Application of Shrinkage and Swelling Factors on State Highway Construction

by

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Abstract

The objectives of the research were to review the state of practice for roadway related earthwork calculations for the southeastern states, develop a calculation tool for comparing various state earthwork methods, demonstrate and compare earthwork calculations methods used in southeastern state departments of transportation (DOTs), and evaluate shrinkage and swelling factors used in southeastern state DOTs. The southeastern states being observed in this research are Alabama, Florida, Georgia, North Carolina, South Carolina, and Tennessee.

First, a background study and literature review was conducted on earthwork calculation methods including shrinkage and swell factors. This study included various southeastern state DOT methods in the United States. Next, an analysis tool was developed. This spreadsheet tool was used for the comparison of earthwork methods and the evaluation of the impact of shrinkage and swell factors. The analysis tool aided in the final aims of the project by using a case study. The state earthwork methods were calculated using the analysis tool which allowed for analysis and comparisons to be made. Finally, from observations of the research and an evaluation of the results of the case study allowed for conclusions to be made based on the findings.

The research concluded:

1. The method by which southern states determine earthwork quantities varies from state-state, and can result in a vast difference when compared side-by-side.
2. The differences in earthwork quantities are substantial between southeastern state DOT methods. This was due to whether or not a swell factor is applied to earthwork (some

DOTs do not use swell factors) or a result of the shrink factor(s) applied to state earthwork calculations (different DOTs use different factors depending on soil type).

3. The shrinkage and swelling factors have a wide range for soils which are typical in the southeastern United States. From the values in this research, typical ranges for general soil types in the this southeastern region of the United States were found to vary. Shrink percentage ranges from 10-18 % for clays, 11-35 % for sands, 20-25 % for residuals, and 5-22 % for rocky, gravely soils. Swell percentage ranges from 30-50 % for clays, 3-45 % for sands, and 5-40% for rocky, gravely soils. No specific swell percentages were discovered for residual soils in the course of this research.
4. Most southeastern state DOTs do not provide a guide for their typical shrinkage and swelling factors. It appears that earthwork is left at the risk of the contractor.
5. Application of swell percentages was inconsistent among the various DOT earthwork calculation methods.
6. The inclusion and definition of rock (drillable rock or at auger refusal) has a large impact on earthwork calculations using the southeastern DOT earthwork methods.

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List of Abbreviations

ALDOT	Alabama Department of Transportation
BF	Bulkage Factor (Also referred to as swelling factor)
DOT	Department of Transportation
FDOT	Florida Department of Transportation
GDOT	Georgia Department of Transportation
NCDOT	North Carolina Department of Transportation
PCC	Portland Cement Concrete
P.S.&E.	Plans, Specifications, and Estimates Bureau
SCDOT	South Carolina Department of Transportation
SF	Shrinkage Factor
SPT	Standard Penetration Test
TDOT	Tennessee Department of Transportation

Chapter 1:

Introduction

1.1 Overview

A large aspect of economic risk on roadway construction projects deals with the earthwork calculations. Risk in earthwork calculations results from borrow or waste material on a project that was not budgeted for prior to construction. Since soils and rocks have the ability to expand and contract volume during the process of cut, haul, and fill, they do not have a constant volume. Geotechnical materials are able to move and shift, producing more or less void space between their particles. Since material volume can vary, initial estimates of earthwork and mass hauls for a project often do not match the actual final quantities. Whether a project results in excess material that becomes waste, or a deficit of material that requires borrow to be brought in, both cases can result in increased project costs. Borrow or waste materials are quantified as cost per unit volume. These costs include excavation, transportation, and placement of the soil plus the material cost. Additional costs from unforeseen unbalanced earthwork come from hauling costs including transportation and labor, and location of the waste or borrow site(s). These additional costs post project construction are usually at the risk of the contractor. Unforeseen unbalanced earthwork is usually as a result of inaccurate earthwork estimations. In an effort to address the additional costs due to volume change of materials on-site that is unbudgeted for, this research aims to understand the methods involved in earthwork calculations and applications of the shrinkage and swelling factors.

Shrinkage and swelling factors account for the volume change on a project between the various stages of soil placement. Generally, soil shrinks when going from a loose state to a compacted state, and soil swells from the insitu soil state to a looser volumetric state. When conducting earthwork estimates, shrinkage and/or swelling factors are applied to the soils present in an attempt to compensate for changes in volumetric amounts.

It is important to note that shrink and swell in this research refers to this volume change in soils during construction. This volume change is due to the shifting of soil particles when a soil is unearthed, moved, and/or compacted. This is not referring to shrink/swell clays which have a high plasticity index. The volume of shrink/swell clays alters when there is a change in water content in the soil, and therefore varies insitu. The topic of discussion in this research, therefore, is the shrinking and swelling of soils in the excavation and placement processes during construction, not shrink/swell clays.

It is also important to note the use of different shrink and swell terms in this report. Shrinkage and swelling factors are the factors applied to earthwork calculations. The factors are used as conversions between different soil volumetric states. On the other hand, shrink and swell values refer to the potential of a soil to shrink and swell in volume. This potential is usually in the form of a percentage which can then be converted to a factor for use in earthwork calculations.

1.2 Objective

The objective of this research was to investigate methods for application of shrink and swell factors to earthwork estimates and make recommendations about shrink and swell factors used by departments of transportation (DOTs) in the southeastern United States. The goals of this report are to:

- Review the state of practice for roadway related earthwork calculations for the southeastern states
- Develop a calculation tool for comparing various state earthwork methods
- Demonstrate and compare earthwork calculations methods used in southeastern state DOTs
- Evaluate shrinkage and swelling factors used in southeastern state DOTs

1.3 Scope of Work

The objectives of this research were completed by:

- Conducting an extensive literature review on earthwork calculation methods including shrinkage and swell factors
- Developing a spreadsheet tool for the comparison of earthwork methods and evaluating the impact of shrinkage and swell factors
- Analyzing a case study applying each state earthwork methodology simultaneously
- Evaluating the results and making conclusions based on the findings

1.4 Limitations of the Research

There were limitations on this research and the conclusions made in the final chapter of this report. The first limitation is that the case study project does not have the final earthwork values after construction. Therefore final conclusions cannot be made on the accuracy of different methodologies when comparing earthwork calculation methods and evaluating shrinkage and swelling values. This research shows the various methods used and comparisons between methods; however, it does not conclude which methods are more effective. The second limitation is that not every state department of transportation in this research had a guide available which shows shrinkage and swelling values used by the state DOTs. Not knowing typical shrinkage and swelling values currently in use limited conclusions made for the shrink and swell factors used in the southeastern state DOTs.

Chapter 2:

Background and Literature Review

2.1 Introduction

In order to improve the application of shrinkage and swelling factors on highway projects, an understanding of the characteristics of these soils as well as their application to the design projects is required. While the construction industry recognizes the effect of volume change due to soil bulking on a job site, the uncertainty in the amounts of shrinkage and swelling result in financial risk. This is the result of inaccurate volume calculations during earthwork estimation, and therefore strains budgets. When estimating the amount of cut and fill, the potential for soil shrinkage and swelling of material must be taken into account; otherwise, volume calculations to and from the site will not be balanced. Having balanced earthwork calculations represents lessened waste of soil or less amount of borrow required to be hauled onto a project. A waste or borrow amount from unbalanced earthwork is an added expense to the project.

2.2 Shrinkage and Swelling of Soils

Soil shrinkage and swelling, as applied to earthwork design and calculations, can be defined as the volume change of soil when moved or distributed from one state to another within a project. Volume of soil varies from one soil state to another because of the cut and fill practices and mass hauls that take place on construction sites. This is because an amount of volume of varies depending on whether the soil is bank, loose, or compacted material (defined subsequently in Section 2.3). The difference in soil volume is based on whether the soil is undisturbed, excavated, or compacted for the project which relates to the soil state whether it is bank, loose, or compacted material, respectively. Shrink and swell factors are used in the earthwork calculations to account for the volume changes, shrinkage and swelling, of soils through excavation, transportation, and placement.

Laboratory tests and equations have been derived to predict the shrink and swell potential of a given soil. These models are then applied to the design procedures to estimate the amount of cut and fill required for a roadway section. The use of shrinkage and swelling factors and their application to earthwork calculations varies from state-to-state, and even with various projects, in the United States. Guidelines have been set by federal agencies for the roadway earthwork calculations and suggested shrinkage and swelling factors are supplied. On the other hand, these guidelines do not represent a standard; therefore, different states and agencies have differences in the earthwork practices and values. As seen in this section, and later sections of this chapter, the effects of shrinking and swelling soils make earthwork calculations increasingly complex.

2.3 Material States

The following terms are typically used for material states on roadway projects:

Bank material: Soil that is in its natural, or in situ, state before disturbance. The measurement of soil that is in its bank state is typically in bank cubic yards (bcy).

Loose material: Soil that has been disturbed and is no longer in its original state. Through the excavation and transportation processes, the soil has developed an increase in void volume and void ratio, e. The measurement of soil that is now in a loose state is measured at loose cubic yards (lcy).

Compacted material: Soil that has been compacted for use in construction projects. The geotechnical report will state specific compaction for each soil type on the site. This volumetric measurement is in compacted cubic yards (ccy).

Figure 1 demonstrates a visual representation of the various material states during construction.

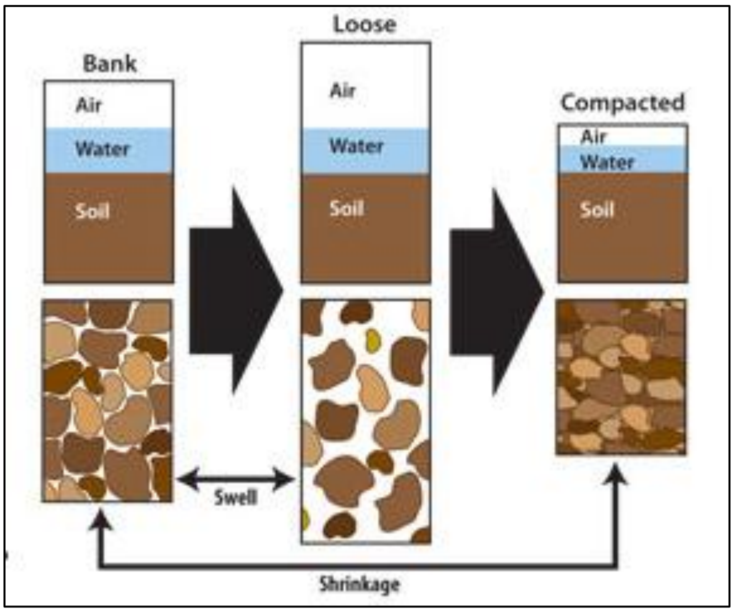

Figure 1. Visual display of material states (CEER 2013).

2.4 Shrinkage and Swelling Factors (or Percentages)

To estimate, more accurately, the amount of cut and fill for a project, shrinkage and swelling factors are used for converting the volume of soil between the various material states. According to Burch (1997), the shrinkage and swelling factors for each soil "consider the *combined* effects of: moisture content, density or unit weight (compacted versus loose) and soil type." However, different volumes (bank, loose, or compacted) are used in different phases of project design based on soil type, the current project timeline, and location within the project. To convert between the various stages of soil volume, the shrinkage and swelling factors or percentages are applied to cut/fill and excavation calculations.

In order to determine shrinkage and swelling factors, generally lab testing is performed for large projects while approximate conversion factors are used for smaller projects (Burch 1997). Lab testing is the most accurate way of determining shrink and swell potential of a soil. Tests for the unclassified excavation material include: moisture density test (Proctor Test), in-place density, and soil analysis (ALDOT 2003). However, it is not always economical to perform these tests on smaller, low budget projects. Therefore, suggested factors based on soil type are used. The amount of shrink percentage is typically between 15-20%, but can be as high as 40-50% (Bowman and Barksdale 2013). Deciding which factor to use then becomes an important step in the earthwork estimation process.

It is also important to understand the difference between shrinkage and swelling factors and percentages. Shrinkage and swelling factors come from the universal equation as described in Chopra (1999):

$$SF = \frac{V_E - V_C}{V_E} = 1 - \frac{\gamma_{d(E)}}{\gamma_{d(C)}} \quad \text{(Eq. 1)}$$

where,

SF = Shrinkage Factor

V_E = Volume of Excavated Material

V_C = Volume of Compacted Material

$\gamma_{d(E)}$ = Dry Unit Weight of Excavated Material

$\gamma_{d(C)}$ = Dry Unit Weight of Compacted Material

$$BF = \frac{V_L - V_E}{V_E} = \frac{\gamma_{d(E)}}{\gamma_{d(L)}} - 1 \quad \text{(Eq. 2)}$$

where,

BF = Bulkage Factor (Also known as Swelling Factor)

V_E = Volume of Excavated Material

V_L = Volume of Loose Material

$\gamma_{d(E)}$ = Dry Unit Weight of Excavated Material

$\gamma_{d(L)}$ = Dry Unit Weight of Loose Material

When developing earthwork quantities these volumes and dry unit weights are oftentimes unknown. Instead, potential for shrinkage or swelling is determined from the soil type or by the combined effect with testing if soil testing is budgeted or permitted. The soil type is either determined on-site or in the lab. On-site soil type investigation includes visual inspection or the Standard Penetration Test (SPT). Lab testing consists of various lab samples and standard tests (which may include particle size analysis, Atterberg limits, etc.). The shrink or swell percentage can then be converted to the shrinkage or swelling factor to be used in calculations by using the ratio value. For shrinkage, the shrink percentage is divided by 100, then subtracted from 1. Therefore, the shrinkage factor is always a positive value less than one. For swelling, the swell percentage is divided by 100, then added to 1. The shrinkage or swelling factor is then multiplied by the material volume to determine the adjusted volume to be used for fill on the project.

2.5 Subsurface Investigation for Road Design

Before the start of any project, a subsurface investigation is conducted. The purpose of subsurface investigations on roadway projects is to identify and characterize soil along the road alignment for use on the project. These investigations can be in the form of insitu soil testing to soil sampling and testing from in a lab. Soil borings should be conducted along the centerline of the intended roadway and along the ditches to the left and right of the roadway along with further details in the following guidelines:

> The spacing of borings along the roadway alignment generally should not exceed 60 m (200 ft) for a fully invasive program.

> Where subsurface conditions are known to be uniform, a minimum spacing of 120 m (400 ft) is generally recommended. In a program supported by geophysical and in-situ tests, such as recommended in Sections 4.5.4 [Geophysical Investigations] and 4.5.5 [In-Situ Testing], a spacing of 150 – 450 m (500 – 1500 ft) as indicated in NCHRP 1-37A may be all that is necessary, depending on the uniformity of site conditions. For new pavement projects, most agencies locate borings along the centerline, unless conditions are anticipated to be variable. Borings should be located to disclose the nature of subsurface materials at the deepest points of cuts, areas of transition from cut to fill, and subgrade areas beneath the highest points of embankments. The spacing and location of the borings should be selected considering the geologic complexity and soil/rock strata continuity within the project area, with the objective of defining the vertical and horizontal boundaries of distinct soil and rock units within the project limits. It should be noted that **the cost for a few extra borings is insignificant in comparison to the cost of unanticipated field conditions or premature pavement failure**. Christopher et al. (2006)

After determining soil type and other factors affecting soil constructability, the suitability of a soil is determined. Soils may need to be treated and/or redistributed across the site, or additional soil (borrow) may be required. Based on this information, grading summaries and mass haul diagrams are made for the design.

2.5.1 ALDOT Procedure for Subsurface Investigation in Roadway Design

ALDOT has its own state procedures for subsurface investigations, as well as specifications under new locations for projects. One specification includes that the division materials engineer will accompany the consultant on a walk through of the site, where a materials and tests soft soils engineer may join upon written request. Specifications are also included by ALDOT (2009) for soil borings along the proposed roadway:

> Perform borings in fill areas every 300 ft (90 m). Extend the boring to 1.5 times the proposed fill height or to auger refusal, whichever is shallowest, but no more than 10 ft (3 m) into competent material (A competent material shall be defined as having [a blow count of] $N \geq 20$). Should soft soils be encountered, follow the guidelines under Subarticle 9, below. If uniform conditions are encountered while drilling every 300 ft (90m), then the boring interval may be extended to 500 feet (150 m). Perform additional borings if there is a noticeable change in the soil between borings.
>
> Perform borings in cut areas every 200 ft (60 m) along and on centerline and extend the boring approximately 3 ft (1 m) below the ditch line. For every third boring along centerline, perform a boring in the left and right ditch lines, extending approximately 3 ft (1 m) below the ditch line. Perform additional borings if there is a noticeable change in the soil between borings. ALDOT (2009)

ALDOT guidelines also include testing and soil identification. SPTs are performed at each boring location in overburden soils every 5 ft (1.5 m) of boring depth in accordance with

AASHTO T 206 (ALDOT 2009). Guidance for state roadway projects is included for testing and identification of soil and application by the materials and test engineers. The Bureau of Materials and Tests evaluates subsurface materials for shrink and swell potential in accordance with Alabama state guidelines for operation (ALDOT 2009).

2.6 Earthwork in Roadway Design

2.6.1 Earthwork Cut/Fill Process

The cut/fill and roadway construction process uses general terms including:

Embankment: For transportation purposes, an embankment is a raised bank of compacted soil to carry the road.

Borrow: The borrow, or borrow pit, is where soil is being hauled from for use on the project. The borrow can be either on-site or hauled from an off-site location. Soil that is required to be transported onto a location of a project site is known as the borrow.

Stockpile: Another term for borrow.

2.6.2 Risk involved in Roadway Earthwork

Risk involved in earthwork estimation depends on the final earthwork quantities. Completely balanced earthwork is when the calculated earthwork is equal to the project material needs. Borrow or waste material can be budgeted for if calculated prior to construction. Unplanned borrow or waste material can then add risk, or added costs to the responsibility of whom the risk falls on, to the project. For example, risk is added if a project results in an excess amount of soil, also known as waste, that was unaccounted for in the earthwork estimation. This is because any waste material needs to be transported to a deposit location. If this waste was unaccounted for prior to construction, then the transportation and location of a waste site adds cost to the budget. Similarly, material that is required to be brought in to the project, borrow material, is an additional cost to the project if not budgeted for by correct earthwork estimations. The cost to transport soil to or from a project due to unforeseen unbalanced earthwork is an added risk to the project.

Risk in earthwork usually falls on the contractor. The amount of risk is then usually dependent upon which pay item is used on the project. According to FHWA (2004), for earthwork in roadway projects, some typical pay items for federal roadway projects include:

- Pay Item 20401-0000, Roadway Excavation
- Pay Item 20441-00, Waste
- Borrow Pit Construction is more complicated,
    - Pay Item 20420-0000, Embankment Construction
    - Combination of Pay Item 20401-0000, Roadway Excavation, and Pay Item 20403-0000, Unclassified Borrow

The pay items usually play a role in the type and use of the project contract, and, therefore, are used in dictating the risk on the project. The primary pay item for earthwork on roadway projects is usually 20401-0000, Roadway Excavation. Under this pay item, the contractor must budget the entire earthwork process including, excavation, transportation, placement, and labor. The waste pay item may be in conjunction with roadway excavation if the project includes waste jobs. By using Pay Item 20420-0000, Embankment Construction, risk and payment to the contractor is based on the embankment in its final state. This places the risk of volume changes due to shrinkage and swelling on the contractor as well. (FHWA 2004). Table 1 includes the various pay items for earthwork.

Table 1. Earthwork pay items (FHWA 2011).

Table 4: Selection of Earthwork Pay Items

Type of Project	Pay Items	Remarks
Balanced Project	▪ 20401-0000 Roadway Excavation ▪ Either 20441-0000 Waste or 20403-0000 Unclassified Borrow	▪ Do not include a pay item for construction of embankments ▪ Typically include a pay item for either waste (Pay Item 20441-0000) or unclassified borrow (Pay Item 20441-0000) to allow flexibility during construction to handle field changes in earthwork.
Waste Project	▪ 20401-0000 Roadway Excavation ▪ 20441-0000 Waste	
Borrow Project	Two options: ▪ 20420-0000 Embankment Construction Or ▪ 20401-0000 Roadway Excavation ▪ 20441-0000 Unclassified Borrow	▪ Borrow projects have several inherent drawbacks, including: 1. During the design phase, roadway excavation and borrow pit shrink/swell factors are sometimes estimated without the benefit of a materials investigation. This leads to uncertainty in the final amount of borrow (based on pit measurements) that will be needed to complete the project. 2. When a borrow pay item is used, borrow is generally measured by determining the volume of material removed from the borrow source (this would be a bank cubic meter measurement, not a compacted cubic meter measurement). Payment of the borrow based on pit cross sections places the risk of shrink/swell changes from those estimated above on the Government. This is true whether the source is a Government-designated source or a contractor-selected source. ▪ By using Pay Item 20420-0000, Embankment construction, (instead of a combination of Pay Item 20401-0000, Roadway excavation, and Pay Item 20441-0000, Unclassified borrow) the contractor is paid on a slope stake basis (embankment in its final position). This places the risk of shrink/swell factor changes at the chosen borrow source on the contractor. When borrow constitutes a significant amount of the earthwork to be performed, and particularly when the selection of the borrow source is up to the contractor, it is recommended that an embankment construction pay item be used. Coordinate with the CFT during the selection of pay items for borrow projects. ▪ Generally, Pay Item 20401-0000, Roadway excavation and Pay Item 20420-0000, Embankment construction, should not be used together in the same contract.

Since the contractor typically assumes most of the risk in roadway construction, a better understanding on the construction end of the project is required. Since material shrink and swell and other factors come from Materials and Testing Bureau and the geotechnical report, it is important that every factor in the project is understood and accounted for.

2.6.2.1 Risk Example

As stated previously, a certain amount of risk is inherent to a roadway construction project due to uncertainty in earthwork calculations. A simple example is provided which shows the nature of the risk in earthwork calculations. This example assumes no rock, muck, or unsuitable material on-site.

Consider the simple cut and fill balance shown in Figure 2.

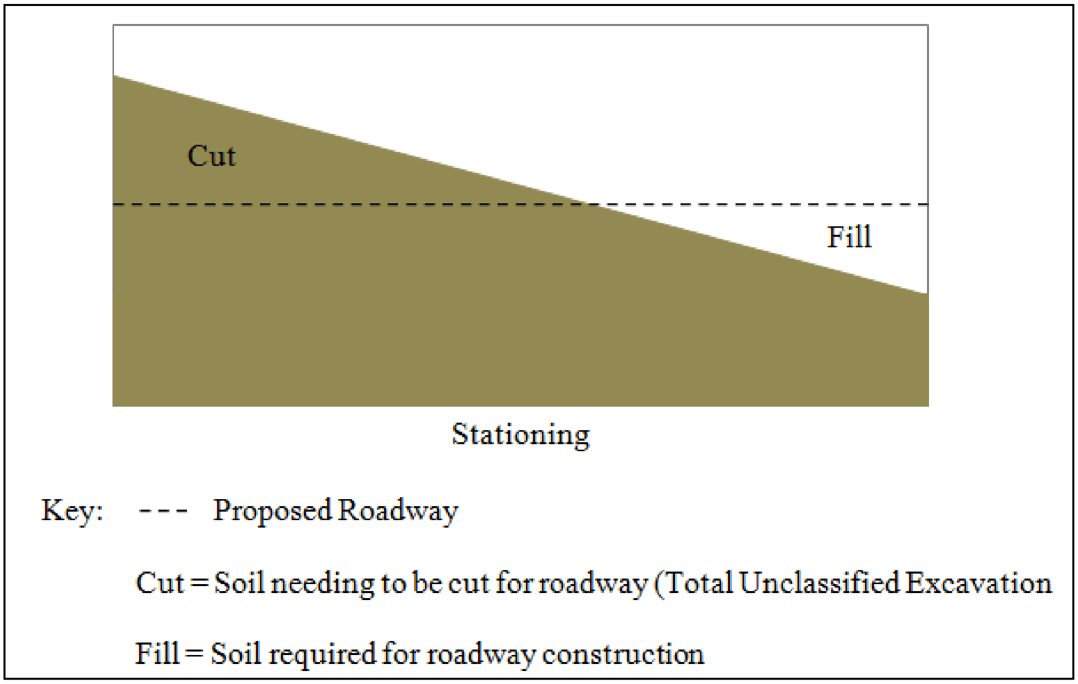

Figure 2. Earthwork example.

Cut Section: Total Unclassified Excavation = 500,000 yd^3 (Cut soil and topsoil)

Total Fill Required = 400,000 yd^3

Scenario 1: Soil Shrink Percentage = 15%

Soil Shrink Factor = 0.85

Adjusted Soil Cut = (Total Unclassified Excavation)*(Soil Shrink Factor)

= (500,000 yd^3)*(0.85)

= 425,000 yd^3

Borrow or Waste = (Total Required Fill) – (Adjusted Soil Cut)

= (400,000 yd^3) – (425,000 yd^3)

= - 25,000 yd^3

= 25,000 yd^3 waste

$$\text{Percent Balanced} = \frac{\text{(Borrow or Waste)}}{\text{Total Unclassified Excavation}} * 100$$

$$= \frac{-25{,}000\ \text{yd}^3}{500{,}000\ \text{yd}^3} * 100$$

= - 5%

Scenario 2: Soil Shrink Percentage = 25%

Soil Shrink Factor = 0.75

Adjusted Soil Cut = (Total Unclassified Excavation)*(Soil Shrink Factor)

= (500,000 yd^3)*(0.75)

= 375,000 yd^3

Borrow/Waste = (Total Required Fill) – (Adjusted Soil Cut)

= (400,000 yd^3) – (375,000 yd^3)

= 25,000 yd^3

= 25,000 yd^3 borrow

$$\text{Percent Balanced} = \frac{(\text{Borrow or Waste})}{\text{Total Unclassified Excavation}} * 100$$

$$= \frac{25{,}000\ \text{yd}^3}{500{,}000\ \text{yd}^3} * 100$$

= 5%

In this hypothetical example, both scenarios required the same amount of fill, and had the same soil type available from the cut. The percent balanced is the relation of the amount of waste or borrow required to the total unclassified excavation. This shows the balance of soil on a particular portion of the project. A negative percent balanced value signifies a waste while a positive shows a borrow. A percent balance of 0% would be perfect balance of cut and fill. The difference between the two scenarios is the shrink percentage being applied to the available cut soil. Scenario 1 applied a 15% shrink to the available soil, and resulted in 25,000 yd^3 of soil being wasted. Unless this soil can be used somewhere else on the project, there is substantial risk for the wasted soil. For example, excess soil can bring on added expenses from haul costs and disposal of the soil to a site. On the other hand, scenario 2 applied a 25% shrink to the available soil, and resulted in 25,000 yd^3 of soil needing to be brought on to the project. Unless soil can be brought to the cut section from another location on the project, bringing in soil is another added expense. Oftentimes, the hauling of soil adds another shrinkage or swelling factor that can further alter the volumetric value for the soil. This borrow and transportation of material adds to the expense of scenario 2.

