				
SUIT_GRADING				
Common Exca	0	0	0.00	
Excavation	17817	19111	1.07	
Subsoil Exca	0	0	0.00	
Subgrade Exca	0	0	0.00	
Fill	18805	18805	1.00	
TOPSOIL				
Common Exca	0	0	0.00	
Excavation	8279	8279	1.00	
Subsoil Exca	0	0	0.00	
Subgrade Exca	0	0	0.00	
Fill	0	0	0.00	
-----				
B A L A N C E P O I N T S U M M A R Y				
Material Name	Unadjusted Volumes (cu. ft.)	Adjusted Volumes (cu. ft.)	Multi Factor	
-----				
Station = 78+45.86 , Region 1				
SUIT_GRADING				
Common Exca	0	0	0.00	
Excavation	219	182	0.83	
Subsoil Exca	0	0	0.00	
Subgrade Exca	0	0	0.00	
Fill	182	182	1.00	
TOPSOIL				
Common Exca	0	0	0.00	
Excavation	307	307	1.00	
Subsoil Exca	0	0	0.00	
Subgrade Exca	0	0	0.00	
Fill	0	0	0.00	
Station = 88+65.89 , Region 1				
SUIT_GRADING				
Common Exca	0	0	0.00	
Excavation	2081	1847	0.89	
Subsoil Exca	0	0	0.00	
Subgrade Exca	0	0	0.00	
Fill	1847	1847	1.00	
TOPSOIL				
Common Exca	0	0	0.00	
Excavation	1866	1866	1.00	
Subsoil Exca	0	0	0.00	
Subgrade Exca	0	0	0.00	
Fill	0	0	0.00	
0.00				
Station = 122+91.07 , Region 1				
SUIT_GRADING				

Common Exca	0	0	0.00
Excavation	17532	18795	1.07
Subsoil Exca	0	0	0.00
Subgrade Exca	0	0	0.00
Fill	18795	18795	1.00
TOPSOIL			
Common Exca	0	0	0.00
Excavation	8251	8251	1.00
Subsoil Exca	0	0	0.00
Subgrade Exca	0	0	0.00
Fill	0	0	0.00

Notice that the calculated effective compaction factor for excavation given in the GEOPAK output is based on the **accumulated** excavation and embankment volumes and not the volumes in the individual balances.

The effective compaction factor for **embankment** within each particular balance is calculated by dividing the unfactored excavation quantity in each balance range by the unfactored fill quantity in each range. These will be the **embankment** compaction factors used in Step 3.

For example, the effective compaction factor for **embankment** between the balance points at Station 88+65.89 and 122+91.07 is calculated as:

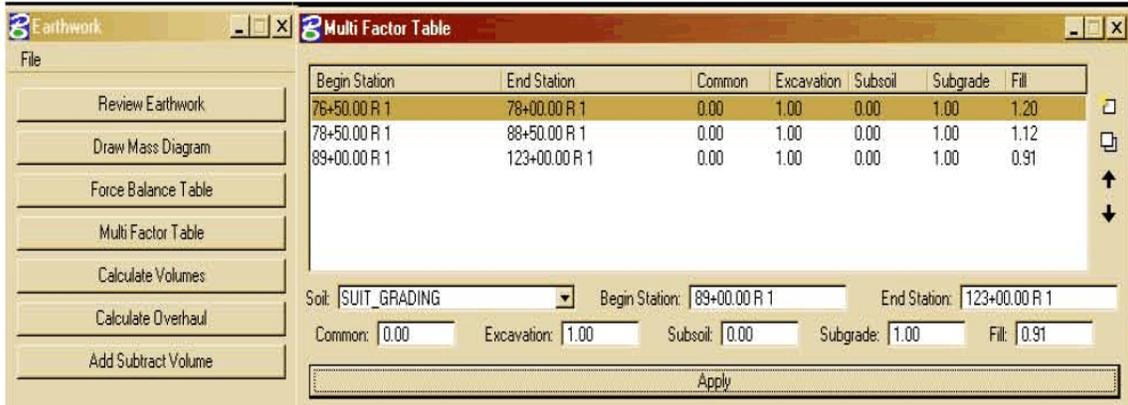
$$(17532 - 2081) \div (18795 - 1847) = 0.912$$

As expected, the effective embankment compaction factor for this balance is close to 0.90 because rock-type material is located over a significant portion of this area (Sta. 88+66± to Sta. 96+00 and Sta. 103+00 to Sta. 122+91).