The hypothetical expenses in both scenario 1 and scenario 2 are to the risk of the project. The expenses include transportation, labor and any additional costs to either remove soil or bring the required borrow material to the site. If these waste or borrow costs are unaccounted for from the earthwork estimation, then this is risk to the project. This risk, as mentioned previously, usually falls on the responsibility of the contractor unless otherwise stated in the project contract. A typical value assigned to amount of soil in construction is around $15 per cubic yard. If this value were assigned to Scenario 1 and 2, then the amount of added cost in both cases would result in $375,000. If the unbalanced earthwork was unaccounted for prior to construction, this cost results in a risk to the responsibility of the liable party, typically the contractor.

2.7 Federal Guidelines for Estimating Earthwork Volumes

Earthwork calculations for federal projects are done through spreadsheet analysis which outlines all parameters in the excavation, embankment, and earthwork process.

Table 2, Table 3, and Table 4 demonstrate the earthwork calculation process that takes place in a spreadsheet from column B to AL. Each table summarizes a portion of the earthwork and mass haul process, including which earthwork value is displayed in each column. The calculation process is done using GEOPAK (Bentley 2013) or hand calculations that are placed in specified columns, identified by the alignment stationing through the various rows of the spreadsheet. GEOPAK is computer aided design software distributed by Bentley primarily used for transportation and design civil engineering. The format identifies unadjusted and adjusted volumes for the final design of the roadway project.

Table 2. Summary of excavation volumes (FHWA 2011).

Table 1: Summary of Excavation Volumes

Column in XS Data	Description	How is Quantity Calculated?	Remarks
B	Roadway Prism Excavation	GEOPAK	▪ *Unadjusted* volumes (the numbers do not account for shrink or swell)
C	Approach Road Excavation	GEOPAK or User Calculated (Input by User)	▪ Input excavation volumes under the mainline stationing that best represents the approach road location. By doing so, the Mass Haul Diagram will better reflect the anticipated haul of material. ▪ If the approach road length is excessive, the volumes can be tabulated in a separate Grading Summary or at the bottom of the mainline summary. If values are tabulated at the bottom of the mainline summary, be sure NOT to include the quantities in the Mass Haul Diagram.
D	Roadway Excavation	Calculated on spreadsheet	▪ Total unadjusted excavation for the specified station. ▪ If roadway excavation is used as a pay item, the quantity in this column is the plan quantity.

E	(+) Structure Excavation (Walls)	GEOPAK	▪ Volume of material displaced by retaining walls and associated backfill below original ground of the existing roadway.
			▪ Walls that typically have this earthwork quantity include:
			  ▪ Mechanically-stabilized earth (MSE) wall
			  ▪ Concrete cut and fill walls
			  ▪ Soil nail wall
			  ▪ Rockery
			  ▪ Guardwall
			  ▪ Shored mechanically-stabilized earth (SMSE) wall
			  ▪ Gabion faced mechanically-stabilized earth (GFMSE) wall

F	(+) Excavation from Roadway Obliteration	User Calculated	▪ Volume of excavation from an obliterated area located outside the project slope stake limits. ▪ Input excavation volumes under the mainline stationing that best represents the obliteration location. ▪ If the roadway obliteration is a significant distance from mainline (e.g. 1000' or more), add these volumes on a separate row at the bottom of the Grading Summary. Do NOT include in the Mass Haul Diagram. ▪ Typically, excavation for roadway obliteration is not paid for under Section 204. Roadway obliteration is paid under Section 211 and is measured as an area. The obliteration area should be calculated separately and shown in the Miscellaneous Summaries. [The exception is when excavation material from one obliteration area is moved to another obliteration area. When material is moved between obliteration areas, the excavation material would need to be paid for under Section 204.]
G	(+) Subexcavation	User Calculated	▪ Volume of subexcavated material ▪ Use Column J also if this material is unsuitable for fill
H	(-) Pavement Removal in Cuts	GEOPAK	▪ Volume of pavement removed in cuts ▪ Quantity included only if existing pavement will not be used in fills (e.g., existing pavement recycled for base course or hauled off project). ▪ If the project will incorporate the existing pavement as fill material, do not use this column.
I	(-) Topsoil Stripping in Cuts	GEOPAK	▪ Volume of topsoil conserved from cuts ▪ Use the depth of topsoil stripping recommended in Geotechnical Report
J	(-) Disposal of Subex	User Calculated	▪ Volume of subexcavation wasted offsite ▪ If subexcavated material can be used for embankment, do not use this column.
K	Shrink/Swell	Input by User	▪ Shrink/swell factors are used to adjust quantities from the bank (BCY (BCM)) state to the compacted (CCY (CCM)) state. ▪ Use the shrink/swell recommended in the Geotechnical Report. ▪ Swell factors (values greater than one) are typically associated with rocky materials and mean that the compacted volume will be greater than the bank volume. ▪ Shrink factors (values less than one) are typically associated with clayey or granular materials and mean that the compacted volume will be less than the bank volume.
L	Total Excavation Available for Fills	Calculated on spreadsheet	▪ Total *adjusted* excavation for the specified station (quantities have been adjusted by estimated shrink/swell factors)

After the excavation summaries have been calculated, the embankment volumes are determined for the project.

Table 3. Summary of embankment volumes (FHWA 2011).

Table 2: Summary of Embankment Volumes

Column in XS Data	Description	How is Quantity Calculated?	Remarks
M	Roadway Prism Embankment	GEOPAK	▪ Unadjusted volumes calculated directly by GEOPAK.
N	Approach Road Embankment	GEOPAK or User Calculated (Input by User)	▪ Input the approach road embankment volumes under the mainline stationing that best represents the approach road location. ▪ If the approach road length is excessive, the volumes can be tabulated in a separate Grading Summary or at the bottom of the mainline summary. If they are tabulated at the bottom of the mainline summary, be sure NOT to include the tabulations in the Mass Haul Diagram

O	(+) Wall Backfill	GEOPAK	▪ Assumes on-site material can meet requirements of SCRs Subsection 704.13(b).
			▪ Walls that typically have this earthwork quantity include:
			  ▪ MSE wall
			  ▪ SMSE wall
			  ▪ Rockery
			  ▪ Concrete retaining wall with parapet

P	(+) Foundation Fill	GEOPAK	▪ Assumes on-site material can meet requirements of the FP-03 Subsection 704.01.
			▪ If foundation fill will be imported from off-site, do not use this column to show the quantities.
			▪ Walls that typically have this earthwork quantity include:
			  ▪ MSE wall
			  ▪ SMSE wall
			  ▪ Rockery
			  ▪ Guardwall
			  ▪ Concrete cut wall
			  ▪ Concrete retaining wall with parapet
			  ▪ Concrete fill wall

Q	(+) Select Wall Backfill	GEOPAK	▪ Assumes on-site material can meet requirements of SCRs Subsection 704.13(a).
			▪ If select wall backfill will be imported from off-site, do not use this column to show the quantities.
			▪ Walls that typically have this earthwork quantity include:
			  ▪ MSE wall
			  ▪ SMSE wall
			  ▪ GFMSE wall

R	(+) Rock	GEOPAK	▪ Assumes on-site material can meet requirements of SCRs Subsection 705.07. ▪ If rockery rocks will be imported from off-site, do not use this column to show the quantities. ▪ Walls that typically have this earthwork quantity include: ▪ Rockery
S	(+) Granular Rock Backdrain	GEOPAK	▪ Assumes on-site material can meet requirements of SCRs Subsection 703.03(c). ▪ If granular rock backdrain will be imported from off-site, do not use this column to show the quantities ▪ Walls that typically have this earthwork quantity include: ▪ Rockery

T	(+) Structural Backfill	GEOPAK	▪ Assumes on-site material can meet requirements of the FP-03 Subsection 704.04.
			▪ If structural backfill material is imported from off-site, do not show any quantities in this column.
			▪ Walls that typically have this earthwork quantity include:
			  ▪ Concrete cut wall
			  ▪ Concrete retaining wall with parapet
			  ▪ Concrete fill wall

U	(+) Backfill Material	GEOPAK	▪ Assumes on-site material can meet requirements of the FP-03 Subsection 704.03.
			▪ If backfill material will be imported from off-site, do not use this column to show the quantities
			▪ Walls that typically have this earthwork quantity include:
			  ▪ Guardwall
			  ▪ Concrete retaining wall with parapet
			  ▪ Soil nail wall

V	(+) Granular Backfill	GEOPAK	▪ Assumes on-site material can meet requirements of the FP-03 Subsection 703.03. ▪ If granular backfill will be imported from off-site, do not use this column to show the quantities. ▪ Walls that typically have this earthwork quantity include: ▪ GFMSE wall
W	(+) Backfill for pavement removal under fill	GEOPAK	▪ Quantity included only if existing pavement will not be used in fills (e.g., existing pavement recycled for base course or hauled off project) ▪ Volume of material needed to backfill the existing pavement area. ▪ If the project will incorporate the existing pavement as fill material, do not use this column.
X	(+) Topsoil replacement under fill	GEOPAK	▪ Volume of fill material needed to replace topsoil conserved under new fills of the roadway.

Table 3 (Continued). Summary of embankment volumes (FHWA 2011).

Column in XS Data	Description	How is Quantity Calculated?	Remarks
Y	(+) Subexcavation	GEOPAK or User Calculated	▪ Typically, this column should have the same quantities identified in Column G (Subexcavation). If the subexcavation quantities are calculated by GEOPAK, the quantity in this column will be larger than the quantity in Column G in embankment sections because GEOPAK assumes all the material from the bottom of subex to the top of subgrade will be subex backfill. ▪ In cases where material will be subexcavated and recompacted in place, Columns G and Y still need to have the same value because subexcavated material will typically experience volume changes once it is excavated and recompacted (note the difference in the definition of material, Column G is bank (BCY (BCM)), while Column AC is compacted (CCY (CCM)).
Z	(+) Aggregate Base	User Calculated	▪ Volume of material conserved from roadway excavation and processed for use as aggregate base. ▪ Assumes on-site material can meet requirements of the FP-03 Subsection 703.05 or 703.06. ▪ If aggregate base will be imported from off-site, do not use this column to show the quantities.
AA	(+) Riprap	User Calculated	▪ Volume of material conserved from roadway excavation and processed for use as riprap ▪ Assumes on-site material can meet requirements of the FP-03 Subsection 705.02. ▪ Quantity included only if onsite material will be conserved for riprap. ▪ If riprap will be imported from off-site, do not use this column to show the quantities.
AB	(+) Special Rock Embankment	User Calculated	▪ Volume of material conserved from roadway excavation and processed for use as special rock embankment ▪ Assumes on-site material can meet requirements of the FP-03 Subsection 705.04. ▪ If material for special rock embankment will be imported from off-site, do not use this column to show the quantities.
AC	(+) Embankment for Roadway Obliteration	User Calculated	▪ Show quantities in this column for obliteration areas where additional embankment will be needed. If the sections of obliterated roadway are adjacent to the proposed construction, input the embankment quantities in the row with the appropriate station. ▪ If the obliterated areas are not nearby the proposed construction, add the quantities in a separate row at the bottom of the Grading Summary. Do not use quantities shown at the bottom of the Grading Summary when making the Mass Haul Diagram, as they will not accurately portray the hauling needs of the project.
AD	(+) Topping or Select Topping	User Calculated	▪ This column represents material conserved from roadway excavation to be used as topping or select topping. ▪ Subsection 704.05 (topping) or Subsection 704.08 (select topping) of the FP-03. ▪ If material for topping or select topping will be imported from off-site, do not use this column to show the quantities.
AE	Total Embankment	Calculated on spreadsheet	▪ Total volume of material required to construct the embankments in the identified station range.

The final design volumes are then verified in the final earthwork calculations. These values are shown in the summary Table 4.

Table 4. Summary of earthwork calculations (FHWA 2011).

Table 3: Earthwork Calculations

<table>
<tr><th>Column in XS Data</th><th>Description</th><th>How is Quantity Calculated?</th><th>Remarks</th></tr>
<tr><td>AF</td><td>Excavation - Embankment</td><td>Calculated on spreadsheet</td><td>▪ Volume of the surplus or shortage of material at each station.
▪ Total Excavation Available for Fills (Column L) minus Total Embankment (Column AE).</td></tr>
<tr><td>AG</td><td>Waste</td><td>Calculated on spreadsheet</td><td>▪ The value in this column is the same as the value in Column AF (Excavation – Embankment)
▪ When all the values in this column are added together, this value represents the volume of waste, or excess material, for the entire project.</td></tr>
<tr><td>AH</td><td>Embankment Construction</td><td>Calculated on spreadsheet</td><td>▪ The values in the column are the same as the values in Column M (Roadway Prism Embankment) + Column N (Approach Road Embankment) for each row.
▪ When all the values in this column are added together, it represents the total prism volume of embankment needed to construct the project.</td></tr>
<tr><td>AI</td><td>Unclassified Borrow Required</td><td>Calculated on spreadsheet</td><td>▪ The value in this column is the same as those in Column AF (Excavation – Embankment).</td></tr>
<tr><td>AJ</td><td>Unclassified Borrow Shrink/Swell</td><td>User Input</td><td>▪ Unclassified borrow is measured in the field in its original position, so the material needs to be in bank state. (See Subsection 204.16(e) of FP-03.) An estimated shrink/swell of the borrow material must be applied to the compacted volumes to get from compacted state to bank state.
▪ A common estimated shrink/swell for unclassified borrow is 0.9.</td></tr>
<tr><td>AK</td><td>Unclassified Borrow</td><td>Calculated on spreadsheet</td><td>▪ This column is associated with Pay Item 20403-0000, Unclassified borrow.
▪ Divide Column AI (Unclassified Borrow Required) by Column AJ (Unclassified Borrow Shrink/Swell).
▪ When the values in this column are totaled at the bottom of the summary, the resulting value is the total volume of unclassified borrow needed to build the embankments for the entire project.</td></tr>
<tr><td>AL</td><td>Mass Ordinate</td><td>Calculated on spreadsheet</td><td>▪ This column represents the cumulative mass differential as the project moves from the start through the end. The values in this column are best shown through the use of an example table:
<table><tr><th>Excavation – Embankment</th><th>Mass Ordinate</th></tr><tr><td>-518</td><td>-518</td></tr><tr><td>1169</td><td>(-518 + 1169) = 651</td></tr><tr><td>2451</td><td>(651 + 2451) = 3102</td></tr><tr><td>-1822</td><td>(3102 + -1822) = 1280</td></tr></table>
▪ The mass ordinate for the first row of the Grading Summary is always identical to the Excavation – Embankment value. To obtain subsequent mass ordinate values, add the mass ordinate in the row above to the Excavation – Embankment value in the row you are working in.</td></tr>
</table>

2.7.1 Shrinkage and Swelling Factors for Federal Roadway Projects

Typical shrink and swell percentages set from Federal Highway Administration guidelines are shown in Figure 3.

Exhibit 4.6–F SHRINK/SWELL FACTORS FOR COMMON MATERIALS (U.S. Customary)

Material	Measured				
	In-Situ	Loose		Embankment	
	Mass Density[1] lb/yd^3	Mass Density[2] lb/yd^3	% Swell[3]	Mass Density[2] lb/yd^3	% Swell or Shrink[3]
Andesite	4,950	2,970	67	3,460	43
Basalt	4,950	3,020	64	3,640	36
Bentonite	2,700	2,000	35	—	—
Breccia	4,050	3,040	33	3,190	27
Calcite-Calcium	4,500	2,700	67		
Caliche	2,430	2,100	16	3,200	-25
Chalk	4,060	2,170	50	3,050	33
Charcoal	—	1,030	—	—	—
Cinders	1,280	960	33	1,420	-10
Clay					
Dry	3,220	2,150	50	3,570	-10
Damp	3,350	2,010	67	3,720	-10
Conglomerate	3,720	2,800	33		
Decomposed rock					
75% R. 25% E.	4,120	3,140	31	3,680	12
50% R. 50% E.	3,750	2,710	38	4,000	-6
25% R. 75% E.	3,380	2,370	43	3,720	-9
Diorite	5,220	3,130	67	67	43
Diatomaceous earth	1,470	910	62		
Dolomite	4,870	2,910	67	3,400	43
Earth, loam					
Dry	3,030	2,070	50	3,520	-12
Damp	3,370	2,360	43	3,520	-4
Wet, mud	2,940	2,940	0	3,520	-20
Feldspar	4,410	2,640	67	3,080	43
Gabbro	5,220	3,130	67	3,650	43
Gneiss	4,550	2,720	67	3,180	43
Gravel (Dry)					
Uniformly Graded	2,980	2,700	10	3,150	-5
Average Gradation	3,280	2,730	20	3,570	-8
Well Graded	3,680	2,770	33	4,130	-11
Gravel (Wet)					
Uniformly Graded	3,310	3,150	5	3,150	-5
Average Gradation	3,640	3,290	10	3,570	-2
Well Graded	4,090	3,520	16	4,130	-1
Granite	4,540	2,640	72	3,170	43
Gumbo					
Dry	3,230	2,150	50	3,570	-10
Wet	3,350	2,020	67	3,720	-10
Gypsum	4,080	2,380	72		

Figure 3. Exhibit 4.6-F shrinkage and swelling factors (FHWA 2007).

Material	Measured				
	In-Situ	Loose		Embankment	
	Mass Density[1] lb/yd[3]	Mass Density[2] lb/yd[3]	% Swell[3]	Mass Density[2] lb/yd[3]	% Swell or Shrink[3]
Igneous rocks	4,170	2,820	67	3,300	43
Kaolinite					
Dry	3,230	2,150	50		
Wet	3,350	2,020	67		
Limestone	4,380	2,690	63	3,220	36
Loess					
Dry	3,220	2,150	50	3,570	-10
Wet	3,350	2,010	67	3,720	-10
Marble	4,520	2,700	67	3,160	43
Marl	3,740	2,240	67	2,620	43
Masonry, rubble	3,920	2,350	67	2,750	43
Mica	4,860	2,910	67		
Pavement					
Asphalt	3,240	1,940	50	3,240	0
Brick	4,050	2,430	67	2,840	43
Concrete	3,960	2,370	67	2,770	43
Macadam	2,840	1,700	67	2,840	0
Peat	1,180	890	33		
Pumice	1,080	650	67		
Quartz	4,360	2,610	67	3,000	43
Quartzite	4,520	2,710	67	3,160	43
Rhyolite	4,050	2,420	67	2,870	43
Riprap rock	4,500	2,610	72	3,150	43
Sand					
Dry	2,880	2,590	11	3,240	-11
Wet	3,090	3,230	5	3,460	-11
Sandstone	4,070	2,520	61	3,030	34
Schist	4,530	2,710	67	3,170	43
Shale	4,450	2,480	79	2,990	49
Shale	3,240	2,380	36	3,890	-17
Siltstone	4,070	2,520	61	4,560	-11
Slate	4,500	2,600	77	3,150	43
Talc	4,640	2,780	67	3,250	43
Topsoil	2,430	1,620	56	3,280	-26
Tuff	4,050	2,700	50	3,050	33

Notes:

1. *Subject to average ±5% variation.*
2. *Mass densities are subject to adjustments in accordance with modified swell and shrinkage factors.*
3. *Based on average in-situ densities. A negative number represents shrinkage. Factors subject to ±33% variation.*

Figure 3 (continued). Exhibit 4.6-F shrinkage and swelling factors (FHWA 2007).

The primary source supporting the FHWA shrinkage and swelling factors is Burch (1997). This source outlines conversion factors for soil shrink and swell used in excavation calculations as presented in Figure 4.

Soil type & moisture level	Swell factor	Shrink factor	Compaction requirements
Dry sand	1.13	1.00	BCY
Dry sand	1.32	0.83	95% S.P.
Dry sand	1.39	0.77	100% S.P.
Dry sand	1.38	0.78	95% M.P.
Dry sand	1.45	0.72	100% M.P.
Damp sand	1.13	1.00	BCY
Damp sand	1.16	0.98	95% S.P.
Damp sand	1.22	0.93	100% S.P.
Damp sand	1.21	0.94	95% M.P.
Damp sand	1.27	0.88	100% M.P.
Damp gravel	1.14	1.00	BCY
Damp gravel	1.23	0.93	95% S.P.
Damp gravel	1.29	0.87	100% S.P.
Damp gravel	1.32	0.84	95% M.P.
Damp gravel	1.39	0.78	100% M.P.
Dry clay	1.31	1.00	BCY
Dry clay	1.18	NA	85% S.P.
Dry clay	1.25	NA	90% S.P.
Dry clay	1.39	0.94	100% S.P.
Dry clay	1.39	0.94	90% M.P.
Dry clay	1.54	0.82	100% M.P.
Dry dirt	1.32	1.00	BCY
Dry dirt	1.31	1.00	85% S.P.
Dry dirt	1.39	0.95	90% S.P.
Dry dirt	1.54	0.83	100% S.P.
Dry dirt	1.45	0.90	90% M.P.
Dry dirt	1.61	0.78	100% M.P.
Damp dirt	1.28	1.00	BCY
Damp dirt	1.17	NA	85% S.P.
Damp dirt	1.23	NA	90% S.P.
Damp dirt	1.37	0.93	100% S.P.
Damp dirt	1.29	1.00	90% M.P.
Damp dirt	1.43	0.89	100% M.P.

BCY = bank cubic yards
S.P. = Standard Proctor
M.P. = Modified Proctor
NA = areas where the bank material has a greater density than required for the compacted material

Figure 8-1
Approximate conversion factors for soil swell and shrinkage

Figure 4. Shrinkage and swelling factors (Burch 1997).

As shown in Figure 4 the shrink or swell factor is based on soil type and compaction. The soil type, however, is a general estimation which leaves the conversion factors for soil swell and shrinkage to be an approximation.

The secondary source for the FHWA shrinkage and swelling factors is by Church (1981). Figures and applications for shrinkage and swelling factors are then included in the source.

Material	sp gr	Cubic yards, in cut—weight, lb	Cubic yards loose		Cubic yards in fill	
			Percent swell	Weight, lb	Swell or shrink, %	Weight, lb
Adobe, S	(1.91)	3230	35	2380	−10	3570
Andesite, I	2.94	4950	67	2970	33	3730
Asbestos	2.40	4040	67	2420		
Ashes, coal	(0.61)	1030	33	800	−50	2060
Asphaltum, S	1.28	2150	67	1390		
Asphalt rock, S	2.41	4050	62	2500		
Aragonite, calcium ore*	3.00	5050	67	3020		
Argentite, silver ore*	7.31	12300	67	7360		
Barite, barium ore*	4.48	7560	67	4520		
Basalt, I	2.94	4950	64	3020	36	3640
Bauxite, aluminum ore*	2.73	4420	50	2940		
Bentonite	1.60	2700	35	2000		
Biotite, mica ore*	2.88	4850	67	2900		
Borax, S	1.73	2920	75	1670		
Breccia, S	2.41	4050	33	3040	27	3190
Calcite, calcium ore*	2.67	4500	67	2700		
Caliche, S	(1.44)	2430	16	2100	−25	3200
Carnotite, uranium ore*	2.47	4150	50	2770		
Cassiterite, tin ore*	7.17	11380	67	6800		
Cement				2700		
Cerrusite, lead ore*	6.50	10970	67	6560		
Chalcocite, copper ore*	5.70	9600	67	5750		
Chalcopyrite, copper ore*	4.20	7060	67	4220		
Chalk, S	2.42	4060	50	2710	33	3050
Charcoal				1030		
Chat, mine tailings				2700		
Cinders	(0.76)	1280	33	960	−10	1420
Cinnabar, mercury ore*	8.10	13630	67	8170		
Clay, S:						
Dry	(1.91)	3220	35	2380	−10	3570
Damp	(1.99)	3350	40	2400	−10	3720
Clinker				2570		
Coal, S:						
Anthracite	1.55	2610	70	1530		
Bituminous	1.35	2280	67	1370		
Coke	(0.51)	860	0	860		
Colemanite, borax ore*	1.73	2920	75	1670		
Concrete:'						
Stone	2.35	3960	72	2310	33	2910
Cyclopean	2.48	4180	72	2430	33	3150
Cinder	1.76	2970	72	1730	33	2240
Conglomerate, S	2.21	3720	33	2800	−8	4030
Decomposed rock:						
75% R, 25% E	(2.45)	4120	25	3300	12	3700
50% R, 50% E	(2.23)	3750	29	2900	−5	3940
25% R, 75% E	(2.01)	3380	26	2660	−8	3680
Diabase, I	3.00	5050	67	3010	33	3810
Diorite, I	3.10	5220	67	3130	33	3930
Diatomite, S:						
Ditomaceous earth	(0.87)	1470	62	910		
Dolomite, S	2.88	4870	67	2910	43	3400
Earth, loam, S:						
Dry	(1.84)	3030	35	2240	−12	3520
Damp	(2.00)	3370	40	2400	−4	3520
Wet, mud	(1.75)	2940	0	2940	−20	3520
Earth-rock mixtures:						
75% E, 25% R	(2.01)	3380	26	2660	−8	3680
50% E, 50% R	(2.23)	3750	29	2900	−5	3940
25% E, 75% R	(2.45)	4120	25	3300	12	3700
Feldspar, I	2.62	4410	67	2640	33	3320
Felsite, I	2.50	4210	67	2520	33	3170
Fluorite, S	3.10	5220	67	3130		
Gabbro, I	3.10	5220	67	3130	33	3940
Galena, lead ore*	7.51	12630	67	7570		
Gneiss, M	2.71	4550	67	2720	33	3420
Gob, mining refuse	(1.75)	2940	0	2940	−20	3520
Gravel, average graduation, S:						
Dry	(1.79)	3020	15	2610	−7	3240
Wet	(2.09)	3530	5	3350	−3	3640
Granite, I	2.69	4540	72	2640	33	3410
Gumbo, S:						
Dry	(1.91)	3230	50	2150	−10	3570
Wet	(1.99)	3350	67	2020	−10	3720
Gypsum, S	2.43	4080	72	2380		
Hematite, iron ore*	5.08	8560	75	4880		
Hessite, silver ore*	8.50	14300	67	8560		
Ice	0.93	1560	67	930		
Ilmenite, titanium ore*	4.75	8000	69	4730		
Kaolinite, S:						
Dry	(1.91)	3230	50	2150		
Wet	(1.99)	3350	67	2010		
Lignite	(1.25)	2100	65	1270		
Lime				2220		
Limestone, S	2.61	4380	63	2690	36	3220
Linnaeite, cobalt ore*	4.89	8230	67	4930		
Limonite, iron ore*	3.80	6400	55	4140		
Loam, earth, S:						
Dry	(1.84)	3030	35	2240	−12	3520

Figure 5. Approximate material characteristics including shrink and swell (Church 1981).

Material	sp gr	Cubic yards, in cut—weight, lb	Cubic yards loose		Cubic yards in fill	
			Percent swell	Weight, lb	Swell or shrink, %	Weight, lb
Damp	(2.00)	3370	40	2400	−4	3520
Wet, Mud	(1.75)	2940	0	2940	−20	3520
Loess, S:						
Dry	(1.91)	3220	35	2380	−10	3570
Wet	(1.99)	3350	40	2400	−10	3720
Magnesite, magnesium ore*	3.00	5050	50	3360		
Magnetite, iron ore*	5.04	8470	54	5520		
Marble, M	2.68	4520	67	2700	33	3400
Marl, S	2.23	3740	67	2240	33	2820
Masonry, rubble	2.33	3920	67	2350	33	2950
Millerite, nickel ore*	5.65	9530	67	5710		
Molybdenite, molybdenum ore*	4.70	7910	67	4750		
Mud, S	(1.75)	2940	0	2940	−20	3520
Muscovite, mica ore*	2.89	4860	67	2910		
Niccolite, nickel ore*	7.49	12600	67	7550		
Orpiment, arsenic ore*	3.51	5900	50	3940		
Pavement:						
Asphalt	1.93	3240	50	1940	0	3240
Brick	2.41	4050	67	2430	33	3050
Concrete	2.35	3960	67	2370	33	2980
Macadam	1.69	2840	67	1700	0	2840
Wood block	0.97	1630	72	950	33	1220
Peat	(0.70)	1180	33	890		
Phosphorite, phosphate rock, S	3.21	5400	50	3600		
Porphyry, I	2.74	4630	67	2770	33	3480
Potash, S	2.20	3700	50	2470		
Pumice, I	0.64	1080	67	650		
Pyrites, iron ore*	5.07	8540	67	5110		
Pyrolusite, manganese ore*	4.50	7560	50	5050		
Quartz, I	2.59	4360	67	2610	33	3280
Quartzite, M	2.68	4520	67	2710	33	3400
Realgar, arsenic ore*	3.51	5900	50	3930		
Rhyolite, I	2.40	4050	67	2420	33	3040
Riprap rock, average	2.67	4500	72	2610	43	3150
Rock-earth mixtures:						
75% R, 25% E	(2.45)	4120	25	3300	12	3700
50% R, 50% E	(2.23)	3750	29	2900	−5	3940
25% R, 75% E	(2.01)	3380	26	2660	−8	3680
Salt, rock, S	2.18	3670	67	2200		
Sand, average graduation, S:						
Dry	(1.71)	2880	11	2590	−11	3240
Wet	(1.84)	3090	5	3230	−11	3460
Sandstone, S	2.42	4070	61	2520	-34	3030
Scheelite, tungsten ore*	5.98	10100	67	6050		
Schist, M	2.59	4530	67	2710	33	3410
Serpentine, asbestos ore*	2.62	4440	67	2650		
Shale, S	2.64	4450	50	2970	33	3350
Silt, S	(1.93)	3240	36	2380	−17	3890
Siltstone, S	2.42	4070	61	2520	−11	4560
Slag:						
Furnace	2.87	4840	98	2690	65	2930
Sand	(0.83)	1400	11	1260	−11	1570
Slate, M	2.68	4500	77	2600	33	3380
Smaltite, cobalt ore*	6.48	10970	67	6560		
Snow:						
Dry	(0.13)	220	0	220		
Wet	(0.51)	860	0	860		
Soapstone, talc ore*	2.70	4550	67	2720		
Sodium niter, chile saltpeter	2.20	2710	50	2470		
Stibnite, antimony ore*	4.58	7710	67	4610		
Sulfur	2.00	3450	50	2310		
Syenite, I	2.64	4460	67	2670	33	3350
Taconite, iron ore*	3.18	5370	60	3360		
Talc, M	2.70	4640	67	2780	33	3490
Topsoil, S	(1.44)	2430	56	1620	−26	3280
Trachyte, I	2.40	4050	67	2420	33	3050
Trap rock, igneous rocks, I	2.79	4710	67	2820	33	3540
Trash				400	−50	800
Tuff, S	2.41	4050	50	2700	33	3050
Witherite, barium ore*	4.29	7230	67	4320		
Wolframite, tungsten ore*	7.28	12280	67	7350		
Zinc blende, zinc ore*	4.02	6780	67	4060		
Zincite, zinc ore*	5.68	9550	67	5710		

Key to table:
I—igneous rock, S—sedimentary rock, M—metamorphic rock.
*—ores in the mineral state, with no gangues. Adjust for percentage of mineral bearing gangue or rock to estimate weight of entire ore body, as explained previously in text.
( )—apparent specific gravity, as material is not solid.

Weights per cubic yard in cut are subject to average ±10 percent variation. Swell and shrinkage factors for loose condition and embankment are subject to average ±33 percent variation. Weights in loose condition and in embankment are subject to adjustments in accordance with modified swell and shrinkage factors.

Figure 6. Continuation of approximate material characteristics including shrink and swell (Church 1981).

Swell, %	Voids, %	cybm/cylm
5	4.8	0.952
10	9.1	0.909
15	13.0	0.870
20	16.7	0.833
25	20.0	0.800
30	23.1	0.769
35	25.9	0.741
40	28.6	0.714
45	31.0	0.690
50	33.3	0.667
55	35.5	0.645
60	37.5	0.625
65	39.4	0.606
70	41.2	0.588
75	42.9	0.571
80	44.4	0.556
85	45.9	0.541
90	47.4	0.526
95	48.7	0.513
100	50.0	0.500

SOURCE: Caterpillar Tractor Co.

Figure 7. Swell versus voids of materials and hauling machine load factors (Church 1981).

FHWA (2007) along with Burch (1997) and Church (1981) are references cited for earthwork shrink and swell guidance by the FHWA and USDOT.

2.8 State Methods for Estimating Earthwork

2.8.1 Alabama Department of Transportation Method for Estimating Earthwork

Earthwork calculations are usually broken into phases based on construction sequence (ALDOT 2008). The earthwork calculations are typically completed by the average end area method. The following list is a summary of the method for earthwork design by ALDOT from ALDOT (2013) with references to example spreadsheets from the ALDOT (2008):

1. The first step in earthwork design for roadways is to develop a preliminary plan. The preliminary plan includes: title sheet, typical section sheets, plan and profile sheets (including topography), grading, paving layouts, and cross sections (ALDOT 2013).
2. The preliminary prints, including the initial profile, are sent to the materials and test engineer for determination of shrink/swell values for the proposed site. These preliminary prints include earthwork balanced based on initial site cut sections. An example of ALDOT preliminary prints can be found in ALDOT (2008).

3. The materials and test engineers provide soil reports including boring logs and soil profiles. These profiles include soil shrink/swell values and any additional factors that need to be considered. (ALDOT 2008)
4. From this information, earthwork is then balanced based on the factors (shrink/swell) provided by the Materials and Test Engineer. If the profile changes significantly, a new set of plans and cross sections are developed and sent to the Materials Bureau. An example of earthwork quantities based on each distinguished layer can be found in ALDOT (2009).
5. The earthwork material up until this point then undergoes inspection by the Plans, Specifications, and Estimates Bureau (P.S.&E. inspection).
6. After inspection, earthwork factors will be kept on file, however, will not be included in the as-let plan assembly.
7. The final earthwork summary will include unclassified excavation, borrow excavation, muck excavation, topsoil, and topsoil from stockpiles (ALDOT 2013).

In summary, preliminary earthwork calculations are determined based on an initial evaluation of the site. After further inspection and testing of site soils have taken place, factors including shrink and swell values for specific materials are applied to the preliminary earthwork calculations in order to obtain revised earthwork values. This earthwork summary is inspected then submitted as the final earthwork summary. The final earthwork summary does not include the shrinkage and swelling factors on the final earthwork plan sheet; however these factors are kept on file until construction has been completed.

2.8.1.1 Determining Shrinkage and Swelling Factors in ALDOT

The ALDOT Bureau of Materials and Tests is responsible for the consideration and application of materials on ALDOT projects. These are the engineers that determine the soil type, and therefore assign the shrinkage and swelling factors that are applied to earthwork calculations.

ALDOT includes procedures for sampling and testing of are listed for various materials encountered in Alabama state transportation projects. For unclassified excavation material from approved cuts or borrow pits, soil tests include: moisture density, in-place density, and soil analysis. For the purposes of roadway earthwork, based on specifications by ALDOT (2003) and AASHTO M-145, soil analysis is conducted for determination of uses in subgrade material on roadway projects.

Shrinkage and swelling factors for earthwork summaries on roadway projects are determined by the materials and test engineers and included in the materials report for a specific project. Based on soil analysis and testing as described in the previous paragraph and specific site characteristics (including historical data) these shrinkage and swelling factors are assigned. Once assigned, the factors are sent to the design engineers for the final earthwork summary.

2.8.2 Florida Department of Transportation

Earthwork calculations are completed by a manual average end area method or by a program, typically GEOPAK (FDOT 2013). The method of computation is primarily based on the pay item designated. Pay for cut is completed as either regular excavation by CY (cubic yard) or Lump Sum while pay for fill is by Embankment or Borrow Excavation, aka Truck Measure (FDOT 2013).

If the pay item of Borrow Excavation is chosen, a fill and truck adjustment are both calculated for. The fill adjustment is added to the net total fill value from the plans. The truck adjustment is the correction to soil volume for hauling the material from the borrow to the fill location. Fill and truck adjustment percentages for each specific project should come from the District Materials Office or the Construction Office. (FDOT 2013)

2.8.3 Georgia Department of Transportation

Georgia assigns shrinkage values through the soil survey, usually based on county/location. While the engineer/desiger completes the earthwork quantities, factors for adjustment values usually come from the materials engineers. It is important to note that “the designer cannot control the shrinkage factor given in the Soil Survey but he can make adjustments if PCC pavement, curb and gutter are being removed” (GDOT 2009). Figure 8 shows the shrinkage values per county.

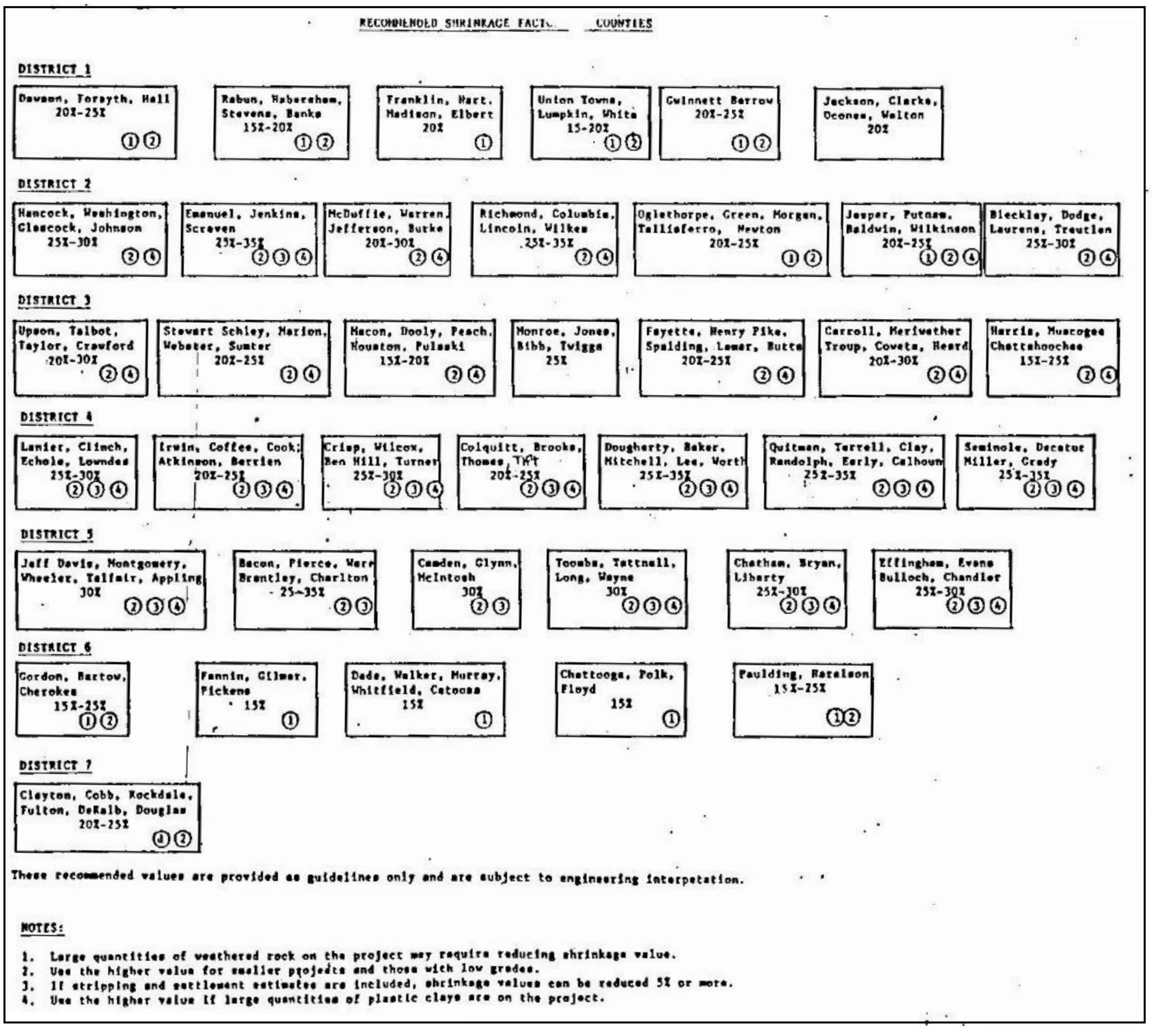

Figure 8. GDOT Shrinkage factors by county (GDOT 2013).

The average end area method is used for excavation quantities unless specified otherwise (GDOT 2013). For general earthwork guidelines:

> If earthwork is required, normal standards shall apply; however, because earthwork is generally minimal, the earthwork shall be let as "Grading Complete - Lump Sum." The designer should calculate earthwork volumes, but no quantities shall be shown in the plans. Removal of vegetation within the clear zone shall be included within the project limits. GDOT (2012)

No table for swelling factors was found from GDOT. According to GDOT (2009), earthwork calculations are typically completed either by the shrink on cut method or the swell on fill method. A main difference with the GDOT method of earthwork is that calculations are done by lump sum instead of cubic yard. Calculation methods by GDOT (2009) include:

- Grading Complete: The quantities are not shown in the plans, but the quantities for excavation and Borrow are completed in order to provide: the construction estimate for Contracts, to Engineering Services with FPR request, and to the District Earthwork Coordinator. Calculations for "Grading Complete" are done the same for Pay Items of "Unclassified Excavation" and "Borrow, Including Material".
- In-Place Embankment: The construction fills are measured "in-place," therefore the quantities for excavation and/or borrow are not shown in the plans. However, the quantities are calculated in order to provide to Engineering Services and the District Earthwork Coordinators. If quantities are correct, the values will be the pay quantity. It is important to note that no adjustment for shrinkage is required under this method. Calculations for "In-Place Embankment" are done the same as if quantities were "Unclassified Excavation" and Borrow.

- Unclassified Excavation and Borrow: Two calculation methods can be used for this Pay Item. Both methods should produce the same results, but they must be used separately
- These methods are:
    - The “Swell the Fill” method mathematically increases the volume of the fill and subtracts the raw cut volumes from this number. Note that the word “Swell” indicates the inverse of the Shrinkage and not the Swell percentage for rock.
    - The “Shrink the Cut” method basically reduces the volume of the excavation and subtracts this volume from the “Raw Fill.”

The “Shrink the Cut” method, aka Shrink on Cut, is primarily used if the soil has different shrinkage coefficients. One case requiring this method is if a soil survey was done at the location of the borrow pit. This is done if the borrow is located for the project (prior to start of the project). However, it is not the GDOT practice to provide borrow locations prior to the start of a project. Another case is if there are large rock deposits on the project site where a swell factor will need to be used.

When using pay items “Unclassified Excavation” and “Borrow, Including Material,” the volume quantity is the measure used for payment. For “Unclassified Excavation,” the volume is on the right-of-way while the “borrow” is the volume, provided by the contractor, not on the right-of-way. This difference affects the risk and budget on the project. Note, if there is a net “waste” in the earthwork, then the inclusion of “borrow” in the pay item is left out.

2.8.4 North Carolina Department of Transportation

Shrinkage factors used by NCDOT typically range from 15% in the mountains to 30% in the Outer Coastal Plain (NCDOT 2004). Figure 9 shows the typical shrinkage factors used for NCDOT based on soil geographical location.

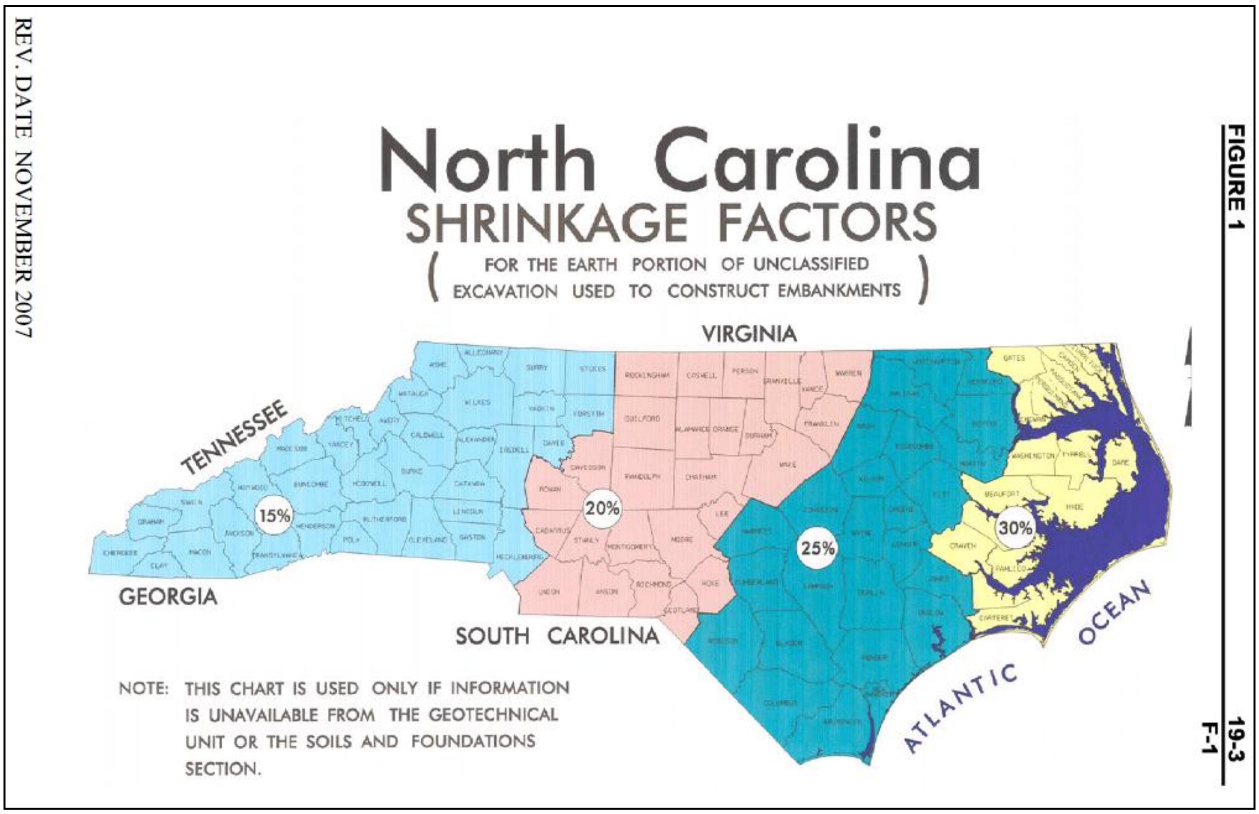

Figure 9. NCDOT Shrinkage factors (NCDOT 2004).

Swell factors are used for rock and soils with larger grain sizes. The swelling factor is usually provided by the geotechnical engineer if being used for a specific project. The given shrinkage and swelling factors are applied to earthwork calculations when used in borrow earthwork calculations.

The earthwork volumes for NCDOT are calculated in the earthwork balance sheet. The NCDOT balances earthwork in a spreadsheet outlined in Table 5 in the "description" column for each spreadsheet column number. Then, the last column in the table below, "Interpreted Earthwork for Analysis Tool," gives the translated earthwork values for use in this research.

Table 5. NCDOT earthwork balance sheet (NCDOT 2007).

Column No.	Description	Interpreted Earthwork for Analysis Tool
1	The survey line reference and beginning station for each summary point.	Beginning stations
2	The ending station for each summary point	Ending stations
3	The volume of all material excavated between summary point stations (except material covered by other excavation pay items such as undercut excavation and drainage ditch excavation).	Total unclassified excavation. This is a sum of the soil volume cut, volume topsoil in cut areas, volume topsoil in fill areas, and rock/"hard" rock. "hard" rock for NCDOT is the rock that cannot be treat as soil (Material that swells).
4	Volumes of "hard" rock that is excavated as a part of unclassified excavation.	Total rock on the project. This is the swelling material.
5	Volumes of material excavated beneath the roadway subgrade.	Material found during the subsurface investigation which is determined unsuitable for the project that is taken out.
6	Volumes of any unclassified excavation that is not suitable for roadway embankments.	The amount of topsoil in fill areas in addition to any other material deemed unsuitable for the project.
7	Unclassified Excavation (less "hard" rock) volume that is suitable for constructing roadway embankments.	Soil volume suitable for construction. The amount of unclassified excavation minus "hard" rock on the project.
8	List the total embankment (include backfill for undercut) in column eight. This figure is the volume of all the different materials used (do not include shrinkage or swell factors).	The area required for construction of an embankment.
9	The volume of embankment that is to be constructed from "hard" rock. Use the "hard" rock portion of unclassified excavation, before the earth, to construct embankments within each summary point.	Total rock material available to be used in construction.
10	The volume of embankment that is to be	The volume of soil to be constructed

	constructed from earth.	from soil. This is the unadjusted soil volume. This is the soil cut volume minus the material excavated beneath roadway.
11	The actual volume of material needed to construct the embankment. A shrinkage factor must be applied to the earth portion and then the "hard" rock is added if applicable. Shrinkage and swelling factors do not apply to "hard" rock unless specified by the Geotechnical Engineering Unit.	The adjust material to be used in construction on the project. This is the amount of soil and rock after shrink and swell adjustments have been applied.
12	The amount of borrow material needed to construct embankments after the suitable excavation (rock and earth) has been utilized within the summary points.	Note: If cut/fill is the amount of surface cut/fill including the amount for embankment, then: This is the total amount of fill required for the project. This is the total amount from volume fill required, volume topsoil from fill area, material excavated beneath roadway subgrade (column 5), and the total embankment.
13	Any "hard" rock excavation not utilized in embankments must have the volume listed in column thirteen.	See note for column 14 for use in analysis tool.
14	The volume of any suitable excavation (undercut or unclassified) not utilized in embankments. NCDOT excludes "hard" rock in this column because it is accounted for in column 13.	In order to calculate waste or borrow amount, total earthwork is calculated in the analysis tool combining column 13 and 14. Therefore, the amount of borrow required is signified by positive value while waste material is a negative value.
15	Record the volume of excavation (unclassified or undercut) that does not have the necessary properties to be used in embankments	This is the total amount of topsoil from cut and fill areas and the material excavated beneath roadway subgrade (column 5).
16	Column sixteen shows the summation of volumes recorded in columns thirteen, fourteen, and fifteen	The project totals include the “hard” rock not used, suitable material not used, and unsuitable material not used.

It is important to note that this method only classifies rock as “hard” rock, determined at auger refusal, and does not separately classify the drillable rock on site. The “hard” rock requires some form of coring or blasting for excavation. So, the “hard” rock, classified as rock by NCDOT, is adjusted for project use with the application of swell factors. It is assumed then that any other rock, which is able to be drilled in the subsurface investigation, is therefore treated as soil. As a result, this rock would have a shrink factor applied to it.

Next, after completing the earthwork balance sheet, the total volume amounts for each section are required for columns three through sixteen. These values will become the "Project Totals" on borrow projects, which then need an additional 5% added to column twelve for replacing the topsoil. The "Earthwork Summary" shown in the final design should only include columns one, two, three, five, eleven, twelve and sixteen of the "Earthwork Balance Sheet." The shrinkage factor for the embankment from the borrow pit (column eleven) is not included in the final design. (NCDOT 2007)

Swelling factors can also be applied to projects. These are usually only applied when significantly hard rock is encountered. Oftentimes, a general swell factor of 25% is applied, as opposed to the 20% used in recent years (15-20 years) ago (Pilipchuk 2013). The general swell value is most commonly used unless specified to a more exact number.

2.8.5 South Carolina Department of Transportation

The SCDOT identifies variation in earthwork quantities due to shrink and swell considerations primarily in two state manuals/specifications: SCDOT Division 200 Earthwork (SCDOT 2004) and SCDOT Standard Specification for Highway Construction (SCDOT 2007). These two manuals/specifications are being identified specifically because assumptions for the SCDOT earthwork method and for the designation and use of shrink and swell values are made in this study based on the guidelines provided.

One of the first steps in a design process is to complete the subsurface investigation. This investigation is done to identify the material on site and if this soil is suitable for the project.

Testing may be required of the soil type to determine the amount of shrinkage or swelling that is to be expected. Specifications for excavation areas by SCDOT (2004):

> If an area of questionable material is encountered, it may be necessary for the Resident Construction Engineer to request additional borings for the purpose of verifying shrink/swell and suitability. This will be determined on a case-by-case basis. The Resident Construction Engineer should contact the Research and Materials Laboratory to arrange the use of any needed boring equipment. See Section 106 for additional information on control of materials. (SCDOT 2004)

Then, based on the borings, soil identification, and cross-sections for the project relating to cut/fill quantities, earthwork calculations are done to determine amount of soil needed, if any, brought to the embankment/roadway area. Specifications for borrow excavation areas by SCDOT (2004):

> It is often necessary to borrow material to balance earthwork, because the shrink/swell factor does not agree with the design factor. Borrow material may be obtained by widening cuts, flattening cut slopes, lowering grades or by obtaining borrow pits. Grade adjustments on primary roads and Interstate projects and those greater than 0.3 feet on secondary roads should be avoided and require approval by the District Construction Engineer. (SCDOT 2004)

SCDOT (2007) outlines when shrinkage values are used in earthwork quantities in the “Shoulders and Slopes” section of the specifications. Since this specification includes earthwork conditions, it is reasonable to assume that this process may be applied to the rest of the earthwork calculation. The steps for earthwork are then as follows by SCDOT (2007):

> 1 The quantity for the pay item Select Material for Shoulders and Slopes is the volume of the approved materials placed and compacted to bring the shoulders and slopes up to the required lines, grades, and cross-section and is measured by the cubic yard (CY) of material, complete in-place, and accepted.
>
> 2 In cases where it is not feasible to measure the compacted in-place volume, it is measured on the cubic yard basis in loose volume at the point of delivery on the road by scaling and counting the loads, with a 25% deduction for shrinkage.
>
> 3 When selected material for shoulders and slopes is placed on irregular areas where it is not feasible to determine the volume of the soil compacted in place, in lieu of scaling and counting the loads, the RCE may designate pit areas from which to obtain selected material for shoulders and slopes and take measurements in accordance with Subsection 203.5. When measurement is made of the material in its original position, no deduction is made for shrinkage. This method of measurement is not allowed when the depth of the pit excavation is less than 18 inches.