**Step 3** To ensure that the log file being processed is created with no compaction factors, load the original log file from Step 1. If only one line comes up and shows factors of 1.0, then the correct file is being used.

Apply the effective **embankment** compaction factor that was calculated in Step 2 to the fill in the station ranges of the balances determined in Step 2. Note that GEOPAK does not allow stations that are not included in the log file to be keyed in, so stations are adjusted to the closest station available. This may result in minor changes in the balance locations and in the effective embankment compaction factors determined in Step 2.

Exhibit 20 shows the calculated effective embankment factor table to be applied to the new log file (ie. Ewfillfact.log).



**EXHIBIT 20**  
GEOPAK MULTIPLE FACTOR TABLE

The Grand Summary Totals and Balance Point Summary output tables resulting from the effective embankment compaction factors are shown below.

Multi Factor	G R A N D Material Name	S U M M A R Y	
		Unadjusted	Adjusted
		Volumes	Volumes
		(cu. ft.)	(cu. ft.)
-----			
	SUIT_GRADING		
	Common Exca	0	0
	Excavation	17817	17817
	Subsoil Exca	0	0
	Subgrade Exca	0	0
	Fill	18805	17516
	TOPSOIL		
	Common Exca	0	0
	Excavation	8279	8279
	Subsoil Exca	0	0
	Subgrade Exca	0	0
	Fill	0	0
-----			
Multi Factor	B A L A N C E Material Name	P O I N T S U M M A R Y	
		Unadjusted	Adjusted
		Volumes	Volumes
		(cu. ft.)	(cu. ft.)
-----			
	Station = 78+42.59 , Region 1		
	SUIT_GRADING		
	Common Exca	0	0
			0.00

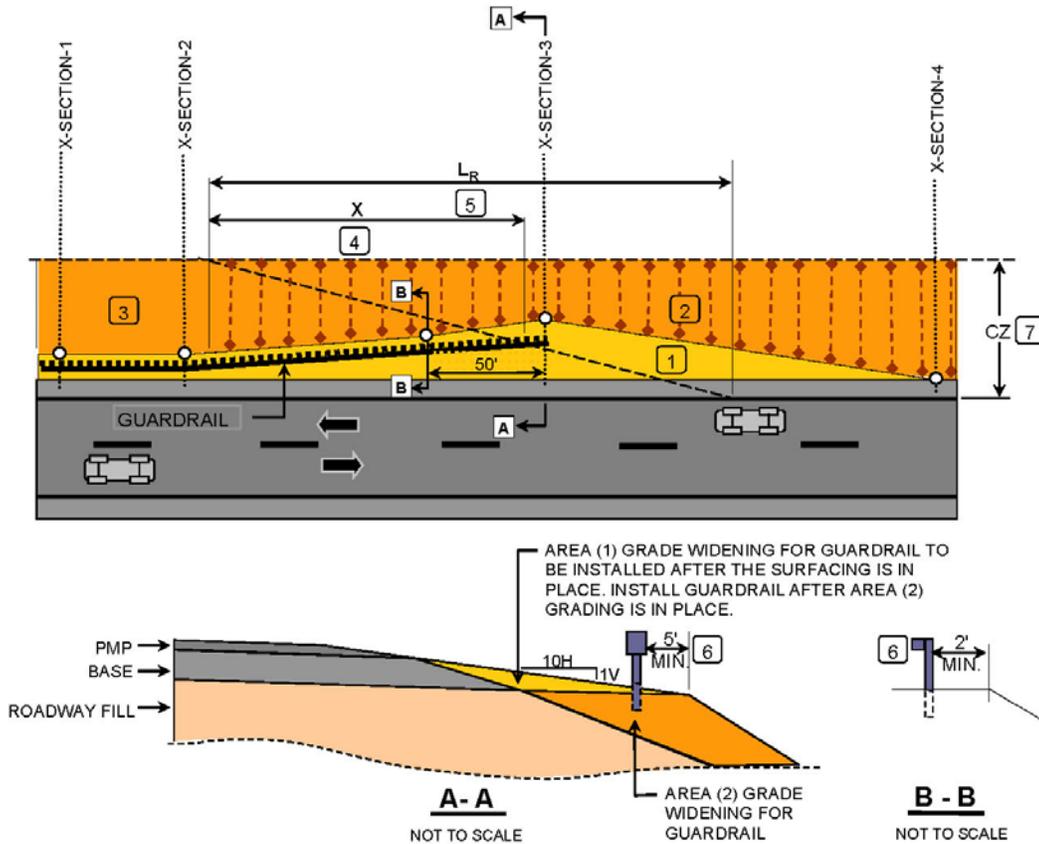
	Excavation	212	212	1.00
	Subsoil Exca	0	0	0.00
	Subgrade Exca	0	0	0.00
	Fill	179	212	1.18
	TOPSOIL			
	Common Exca	0	0	0.00
	Excavation	301	301	1.00
	Subsoil Exca	0	0	0.00
	Subgrade Exca	0	0	0.00
	Fill	0	0	0.00
Station = 88+70.30 , Region 1	SUIT_GRADING			
	Common Exca	0	0	0.00
	Excavation	2083	2083	1.00
	Subsoil Exca	0	0	0.00
	Subgrade Exca	0	0	0.00
	Fill	1882	2083	1.11
	TOPSOIL			
	Common Exca	0	0	0.00
	Excavation	1874	1874	1.00
	Subsoil Exca	0	0	0.00
	Subgrade Exca	0	0	0.00
	Fill	0	0	0.00
Station = 122+90.26 , Region 1	SUIT_GRADING			
	Common Exca	0	0	0.00
	Excavation	17506	17506	1.00
	Subsoil Exca	0	0	0.00
	Subgrade Exca	0	0	0.00
	Fill	18794	17506	0.93
	TOPSOIL			
	Common Exca	0	0	0.00
	Excavation	8249	8249	1.00
	Subsoil Exca	0	0	0.00
	Subgrade Exca	0	0	0.00
	Fill	0	0	0.00