4 Material used in the construction of shoulders, other than that obtained from sources specified in Subsection 209.2, is not measured or paid under the item Select Material for Shoulders and Slopes. When the material used in the shoulders and slopes consists of ordinary roadway or drainage excavation the material is measured as Unclassified Excavation.

(SCDOT 2007)

2.8.6 Tennessee Department of Transportation

The TDOT categorizes most roadway projects as unclassified excavation. Earthwork values are calculated by the average end area method. The earthwork for road projects will typically, unless otherwise stated, fall under pay item 203-01, Road and Drainage Excavation (Unclassified), by cubic yards (instead of a lump sum). In special cases, earthwork may be classified under separate bid items or embankment in place bid items. (TDOT 2013)

According to the TDOT (2013), shrinkage and swelling of soil and rock will vary based on soil type, weather, equipment, depth of cuts and fills, and length of haul. Shrinkage and swelling percentages used by the TDOT are shown in Figure 10.

The following examples are offered as a guide:

1. Light cuts and fills

   1 - 2 foot cuts and fills

   Earth 30% to 50%
   Chert 20% to 30%

   2 - 4 foot cuts and fills

   Earth 25% to 30%
   Chert 10% to 15%

   4 - 6 foot cuts and fills

   Earth 15% to 20%
   Chert 8% to 12%

2. Heavy cuts and fills

   Earth 10%
   Chert 0% to 8%

3. Heavy cuts and light fills

   Cuts 12 feet +, Fills 1 - 2 feet (average)

   Earth 15% to 20%
   Chert 5% to 10%

   Cuts 12 feet +, Fills 2 - 4 feet (average)

   Earth 10% to 15%
   Chert 5% to 10%

4. Shale and slate

   5% to 10% shrinkage; varies with type of material

5. Sandstone

   0% shrinkage to 15% swell; varies with type of material and weather conditions

6. Limestone

   If material is a small percentage and mixed with embankment, 0% shrinkage

   Heavy cuts and fills: 15% to 20% swell

   Light fills: 20% swell

Figure 10. Shrinkage and swelling factors used in TDOT (TDOT 2013).

The TDOT (2013) shows examples of how the TDOT calculates earthwork to be shown in the profile sheet. The following figure shows how the calculations are done when the earthwork is balanced.

1. Earthwork balanced.

A. Show on profile sheet.

EXC. (UNCL.) 295,000 C.Y.	COMMON	250,000 C.Y.	(INCL. 13,000 C.Y. FROM EXCAVATION AREAS AND 5,000 C.Y. FROM EMBANKMENT AREAS; 12,500 C.Y. FROM COUNTY ROADS AND PRIVATE DRIVES)
	ROCK	45,000 C.Y.	

<u>EXC.</u>
EMB.

	EMB.	253,489 C.Y.	(INCL. 5,490 C.Y. FOR COUNTY ROADS AND PRIVATE DRIVES; 5,000 C.Y. TO REPLACE STRIPPED TOPSOIL)
		SHR. 15% SW. 15%	

B. Calculation procedure for balanced section

250,000 C.Y.	Exc. (Common)
-13,000 C.Y.	Topsoil from exc. areas
- 5,000 C.Y.	Topsoil from emb. areas
232,000 C.Y.	Exc. (Common) available for balance

$$\frac{\text{Exc. (Com)}}{1.15} + [\text{Exc. (Rock)} \times 1.15] \quad \text{vs.} \quad \text{Emb.}$$

$$\frac{232{,}000}{1.15} + (45{,}000 \times 1.15) \quad \text{vs.} \quad 253{,}489 \text{ C.Y.}$$

$$201{,}739 + 51{,}750 \quad \text{vs.} \quad 253{,}489 \text{ C.Y.}$$

$$253{,}489 \text{ C.Y.} = 253{,}489 \text{ C.Y.}$$

Balanced

Figure 11. Example calculation for earthwork values when balanced (TDOT 2013)

On the other hand, Figure 12 shows an example of earthwork in the plan set when the values end up unbalanced.

2. Earthwork unbalanced.

A. Show on profile sheet.

EXC. (UNCL.) [COMMON 350,000 C.Y. (INCL. 13,000 C.Y. TOPSOIL EXCAVATION AREAS AND 5,000 C.Y. FROM EMBANKMENT AREAS; 12,500 C.Y.FROM COUNTY ROADS AND PRIVATE DRIVES; 100,000 C.Y. EXCESS MATERIAL.)

ROCK 45,000 C.Y.]

<u>EXC.</u>
EMB.

[EMB. 253,489 C.Y. (INCL. 5,490 C.Y. FOR COUNTY ROADS AND PRIVATE DRIVES; 5,000 C.Y. TO REPLACE STRIPPED TOPSOIL)]

SHR. 15%
SW. 15%

B. Calculation procedure for unbalanced section

350,000 C.Y.	Exc. (Common)
-13,000 C.Y.	Topsoil from exc. areas
- 5,000 C.Y.	Topsoil for emb. area
332,000 C.Y.	Exc. (Common) available for balance

$$\frac{\text{Exc. (Com)}}{1.15} + [\text{Exc. (Rock)} \times 1.15] \quad \text{vs. Emb.}$$

$$\frac{332{,}000}{1.15} + (45{,}000 \times 1.15) \quad \text{vs. } 253{,}489 \text{ C.Y.}$$

$$340{,}446 \text{ C.Y.} \quad \text{vs. } 253{,}489 \text{ C.Y.}$$

The 86,957 C.Y. of excess material has had the shrinkage factor applied to it (this assumes all excess material will be common). When this quantity is multiplied by the shrinkage factor (to "un-shrink" it), the excess then becomes 100,000 C.Y.

Figure 12. Example calculation for earthwork values when unbalanced (TDOT 2013).

For earthwork quantities, TDOT follows the previously mentioned methods with the application of shrinkage and/or swelling values.

2.8.7 Summary of DOT Earthwork Calculation Methods

The southeastern state DOT earthwork calculation methods are separately discussed in this background and literature review. A summary of the earthwork calculation methods is included in this background study in order to compare the methods side-by-side. This summary is presented in Table 6.

Table 6. Summary of southeastern state DOT earthwork calculation methods.

State DOT	**Calculation Method**
ALDOT	$Adjusted\ Soil\ = (Soil\ Volume\ Cut) * SF$ $Adjusted\ Rock\ = (Rock\ Volume\ Cut) * BF$ $Borrow(+)or\ Waste\ (-)$ $= [(Volume\ Fill) + (Topsoil\ from\ Fill)] - [(Adjusted\ Soil) + (Adjusted\ Rock)]$ $Percent\ Balanced = \frac{Borrow(+)or\ Waste(-)}{Total\ Unclassified\ Excavation} * 100$
FDOT	• Same calculation method as ALDOT with one exception: ○ FDOT includes truck adjustments to the earthwork estimation. This is a factor applied to earthwork values for hauling of material. ○ This truck adjustment is to account for hauling of material, and not final earthwork.

GDOT	Using Unclassified Excavation pay item: *Swell on Fill calculation method:* $Borrow(+) or\ Waste\ (-)$ $= \left[\frac{(Volume\ Fill) + (Topsoil\ from\ Fill)}{SF}\right] - (Soil\ Volume\ Cut)$ $- (Rock\ Volume\ Cut)$ $Percent\ Balanced = \frac{Borrow\ Excavation}{Total\ Unclassified\ Excavation} * 100$ *Shrink on Cut calculation method:* $Borrow(+) or\ Waste\ (-)$ $= \frac{\left[[(Volume\ Fill) + (Topsoil\ from\ Fill)] - \left((Volume\ Soil\ Cut) * SF\right)\right]}{SF}$ $- (Volume\ Rock\ Cut)$ $Percent\ Balanced = \frac{Borrow\ Excavation}{Total\ Unclassified\ Excavation} * 100$ • GDOT does not swell material. The term “swell” in Swell on Fill” method refers to the inverse of shrink.
NCDOT	• NCDOT completes earthwork in specified values, then determines final values. $Percent\ Balanced$ $= \frac{Total\ Volume\ of\ Suitable\ Material, not\ used\ in\ the\ Embankment}{Total\ Unclassified\ Excavation} * 100$

SCDOT	• SCDOT does not swell any material. • Typical state shrink amount is 25%. $Adjusted\ Soil\ = (Soil\ Volume\ Cut) * SF$ $Borrow = [(Volume\ Fill) + (Topsoil\ from\ Fill)] - [(Adjusted\ Soil) + (Excavated\ Rock)]$
TDOT	$Adjusted\ Soil\ = \frac{Soil\ Volume\ Cut}{1 + SF}$ $Adjusted\ Rock\ = (Rock\ Volume\ Cut) * BF$ $Borrow(+) or\ Waste\ (-) = [(Volume\ Fill) + (Topsoil\ from\ Fill)] - [(Adjusted\ Soil) + (Adjusted\ Rock)]$

Chapter 3:

Analysis Tool

An analysis tool was developed to simultaneously calculate earthwork values for the previously mentioned southeastern DOTs, while applying shrink and swell adjustments, for use in roadway design projects.

3.1 Analysis Tool Introduction to User Input and Cross-Sections

The analysis tool is a spreadsheet developed in Microsoft Excel® 2010 (Excel ®). This Excel® spreadsheet was created in order to calculate the earthwork values (including adjustments for material shrink and swell) and percent balanced for a 10-station alignment by each state method, simultaneously for comparison. The first worksheet, titled “Cross-Sections,” is where the user inputs the stations, the volumetric values hand calculated from the average end area method, and the shrink percentage. For simplicity, the worksheet is presented with a 10-station increment or a 1000 feet section, but this could easily be expanded to work with a larger section or entire project. The user inputs into the designated cells. The swell value(s) are not included in this user input section since rock is treated in different ways among the various southeastern state DOTs. Some swell use is determined based on: the state DOT earthwork method, whether the swelling material is used on for the final project, rock hardness (if the material is rock). This first worksheet is the primary sheet where the other state methods and calculations are referenced from. The worksheet presented in Figure 13 is the first sheet of the analysis tool, the “Cross-Sections” page:

	A	B	C	D	E	F	G	H	I
1	ALDOT/HMB Corridor X Project								
2									
3	User INPUT data for ten station lengths at a time:								
4									
5	Station	Volume Cut	Volume Fill	Volume Topsoil (Cut Areas)	Volume Topsoil (Fill Areas)	Volume Sandstone	Volume Shale	Volume Refusal (Sandstone)	Volume Refusal (Shale)
6		(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)
7	1+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	2+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	3+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	4+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	5+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	6+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	7+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	8+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	9+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	10+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17									
18	Totals:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19									
20	**Note:** Volumetric calculations completed by the average end area method.								
21									
22	Shrink percentage =		0 %						

Figure 13. "Cross-Sections" worksheet as a user input page for earthwork calculations.

The other worksheets in this analysis tool include each state method and final comparison sheets. Each of these sheets following the initial "Cross-Sections" page cross-references the stationing, volumetric values, and shrink percentage from the first worksheet. Each state method and the comparison sheet then automatically complete the earthwork calculations with minimal user input. The user input that is required is indicated in red by the input cell. The outline of the Excel® file is set-up with tabs, as shown in Figure 14.

Figure 14. Tabs for the developed analysis tool showing the file layout.

3.2 State DOT Earthwork Calculations

The remaining worksheets are linked to the values from the "Cross-Sections" sheet for use in the separate state calculation methods. Additional user input may be required, depending on the state, designated in red lettering by the cells. If swell is being applied to a state method, a swelling factor must be input into that state sheet. For each state earthwork, the cells highlighted in green are the total excavated values and the adjusted values for stockpile use. The cell in blue is the percent balanced value which compares the total excavated value and the adjusted material value (cells in green). If the percent balanced value is 0%, then the earthwork values are completely balanced. Therefore, theoretically, to have the most economic earthwork method would require a method where the percent balanced value is the closest to 0%. If percent balanced is positive, then the observed stations require material from a borrow source. On the other hand, if the percent balanced is negative, the stations have a waste amount that requires disposal, or use on another section of the project. Since this chapter merely introduces the analysis tool structure, the volumetric values are all provided as 0.00, therefore the calculation cells show a "#DIV/0" error message.

The first state calculated by the analysis tool is ALDOT. Since the case study in this research uses an HMB Alabama, LLC project, the calculation tab is "ALDOT-HMB."

	A	B	C	D	E	F	G	H	I
1	ALDOT/HMB								
2									
3	Station	Volume Cut	Volume Fill	Volume Topsoil (Cut Areas)	Volume Topsoil (Fill Areas)	Volume Sandstone	Volume Shale	Volume Refusal (Sandstone)	Volume Refusal (Shale)
4		(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)
5									
6	1+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	2+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	3+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	4+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	5+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	6+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	7+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	8+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	9+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	10+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16									
17	Totals:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18									
19	Total Unclassified Excavation =			0.00	yd³				
20									
21	Shrink/Swell Factors:								
22	Shrink Percentage =			0	%				
23	Shrink Factor =			1.00					
24	Sandstone and Shale Swell Factor =			1.10	User INPUT				
25	Refusal Sandstone Swell Factor =			1.25	User INPUT				
26	Refusal Shale Swell Factor =			1.20	User INPUT				
27									
28	Adjusted Soil Cut =			0.00	yd³				
29	Adjusted Sandstone =			0.00	yd³				
30	Adjusted Shale =			0.00	yd³				
31	Adjusted Refusal (Sandstone) =			0.00	yd³				
32	Adjusted Refusal (Shale) =			0.00	yd³				
33									
34	Borrow (+) or Waste (-)			0.00	yd³				
35									
36	Percent Balanced =			#DIV/0!	%				

Figure 15. Earthwork calculation sheet for ALDOT/HMB method.

Next, Figure 16 through Figure 20 show the worksheets for the rest of the southeastern state DOTs including Florida, Georgia, North Carolina, South Carolina, and Tennessee. The same color coding and user input signaling applies for these sheets as for the ALDOT-HMB worksheet. As mentioned, the volumes are read from the "Cross-Sections" worksheet, and then earthwork values are calculated using the various state methods.

	A	B	C	D	E	F	G	H	I
1	FDOT								
2									
3	Station	Volume Cut	Volume Fill	Volume Topsoil (Cut Areas)	Volume Topsoil (Fill Areas)	Volume Sandstone	Volume Shale	Volume Refusal (Sandstone)	Volume Refusal (Shale)
4		(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)
5	1+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	2+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	3+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	4+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	5+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	6+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	7+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	8+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	9+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	10+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15									
16	Totals:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17									
18	Shrink/Swell Factors:								
19	Shrink Percentage =				0	%			
20	Shrink Factor =				1.00				
21	Sandstone and Shale Swell Factor =				1.10	User INPUT			
22	Refusal Sandstone Swell Factor =				1.25	User INPUT			
23	Refusal Shale Swell Factor =				1.20	User INPUT			
24									
25	Total Topsoil Being Excavated =				0.00				
26	Total Suitable Soil Excavation (- Topsoil)=				0.00	yd^3			
27	Total Rock Excavation =				0.00	yd^3			
28	Refusal Sandstone Excavation =				0.00	yd^3			
29	Refusal Shale Excavation =				0.00	yd^3			
30	Total Unclassified Excavation =				0.00	yd^3			
31									
32	Shrink/Swell Adjustments:								
33	Adjusted Soil Cut =				0.00	yd^3			
34	Adjusted Sandstone =				0.00	yd^3			
35	Adjusted Shale =				0.00	yd^3			
36	Adjusted Refusal (Sandstone) =				0.00	yd^3			
37	Adjusted Refusal (Shale) =				0.00	yd^3			
38	Total Adjusted Soil for Shrink/swell =				0.00	yd^3			
39									
40	Amount Required for Fill =				0.00	yd^3			
41									
42	Borrow (+) or Waste (-)				0.00	yd^3			
43									
44	Required from Off-Site Borrow =				none	yd^3			
45									
46	Percent Balanced =				#DIV/0!	%			

Figure 16. Earthwork calculation sheet for FDOT method.

GDOT calculations vary based on pay item. Since the unclassified excavation is a typical pay item used in roadway construction, the GDOT calculation methods for unclassified excavation are calculated in this analysis tool. Therefore, the GDOT calculation sheet calculates for both the “unclassified excavation and borrow” earthwork estimation methods: Swell on Fill and Shrink on Cut. These methods are outlined in the Background and Literature Review chapter of this report. Figure 17 shows the GDOT worksheet.

	A	B	C	D	E	F	G	H	I
1	GDOT								
2									
3	**Station**	**Volume Cut**	**Volume Fill**	**Volume Topsoil (Cut Areas)**	**Volume Topsoil (Fill Areas)**	**Volume Sandstone**	**Volume Shale**	**Volume Refusal (Sandstone)**	**Volume Refusal (Shale)**
4		(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)
5	1+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	2+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	3+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	4+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	5+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	6+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	7+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	8+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	9+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	10+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15									
16	Totals:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17									
18	Borrow Excavation, Including Material:								
19									
20	Shrink Percentage =			0	%				
21	Shrinkage Factor =			1.00					
22									
23	Excavation From Cross Sections =			0.00	yd^3				
24									
25	Soil Available for Fill =			0.00	yd^3				
26	Rock Available for Fill =			0.00	yd^3				
27		Volume Sandstone, Shale, and Total Refusaal							
28	Total Available soil/rock for fill =			0.00	yd^3				
29									
30	Total Fill needed for Embankment =			0.00	yd^3				
31									
32	Borrow Excavation: Swell on Fill Method								
33	Borrow (+) or Waste (-)			0.00	yd^3				
34									
35	Percent Balanced =			#DIV/0!	%				
36									
37	Borrow Excavation: Shrink on Cut Method								
38	Borrow (+) or Waste (-)			0.00	yd^3				
39									
40	Percent Balanced =			#DIV/0!	%				
41									
42	**Note:** no rock swell.								

Figure 17. Earthwork calculation sheet for GDOT method.

The worksheet displayed in Figure 18 is for the NCDOT earthwork method.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	NCDOT															
2																
3	Station	Volume Cut	Volume Fill	Volume Topsoil (Cut Areas)	Volume Topsoil (Fill Areas)	Volume Sandstone	Volume Shale	Volume Refusal (Sandstone)	Volume Refusal (Shale)							
4		(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)							
5	1+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
6	2+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
7	3+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
8	4+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
9	5+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
10	6+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
11	7+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
12	8+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
13	9+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
14	10+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
15																
16	Totals:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							
17																
18	NCDOT Column Numbers:									Note: Includes Non-Refusal Rock						
19	1	2	3	4	5	6	7	8	9	10	11	12	13 and 14	15	16	Project Totals
20	Beginning Station	Ending Station	Excavated Material	Hard Rock Excavated (Unclassified Excavation)	Material Excavated Beneath Roadway Subgrade	Unclassified Excavation not suitable for Embankment	Unclassified Excavation (Less (-) "Hard" Rock) Volumes	Total Embankment	Volume of Embankment Constructed from "Hard" Rock	Volume of Embankment Constructed from Earth	Adjusted Volume to be Used for Embankment	Amount of Material Needed for the Embankment	Total Volume of Suitable Material, not used in the Embankment	Total Volume of Unsuitable Material, not used in the Embankment	Total Waste	Project Totals: Amount of Material Needed for the Fill Section
21					User INPUT	User INPUT (This includes topsoil)		(0.00 if cut/fill process includes construction for embankment)	(Adjusted Rock)			(If cut/fill includes embankment, then this is the total fill)	(Borrow (+), Waste (-))			
22			(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)
23	1+00	2+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	2+00	3+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	3+00	4+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	4+00	5+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	5+00	6+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	6+00	7+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	7+00	8+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	8+00	9+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	9+00	10+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	10+00	#REF!	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33																
34	Totals (yd³):		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35																
36	Shrink Percentage =			0												
37	Shrinkage Factor =			1.00												
38	Refusal Sandstone Swell Factor =			1.25	User INPUT											
39	Refusal Shale Swell Factor =			1.20	User INPUT											
40																
41																
42	Percent Balanced =			#DIV/0!	%											

Figure 18. Earthwork calculation sheet for NCDOT method

The SCDOT earthwork worksheet calculates earthwork quantities for the SCDOT 25% shrinkage as well as the shrink percentage referenced from the "Cross-Sections" worksheet. Having the SCDOT page calculate for both shrink percentages allows for a more in-depth comparison of the SCDOT earthwork calculation method, and comparing the method to the other southeastern state DOT methods. The SCDOT worksheet is shown in Figure 19.

	A	B	C	D	E	F	G	H	I
1	SCDOT								
2									
3	Station	Volume Cut	Volume Fill	Volume Topsoil (Cut Areas)	Volume Topsoil (Fill Areas)	Volume Sandstone	Volume Shale	Volume Refusal (Sandstone)	Volume Refusal (Shale)
4		(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)
5	1+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	2+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	3+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	4+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	5+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	6+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	7+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	8+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	9+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	10+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15									
16	Totals:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17									
18	SCDOT Typical Shrink Percentage =				25	%			
19	SCDOT Typical Shrink Factor =				0.75				
20									
21	Total Topsoil Being Excavated =				0.00	yd^3			
22	Total Suitable Soil Excavation (- Topsoil)=				0.00	yd^3			
23	Total Rock + Refusal Rock Excavation =				0.00	yd^3			
24	Total Unclassified Excavation =				0.00	yd^3			
25									
26	Shrink/Swell Adjustments:								
27	Adjusted Soil Excavated =				0.00	yd^3			
28									
29	Total Material Available for Fill =				0.00	yd^3			
30		After Adjustments							
31									
32	Borrow (+) or Waste (-)				0.00	yd^3			
33									
34	Percent Balanced =				#DIV/0!	%			
35									
36	If SCDOT used the provided shrink value:								
37	Shrink percentage =				0	%			
38	Shrinkage Factor =				1.00				
39									
40	Shrink/Swell Adjustments:								
41	Adjusted Soil Excavated =				0.00	yd^3			
42									
43	Total Material Available for Fill =				0.00	yd^3			
44		After Adjustments							
45									
46	Borrow (+) or Waste (-)				0.00	yd^3			
47									
48	Percent Balanced =				#DIV/0!	%			

Figure 19. Earthwork calculation sheet for SCDOT method.

Figure 20 is the worksheet for the TDOT method. The TDOT earthwork method also "un-shrinks" any excess on the project. Therefore, if any "waste" is detected in the earthwork estimations, the analysis tool will multiply the excess material by one plus the shrink factor divided by one hundred percent. If no waste is detected for the section, the “Unbalanced Value” will read “no waste,” telling the user the earthwork is either complete balanced or results in required borrow material. If “no waste” is determined, the amount of “Waste(-) after Adjustment” will read “#VALUE!” as an error message since the calculations were not able to be completed because of the text in the “no waste” cell.

	A	B	C	D	E	F	G	H	I
1	TDOT								
2									
3	**Station**	**Volume Cut**	**Volume Fill**	**Volume Topsoil (Cut Areas)**	**Volume Topsoil (Fill Areas)**	**Volume Sandstone**	**Volume Shale**	**Volume Refusal (Sandstone)**	**Volume Refusal (Shale)**
4		**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**
5	1+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	2+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	3+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	4+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	5+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	6+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	7+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	8+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	9+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	10+00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15									
16	Totals:	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17									
18	Soil Excavation =			0.00	yd^3				
19	Rock Excavation =			0.00	yd^3				
20	Total Unclassified Excavation =			0.00	yd^3				
21									
22	Percent Shrinkage =			0	%				
23	Shrink Factor (to be divided by value)=			1.00	(/)				
24	Sandstone and Shale Swell Factor =			1.10	User INPUT				
25	Refusal Sandstone Swell Factor =			1.25	User INPUT				
26	Refusal Shale Swell Factor =			1.20	User INPUT				
27									
28	Adjusted Soil Cut =			0.00	yd^3				
29	Adjusted Rock =			0.00	yd^3				
30	Adjusted Refusal (Sandstone) =			0.00	yd^3				
31	Adjusted Refusal (Shale) =			0.00	yd^3				
32		Total Adjusted Rock =		0.00	yd^3				
33									
34	Total Available for Fill (Borrow) =			0.00	yd^3				
35	Fill Required for Embankment =			0.00	yd^3				
36									
37	Borrow (+) or Waste (-)			0.00	yd^3				
38									
39	Percent Balanced =			#DIV/0!	%				
40									
41	TDOT Comparison:								
42	Unbalanced Value =			no waste	yd^3				
43	"Un-Shrink" =			1.00					
44	Waste(-) after Adjustment =			#VALUE!	yd^3				
45									
46	Required From Borrow Source =			none					

Figure 20. Earthwork calculation sheet for TDOT method.

After the state earthwork methods, the next worksheet in the proposed analysis tool is "Method Comparison." This worksheet first displays the "Section Characteristics" of the section being observed. Under this section, the starting station and primary shrink percentage is automatically updated from the "Cross-Sections" page. The ending station is automatically updated if the section is a 10-station increment; otherwise user input is required for the ending station. Next, the quantity budget is input by the user, as dollars per unit volume, for the project. Then, the "Method (State DOT)," "Total Borrow (+) or Waste (-)," and "Percent Balanced," columns are automatically updated values from calculations made by the state worksheets. The "Unbalanced Earthwork Cost" is calculated in this page from the "Total Borrow(+) or Waste(-)" multiplied by the quantity budget mount. Finally, the "Comments" section allows the user to include any additional information.

The comparison worksheet , "Method Comparison" page, shows each state method's values side-by-side. The GDOT, SCDOT, and TDOT worksheets each have two rows instead of one. GDOT distinguishes between the two methods used for earthwork calculation in unclassified excavation. SCDOT calculates earthwork with the SCDOT shrink percentage of 25%. The analysis tool then also calculates SCDOT earthwork with the same shrink percentage used by the other states, as input in the "Cross-Sections" worksheet. This allows the actual SCDOT calculation method to be compared to the other state DOT earthwork methods; otherwise the comparison includes a further comparison between the shrinkage values used. Lastly, TDOT calculates the earthwork estimates in the first row. Then, if any waste is detected, the waste values after "un-shrink[ing]" the excess material is presented in the final row.

Having the "Earthwork Method Comparison" summary sheet set up in this manner allows the user to compare the southeastern state DOT earthwork methods more efficiently. Having a dollar amount assigned to any unbalanced earthwork, displays the amount of risk the project could potentially take on. This risk is added if an unbalanced earthwork is not budgeted for the project prior to construction. The “Earthwork Method Comparison” summary sheet is shown in Figure 21.