Note that the balance points are changed by  $\pm 3$  feet. This difference is caused by the number of significant figures and approximate station ranges used for the effective compaction factors, etc.

The final earthwork log file produced with this example can be used with the Mass Haul Diagram within GEOPAK, and the effective embankment compaction factors can be given in the Grading Summary.

**Spreadsheet Process For Multiple Compaction Factors:** The process for using a spreadsheet is basically the same as that outlined above and involves manipulating actual excavation volumes and embankment volumes from the initial GEOPAK output, along with variable compaction factors, in the three-step process described in this chapter. Additionally, incremental Haul and total Haul for each balance can be calculated and a mass haul diagram can be produced using spreadsheet software such as Excel.

**Widening for Guardrail:** Once the design has progressed to where the guardrail placement is known, the designer will have to rerun the earthwork to include the guardrail grading. Exhibit 21 shows typical grade widening for guardrail.



- 1 CRITICAL AREA APPROACHING THE GUARDRAIL THAT REQUIRES A 1V:10H SURFACE OR FLATTER.
- 2 UNPROTECTED AREA THAT REQUIRES TRAVERSABLE SLOPES OF 1V:4H OR FLATTER.
- 3 GUARDRAIL PROTECTED AREA WHERE TRAVERSABLE SLOPES ARE NOT REQUIRED.
- 4 TRAVERSABLE SLOPES NEED TO EXTEND "X" DISTANCE BEYOND THE POST 3 OF TERMINAL END.
- 5  $L_R$  = RUNOUT LENGTH, PER ROADWAY DESIGN SPEED & ADT.
- 6 SECTION A-A: A MIN. DISTANCE OF 5 FT. TO THE FILL SLOPE HINGE POINT IS REQUIRED TO KEEP VEHICLES ALIGNED WHEN IMPACTING THE TERMINAL END. AT SECTION B-B: (50± FT. FROM THE TERMINAL END) A MINIMUM DISTANCE OF 2 FT. FROM OF THE BACK OF THE GUARDRAIL POST TO THE FILL SLOPE HINGE POINT IS REQUIRED FOR POST STABILITY.
- 7 CZ = CLEAR ZONE WIDTH PER ROADWAY DESIGN SPEED/ADT.