	A	B	C	D	E
1	Earthwork Method Comparison				
2					
3	Section Characteristics:				
4	Starting Station =		1+00		
5	Ending Station =		10+00	User INPUT if not 10-station increment	
6	Shrink Percentage =		0	%	
7					
8	Quantity budget (User INPUT)=		$15.00	/yd^3	
9					
10	Method (State DOT)	Total Borrow (+) or Waste (-)	Percent Balanced	Unbalanced Earthwork Cost	Comments (User INPUT)
11		(yd^3)	(%)	($)	
12	ALDOT/HMB	0.00	#DIV/0!	0.00	
13	FDOT	0.00	#DIV/0!	0.00	
14	GDOT	0.00	#DIV/0!	0.00	Swell on Fill method
15		0.00	#DIV/0!	0.00	Shrink on Cut method
16	NCDOT	0.00	#DIV/0!	0.00	
17	SCDOT	0.00	#DIV/0!	0.00	Typical 25% shrink
18		0.00	#DIV/0!	0.00	Same shrink value as other DOTs
19	TDOT	0.00	#DIV/0!	0.00	Earthwork estimate prior to "un-shrink"
20		#VALUE!	-	#VALUE!	Waste amount fter "un-shrinking" the value

Figure 21. “Earthwork Method Comparison” sheet for the analysis tool.

This analysis tool compares the southeastern state DOT earthwork evaluation methods. To use this Excel® file for any other project, the user inputs the cut and fill volumetric quantities, and the shrink percentage for a 10 station alignment. If the section being observed is greater than 10 stations, then additional rows must be inserted by the user as well as an incorporation of the new rows in the “Totals” for the initial volume quantities (“Totals” shown in row 18 of Figure 13). Additional user input is then required for the state calculation pages if swell values are used or required, and the NCDOT method requires an input if special material is found and needs to be observed for use on the project. The spreadsheet calculates earthwork values for ALDOT, FDOT, GDOT, NCDOT, SCDOT, and TDOT.

Chapter 4:

Case Study and Analysis

This chapter presents results of a case study. The analysis tool, presented in Chapter 3, is used to determine the borrow or waste volume required for a short roadway section based on a set of drawings and provided shrink and swell factors. The purpose of the case study analysis was to compare the earthwork methods of some of the southeastern state DOTs and observe the effect of shrinkage and swelling factors on an earthwork problem.

4.1 Case Study

The case study used in this research was the ALDOT Corridor-X project. Calculations and earthwork values that were conducted by HMB Alabama, LLC, were provided by Mr. Brian K. Hynniman. The earthwork calculations provided by HMB for the entire Corridor X project are divided into earthwork east and west of Mulberry Fork. Figure 22 shows the earthwork totals for the entire Corridor X project. This earthwork summary demonstrates the earthwork calculation method used by HMB and ALDOT, as well as provides the shrinkage and swelling factors used on the project.

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TOTAL EARTHWORK WEST OF MULBERRY FORK

ROADWAY	CUT VOLUME (cu. Yds.)	TOPSIOL ON CUT (cu. Yds.)	TOPSIOL BENEATH FILL (cu. Yds.)	SHRINK/SWELL	AVAILABLE CUT (cu. Yds.)	FILL VOLUME (cu. Yds.)
CORRIDOR X		69962.07	55869.48			1285919.40
CUT	815304.04			0.85	693008.43	
SANDSTONE	89787.41			1.10	98766.15	
SHALE	32663.22			1.10	35929.54	
REFUSAL (SANDSTONE)	0.00			1.25	0.00	
REFUSAL (SHALE)	769245.44			1.20	923094.53	
REED ROAD	7082.96	1554.76	3845.47	0.85	6020.51	77020.77
PEA RIDGE ROAD	4504.22	989.41	2031.48	0.85	3828.59	47140.39
GRANNY HYCHE ROAD	9229.67	1788.17	12941.48	0.85	7845.22	362745.26
NORTHWEST ACCESS ROAD	0.00	0.00	86.85	0.85	0.00	89.22
ACCESS ROAD 2	9805.68	0.00	0.00	0.85	8334.83	15973.09
TOTALS	1737622.64	74294.40	74774.77		1776827.80	1788888.13

NOTE: Cut does not include topsoil.

CUT (CUT + TOPSOIL ON CUT)	1,811,917 cu. Yds.	
TOPSOIL BENEATH FILL	74,775 cu. Yds.	
TOTAL UNCLASSIFIED EXCAVATION:	1,886,692 cu. Yds.	
TOPSOIL AVAILABLE	149,069 cu. Yds.	
AVAILABLE CUT	1,776,828 cu. Yds.	
FILL (FILL + TOPSOIL BENEATH FILL)	1,863,663 cu. Yds.	
TEMPORARY RIPRAP (ROCK)	1,841 cu. Yds.	
IMPROVED ROADBED	41,728 cu. Yds.	
BORROW EXCAVATION	130,404 cu. Yds.	***PERCENT BALANCED*** ***6.9%***

TOTAL EARTHWORK EAST OF MULBERRY FORK

ROADWAY	CUT VOLUME (cu. Yds.)	TOPSIOL ON CUT (cu. Yds.)	TOPSIOL BENEATH FILL (cu. Yds.)	SHRINK/SWELL	AVAILABLE CUT (cu. Yds.)	FILL VOLUME (cu. Yds.)
CORRIDOR X		65564.83	25714.81			1831848.71
CUT	615804.23			0.85	523433.60	
SANDSTONE	286292.74			1.10	314922.01	
SHALE	0.00			1.10	0.00	
REFUSAL (SANDSTONE)	1192980.97			1.25	1491226.22	
REFUSAL (SHALE)	0.00			1.20	0.00	
RIVER ROAD	41495.33	3180.85	927.41	0.85	35271.03	4009.90
RIVER ROAD DETOUR	657.00	0.00	0.00	0.85	558.45	2503.00
RIVERVIEW ROAD	11214.07	2033.58	0.00	0.85	9531.96	0.00
HOOVER ROAD	1230.38	0.00	0.00	0.85	1045.83	0.92
RIVEROAKS ROAD	261933.57	16867.53	31288.63	0.85	222643.53	1017988.63
TOTALS	2411608.31	87646.79	57930.85		2598632.63	2856351.18

NOTE: Cut does not include topsoil.

CUT (CUT + TOPSOIL ON CUT)	2,499,255 cu. Yds.	
TOPSOIL BENEATH FILL	57,931 cu. Yds.	
TOTAL UNCLASSIFIED EXCAVATION:	2,557,186 cu. Yds.	
TOPSOIL AVAILABLE	145,578 cu. Yds.	
AVAILABLE CUT	2,598,633 cu. Yds.	
FILL (FILL + TOPSOIL BENEATH FILL)	2,914,282 cu. Yds.	
TEMPORARY RIPRAP (ROCK)	1,872 cu. Yds.	
IMPROVED ROADBED	42,589 cu. Yds.	
FILL FOR SLOUGH AREA (ROCK)	8,551 cu. Yds.	
BORROW EXCAVATION	368,662 cu. Yds.	***PERCENT BALANCED*** ***14.4%***

PROJECT TOTALS

TOTAL UNCLASSIFIED EXCAVATION	4,443,878 cu. Yds.
BORROW EXCAVATION	499,066 cu. Yds.
TOPSOIL AVAILABLE	294,647 cu. Yds.
TOPSOIL FROM STOCKPILES	104,000 cu. Yds.

Figure 22. Corridor X earthwork calculation totals including adjustment values (HMB 2011).

Figure 23 through display the calculated volumes for each station along the Corridor X project line. These volumes were calculated using the average end area method. The total volumes shown in the following figures were used in the earthwork summary sheet, Figure 22, separated into values east and west of Mulberry Fork. The volumetric values used in the examples from the case study come from these figures for the respective station increments.

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STATION	AREA CUT (ft²)	AREA FILL (ft²)	AREA TOPSOIL (CUT AREAS) (ft²)	AREA TOPSOIL (FILL AREAS) (ft²)	AREA SANDSTONE (ft²)	AREA SHALE (ft²)	AREA REFUSAL (SANDSTONE) (ft²)	AREA REFUSAL (SHALE) (ft²)	VOLUME CUT (cu yd)	VOLUME FILL (cu yd)	VOLUME TOPSOIL (CUT AREAS) (cu yd)	VOLUME TOPSOIL (FILL AREAS) (cu yd)	VOLUME SANDSTONE (cu yd)	VOLUME SHALE (cu yd)	VOLUME REFUSAL (SANDSTONE) (cu yd)	VOLUME REFUSAL (SHALE) (cu yd)
80+00	2549.30	2090.67	191.46	177.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
81+00	3711.07	349.99	279.28	126.81	0.00	0.00	0.00	2281.29	11593.28	4519.74	871.74	563.70	0.00	0.00	0.00	4224.61
82+00	5045.06	0.00	312.04	0.00	0.00	0.00	0.00	1904.51	16215.06	648.13	1095.04	234.83	0.00	0.00	0.00	7751.48
83+00	6008.30	0.00	329.51	0.00	0.00	571.63	0.00	1052.35	20469.19	0.00	1188.06	0.00	0.00	1058.57	0.00	5475.67
84+00	6227.43	0.00	336.48	0.00	0.00	1453.42	0.00	1052.19	22658.76	0.00	1233.31	0.00	0.00	3750.09	0.00	3897.30
85+00	5669.81	0.00	337.84	0.00	1059.38	255.62	0.00	3381.75	22031.93	0.00	1248.74	0.00	1961.81	3164.89	0.00	8211.00
86+00	4749.27	0.00	373.05	0.00	1200.46	290.38	0.00	4284.74	19294.59	0.00	1316.46	0.00	4184.89	1011.11	0.00	14197.20
87+00	3699.32	0.00	388.91	0.00	2048.73	328.85	0.00	7205.73	15645.54	0.00	1411.04	0.00	6017.02	1146.72	0.00	21278.65
88+00	4808.84	0.00	425.96	0.00	1828.54	702.36	0.00	7989.70	15755.85	0.00	1509.02	0.00	7180.13	1909.65	0.00	28139.69
89+00	7741.92	0.00	409.12	0.00	3570.24	0.00	0.00	3393.35	23242.15	0.00	1546.44	0.00	9997.74	1300.67	0.00	21079.72
90+00	8483.59	0.00	394.12	0.00	0.00	3759.55	0.00	3431.04	30047.24	0.00	1487.48	0.00	6611.56	6962.13	0.00	12637.76
91+00	0.00	0.00	420.09	0.00	8873.40	0.00	0.00	6118.47	15710.35	0.00	1507.80	0.00	16432.22	6962.13	0.00	17684.28
92+00	0.00	1406.45	351.20	159.38	5661.85	0.00	0.00	2827.90	0.00	2604.54	1428.31	295.15	26917.13	0.00	0.00	16567.35
93+00	2711.81	7180.64	185.68	361.50	0.00	0.00	0.00	0.00	5021.87	15902.02	994.22	964.59	10484.91	0.00	0.00	5236.85
94+00	90.09	12390.09	74.60	449.80	0.00	0.00	0.00	0.00	5188.70	36242.09	482.00	1502.41	0.00	0.00	0.00	0.00
95+00	186.62	18249.03	75.96	510.60	0.00	0.00	0.00	0.00	512.43	56739.11	278.81	1778.52	0.00	0.00	0.00	0.00
96+00	43.23	19400.70	32.01	545.59	0.00	0.00	0.00	0.00	425.65	69721.72	199.94	1955.91	0.00	0.00	0.00	0.00
97+00	18.99	19508.50	26.57	552.92	0.00	0.00	0.00	0.00	115.22	72054.07	108.48	2034.28	0.00	0.00	0.00	0.00
98+00	53.48	18552.58	42.62	554.73	0.00	0.00	0.00	0.00	134.20	70483.48	128.13	2051.20	0.00	0.00	0.00	0.00
99+00	67.10	17580.85	26.73	528.94	0.00	0.00	0.00	0.00	223.30	66913.76	128.43	2006.80	0.00	0.00	0.00	0.00
100+00	1.85	12156.27	11.76	467.77	0.00	0.00	0.00	0.00	127.69	55068.74	71.28	1845.76	0.00	0.00	0.00	0.00
101+00	5.16	8046.05	9.64	397.11	0.00	0.00	0.00	0.00	12.98	37411.70	39.63	1601.63	0.00	0.00	0.00	0.00
102+00	56.37	5258.94	26.03	336.61	0.00	0.00	0.00	0.00	113.94	24638.87	66.06	1358.74	0.00	0.00	0.00	0.00
103+00	274.39	2139.60	84.16	244.06	0.00	0.00	0.00	0.00	612.52	13701.00	204.06	1075.31	0.00	0.00	0.00	0.00
104+00	1421.19	1324.65	180.11	202.45	0.00	0.00	0.00	0.00	3139.96	6415.28	489.39	826.87	0.00	0.00	0.00	0.00
105+00	1990.89	2169.45	178.34	228.70	0.00	0.00	0.00	0.00	6318.67	6470.56	663.80	798.43	0.00	0.00	0.00	0.00
106+00	1990.55	1779.16	161.85	211.37	0.00	0.00	0.00	0.00	7373.04	7312.24	629.98	814.94	0.00	0.00	0.00	0.00
107+00	4669.92	1051.44	250.06	130.27	0.00	0.00	0.00	0.00	12334.20	5241.85	762.80	632.67	0.00	0.00	0.00	0.00
108+00	3279.40	702.72	237.26	126.11	0.00	0.00	0.00	0.00	14720.96	3248.44	902.44	474.78	0.00	0.00	0.00	0.00
109+00	264.26	2184.26	78.34	291.55	0.00	0.00	0.00	0.00	6562.33	5346.26	584.44	773.44	0.00	0.00	0.00	0.00
110+00	1.63	9145.45	12.78	437.94	0.00	0.00	0.00	0.00	492.39	20980.94	168.74	1350.91	0.00	0.00	0.00	0.00
111+00	16.35	14490.64	16.20	424.70	0.00	0.00	0.00	0.00	33.30	43770.54	53.67	1597.48	0.00	0.00	0.00	0.00
112+00	916.34	12658.78	104.96	362.36	0.00	0.00	0.00	0.00	1727.20	50276.70	224.37	1457.52	0.00	0.00	0.00	0.00
113+00	278.82	13882.05	63.00	423.26	0.00	0.00	0.00	0.00	2213.26	49149.69	311.04	1454.85	0.00	0.00	0.00	0.00
114+00	124.05	13556.54	39.06	431.50	0.00	0.00	0.00	0.00	746.06	50812.20	189.00	1582.89	0.00	0.00	0.00	0.00
115+00	80.83	10279.19	47.51	377.65	0.00	0.00	0.00	0.00	379.41	44140.24	160.31	1498.43	0.00	0.00	0.00	0.00
116+00	169.90	7715.80	61.00	359.51	0.00	0.00	0.00	0.00	464.31	33324.06	200.94	1365.11	0.00	0.00	0.00	0.00
117+00	139.15	4412.60	64.18	323.35	0.00	0.00	0.00	0.00	572.31	22460.00	231.81	1264.56	0.00	0.00	0.00	0.00
118+00	796.06	1469.58	142.16	173.10	0.00	0.00	0.00	0.00	1731.87	10892.93	382.11	919.35	0.00	0.00	0.00	0.00
119+00	1991.29	0.00	272.90	0.00	0.00	0.00	0.00	0.00	5161.76	2721.44	768.63	320.56	0.00	0.00	0.00	0.00
120+00	3155.02	0.00	272.12	0.00	0.00	0.00	0.00	0.00	9530.20	0.00	1009.30	0.00	0.00	0.00	0.00	0.00
121+00	2533.07	1371.81	211.59	183.59	0.00	0.00	0.00	0.00	10533.50	2540.39	895.76	339.98	0.00	0.00	0.00	0.00
122+00	40.74	9542.95	38.24	359.42	0.00	0.00	0.00	0.00	4766.31	20212.52	462.65	1005.57	0.00	0.00	0.00	0.00

Figure 23. Earthwork values page 1 (HMB 2011).

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STATION	AREA CUT (ft^2)	AREA FILL (ft^2)	AREA TOPSOIL (CUT AREAS) (ft^2)	AREA TOPSOIL (FILL AREAS) (ft^2)	AREA SANDSTONE (ft^2)	AREA SHALE (ft^2)	AREA REFUSAL (SANDSTONE) (ft^2)	AREA REFUSAL (SHALE) (ft^2)	VOLUME CUT (cu yd)	VOLUME FILL (cu yd)	VOLUME TOPSOIL (CUT AREAS) (cu yd)	VOLUME TOPSOIL (FILL AREAS) (cu yd)	VOLUME SANDSTONE (cu yd)	VOLUME SHALE (cu yd)	VOLUME REFUSAL (SANDSTONE) (cu yd)	VOLUME REFUSAL (SHALE) (cu yd)
123+00	308.44	7119.51	26.81	430.85	0.00	0.00	0.00	0.00	646.63	30856.41	120.46	1463.46	0.00	0.00	0.00	0.00
124+00	918.31	425.04	212.52	201.93	0.00	0.00	0.00	0.00	2271.76	13971.39	443.20	1171.81	0.00	0.00	0.00	0.00
125+00	1986.21	54.29	386.48	21.13	0.00	0.00	0.00	0.00	5378.74	887.65	1109.26	413.07	0.00	0.00	0.00	0.00
126+00	2357.59	1618.58	211.58	165.53	0.00	0.00	0.00	0.00	8044.07	3097.91	1107.52	345.67	0.00	0.00	0.00	0.00
127+00	0.00	9656.42	0.00	490.40	0.00	0.00	0.00	0.00	4365.91	20879.63	391.81	1214.69	0.00	0.00	0.00	0.00
128+00	88.22	8330.56	101.53	333.00	0.00	0.00	0.00	0.00	163.37	33309.22	188.02	1524.81	0.00	0.00	0.00	0.00
129+00	2224.25	1028.09	256.14	217.66	0.00	0.00	0.00	0.00	4282.35	17330.83	662.35	1019.74	0.00	0.00	0.00	0.00
130+00	2257.13	0.00	284.96	0.00	0.00	0.00	0.00	0.00	8298.85	1903.87	1002.04	403.07	0.00	0.00	0.00	0.00
131+00	2670.11	0.00	308.30	0.00	0.00	0.00	0.00	0.00	9124.52	0.00	1098.63	0.00	0.00	0.00	0.00	0.00
132+00	3489.26	0.00	320.64	0.00	0.00	0.00	0.00	0.00	11406.24	0.00	1164.70	0.00	0.00	0.00	0.00	0.00
133+00	4887.38	0.00	334.95	0.00	0.00	0.00	0.00	0.00	15512.30	0.00	1214.06	0.00	0.00	0.00	0.00	0.00
134+00	4440.36	0.00	303.25	0.00	0.00	0.00	0.00	0.00	17273.59	0.00	1181.85	0.00	0.00	0.00	0.00	0.00
135+00	2122.51	0.79	434.85	11.54	0.00	0.00	0.00	0.00	12153.46	1.46	1366.85	21.37	0.00	0.00	0.00	0.00
136+00	159.06	9282.81	78.78	487.95	0.00	0.00	0.00	0.00	4225.13	17191.85	951.17	924.98	0.00	0.00	0.00	0.00
137+00	895.05	13189.00	131.82	399.05	0.00	0.00	0.00	0.00	1952.06	41614.46	390.00	1642.59	0.00	0.00	0.00	0.00
138+00	1609.06	9096.25	154.82	337.50	0.00	0.00	0.00	0.00	4637.24	41268.98	530.81	1363.98	0.00	0.00	0.00	0.00
139+00	441.95	9722.55	97.27	341.61	0.00	0.00	0.00	0.00	3798.17	34849.63	466.83	1257.61	0.00	0.00	0.00	0.00
140+00	211.55	11181.87	87.25	363.34	0.00	0.00	0.00	0.00	1210.19	38711.89	341.70	1305.46	0.00	0.00	0.00	0.00
141+00	104.57	9711.27	57.81	375.78	0.00	0.00	0.00	0.00	585.41	38691.00	268.63	1368.74	0.00	0.00	0.00	0.00
142+00	896.13	3481.99	173.05	266.62	0.00	0.00	0.00	0.00	1853.15	24431.96	427.52	1189.63	0.00	0.00	0.00	0.00
143+00	4658.12	31.05	266.17	38.44	0.00	0.00	0.00	0.00	10285.65	6505.63	813.37	564.93	0.00	0.00	0.00	0.00
144+00	4312.78	0.00	345.72	0.00	0.00	0.00	0.00	4197.18	16612.78	57.50	1133.13	71.19	0.00	0.00	0.00	7772.56
145+00	6168.63	0.00	370.98	0.00	0.00	0.00	0.00	6413.26	19410.02	0.00	1327.22	0.00	0.00	0.00	0.00	19648.96
146+00	7249.81	0.00	377.45	0.00	0.00	0.00	0.00	6298.06	24848.96	0.00	1385.98	0.00	0.00	0.00	0.00	23539.48
147+00	5489.70	0.00	388.27	0.00	0.00	0.00	0.00	8459.36	23591.69	0.00	1418.00	0.00	0.00	0.00	0.00	27328.56
148+00	5623.87	0.00	366.99	0.00	0.00	0.00	0.00	8251.36	20580.69	0.00	1398.63	0.00	0.00	0.00	0.00	30945.78
149+00	5796.34	0.00	398.72	0.00	0.00	0.00	0.00	8593.39	21148.54	0.00	1417.98	0.00	0.00	0.00	0.00	31193.98
150+00	3701.14	0.00	359.80	0.00	0.00	0.00	0.00	9479.03	17587.93	0.00	1404.67	0.00	0.00	0.00	0.00	33467.44
151+00	4321.28	0.00	413.61	0.00	0.00	0.00	0.00	11822.77	14856.33	0.00	1432.24	0.00	0.00	0.00	0.00	39447.78
152+00	5010.40	0.00	454.70	0.00	0.00	0.00	0.00	10789.87	17280.89	0.00	1607.98	0.00	0.00	0.00	0.00	41875.26
153+00	5502.23	0.00	454.31	0.00	0.00	378.91	0.00	12094.30	19467.83	0.00	1683.35	0.00	0.00	701.69	0.00	42378.09
154+00	6079.25	0.00	467.46	0.00	0.00	418.78	0.00	15433.25	21447.19	0.00	1706.98	0.00	0.00	1477.20	0.00	50976.94
155+00	8704.03	0.00	430.16	0.00	0.00	297.89	0.00	10850.40	27376.44	0.00	1662.26	0.00	0.00	1327.17	0.00	48673.43
156+00	9392.83	0.00	463.65	0.00	0.00	361.68	0.00	10969.71	33512.70	0.00	1655.20	0.00	0.00	1221.43	0.00	40407.61
157+00	12128.72	0.00	462.98	0.00	0.00	0.00	0.00	9572.14	39854.72	0.00	1715.98	0.00	0.00	669.78	0.00	38040.46
158+00	0.00	0.00	399.90	0.00	0.00	0.00	0.00	13734.97	22460.59	0.00	1597.93	0.00	0.00	0.00	0.00	43161.31
159+00	0.00	33.48	297.54	57.30	0.00	0.00	0.00	7209.00	0.00	62.00	1291.56	106.11	0.00	0.00	0.00	38785.13
160+00	0.00	547.91	373.35	83.54	0.00	0.00	0.00	8605.20	0.00	1076.65	1242.39	260.81	0.00	0.00	0.00	29285.56
161+00	9184.30	914.52	393.82	100.16	0.00	0.00	0.00	0.00	17007.96	2708.20	1420.69	340.19	0.00	0.00	0.00	15935.56
161+80	2180.35	2154.04	0.00	0.00	0.00	0.00	0.00	0.00	16836.52	4546.01	583.44	148.39	0.00	0.00	0.00	0.00
Totals (West of Mulberry Fork)									815304.04	1285919.40	69962.07	55869.48	89787.41	32663.22	0.00	769245.44

Figure 24. Earthwork values page 2 (HMB 2011).