**EXHIBIT 21**  
WIDENING FOR GUARDRAIL

To ensure the grade widening is staked and constructed correctly, add x-sections at the beginning, at break points, and each end of the widening section. Note that Area (2) grade widening is staked and constructed as part of the overall roadway embankment and is paid for as Unclassified Excavation, but the top 1V:10H final slope portion of the widening, shown as Area (1), must be constructed after the surfacing is in place. At this point in the construction process, embankment fill material may not be readily available; therefore, Area (1) will most likely be constructed with a suitable material, such as crushed base, pit run base, mill tailing, etc., after the surfacing material is in place.

**Graphically Fixing Slopes:** GEOPAK uses slope criteria to establish the roadway cut and fill slopes with the option for the designer to review and modify individual slopes graphically on screen. The graphical slope modification process allows the designer to quickly make slope modifications to a specific earthwork. Use this feature with caution because all the graphically changed slopes will be lost if the grade line needs to be changed and the earthwork needs to be rerun. It is very easy for designers to make the mistake of spending several hours refining the earthwork slopes graphically and then find out all this work is lost due to a grade change that requires the earthwork to be rerun. It is best to use criteria to refine the majority of earthwork slopes and keep the use of graphically modified slopes to a minimum.

## **GUIDELINES FOR SNOW DRIFTING**

**General:** The designer has the option to mitigate snow drifting problems by applying specific criteria to the roadway geometric design and earthwork cross sectional elements. Typically earthwork modification for snow mitigation is more costly than other methods, such as installing snow fence. However, if reconstruction is an option, then apply the following guidelines to mitigate snow drifting in problem areas that are identified by the District in terms of prevailing wind direction and station range.

AASHTO standard geometric design and WYDOT guidelines govern over slope modification for snow drifting.

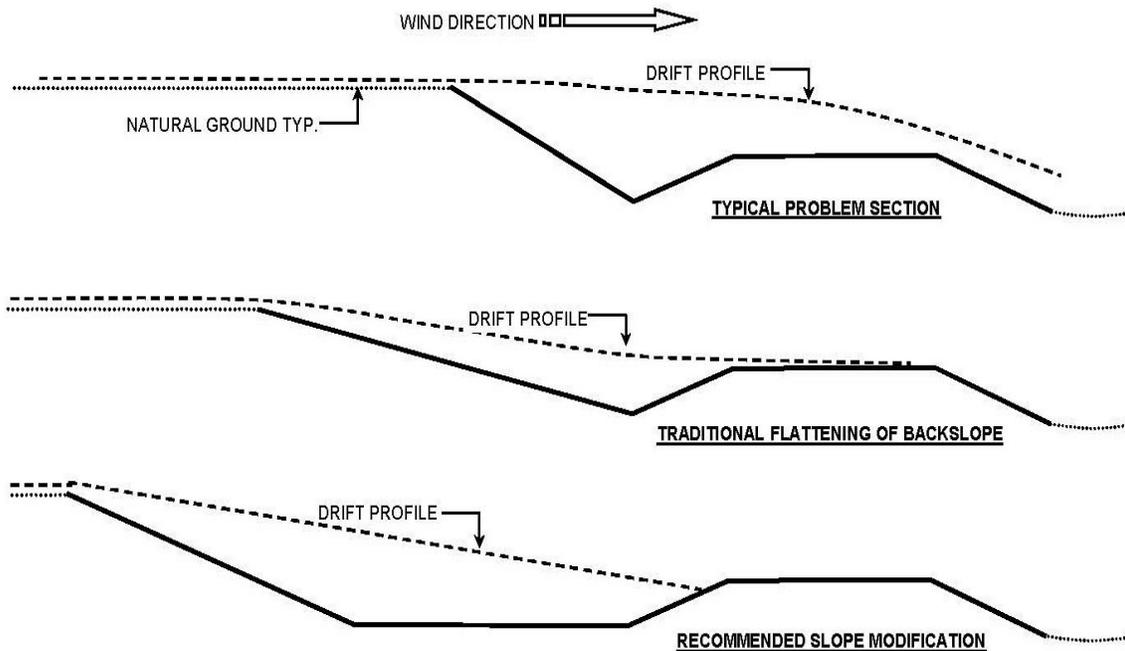
**Road Surface Elevation:** It may be desirable to elevate the road surface above the mean annual snow depth, with allowance for storing plowed snow. Use a 1V:4H frontslope if possible to help keep the plowed snow accumulation below the shoulder.