APD-471(46)
WALKER COUNTY

revised:1/14/2011

MAINLINE EARTHWORK SUMMARY

STATION	AREA CUT (ft^2)	AREA FILL (ft^2)	AREA TOPSOIL (CUT AREAS) (ft^2)	AREA TOPSOIL (FILL AREAS) (ft^2)	AREA SANDSTONE (ft^2)	AREA SHALE (ft^2)	AREA REFUSAL (SANDSTONE) (ft^2)	AREA REFUSAL (SHALE) (ft^2)	VOLUME CUT (cu yd)	VOLUME FILL (cu yd)	VOLUME TOPSOIL (CUT AREAS) (cu yd)	VOLUME TOPSOIL (FILL AREAS) (cu yd)	VOLUME SANDSTONE (cu yd)	VOLUME SHALE (cu yd)	VOLUME REFUSAL (SANDSTONE) (cu yd)	VOLUME REFUSAL (SHALE) (cu yd)
174+20	3068.48	12946.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
175+00	3479.86	12503.01	0.00	0.00	0.00	0.00	0.00	0.00	9701.24	37703.51	0.00	0.00	0.00	0.00	0.00	0.00
176+00	3363.21	13117.00	0.00	0.00	0.00	0.00	0.00	0.00	12672.35	47444.46	0.00	0.00	0.00	0.00	0.00	0.00
177+00	3135.04	13440.31	0.00	0.00	0.00	0.00	0.00	0.00	12033.80	49180.20	0.00	0.00	0.00	0.00	0.00	0.00
178+00	3861.46	12390.48	0.00	0.00	0.00	0.00	0.00	0.00	12956.48	47834.80	0.00	0.00	0.00	0.00	0.00	0.00
179+00	4162.76	12351.03	0.00	0.00	0.00	0.00	0.00	0.00	14859.67	45817.61	0.00	0.00	0.00	0.00	0.00	0.00
180+00	1512.94	15028.92	0.00	0.00	0.00	0.00	0.00	0.00	10510.56	50703.61	0.00	0.00	0.00	0.00	0.00	0.00
181+00	158.94	22273.09	0.00	0.00	0.00	0.00	0.00	0.00	3096.07	69077.80	0.00	0.00	0.00	0.00	0.00	0.00
182+00	301.92	22002.18	0.00	0.00	0.00	0.00	0.00	0.00	853.44	81991.24	0.00	0.00	0.00	0.00	0.00	0.00
183+00	459.34	10828.64	0.00	0.00	0.00	0.00	0.00	0.00	1409.74	60797.81	0.00	0.00	0.00	0.00	0.00	0.00
184+00	8563.35	4055.68	323.24	0.00	0.00	0.00	0.00	0.00	16708.69	27563.56	598.59	0.00	0.00	0.00	0.00	0.00
185+00	0.00	0.00	422.78	0.00	0.00	0.00	18878.88	0.00	15858.06	7510.52	1381.52	0.00	0.00	0.00	34960.89	0.00
186+00	1242.36	0.00	422.86	0.00	5358.29	0.00	16565.11	0.00	2300.67	0.00	1566.00	0.00	9922.76	0.00	65637.02	0.00
187+00	3140.54	0.00	410.11	0.00	3238.58	0.00	16513.40	0.00	8116.48	0.00	1542.54	0.00	15920.13	0.00	61256.50	0.00
188+00	1535.44	0.00	394.96	0.00	3591.40	0.00	16199.42	0.00	8659.22	0.00	1490.87	0.00	12648.11	0.00	60579.30	0.00
189+00	1535.14	0.00	390.16	0.00	6569.22	0.00	9596.57	0.00	5686.26	0.00	1453.93	0.00	18815.96	0.00	47770.35	0.00
190+00	0.00	0.00	342.21	0.00	1349.09	0.00	14758.94	0.00	2842.85	0.00	1356.24	0.00	14663.54	0.00	45102.80	0.00
191+00	1887.27	0.00	392.06	0.00	3091.20	0.00	17268.60	0.00	3494.94	0.00	1359.76	0.00	8222.76	0.00	59310.26	0.00
192+00	1571.68	0.00	401.27	0.00	6047.63	0.00	18050.61	0.00	6405.46	0.00	1469.13	0.00	16923.76	0.00	65405.94	0.00
193+00	2247.20	0.00	387.60	0.00	3785.04	0.00	17397.82	0.00	7072.00	0.00	1460.87	0.00	18208.65	0.00	65645.24	0.00
194+00	3229.42	0.00	348.78	0.00	1189.04	0.00	12584.38	0.00	10141.89	0.00	1363.67	0.00	9211.26	0.00	55522.59	0.00
195+00	0.00	0.00	379.28	0.00	0.00	0.00	10278.91	0.00	5980.41	0.00	1348.26	0.00	2201.93	0.00	42339.43	0.00
196+00	651.12	2393.02	228.19	139.76	0.00	0.00	5909.50	0.00	1205.78	4431.52	1124.94	258.81	0.00	0.00	29978.54	0.00
197+00	1295.02	4318.59	209.15	176.54	0.00	0.00	3409.67	0.00	3603.96	12428.91	809.89	585.74	0.00	0.00	17257.72	0.00
198+00	3536.60	6613.21	220.47	231.32	0.00	0.00	0.00	0.00	8947.44	20244.07	795.59	755.30	0.00	0.00	6314.20	0.00
199+00	49.54	11861.39	24.55	342.84	0.00	0.00	0.00	0.00	6641.00	34212.22	453.74	1063.26	0.00	0.00	0.00	0.00
200+00	187.65	10627.09	82.16	340.60	0.00	0.00	0.00	0.00	439.24	41645.33	197.61	1265.63	0.00	0.00	0.00	0.00
201+00	1314.18	3220.54	0.00	0.00	0.00	0.00	0.00	0.00	2781.17	25643.76	152.15	630.74	0.00	0.00	0.00	0.00
202+00	0.00	969.41	0.00	0.00	0.00	0.00	4243.82	0.00	2433.67	7759.17	0.00	0.00	0.00	0.00	7858.93	0.00
203+00	0.00	79.81	0.00	0.00	0.00	0.00	6795.08	0.00	0.00	1943.00	0.00	0.00	0.00	0.00	20442.41	0.00
204+00	1625.30	0.00	428.15	4.55	0.00	0.00	7772.46	0.00	3009.81	147.80	792.87	8.43	0.00	0.00	26976.93	0.00
205+00	3674.79	43.34	473.14	18.68	0.00	0.00	9099.98	0.00	9814.98	80.26	1669.06	43.02	0.00	0.00	31245.26	0.00
206+00	1864.99	0.00	472.55	0.00	460.52	0.00	12417.41	0.00	10258.85	80.26	1751.28	34.59	852.81	0.00	39847.02	0.00
207+00	1739.26	0.00	444.71	0.00	852.34	0.00	10682.01	0.00	6674.54	0.00	1698.63	0.00	2431.22	0.00	42776.70	0.00
208+00	0.00	0.00	430.55	0.00	1678.39	0.00	11375.50	0.00	3220.85	0.00	1620.85	0.00	4686.54	0.00	40847.24	0.00
209+00	4597.07	0.00	437.06	0.00	794.56	0.00	9132.68	0.00	8513.09	0.00	1606.69	0.00	4579.54	0.00	37978.11	0.00
210+00	4009.64	0.00	416.94	0.00	3010.32	0.00	6053.77	0.00	15938.35	0.00	1581.48	0.00	7046.07	0.00	28123.06	0.00
211+00	1485.94	0.00	379.36	0.00	3499.72	0.00	4917.70	0.00	10177.00	0.00	1474.63	0.00	12055.63	0.00	20317.54	0.00
212+00	5484.92	0.00	346.33	0.00	1931.38	0.00	0.00	0.00	12909.00	0.00	1343.87	0.00	10057.59	0.00	9106.85	0.00
213+00	2881.51	0.00	318.71	0.00	500.74	0.00	390.09	0.00	15493.39	0.00	1231.56	0.00	4503.93	0.00	722.39	0.00
214+00	231.42	5341.94	95.77	419.16	79.86	0.00	0.00	0.00	5764.69	9892.48	767.56	776.22	1075.19	0.00	722.39	0.00
215+00	5.08	29464.75	0.00	0.00	0.00	0.00	0.00	0.00	437.96	64456.83	177.35	776.22	147.89	0.00	0.00	0.00
216+00	2.51	37373.42	0.00	0.00	0.00	0.00	0.00	0.00	14.06	123774.39	0.00	0.00	0.00	0.00	0.00	0.00
217+00	336.57	34726.60	0.00	0.00	0.00	0.00	0.00	0.00	627.93	133518.56	0.00	0.00	0.00	0.00	0.00	0.00

Figure 25. Earthwork values page 3 (HMB 2011).

APD-471(46)
WALKER COUNTY

revised:1/14/2011

MAINLINE EARTHWORK SUMMARY

STATION	AREA CUT (ft^2)	AREA FILL (ft^2)	AREA TOPSOIL (CUT AREAS) (ft^2)	AREA TOPSOIL (FILL AREAS) (ft^2)	AREA SANDSTONE (ft^2)	AREA SHALE (ft^2)	AREA REFUSAL (SANDSTONE) (ft^2)	AREA REFUSAL (SHALE) (ft^2)	VOLUME CUT (cu yd)	VOLUME FILL (cu yd)	VOLUME TOPSOIL (CUT AREAS) (cu yd)	VOLUME TOPSOIL (FILL AREAS) (cu yd)	VOLUME SANDSTONE (cu yd)	VOLUME SHALE (cu yd)	VOLUME REFUSAL (SANDSTONE) (cu yd)	VOLUME REFUSAL (SHALE) (cu yd)
218+00	314.65	20994.63	0.00	0.00	0.00	0.00	0.00	0.00	1205.96	103187.46	0.00	0.00	0.00	0.00	0.00	0.00
219+00	99.73	10417.77	0.00	0.00	0.00	0.00	0.00	0.00	767.37	58171.11	0.00	0.00	0.00	0.00	0.00	0.00
220+00	648.01	1616.39	142.46	202.58	0.00	0.00	0.00	0.00	1384.70	22285.48	263.81	375.15	0.00	0.00	0.00	0.00
221+00	2211.33	118.53	265.65	114.18	0.00	0.00	0.00	0.00	5295.07	3212.81	755.76	586.59	0.00	0.00	0.00	0.00
222+00	697.00	5361.40	108.92	249.04	0.00	0.00	0.00	0.00	5385.80	10148.02	693.65	672.63	0.00	0.00	0.00	0.00
223+00	3.40	4383.37	3.92	342.52	0.00	0.00	0.00	0.00	1297.04	18045.87	208.96	1095.48	0.00	0.00	0.00	0.00
224+00	1089.50	6846.78	133.73	251.00	0.00	0.00	0.00	0.00	2023.89	20796.57	254.91	1099.11	0.00	0.00	0.00	0.00
225+00	1190.60	7639.73	160.06	236.75	0.00	0.00	0.00	0.00	4222.41	26826.87	544.06	903.24	0.00	0.00	0.00	0.00
226+00	315.73	8482.52	85.46	297.64	0.00	0.00	0.00	0.00	2789.50	29856.02	454.67	989.61	0.00	0.00	0.00	0.00
227+00	2502.79	0.00	355.51	12.33	0.00	0.00	0.00	0.00	5219.48	15708.37	816.61	574.02	0.00	0.00	0.00	0.00
228+00	3705.77	858.79	282.75	94.35	0.00	0.00	507.25	0.00	11497.33	1590.35	1181.96	197.56	0.00	0.00	939.35	0.00
229+00	5168.03	2498.72	369.08	68.45	0.00	0.00	1442.56	0.00	16432.96	6217.61	1207.09	301.48	0.00	0.00	3610.76	0.00
230+00	3612.15	7955.66	249.58	207.94	0.00	0.00	1348.39	0.00	16259.59	19359.96	1145.67	511.83	0.00	0.00	5168.43	0.00
231+00	3451.60	10676.27	184.35	233.67	0.00	0.00	1182.32	0.00	13081.02	34503.57	803.57	817.80	0.00	0.00	4686.50	0.00
232+00	4673.75	10198.84	230.92	203.74	0.00	0.00	1277.97	0.00	15046.94	38657.61	769.02	810.02	0.00	0.00	4556.09	0.00
233+00	3866.02	8817.22	185.37	230.44	0.00	0.00	406.31	0.00	15814.39	35214.93	770.91	804.04	0.00	0.00	3119.04	0.00
234+00	3636.97	5847.32	233.41	161.57	0.00	0.00	801.17	0.00	13894.43	27156.56	775.52	725.94	0.00	0.00	2236.07	0.00
235+00	2178.56	6166.29	157.61	183.08	0.00	0.00	734.36	0.00	10769.50	22247.43	724.11	638.24	0.00	0.00	2843.57	0.00
236+00	4067.41	11557.46	146.51	355.58	0.00	0.00	866.94	0.00	11566.61	32821.76	563.19	997.52	0.00	0.00	2965.37	0.00
237+00	4295.99	11564.97	221.70	284.95	0.00	0.00	1081.11	0.00	15487.78	42819.31	681.87	1186.17	0.00	0.00	3607.50	0.00
238+00	5979.79	15942.09	127.90	326.12	0.00	0.00	1736.04	0.00	19029.22	50939.00	647.41	1131.61	0.00	0.00	5216.94	0.00
239+00	6075.06	17899.66	80.92	371.72	0.00	0.00	1393.00	0.00	22323.80	62669.91	386.70	1292.30	0.00	0.00	5794.52	0.00
240+00	4538.30	14847.05	87.16	366.88	0.00	0.00	292.00	0.00	19654.37	60642.06	311.26	1367.78	0.00	0.00	3120.37	0.00
241+00	1680.81	14731.31	53.99	438.06	0.00	0.00	363.24	0.00	11516.87	54774.74	261.39	1490.63	0.00	0.00	1213.41	0.00
242+00	3742.25	23.42	331.88	0.00	0.00	0.00	0.00	0.00	10042.70	27323.57	714.57	811.22	0.00	0.00	672.67	0.00
243+00	1596.78	0.00	341.00	0.00	3960.48	0.00	571.54	0.00	9887.09	43.37	1246.07	0.00	7334.22	0.00	1058.41	0.00
244+00	1268.82	0.00	329.01	0.00	4327.22	0.00	2025.11	0.00	5306.67	0.00	1240.76	0.00	15347.59	0.00	4808.61	0.00
245+00	1069.85	0.00	305.55	0.00	3398.81	0.00	2362.59	0.00	4330.87	0.00	1175.11	0.00	14307.46	0.00	8125.37	0.00
246+00	1196.40	0.00	310.44	0.00	2486.87	0.00	4717.25	0.00	4196.76	0.00	1140.72	0.00	10899.41	0.00	13110.81	0.00
247+00	873.49	192.19	321.65	36.96	2027.30	0.00	3528.27	0.00	3833.13	355.91	1170.54	68.44	8359.57	0.00	15269.48	0.00
248+00	1667.56	0.00	291.90	0.00	0.00	0.00	6024.85	0.00	4705.65	355.91	1136.20	68.44	6842.33	0.00	17690.96	0.00
249+00	950.41	8.88	308.47	0.00	2231.59	0.00	5455.26	0.00	4848.09	16.44	1111.80	0.00	7220.65	0.00	21259.46	0.00
250+00	1142.17	0.00	295.57	0.00	1344.10	0.00	5717.58	0.00	3875.15	16.44	1118.59	0.00	6621.65	0.00	20690.44	0.00
251+00	31.65	0.00	288.16	0.00	2393.52	0.00	6065.87	0.00	2173.74	0.00	1080.98	0.00	6921.52	0.00	21821.20	0.00
252+00	5190.45	0.00	496.51	0.00	754.16	0.00	5740.09	0.00	9670.56	0.00	1453.09	0.00	5829.04	0.00	21862.89	0.00
253+00	0.00	0.00	312.58	0.00	4419.25	0.00	3894.39	0.00	9611.94	0.00	1498.31	0.00	9580.39	0.00	17841.63	0.00
254+00	0.00	0.00	334.64	0.00	1867.94	0.00	3126.27	0.00	0.00	0.00	1198.56	0.00	11642.94	0.00	13001.22	0.00
254+35	1679.87	0.00	307.67	0.00	0.00	0.00	953.49	0.00	1088.80	0.00	416.31	0.00	1210.70	0.00	2644.29	0.00
Totals (East of Mulberry Fork)									615804.23	1831848.71	65564.83	25714.81	286292.74	0.00	1192980.97	0.00

Figure 26. Earthwork values page 4 (HMB 2011).

Selected plan sheets used in the examples as well as photographs taken from the roadway site are included in Appendix A. It is important to note, however, that not all of the plan sets or stationing photographs are available from the case study.

4.1.1 Method for Analysis of the Case Study

Stationing data and preliminary earthwork values for the examples were taken from the case study. Stations and volumetric values were taken from the tables in Figure 23 through . The shrinkage and swelling values for the project were taking from the Corridor X earthwork summary sheet, Figure 22. Details for the shrink and swell percentages used in the project are found in the profile plan sheets located in Appendix A. It is important to note that the shrinkage and swelling values are the ALDOT values. Some states will treat soil types with different shrink and swell percentages, as well as apply these factors differently. The variation of shrinkage and swelling factors is discussed later in this chapter.

The earthwork calculation analysis tool, presented in Chapter 3, was used for the calculation and comparison of the state earthwork methods as well as the assessment of shrink and swell values on these methods. Therefore, the analysis tool was applied to methods used by ALDOT, FDOT, GDOT, NCDOT, SCDOT, and TDOT. This way, the state DOT methods are conducted at the same time and, therefore, available for comparison. The earthwork computation for each southeastern state DOT uses the earthwork methods described in the Background and Literature Review chapter of this report. The earthwork values by station, shown in Figure 23 through , were completed using the average end area method for volume calculation in cross-sections. It was observed that each state in this project uses the average end area method for hand calculations. Some states may also use a computer or program for volumetric computations; however, in this case study, it is assumed that all states use the average end area method for initial bank material volume calculations for comparison purposes. In order to compare the southeastern state DOT earthwork methods, two examples of the case study were conducted. The two examples varied by the amounts of cut material or fill required for the station increments. Then, the assessment of shrinkage and swelling values was completed by altering the shrinkage percentages in the case study examples and referring to the shrink and swell values used for each method as presented in the Background and Literature Review chapter of this report.

4.1.2 Case Study Example: Stations 81+00 to 101+00

The first step in the analysis of the provided case study was to select a cross-section as an example to be used in the comparative calculations. Calculations for the case study were completed using the analysis tool for a 20-station increment. The cross-sections observed are stations 81+00 to 101+00. The case study stationing and preliminary volumetric values were to input into the "Cross-Sections" worksheet of the analysis tool. The stationing, volumes, and shrink percentage are user inputs for the first worksheet in the analysis tool. The "Cross-Sections" worksheet for the case study example is shown in Figure 27.

	A	B	C	D	E	F	G	H	I
1	ALDOT/HMB Corridor X Project								
2									
3	User INPUT data for ten station lengths at a time:								
4									
5	**Station**	**Volume Cut**	**Volume Fill**	**Volume Topsoil (Cut Areas)**	**Volume Topsoil (Fill Areas)**	**Volume Sandstone**	**Volume Shale**	**Volume Refusal (Sandstone)**	**Volume Refusal (Shale)**
6		**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**
7	81+00	11,593.28	4,519.74	871.74	563.70	0.00	0.00	0.00	4,224.61
8	82+00	16,215.06	648.13	1,095.04	234.83	0.00	0.00	0.00	7,751.48
9	83+00	20,469.19	0.00	118,806.00	0.00	0.00	1,058.57	0.00	5,475.67
10	84+00	22,658.76	0.00	1,233.31	0.00	0.00	3,750.09	0.00	3,897.30
11	85+00	22,031.93	0.00	1,248.74	0.00	1,961.81	3,164.89	0.00	8,211.00
12	86+00	19,294.59	0.00	1,316.46	0.00	4,184.89	1,011.11	0.00	14,197.20
13	87+00	15,645.54	0.00	1,411.04	0.00	6,017.02	1,146.72	0.00	21,278.65
14	88+00	15,755.85	0.00	1,509.02	0.00	7,180.13	1,909.65	0.00	28,139.69
15	89+00	23,242.15	0.00	1,546.44	0.00	9,997.74	1,300.67	0.00	21,079.72
16	90+00	30,047.24	0.00	1,487.48	0.00	6,611.56	6,962.13	0.00	12,637.76
17	91+00	15,710.35	0.00	1,507.80	0.00	16,432.22	6,962.13	0.00	17,684.28
18	92+00	0.00	2,604.54	1,428.31	295.15	26,917.13	0.00	0.00	16,567.35
19	93+00	5,021.87	15,902.02	994.22	964.59	10,484.91	0.00	0.00	5,236.85
20	94+00	5,188.70	36,242.09	482.00	1,502.41	0.00	0.00	0.00	0.00
21	95+00	512.43	56,739.11	278.81	1,778.52	0.00	0.00	0.00	0.00
22	96+00	425.65	69,721.72	199.94	1,955.91	0.00	0.00	0.00	0.00
23	97+00	115.22	72,054.07	108.48	2,034.28	0.00	0.00	0.00	0.00
24	98+00	134.20	70,483.48	128.13	2,051.20	0.00	0.00	0.00	0.00
25	99+00	223.30	66,913.76	128.43	2,006.80	0.00	0.00	0.00	0.00
26	100+00	127.69	55,068.74	71.28	1,845.76	0.00	0.00	0.00	0.00
27	101+00	12.98	37,411.70	39.63	1,601.63	0.00	0.00	0.00	0.00
28									
29	Totals:	224,425.98	488,309.10	135,892.30	16,834.78	89,787.41	27,265.96	0.00	166,381.56
30									
31	**Note:** Volumetric calculations completed by the average end area method.								
32									
33	Shrink percentage =		15	%					

Figure 27. "Cross-Sections" worksheet for stations 81+00 to 101+00.

As described in Chapter 3, the worksheets follow the southeastern state DOT methods for earthwork calculation. Again, for these sheets, the earthwork values are shown in green and the percent balanced value is highlighted in blue. Some worksheets require few user input cells, especially when swell values are being used. Most of the states require some input value(s) for material swelling except GDOT and SCDOT. Other than the user inputs, depicted in red writing next to the cell, each state earthwork worksheet reads stationing, earthwork values, and shrink percentage from the "Cross-Sections" page and completes the necessary calculations through formulas already in-place for the analysis tool. The first state earthwork calculations are for

ALDOT. The calculations given for the provided case studied were evaluated and understood as the ALDOT method of earthwork calculation. The ALDOT earthwork calculation method was recreated for the selected cross-sections for the research study. These values are shown in the "ALDOT-HMB" tab, noting that earthwork calculations for the case study were completed by HMB for the ALDOT project. Also, since the ALDOT earthwork method uses swell values on the rock material, swell factors were input into the worksheet. These swell values come from the Corridor X case study in the earthwork summary sheet as well as the plan sheets for the stations.

	A	B	C	D	E	F	G	H	I
1	ALDOT/HMB								
2									
3	**Station**	**Volume Cut**	**Volume Fill**	**Volume Topsoil (Cut Areas)**	**Volume Topsoil (Fill Areas)**	**Volume Sandstone**	**Volume Shale**	**Volume Refusal (Sandstone)**	**Volume Refusal (Shale)**
4		**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**	**(yd^3)**
5									
6	81+00	11,593.28	4,519.74	871.74	563.70	0.00	0.00	0.00	4,224.61
7	82+00	16,215.06	648.13	1,095.04	234.83	0.00	0.00	0.00	7,751.48
8	83+00	20,469.19	0.00	118,806.00	0.00	0.00	1,058.57	0.00	5,475.67
9	84+00	22,658.76	0.00	1,233.31	0.00	0.00	3,750.09	0.00	3,897.30
10	85+00	22,031.93	0.00	1,248.74	0.00	1,961.81	3,164.89	0.00	8,211.00
11	86+00	19,294.59	0.00	1,316.46	0.00	4,184.89	1,011.11	0.00	14,197.20
12	87+00	15,645.54	0.00	1,411.04	0.00	6,017.02	1,146.72	0.00	21,278.65
13	88+00	15,755.85	0.00	1,509.02	0.00	7,180.13	1,909.65	0.00	28,139.69
14	89+00	23,242.15	0.00	1,546.44	0.00	9,997.74	1,300.67	0.00	21,079.72
15	90+00	30,047.24	0.00	1,487.48	0.00	0.00	6,962.13	0.00	12,637.76
16	91+00	15,710.35	0.00	1,507.80	0.00	16,432.22	6,962.13	0.00	17,684.28
17	92+00	0.00	2,604.54	1,428.31	295.15	26,917.13	0.00	0.00	16,567.35
18	93+00	5,021.87	15,902.02	994.22	964.59	10,484.91	0.00	0.00	5,236.85
19	94+00	5,188.70	36,242.09	482.00	1,502.41	0.00	0.00	0.00	0.00
20	95+00	512.43	56,739.11	278.81	1,778.52	0.00	0.00	0.00	0.00
21	96+00	425.65	69,721.72	199.94	1,955.91	0.00	0.00	0.00	0.00
22	97+00	115.22	72,054.07	108.48	2,034.28	0.00	0.00	0.00	0.00
23	98+00	134.20	70,483.48	128.13	2,051.20	0.00	0.00	0.00	0.00
24	99+00	223.30	66,913.76	128.43	2,006.80	0.00	0.00	0.00	0.00
25	100+00	127.69	55,068.74	71.28	1,845.76	0.00	0.00	0.00	0.00
26	101+00	12.98	37,411.70	39.63	1,601.63	0.00	0.00	0.00	0.00
27									
28	Totals:	224,425.98	488,309.10	135,892.30	16,834.78	83,175.85	27,265.96	0.00	166,381.56
29									
30	Total Unclassified Excavation =			653,976.43	yd^3				
31									
32	Shrink/Swell Factors:								
33	Shrink Percentage =			15	%				
34	Shrink Factor =			0.85					
35	Sandstone and Shale Swell Factor =			1.10	User INPUT				
36	Refusal Sandstone Swell Factor =			1.25	User INPUT				
37	Refusal Shale Swell Factor =			1.20	User INPUT				
38									
39	Adjusted Soil Cut =			190,762.08	yd^3				
40	Adjusted Sandstone =			91,493.44	yd^3				
41	Adjusted Shale =			29,992.56	yd^3				
42	Adjusted Refusal (Sandstone) =			0.00	yd^3				
43	Adjusted Refusal (Shale) =			199,657.87	yd^3				
44									
45	Borrow (+) or Waste (-)			-6,762.07	yd^3				
46									
47	Percent Balanced =			-1.03	%				

Figure 28. ALDOT/HMB earthwork for stations 81+00 to 101+00.

The next state earthwork calculations are for FDOT. The Florida DOT method mentions a truck adjustment used in earthwork calculations. However, for the purposes of this research, a truck adjustment was intentionally not included in order to compare just the soil values and what is required for fill and what is available. Swell factors for the rock and refusal rock were input by the user. The earthwork method and computation values are shown in Figure 29.

	A	B	C	D	E	F	G	H	I
1	FDOT								
2									
3	Station	Volume Cut	Volume Fill	Volume Topsoil (Cut Areas)	Volume Topsoil (Fill Areas)	Volume Sandstone	Volume Shale	Volume Refusal (Sandstone)	Volume Refusal (Shale)
4		(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)	(yd³)
5	81+00	11,593.28	4,519.74	871.74	563.70	0.00	0.00	0.00	4,224.61
6	82+00	16,215.06	648.13	1,095.04	234.83	0.00	0.00	0.00	7,751.48
7	83+00	20,469.19	0.00	118,806.00	0.00	0.00	1,058.57	0.00	5,475.67
8	84+00	22,658.76	0.00	1,233.31	0.00	0.00	3,750.09	0.00	3,897.30
9	85+00	22,031.93	0.00	1,248.74	0.00	1,961.81	3,164.89	0.00	8,211.00
10	86+00	19,294.59	0.00	1,316.46	0.00	4,184.89	1,011.11	0.00	14,197.20
11	87+00	15,645.54	0.00	1,411.04	0.00	6,017.02	1,146.72	0.00	21,278.65
12	88+00	15,755.85	0.00	1,509.02	0.00	7,180.13	1,909.65	0.00	28,139.69
13	89+00	23,242.15	0.00	1,546.44	0.00	9,997.74	1,300.67	0.00	21,079.72
14	90+00	30,047.24	0.00	1,487.48	0.00	0.00	6,962.13	0.00	12,637.76
15	91+00	15,710.35	0.00	1,507.80	0.00	16,432.22	6,962.13	0.00	17,684.28
16	92+00	0.00	2,604.54	1,428.31	295.15	26,917.13	0.00	0.00	16,567.35
17	93+00	5,021.87	15,902.02	994.22	964.59	10,484.91	0.00	0.00	5,236.85
18	94+00	5,188.70	36,242.09	482.00	1,502.41	0.00	0.00	0.00	0.00
19	95+00	512.43	56,739.11	278.81	1,778.52	0.00	0.00	0.00	0.00
20	96+00	425.65	69,721.72	199.94	1,955.91	0.00	0.00	0.00	0.00
21	97+00	115.22	72,054.07	108.48	2,034.28	0.00	0.00	0.00	0.00
22	98+00	134.20	70,483.48	128.13	2,051.20	0.00	0.00	0.00	0.00
23	99+00	223.30	66,913.76	128.43	2,006.80	0.00	0.00	0.00	0.00
24	100+00	127.69	55,068.74	71.28	1,845.76	0.00	0.00	0.00	0.00
25	101+00	12.98	37,411.70	39.63	1,601.63	0.00	0.00	0.00	0.00
26									
27	Totals:	224,425.98	488,309.10	135,892.30	16,834.78	83,175.85	27,265.96	0.00	166,381.56
28									
29	Shrink/Swell Factors:								
30	Shrink Percentage =				15	%			
31	Shrink Factor =				0.85				
32	Sandstone and Shale Swell Factor =				1.10	User INPUT			
33	Refusal Sandstone Swell Factor =				1.25	User INPUT			
34	Refusal Shale Swell Factor =				1.20	User INPUT			
35									
36	Total Topsoil Being Excavated =				152,727.08				
37	Total Suitable Soil Excavation (- Topsoil)=				224,425.98	yd³			
38	Total Rock Excavation =				110,441.81	yd³			
39	Refusal Sandstone Excavation =				0.00	yd³			
40	Refusal Shale Excavation =				166,381.56	yd³			
41	Total Unclassified Excavation =				653,976.43	yd³			
42									
43	Shrink/Swell Adjustments:								
44	Adjusted Soil Cut =				190,762.08	yd³			
45	Adjusted Sandstone =				91,493.44	yd³			
46	Adjusted Shale =				29,992.56	yd³			
47	Adjusted Refusal (Sandstone) =				0.00	yd³			
48	Adjusted Refusal (Shale) =				199,657.87	yd³			
49	Total Adjusted Soil for Shrink/swell =				511,905.95	yd³			
50									
51	Amount Required for Fill =				505,143.88	yd³			
52									
53	Borrow (+) or Waste (-)				-6,762.07	yd³			
54									
55	Required from Off-Site Borrow =				none	yd³			
56									
57	Percent Balanced =				-1.03	%			

Figure 29. FDOT earthwork for stations 81+00 to 101+00.