The minimum height ( $H_c$ ) of the road surface above the surrounding terrain is given by:  $H_c = 0.4 \times S + 1.958$  (ft) Where: S = Mean annual snow fall. (ft)

**Barn Roof Section:** Using a barn-roof section with 1V:6H frontslope will reduce snow drifting on the roadway surface as opposed to flatter slopes.

**Median Section:** When the opposing lanes of a divided highway are separated by a narrow median, the downwind lane should be at the same elevation or slightly higher than the upwind lane. As the median width ( $W$ ) increases, the downwind lane can be as much as  $0.04 \times W$  below the upwind lane without drift encroachment. However, it may be necessary to keep the opposing lanes at the same elevation so that the median can be constructed with uniform slopes to locate the ditch bottom in the center of the median to accommodate the placement of median barrier.

**Roadway Cuts:** Snow drifting across the roadway surface in cut areas can be eliminated by flattening or modifying the upwind back slope to allow the wind to form an equilibrium drift that tails out below the shoulder of the road. The following scenario shows the typical problem section, the traditional flattening of backslopes, and a recommended backslope modification section.



**EXHIBIT 22**  
CROSS-SECTION SCENARIO WITH SNOW DRIFTING

Note that the traditional flattening of backslopes reduces the amount of snow drifting on the roadway, but does not fully eliminate the drifting problem. Designers should strive to use the “Recommended Option” to fully eliminate drifting on the roadway.

**Cut Slope Configuration to Prevent Snow Drift Encroachment:** For unclassified **side hill cuts (not rock)** the distance from the shoulder to the top of the cut can be calculated as:

$$W_{\text{TOP}} = 95.144 + (5.8 \times H_c \times \sin \alpha) \text{ ft}$$

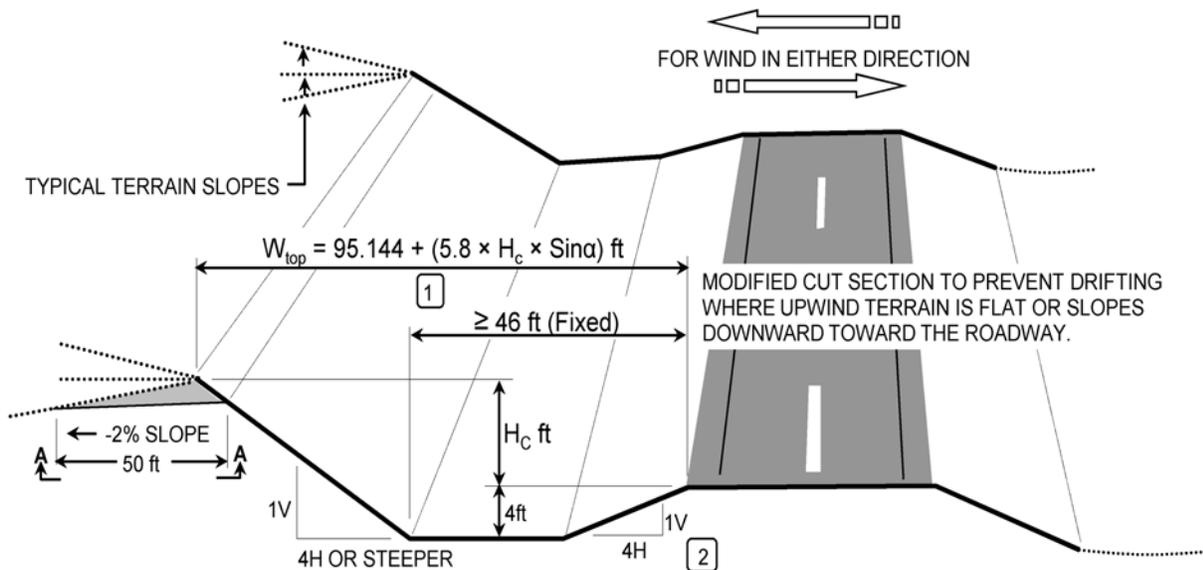
Where:

$W_{\text{TOP}}$  = distance (in feet) from the pavement edge to the top of the cut slope.

$H_c$  = depth of cut (in feet) measured from the roadway surface to the top of cut.

$\alpha$  = acute angle between the road centerline and the prevailing wind direction.