The earthwork calculations for GDOT are in the next worksheet. Since the Georgia DOT uses two methods for earthwork calculation in unclassified excavation, the Swell on Fill and Shrink on Cut methods are both used in the worksheet. Remember from the Literature Review that the Georgia method for earthwork calculation defines swell in Swell on Fill as the inverse of shrinkage. GDOT does not usually apply swell values to rock quantities, and, therefore, does not require the swell factor user input.

	A	B	C	D	E	F	G	H	I
1	GDOT								
2									
3	**Station**	**Volume Cut**	**Volume Fill**	**Volume Topsoil (Cut Areas)**	**Volume Topsoil (Fill Areas)**	**Volume Sandstone**	**Volume Shale**	**Volume Refusal (Sandstone)**	**Volume Refusal (Shale)**
4		(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)
5	81+00	11,593.28	4,519.74	871.74	563.70	0.00	0.00	0.00	4,224.61
6	82+00	16,215.06	648.13	1,095.04	234.83	0.00	0.00	0.00	7,751.48
7	83+00	20,469.19	0.00	118,806.00	0.00	0.00	1,058.57	0.00	5,475.67
8	84+00	22,658.76	0.00	1,233.31	0.00	0.00	3,750.09	0.00	3,897.30
9	85+00	22,031.93	0.00	1,248.74	0.00	1,961.81	3,164.89	0.00	8,211.00
10	86+00	19,294.59	0.00	1,316.46	0.00	4,184.89	1,011.11	0.00	14,197.20
11	87+00	15,645.54	0.00	1,411.04	0.00	6,017.02	1,146.72	0.00	21,278.65
12	88+00	15,755.85	0.00	1,509.02	0.00	7,180.13	1,909.65	0.00	28,139.69
13	89+00	23,242.15	0.00	1,546.44	0.00	9,997.74	1,300.67	0.00	21,079.72
14	90+00	30,047.24	0.00	1,487.48	0.00	0.00	6,962.13	0.00	12,637.76
15	91+00	15,710.35	0.00	1,507.80	0.00	16,432.22	6,962.13	0.00	17,684.28
16	92+00	0.00	2,604.54	1,428.31	295.15	26,917.13	0.00	0.00	16,567.35
17	93+00	5,021.87	15,902.02	994.22	964.59	10,484.91	0.00	0.00	5,236.85
18	94+00	5,188.70	36,242.09	482.00	1,502.41	0.00	0.00	0.00	0.00
19	95+00	512.43	56,739.11	278.81	1,778.52	0.00	0.00	0.00	0.00
20	96+00	425.65	69,721.72	199.94	1,955.91	0.00	0.00	0.00	0.00
21	97+00	115.22	72,054.07	108.48	2,034.28	0.00	0.00	0.00	0.00
22	98+00	134.20	70,483.48	128.13	2,051.20	0.00	0.00	0.00	0.00
23	99+00	223.30	66,913.76	128.43	2,006.80	0.00	0.00	0.00	0.00
24	100+00	127.69	55,068.74	71.28	1,845.76	0.00	0.00	0.00	0.00
25	101+00	12.98	37,411.70	39.63	1,601.63	0.00	0.00	0.00	0.00
26									
27	Totals:	224,425.98	488,309.10	135,892.30	16,834.78	83,175.85	27,265.96	0.00	166,381.56
28									
29	Borrow Excavation, Including Material:								
30									
31	Shrink Percentage =			15	%				
32	Shrinkage Factor =			0.85					
33									
34	Excavation From Cross Sections =			653,976.43	yd^3				
35									
36	Soil Available for Fill =			224,425.98	yd^3				
37	Rock Available for Fill =			276,823.37	yd^3				
38		Volume Sandstone, Shale, and Total Refusaal							
39	Total Available soil/rock for fill =			501,249.35	yd^3				
40									
41	Total Fill needed for Embankment =			505,143.88	yd^3				
42									
43	Borrow Excavation: Swell on Fill Method								
44	Borrow (+) or Waste (-)			93,037.57	yd^3				
45									
46	Percent Balanced =			14.23	%				
47									
48	Borrow Excavation: Shrink on Cut Method								
49	Borrow (+) or Waste (-)			93,037.57	yd^3				
50									
51	Percent Balanced =			14.23	%				
52									
53	**Note:** no rock swell.								

Figure 30. GDOT earthwork for stations 81+00 to 101+00.

The NCDOT earthwork calculation method is the next worksheet in the analysis tool. This method displays each useful quantity in earthwork calculation in individual cells. Then, the method totals the columns to make comparisons for construction earthwork values. It is important to note that this method only classifies “hard” rock, and does not separately classify the drillable rock on site. Since the rock in this case study is not sufficiently hard enough to require coring or blasting, it is classified in the soil values. Therefore, the “Volume Sandstone” and “Volume Shale” (not Refusal) also have the shrinkage value applied to it for adjusted reuse values on the project. Columns 5 and 6 denote a user input to be used if material is found in the subsurface investigation that is underneath the roadway or material in the unclassified excavation that unsuitable for construction.

NCDOT

Station	Volume Cut (yd³)	Volume Fill (yd³)	Volume Topsoil (Cut Areas) (yd³)	Volume Topsoil (Fill Areas) (yd³)	Volume Sandstone (yd³)	Volume Shale (yd³)	Volume Refusal (Sandstone) (yd³)	Volume Refusal (Shale) (yd³)
81+00	11,593.28	4,519.74	871.74	563.70	0.00	0.00	0.00	4,224.61
82+00	16,215.06	648.13	1,095.04	234.83	0.00	0.00	0.00	7,751.48
83+00	20,469.19	0.00	118,806.00	0.00	0.00	1,058.57	0.00	5,475.67
84+00	22,658.76	0.00	1,233.31	0.00	0.00	3,750.09	0.00	3,897.30
85+00	22,031.93	0.00	1,248.74	0.00	1,961.81	3,164.89	0.00	8,211.00
86+00	19,294.59	0.00	1,316.46	0.00	4,184.89	1,011.11	0.00	14,197.20
87+00	15,645.54	0.00	1,411.04	0.00	6,017.02	1,146.72	0.00	21,278.65
88+00	15,755.85	0.00	1,509.02	0.00	7,180.13	1,909.65	0.00	28,139.69
89+00	23,242.15	0.00	1,546.44	0.00	9,997.74	1,300.67	0.00	21,079.72
90+00	30,047.24	0.00	1,487.48	0.00	6,611.56	6,962.13	0.00	12,637.76
91+00	15,710.35	0.00	1,507.80	0.00	16,432.22	6,962.13	0.00	17,684.28
92+00	0.00	2,604.54	1,428.31	295.15	26,917.13	0.00	0.00	16,567.35
93+00	5,021.87	15,902.02	994.22	964.59	10,484.91	0.00	0.00	5,236.85
94+00	5,188.70	36,242.09	482.00	1,502.41	0.00	0.00	0.00	0.00
95+00	512.43	56,739.11	278.81	1,778.52	0.00	0.00	0.00	0.00
96+00	425.65	69,721.72	199.94	1,955.91	0.00	0.00	0.00	0.00
97+00	115.22	72,054.07	108.48	2,034.28	0.00	0.00	0.00	0.00
98+00	134.20	70,483.48	128.13	2,051.20	0.00	0.00	0.00	0.00
99+00	223.30	66,913.76	128.43	2,006.80	0.00	0.00	0.00	0.00
100+00	127.69	55,068.74	71.28	1,845.76	0.00	0.00	0.00	0.00
101+00	12.98	37,411.70	39.63	1,601.63	0.00	0.00	0.00	0.00
Totals:	80,621.11	390,660.79	8,290.04	12,588.86	70,443.56	15,224.93	0.00	73,205.96

NCDOT Column Numbers:

Note: Includes Non-Refusal Rock

1	2	3	4	5	6	7	8	9	10	11	12	13 and 14	15	16	Project Totals
Beginning Station	Ending Station	Excavated Material (yd³)	Hard Rock Excavated (Unclassified Excavation) (yd³)	Material Excavated Beneath Roadway Subgrade User INPUT (yd³)	Unclassified Excavation not suitable for Embankment User INPUT (This includes topsoil) (yd³)	Unclassified Excavation (Less (-) "Hard" Rock) Volumes (yd³)	Total Embankment (0.00 if cut/fill process includes construction for (yd³)	Volume of Embankment Constructed from "Hard" Rock (Adjusted Rock) (yd³)	Volume of Embankment Constructed from Earth (yd³)	Adjusted Volume to be Used for Embankment (yd³)	Amount of Material Needed for the Embankment (If cut/fill includes embankment, then this is the total fill) (yd³)	Total Volume of Suitable Material, not used in the Embankment (Borrow (+), Waste (-)) (yd³)	Total Volume of Unsuitable Material, not used in (yd³)	Total Waste (yd³)	Project Totals: Amount of Material Needed for the Fill Section (yd³)
81+00	82+00	17,253.33	4,224.61	0.00	871.74	13,028.72	0.00	4,224.61	11,593.28	14,923.82	5,083.44	-9,840.38	-1,435.44	-11,275.82	5,337.61
82+00	83+00	25,296.41	7,751.48	0.00	1,095.04	17,544.93	0.00	7,751.48	16,215.06	23,084.58	882.96	-22,201.62	-1,329.87	-23,531.49	927.11
83+00	84+00	145,809.43	6,534.24	0.00	118,806.00	139,275.19	0.00	6,534.24	20,469.19	24,869.40	0.00	-24,869.40	-118,806.00	-143,675.40	0.00
84+00	85+00	31,539.46	7,647.39	0.00	1,233.31	23,892.07	0.00	7,647.39	22,658.76	27,124.28	0.00	-27,124.28	-1,233.31	-28,357.59	0.00
85+00	86+00	36,618.37	13,337.70	0.00	1,248.74	23,280.67	0.00	13,337.70	22,031.93	32,938.04	0.00	-32,938.04	-1,248.74	-34,186.78	0.00
86+00	87+00	40,004.25	19,393.20	0.00	1,316.46	20,611.05	0.00	19,393.20	19,294.59	37,853.64	0.00	-37,853.64	-1,316.46	-39,170.10	0.00
87+00	88+00	45,498.97	28,442.39	0.00	1,411.04	17,056.58	0.00	28,442.39	15,645.54	44,922.27	0.00	-44,922.27	-1,411.04	-46,333.31	0.00
88+00	89+00	54,494.34	37,229.47	0.00	1,509.02	17,264.87	0.00	37,229.47	15,755.85	54,886.41	0.00	-54,886.41	-1,509.02	-56,395.43	0.00
89+00	90+00	57,166.72	32,378.13	0.00	1,546.44	24,788.59	0.00	32,378.13	23,242.15	54,655.14	0.00	-54,655.14	-1,546.44	-56,201.58	0.00
90+00	91+00	57,746.17	26,211.45	0.00	1,487.48	31,534.72	0.00	26,211.45	30,047.24	52,243.10	0.00	-52,243.10	-1,487.48	-53,730.58	0.00
91+00	92+00	58,296.78	41,078.63	0.00	1,507.80	17,218.15	0.00	41,078.63	15,710.35	54,460.13	0.00	-54,460.13	-1,507.80	-55,967.93	0.00
92+00	93+00	45,207.94	43,484.48	0.00	1,428.31	1,723.46	0.00	43,484.48	0.00	42,760.38	2,899.69	-39,860.69	-1,723.46	-41,584.15	3,044.67
93+00	94+00	22,702.44	15,721.76	0.00	994.22	6,980.68	0.00	15,721.76	5,021.87	19,464.38	16,866.61	-2,598.37	-1,958.81	-4,557.18	17,709.94
94+00	95+00	7,173.11	0.00	0.00	482.00	7,173.11	0.00	0.00	5,188.70	4,410.40	37,744.50	33,334.11	-1,984.41	31,349.70	39,631.73
95+00	96+00	2,569.76	0.00	0.00	278.81	2,569.76	0.00	0.00	512.43	435.57	58,517.63	58,082.06	-2,057.33	56,024.73	61,443.51
96+00	97+00	2,581.50	0.00	0.00	199.94	2,581.50	0.00	0.00	425.65	361.80	71,677.63	71,315.83	-2,155.85	69,159.98	75,261.51
97+00	98+00	2,257.98	0.00	0.00	108.48	2,257.98	0.00	0.00	115.22	97.94	74,088.35	73,990.41	-2,142.76	71,847.65	77,792.77
98+00	99+00	2,313.53	0.00	0.00	128.13	2,313.53	0.00	0.00	134.20	114.07	72,534.68	72,420.61	-2,179.33	70,241.28	76,161.41
99+00	100+00	2,358.53	0.00	0.00	128.43	2,358.53	0.00	0.00	223.30	189.81	68,920.56	68,730.76	-2,135.23	66,595.53	72,366.59
100+00	101+00	2,044.73	0.00	0.00	71.28	2,044.73	0.00	0.00	127.69	108.54	56,914.50	56,805.96	-1,917.04	54,888.92	59,760.23
101+00	102+00	1,654.24	0.00	0.00	39.63	1,654.24	0.00	0.00	12.98	11.03	39,013.33	39,002.30	-1,641.26	37,361.04	40,964.00
Totals (yd³):		660,587.99	283,434.93	0.00	135,892.30	377,153.06	0.00	283,434.93	224,425.98	489,915.32	505,143.88	15,228.56	-152,727.08	-137,498.52	530,401.07

Shrink Percentage = 15

Shrinkage Factor = 0.85

Refusal Sandstone Swell Factor = 1.25 User INPUT

Refusal Shale Swell Factor = 1.20 User INPUT

Percent Balanced [illegible]

Figure 31. NCDOT earthwork for stations 81+00 to 101+00

Next, the SCDOT earthwork calculation method was reproduced. South Carolina does not usually apply a swell value for rock. Also, as noted in the Background and Literature Review, South Carolina typically uses a general shrink percentage of 25%. This shrinkage value is noted by the SCDOT which outlines when shrinkage values are used in earthwork quantities. For the purposes of comparing the SCDOT method, the analysis tool calculates SCDOT with the 25% shrinkage as well as the shrinkage value used by the other states.

	A	B	C	D	E	F	G	H	I
1	SCDOT								
2									
3	Station	Volume Cut	Volume Fill	Volume Topsoil (Cut Areas)	Volume Topsoil (Fill Areas)	Volume Sandstone	Volume Shale	Volume Refusal (Sandstone)	Volume Refusal (Shale)
4		(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)	(yd^3)
5	81+00	11,593.28	4,519.74	871.74	563.70	0.00	0.00	0.00	4,224.61
6	82+00	16,215.06	648.13	1,095.04	234.83	0.00	0.00	0.00	7,751.48
7	83+00	20,469.19	0.00	118,806.00	0.00	0.00	1,058.57	0.00	5,475.67
8	84+00	22,658.76	0.00	1,233.31	0.00	0.00	3,750.09	0.00	3,897.30
9	85+00	22,031.93	0.00	1,248.74	0.00	1,961.81	3,164.89	0.00	8,211.00
10	86+00	19,294.59	0.00	1,316.46	0.00	4,184.89	1,011.11	0.00	14,197.20
11	87+00	15,645.54	0.00	1,411.04	0.00	6,017.02	1,146.72	0.00	21,278.65
12	88+00	15,755.85	0.00	1,509.02	0.00	7,180.13	1,909.65	0.00	28,139.69
13	89+00	23,242.15	0.00	1,546.44	0.00	9,997.74	1,300.67	0.00	21,079.72
14	90+00	30,047.24	0.00	1,487.48	0.00	6,611.56	6,962.13	0.00	12,637.76
15	91+00	15,710.35	0.00	1,507.80	0.00	16,432.22	6,962.13	0.00	17,684.28
16	92+00	0.00	2,604.54	1,428.31	295.15	26,917.13	0.00	0.00	16,567.35
17	93+00	5,021.87	15,902.02	994.22	964.59	10,484.91	0.00	0.00	5,236.85
18	94+00	5,188.70	36,242.09	482.00	1,502.41	0.00	0.00	0.00	0.00
19	95+00	512.43	56,739.11	278.81	1,778.52	0.00	0.00	0.00	0.00
20	96+00	425.65	69,721.72	199.94	1,955.91	0.00	0.00	0.00	0.00
21	97+00	115.22	72,054.07	108.48	2,034.28	0.00	0.00	0.00	0.00
22	98+00	134.20	70,483.48	128.13	2,051.20	0.00	0.00	0.00	0.00
23	99+00	223.30	66,913.76	128.43	2,006.80	0.00	0.00	0.00	0.00
24	100+00	127.69	55,068.74	71.28	1,845.76	0.00	0.00	0.00	0.00
25	101+00	12.98	37,411.70	39.63	1,601.63	0.00	0.00	0.00	0.00
26									
27	Totals:	224,425.98	488,309.10	135,892.30	16,834.78	89,787.41	27,265.96	0.00	166,381.56
28									
29	SCDOT Typical Shrink Percentage =				25	%			
30	SCDOT Typical Shrink Factor =				0.75				
31									
32	Total Topsoil Being Excavated =				152,727.08	yd^3			
33	Total Suitable Soil Excavation (- Topsoil)=				224,425.98	yd^3			
34	Total Rock + Refusal Rock Excavation =				283,434.93	yd^3			
35	Total Unclassified Excavation =				660,587.99	yd^3			
36									
37	Shrink/Swell Adjustments:								
38	Adjusted Soil Excavated =				168,319.49	yd^3			
39									
40	Total Material Available for Fill =				451,754.42	yd^3			
41		After Adjustments							
42									
43	Borrow (+) or Waste (-)				53,389.47	yd^3			
44									
45	Percent Balanced =				8.08	%			
46									
47	If SCDOT used the provided shrink value:								
48	Shrink percentage =				15	%			
49	Shrinkage Factor =				0.85				
50									
51	Shrink/Swell Adjustments:								
52	Adjusted Soil Excavated =				190,762.08	yd^3			
53									
54	Total Material Available for Fill =				474,197.01	yd^3			
55		After Adjustments							
56									
57	Borrow (+) or Waste (-)				30,946.87	yd^3			
58									
59	Percent Balanced =				4.68	%			

Figure 32. SCDOT earthwork for stations 81+00 to 101+00.

Lastly, the TDOT method for earthwork calculation is shown in the next worksheet. Tennessee uses swell factors for the rock and requires the user to input these values for TDOT. Along with calculating earthwork and the percent balanced value, this method also shows what Tennessee does to the extra (waste) soil. For any excess, or unbalanced, material on site TDOT “un-shrinks” the soil to show a more reasonable value to be dealt with on site. This means that the waste material found for TDOT has the shrink factor originally applied to the soil taken out of the equation.

TDOT

Station	Volume Cut (yd^3)	Volume Fill (yd^3)	Volume Topsoil (Cut Areas) (yd^3)	Volume Topsoil (Fill Areas) (yd^3)	Volume Sandstone (yd^3)	Volume Shale (yd^3)	Volume Refusal (Sandstone) (yd^3)	Volume Refusal (Shale) (yd^3)
81+00	11,593.28	4,519.74	871.74	563.70	0.00	0.00	0.00	4,224.61
82+00	16,215.06	648.13	1,095.04	234.83	0.00	0.00	0.00	7,751.48
83+00	20,469.19	0.00	118,806.00	0.00	0.00	1,058.57	0.00	5,475.67
84+00	22,658.76	0.00	1,233.31	0.00	0.00	3,750.09	0.00	3,897.30
85+00	22,031.93	0.00	1,248.74	0.00	1,961.81	3,164.89	0.00	8,211.00
86+00	19,294.59	0.00	1,316.46	0.00	4,184.89	1,011.11	0.00	14,197.20
87+00	15,645.54	0.00	1,411.04	0.00	6,017.02	1,146.72	0.00	21,278.65
88+00	15,755.85	0.00	1,509.02	0.00	7,180.13	1,909.65	0.00	28,139.69
89+00	23,242.15	0.00	1,546.44	0.00	9,997.74	1,300.67	0.00	21,079.72
90+00	30,047.24	0.00	1,487.48	0.00	6,611.56	6,962.13	0.00	12,637.76
91+00	15,710.35	0.00	1,507.80	0.00	16,432.22	6,962.13	0.00	17,684.28
92+00	0.00	2,604.54	1,428.31	295.15	26,917.13	0.00	0.00	16,567.35
93+00	5,021.87	15,902.02	994.22	964.59	10,484.91	0.00	0.00	5,236.85
94+00	5,188.70	36,242.09	482.00	1,502.41	0.00	0.00	0.00	0.00
95+00	512.43	56,739.11	278.81	1,778.52	0.00	0.00	0.00	0.00
96+00	425.65	69,721.72	199.94	1,955.91	0.00	0.00	0.00	0.00
97+00	115.22	72,054.07	108.48	2,034.28	0.00	0.00	0.00	0.00
98+00	134.20	70,483.48	128.13	2,051.20	0.00	0.00	0.00	0.00
99+00	223.30	66,913.76	128.43	2,006.80	0.00	0.00	0.00	0.00
100+00	127.69	55,068.74	71.28	1,845.76	0.00	0.00	0.00	0.00
101+00	12.98	37,411.70	39.63	1,601.63	0.00	0.00	0.00	0.00
Totals:	224,425.98	488,309.10	135,892.30	16,834.78	89,787.41	27,265.96	0.00	166,381.56

Soil Excavation =	377,153.06	yd^3
Rock Excavation =	283,434.93	yd^3
Total Unclassified Excavation =	660,587.99	yd^3
Percent Shrinkage =	15	%
Shrink Factor (to be divided by value)=	1.15	(/)
Sandstone and Shale Swell Factor =	1.10	User INPUT
Refusal Sandstone Swell Factor =	1.25	User INPUT
Refusal Shale Swell Factor =	1.20	User INPUT
Adjusted Soil Cut =	195,153.03	yd^3
Adjusted Rock =	128,758.71	yd^3
Adjusted Refusal (Sandstone) =	0.00	yd^3
Adjusted Refusal (Shale) =	199,657.87	yd^3
Total Adjusted Rock =	328,416.58	yd^3
Total Available for Fill (Borrow) =	523,569.61	yd^3
Fill Required for Embankment =	505,143.88	yd^3
Borrow (+) or Waste (-)	-18,425.73	yd^3
Percent Balanced =	-2.79	%
TDOT Comparison:		
Unbalanced Value =	-18,425.73	yd^3
"Un-Shrink" =	1.15	
Waste(-) after Adjustment =	-21,189.58	yd^3
Required From Borrow Source =	none	

Figure 33. TDOT earthwork for stations 81+00 to 101+00.

Finally, the totals for each method are shown in the “Earthwork Method Comparison” worksheet. In this worksheet, the “Section Characteristics” for this example are referenced from the user input page, “Cross-Sections” worksheet with the exception of the ending station. Since the ending station is not part of a 10-station increment, the user must input this final station. The user also inputs the quantity budget for the material in row 8. This adds a cost value to the material being observed. For the case study, a typical value of $15.00 per cubic yard was chosen. Then, the “Method (State DOT),” “Total Borrow (+) or Waste (-),” “Percent Balanced,” “Unbalanced Earthwork Cost” are recorded for each state method. The user can then add comments in the last row of the totals sheet.

	A	B	C	D	E
1	Earthwork Method Comparison				
2					
3	Section Characteristics:				
4	Starting Station =		81+00		
5	Ending Station =		101+00	User INPUT if not 10-station increment	
6	Shrink Percentage =		15	%	
7					
8	Quantity budget (User INPUT)=		$15.00	/yd^3	
9					
10	Method (State DOT)	Total Borrow (+) or Waste (-)	Percent Balanced	Unbalanced Earthwork Cost	Comments (User INPUT)
11		(yd^3)	(%)	($)	
12	ALDOT/HMB	-6,762.07	-1.03	101,430.99	
13	FDOT	-6,762.07	-1.03	101,430.99	
14	GDOT	93,037.57	14.23	1,395,563.51	Swell on Fill method
15		93,037.57	14.23	1,395,563.51	Shrink on Cut method
16	NCDOT	15,228.56	2.31	228,428.41	
17	SCDOT	53,389.47	8.08	800,841.98	Typical 25% shrink
18		30,946.87	4.68	464,203.01	Same shrink value as other DOTs
19	TDOT	-18,425.73	-2.79	276,385.88	Earthwork estimate prior to "un-shrink"
20		-21,189.58	-	317,843.76	Waste amount fter "un-shrinking" the value

Figure 34. Earthwork comparison for stations 81+00 to 101+00.

For the case study comparison of earthwork methods, stations 81+00 to 101+00, the southeastern state DOT earthwork methods are compared next to one-another. One of the aims of this report was to compare the methods. This “Earthwork Method Comparison” sheet compares the different state DOT earthwork calculation methods side-by-side and shows the characteristics of the project location being observed.

This ALDOT case study example chosen for research was a primarily balanced section for the ALDOT/HMB earthwork quantities. The quantity unbalanced for ALDOT/HMB resulted in waste. Waste means the soil is being disposed of off project unless it can be used somewhere else on the project, while borrow means the station requires soil to be brought in from another source.

When discussing accuracy of the totals in the findings, there are some important notes to observe. First, a perfectly balanced earthwork would be at 0%. Also, remember this example is of a 20-station increment and only a portion of the entire Corridor X project. Lastly, the final earthwork quantities are not available in for this case study. Therefore, the actual final amount of waste or borrow resulting from this project are unknown. Without these values, making a final statement on the accuracy of the DOT earthwork methods is impossible.

4.2 Evaluating Shrinkage and Swelling Factors

The last step of the case study is to evaluate shrinkage and swelling factors used in the southeastern states as well as their application to earthwork estimation. First, based on the factors found from the background and literature review, a summary of the factors used for soils in the southeastern states is concluded. The published range of shrink and swell factors for typical soil types found in the southeast are shown in Table 7. These shrink and swell values were gathered from the Background and Literature Review of this research from FWHA (2007), Burch (1997), Church (1981), GDOT (2013), and NCDOT (2004).

Table 7. Typical shrink and swell values from research.

Soil Type	Shrink Percentage	Swell Percentage
Clay	10-18 %	30-50 %
Sand	11-35 %	3-45 %
Residual	20-25 %	-
Rocky, gravely soil	5-22 %	5-40 %

The last step of the case study was then to evaluate the application of these shrinkage and swelling factors used in southeastern state DOT earthwork estimate calculations. In order to do this, the final percent balanced sheets for both examples are shown with different shrink and swell percentages. Based on the summary table of typical shrink and swell values in the southeastern states, Table 7, a range of shrink and swell percentages were chosen to be applied for analysis in the case study. For the comparison of the shrinkage percentages on earthwork values, shrinkage percentages of 10%, 15%, 25%, and 35% were chosen. This variety of shrinkage percentages provides the lower end values, the typical shrink values, and values that are on the higher end of the typical shrink value spectrum. Using 25% also provides another comparison against SCDOT which uses 25% shrinkage as the typical value. Then, based on the summary values presented in Table 7, typical swell values applied to the case study analysis are 5%, 10%, 25%, and 40%.

First, the different shrinkage values are applied to the stationing 81+00 to 101+00 case study example. Both the GDOT calculation methods result in the same amount of borrow or waste, even when the shrink percentage changes. Again, these two calculation methods are the Shrink on Cut and Swell on Fill. Therefore, for simplicity of reading the figure, GDOT is represented as one method on the graph.

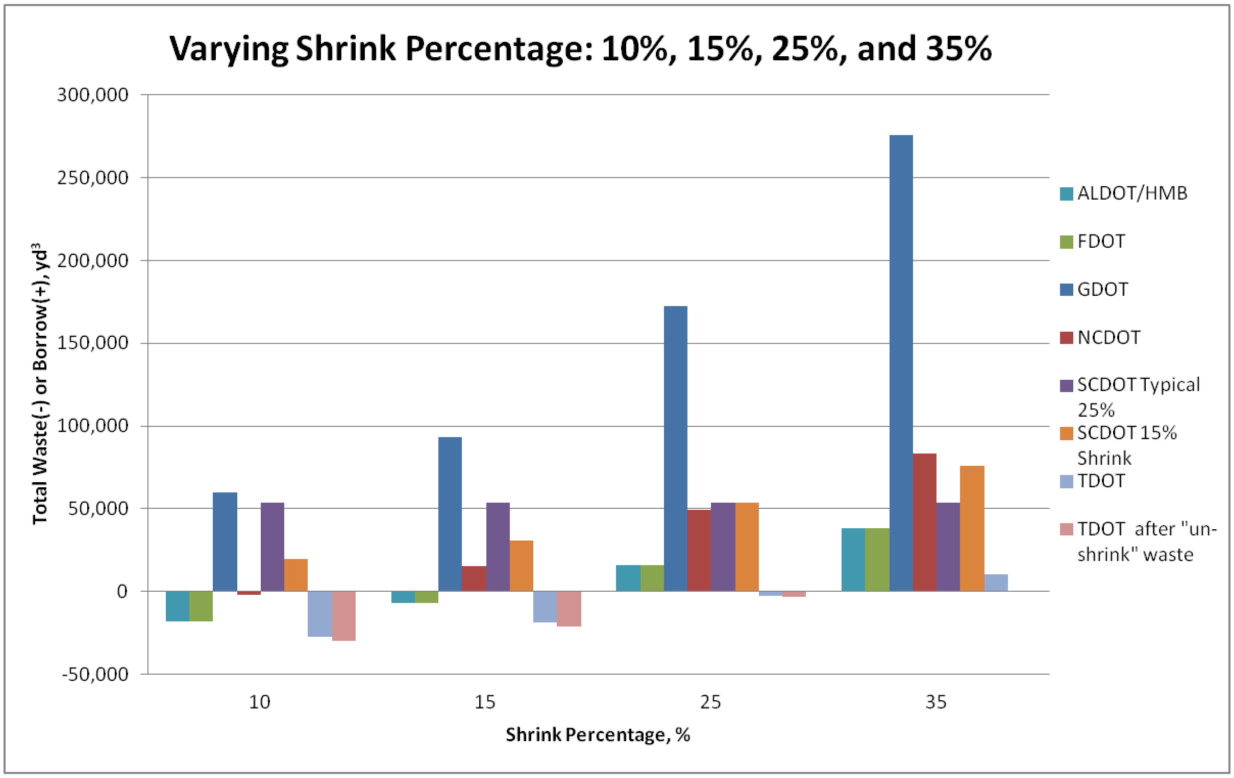

Figure 35. Varying shrink percentage for stations 81+00 to 101+00.

By showing the application of various shrink percentages side-by-side allows comparisons to be made. Of all the states observed in this research, GDOT and SCDOT have the only methods which do not apply swell factors to the earthwork calculations. The differences in the SCDOT methods are in part due to the fact that SCDOT does not apply a swell factor to the material. Also, the typical SCDOT method is to apply a consistent 25% shrinkage value. Applying the same percentage used by the other states to the SCDOT method alters the percent difference. The fact that GDOT values are so much larger than the others is reasonably due to the fact that the two methods apply the shrinkage factor in a different way than the other DOTs do. The earthwork calculation methods by state DOT are presented in Table 6. This differences in the state earthwork methods are shown in this table.

Next, the various swell percentages were applied to the case study stations 81+00 to 101+00. The typical swell values applied to the earthwork calculations are 5%, 10%, 25%, and

40%. These swell values are applied as the only swell factor for each calculation; therefore, swelling the same percentage to both rock/material being swelled and to the "hard" rock determined at auger refusal. This allows comparison of direct changes one factor at a time, which is a separate comparison than that of the calculation methods which has already been completed in this chapter. The various swell factors are then applied to the case study with a consistent shrink value which is the 15% shrink value used in the actual case study. The different swell values applied to the case study is presented in Figure 36. As with the change in shrink percentage, when the swell percentage changes, both the GDOT calculation methods result in the same amount of borrow or waste. Therefore, only one value for GDOT for each of the varying swell is shown in the figure.

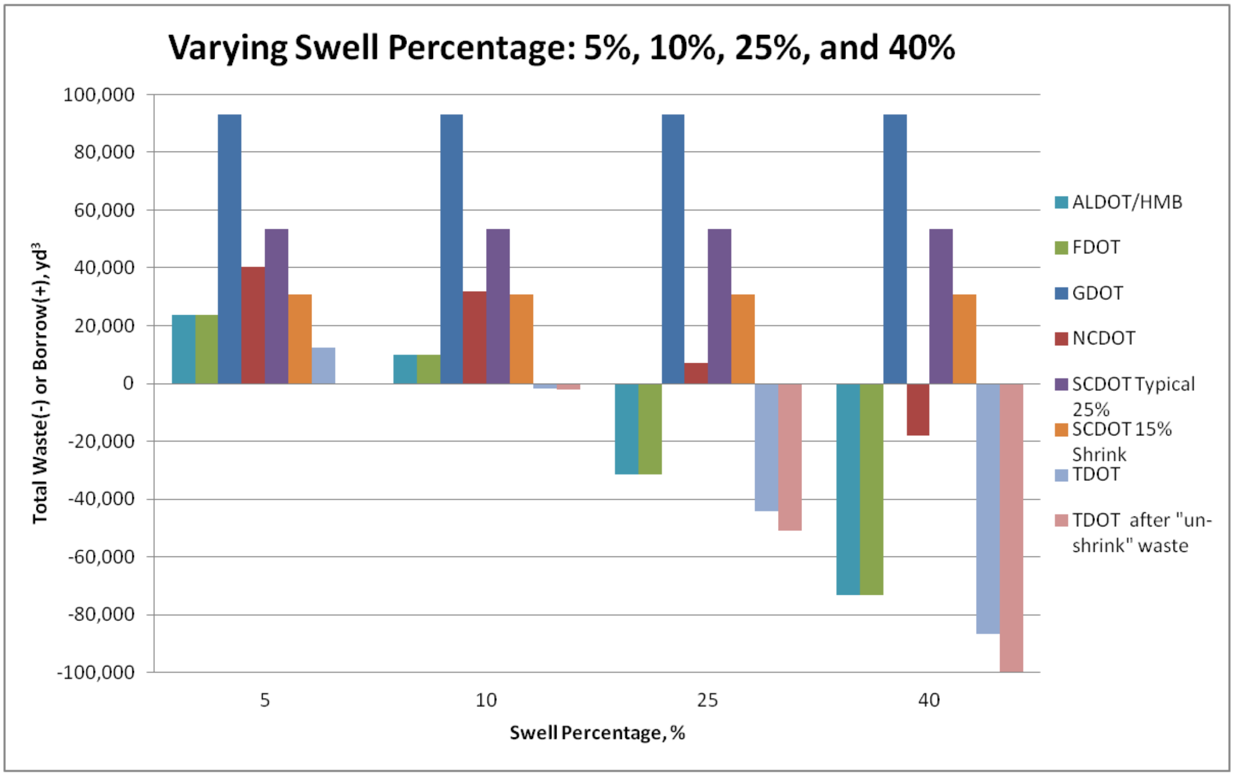

Figure 36. Varying swell percentage for stations 81+00 to 101+00.

The application of various swell factors while using a constant shrink percentage allows for a comparison to be made only of the swell factors with the varying DOT earthwork estimation methods. Remember that this example is for a primarily balanced earthwork for the ALDOT/HMB calculations.

Lastly, the unbalanced earthwork costs were evaluated for the varying shrink and swell percentages. In order to show the differences more clearly, two representative graphs were made only for the changes in the ALDOT/HMB values. The difference in cost due to the change of shrinkage or swelling factors is indicative of the overall effect of changing the factors in earthwork estimation. The effects of different shrink and swell percentages on the unbalanced earthwork cost for the ALDOT/HMB method in the case study are displayed in Figure 37 and Figure 38.

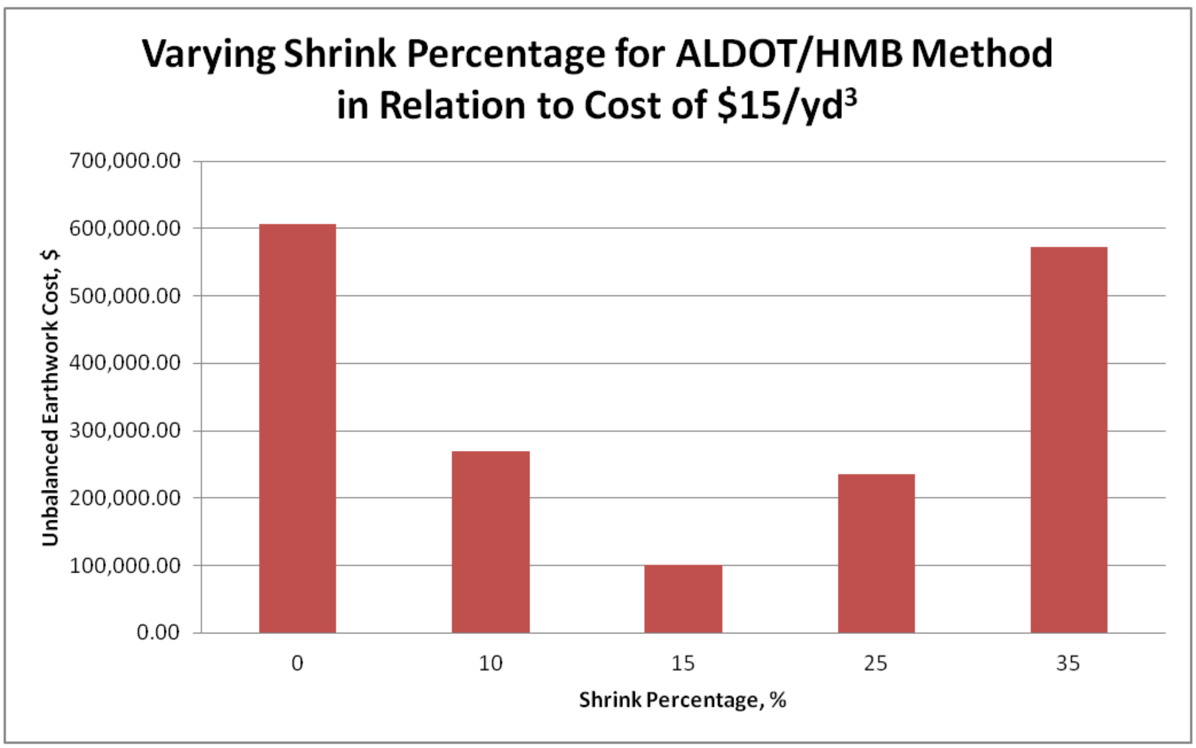

Figure 37. Varying shrink percentage for ALDOT/HMB earthwork estimates.

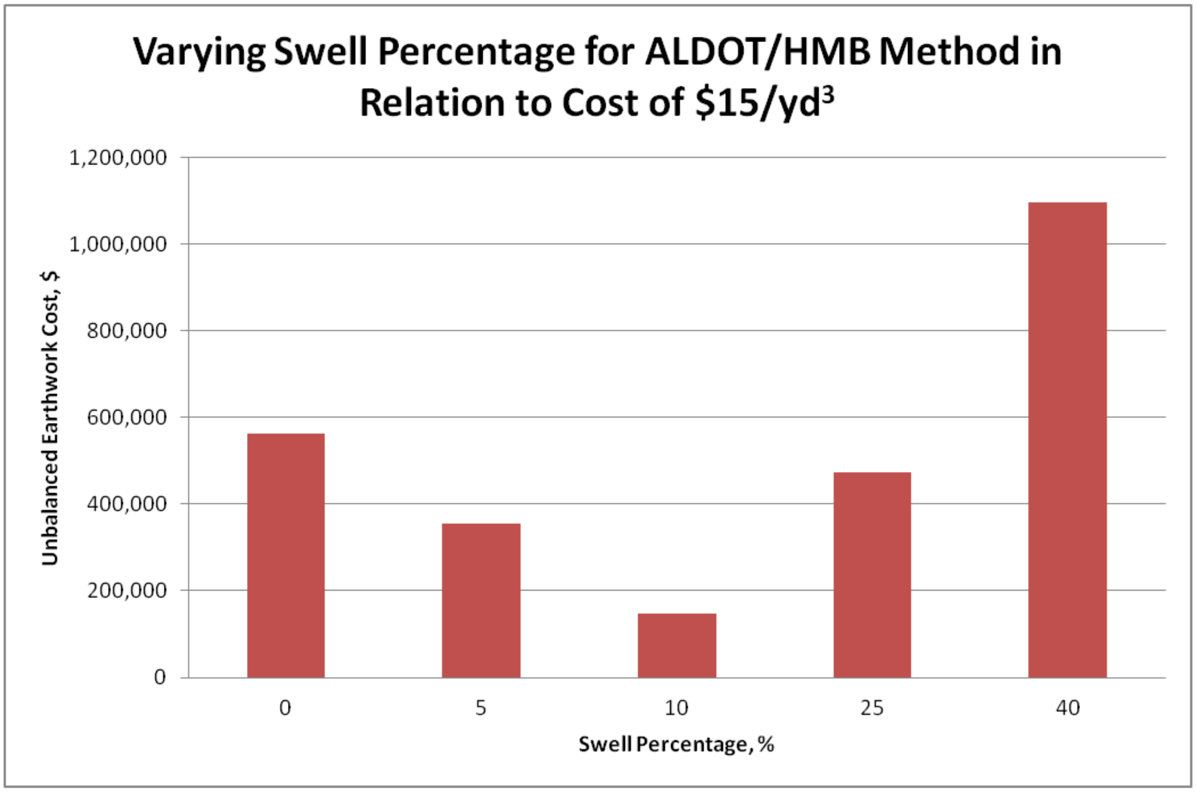

Figure 38. Varying swell percentage for ALDOT/HMB earthwork estimates.

Chapter 5:

Findings from the Research

Findings are based on analysis of the literature, individual DOT earthwork methods, and examination of the case study. The outcomes for this case study are from observations of the: differences between the earthwork methods, varying shrink and swell percentages on earthwork values, and varying shrink and swell percentages on the unbalanced earthwork cost.

It is important to note the limitations in comparisons that can be made in the case study. First, the earthwork values of the case study example are not compared to final earthwork quantities. Therefore, no statement can be made on the accuracy of the methods. The findings point out the differences and trends in the methods and shrink and swell factor application; this is not an endorsement for any of the methods in this research. It is also important to recognize that observations on the shrink and swell percentages as used in the case study should be made separately. The shrink percentages vary with constant swell factors of which some methods use multiple swell factors. Similarly, the swell percentages vary with a consistent shrink percentage. Therefore, one cannot make inferences by comparing Figure 35 and Figure 36 simultaneously.

Observations from the research include:

- ALDOT and FDOT result in the same earthwork values when no truck adjustments are applied to the FDOT earthwork quantities.
- As shown in Table 7, there are very wide ranges for the typical shrink and swell percentages in the southeastern state DOTs.

- Varying the shrink percentage changes the earthwork values. As shown in Figure 35, amount of borrow required (or a decrease in waste) results from an increase in shrink percentage. Figure 37 shows this effect on cost when deviating from the close-to-balanced earthwork estimation.
- From Figure 37, the earthwork calculation in the case study is for 2,000 feet of roadway. At nearly balanced, the earthwork would cost around $100,000.00. Varying the shrink percentage increases cost significantly. In this case, the cost varies to six times the close-to-balanced amount.
- Varying the swell percentage changes the earthwork values more significantly than changing the shrink percentages in this case study. As shown in Figure 36, as swell percentage increases, the trend shows an increase in waste material, with the exception of the states that do not apply swell factors to earthwork calculations. Also, Figure 38 shows this observation by comparing earthwork costs in the ALDOT/HMB method.
- Figure 38 demonstrates how much an excess swell percentage can increase the unbalanced earthwork cost on a project. Similar to Figure 37, the costs multiply approximately three to six times, based on a typical range of swell factors for the soil region.
- In this case study, the GDOT earthwork calculation method is indicative that GDOT will yield a higher earthwork estimate when compared to the other southeastern state DOTs. This is demonstrated when the shrink percentages are varied.

- Earthwork estimations for GDOT and SCDOT do not change when swell percentage is altered. This is because GDOT and SCDOT do not apply swell factors in their calculation methods.
- If TDOT results in waste on a project, the amount of waste increases after “un-shrink[ing]” the volumetric amount.
- NCDOT only classifies “hard” rock, or rock at auger refusal. This accounts for difference in earthwork volumes between the various methods as well as when varying the shrink and swell percentages. The fact that NCDOT only classifies “hard” rock affects values when both the swell and shrink factor are altered. This is because the “hard” rock has the swell factor applied to it, while, using the assumption that the softer rock is treated like soil by NCDOT, the rock has the shrinkage factor applied to it.

Chapter 6:

Summary and Conclusions

6.1 Summary

In order gain a full understanding of shrinkage and swelling factors and the earthwork calculations, an extensive background study and literature review was completed in chapter 2. Completing the initial study of the research included a review the earthwork methods currently in practice in the southeastern state DOTs. The review of state methods along with the study of current earthwork and shrink and swell practices allowed for the final aims of this research to be carried out.

The calculation tool for completing earthwork values for the southeastern state DOTs uses the Excel® program. The developed Excel® program is user friendly, requiring some user inputs for the program to do the actual calculations and comparisons. The user inputs for the program include: Updating the "Cross-Sections" worksheet for volumetric values and shrink percentage, inputting swell values where appropriate for the state methods, and some specialized evaluation for the NCDOT method. The Excel® document then calculates the earthwork quantities, making required adjustments for material shrinkage and swelling. Based on the goals of this research, the Excel® file completes earthwork quantities for the following State Departments of Transportation: ALDOT, FDOT, GDOT, NCDOT, SCDOT, and TDOT.

The next goal of this study was to assess earthwork calculation methods used in southeastern state DOTs. This was done by using the analysis tool on the case study. The case study for this research is the ALDOT/HMB Corridor X project. For the study, one 20-station roadway section was chosen and analyzed using each state DOT earthwork method. The section analyzed was close to balanced for the ALDOT/HMB method. Based on the Excel® file, the percent balanced value aims in being closest to 0%. A balanced value closest to 0% means the earthwork values for cut and adjusted material available were similar. This means that the more balanced the earthwork values are, requires less borrow or waste on the project. Comparing the various southeastern state DOT methods analyses the final earthwork values and the percent balanced for each method. By observing the percent balanced of the earthwork values, this research shows the differences between the methods.

The final aim of this study was to evaluate the shrinkage and swelling factors used in the southeastern state DOT earthwork methods. This included comparing the shrinkage and swelling factors used in the DOT calculation methods as well as comparing the state factors (upon availability) between similar soil types. One result that the research concluded on shrinkage and swelling factors used in southeastern state DOTs is that varying the shrink percentage changes the earthwork values. Also, applying a swell percentage alters the earthwork values as well as the percent difference. Some of the DOTs had their shrink and swell values available while others did not. Therefore a definite conclusion on the factors used by each DOT cannot be made.

6.2 Conclusions

1. The method by which southern states determine earthwork quantities varies from state-state, and can result in a vast difference when compared side-by-side.
2. The differences in earthwork quantities are substantial between southeastern state DOT methods. This was due to whether or not a swell factor is applied to earthwork (some DOTs do not use swell factors) or a result of the shrink factor(s) applied to state earthwork calculations (different DOTs use different factors depending on soil type).

3. The shrinkage and swelling factors have a wide range for soils which are typical in the southeastern United States. From the values in this research, typical ranges for general soil types in the this southeastern region of the United States were found to vary. Shrink percentage ranges from 10-18 % for clays, 11-35 % for sands, 20-25 % for residuals, and 5-22 % for rocky, gravely soils. Swell percentage ranges from 30-50 % for clays, 3-45 % for sands, and 5-40% for rocky, gravely soils. No specific swell percentages were discovered for residual soils in the course of this research.
4. Most southeastern state DOTs do not provide a guide for their typical shrinkage and swelling factors. It appears that earthwork is left at the risk of the contractor.
5. Application of swell percentages was inconsistent among the various DOT earthwork calculation methods.
6. The inclusion and definition of rock (drillable rock or at auger refusal) has a large impact on earthwork calculations using the southeastern DOT earthwork methods.

6.3 Recommendations and Future Study

After making conclusions based on the findings of this study, it is further concluded that further research on the subject should be completed.

1. An analysis of a study with final earthwork values should be conducted in order to make final observations on the earthwork estimation methods.
2. An evaluation if how each state determines material shrink and swell potential, and how shrinkage and swelling factors are chosen.
3. Development of a large database of measured shrinkage and swelling factors for soils throughout the United States that is tied to quantitative measurements such as grain size, Atterberg limits, fines content, etc..

4. A detailed study of how excavated rock is used in roadway fills for transportation earthwork.
5. Propose a true universal method which can be adopted nationally, rather than methods that vary state-to-state.

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Appendix A:
Case Study

The following figures, Figure 39 through Figure 41, are photos taken at specific stations along the Corridor X project:

Figure 39: Station 155+00, Corridor X project (Photo courtesy of HMB).

Figure 40: Station 185+00, Corridor X project (Photo courtesy of HMB).

Figure 41: Station 250+00, Corridor X project (Photo courtesy of HMB).

The final page in Appendix A is the profile sheet from the Corridor X project that is relative to the case study, stations 81+00 to 101+00..

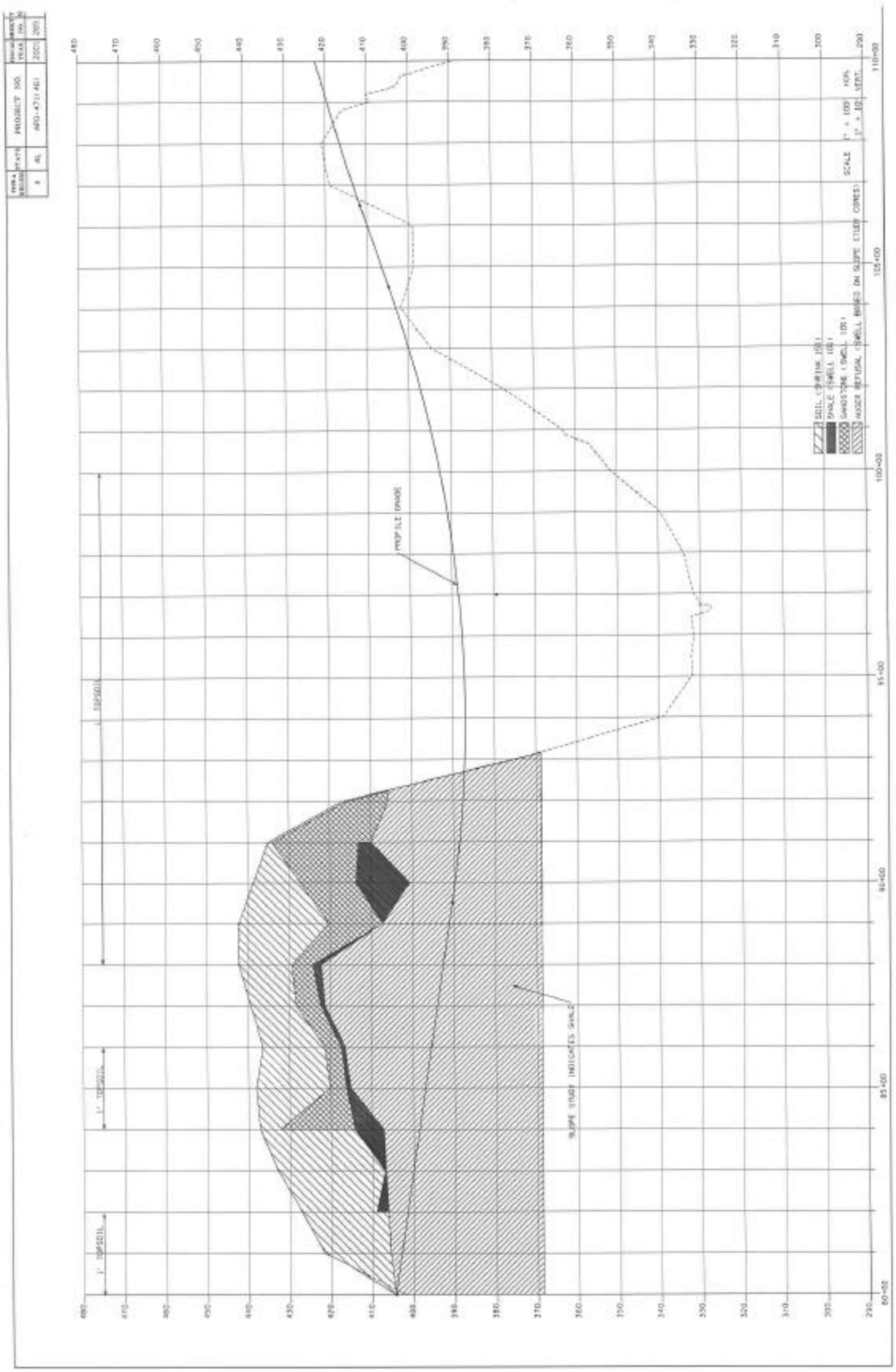

Figure 42: Corridor X Profile Sheet.