The equation assumes a 4 ft [1.2m] minimum ditch depth consisting of a 1V:4H fixed foreslope and trapezoidal ditch that extends a fixed distance of 46 ft [14m] from the pavement edge to the back of the ditch or toe of backslope, with a 1V:4H or steeper backslope. Note that snow storage increases when steeper backslopes are used.



**SECTION A - A** WHEN THE TERRAIN SLOPES UPWARD TOWARDS THE CUT, EXCAVATE A NEAR HORIZONTAL SURFACE FOR AT LEAST 50 ft UPWIND OF TOP OF BACKSLOPE.

- 1 IN THROUGH-CUT SECTIONS WHERE THE AREA IS SUBJECT TO SNOW DRIFTING FROM EITHER DIRECTION, APPLY THE SLOPE MODIFICATION TO CUT SLOPES ON BOTH SIDES OF THE ROADWAY.
- 2 THE USE OF A 1V:4H FORESLOPE IS THE OPTIMUM SLOPE FOR SNOW STORAGE, HOWEVER SLOPES OF 1V:6H OR FLATTER SHOULD BE USED ADJACENT TO THE ROADWAY TO IMPROVE ROADSIDE SAFETY. IT SHOULD BE NOTED THAT THE USE OF FLATTER SLOPES WILL DECREASE SNOW STORAGE.

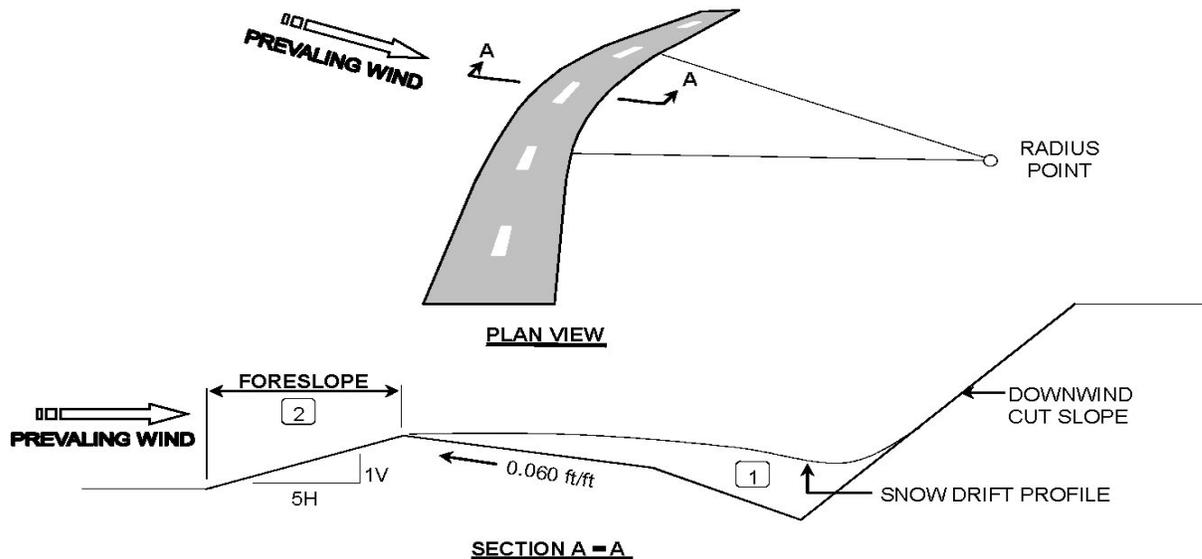
### EXHIBIT 23

#### CUT SLOPE MODIFICATION FOR SNOW DRIFT CONTROL

Slope Modifications To Reduce Snow Drifting: (Tabler 1993)

- A 1V:4H foreslope is recommended.
- Minimum ditch depth: 4 ft [1.2 m]
- Minimum distance from edge of shoulder to the ditch bottom (toe of backslope): 46 ft [14 m]
- If needed to accommodate drainage the trapezoidal ditch shown can be replaced with a wide U or V- shaped ditch section.
- Snowdrift prevention through modification of cross-section slopes or roadway geometry is most cost effective for shallow cuts.

**Superelevation Drifting Problems:** The combination of prevailing wind direction, foreslope, and superelevation drop across the road surface can create serious drifting problems when a sidehill cut is on the inside of a curve, as shown below:



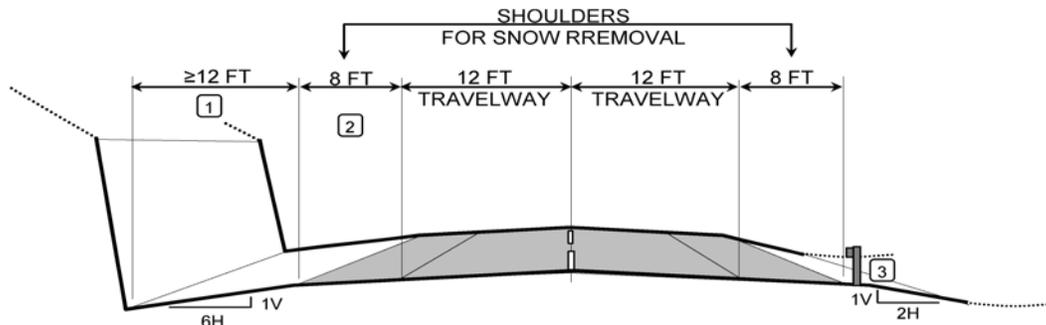
- 1 SNOW DRIFTING CAUSED BY THIS CONFIGURATION OF PREVAILING WIND, SUPERELEVATION, WINDWARD FORESLOPE, AND A SIDEHILL CUT.
- 2 FLATTING THE FORESLOPE WILL REDUCE OR ELIMINATE DRIFTING ACROSS THE ROADWAY. THE OPTIMUM SLOPE IS GIVEN BY:

STEEPEST FORESLOPE =  $1 \div (0.18 + \text{SUPER SLOPE})$   
 OR IN THIS EXAMPLE: THE SLOPE =  $1 \div (0.18 + 0.060) = 1\text{V}:4.2\text{H}$   
 (ROUNDED TO A 1V:5H SLOPE)

### EXHIBIT 24

LOW SIDE OF SUPERELEVATED ROADWAY IN CUT SECTION

**Snow Management For Rock Cuts:** The following slope configuration for snow management and drifting is recommended in rock cuts.



- 1 A MINIMUM DITCH WIDTH OF 12 ft PROVIDES SPACE TO CONTAIN SNOW SLIDING OFF OF BACKSLOPE AND TO STORE SNOW REMOVED FROM THE ROADWAY OVER THE COURSE OF A STORM. USE A 1V:6H DITCH FORESLOPE SO THAT EQUIPMENT CAN BE OPERATED ON THE SLOPE TO REMOVE EXCESS SNOW.
- 2 A MINIMUM OF 8 ft PAVED SHOULDERS (SNOW LANE) ARE REQUIRED FOR HIGH SPEED SNOW PLOWS TO DISPLACE THE SNOW BERM FARTHER AWAY FROM THE TRAVELWAY, WHICH REDUCES THE TENDENCY FOR SNOW BLOWING DOWN THE ROADWAY TO ACCUMULATE ON THE TRAVELWAY. IT ALSO ALLOWS EXTRA WIDTH TO PASS SNOW PLOWS AND PROVIDES FOR ROCKFALL PROTECTION.
- 3 PLACE SAFETY BARRIER AS FAR FROM THE PAVEMENT EDGE AS BARRIER TYPE AND TOPOGRAPHY WILL PERMIT.

### EXHIBIT 25

#### CROSS-SECTION FOR SNOW MANAGEMENT

## BARRIERS AND SNOW DRIFTING

**General:** Safety barriers compound the blowing snow issues. Although barriers are necessary to protect the motorist from roadside hazards or opposing traffic encroachments, they do have a propensity to drift snow onto the roadway and/or decrease visibility when blowing snow accelerates over the top of less porous barriers. Barriers can also hinder snow removal operations. Generally, a smaller overall cross-section of the barrier perpendicular to the wind will provide the most streamlined profile to reduce snow deposition. There are a number of safety considerations which must be factored into barrier selection. In terms of blowing snow, the following options are prioritized below:

1. Eliminate or reduce the length of guardrail by mitigating the hazard requiring its use.
2. For median installations, use cable barriers when practical.
3. For shoulder installations, use box-beam barriers when practical.
4. Avoid the combination of barriers and curbs when practical.
5. Use concrete barriers only when barrier performance issues dictate their use.