Earthwork Essentials

Before beginning any earthwork project, designers should have a basic understanding of the soil classifications, and earthwork classifications and construction specifications, which dictate the removal, placement, and quantification of earthwork materials. They should also be familiar with the standard road plans that govern placement of certain materials, and the engineering properties of the materials that may be encountered during excavation.

The types of soils that exist within the project corridor will determine the complexity of the earthwork calculation process. The physical characteristics and location of these materials will determine how they should be excavated and placed within the project limits, how long it may take the contractor to excavate or re-compact the soil, and more importantly, how much it will cost to do either.

This section provides designers with a basic understanding of the following topics:

- **Soils Classifications** - A general understanding of the Iowa DOT soils classification process.
- **Roadway and Borrow Excavation Classifications** – Description of Iowa DOT soils classifications.
- **Earthwork Standard Road Plans** – General requirements of how different soils are to be removed and\or placed within the project embankment.
- **Earthwork Payment Items, Methods and Tabulations** - An overview of the different payment methods for earthwork and necessary tabulations that accompany these payment methods.
- **Shrink and Swell Factors** – Definitions of Shrink and Swell factors and how they affect earthwork calculations.
- **Manual Plus Cuts and Fills** – Method of adding or subtracting additional soil volumes to the cross sections

The Soils Design Section uses soil borings and other methods to determine the approximate location, depth, and types of soils anticipated to be encountered during construction. This information is typically provided in profile view on the Q sheets and on the design cross sections. The geotechnical information is used by the roadway designers to calculate earthwork material volumes.

An example of the type of information shown on a typical Q sheet profiles and design cross sections is shown in Figure 1. The soil profiles are plotted on the profile sheet, along with locations of subgrade treatment or unsuitable soils. Subsurface soil classification lines are plotted on the design cross sections.

Note: Soil lines drawn into the design cross sections represent the bottom of the subsurface soil layers.

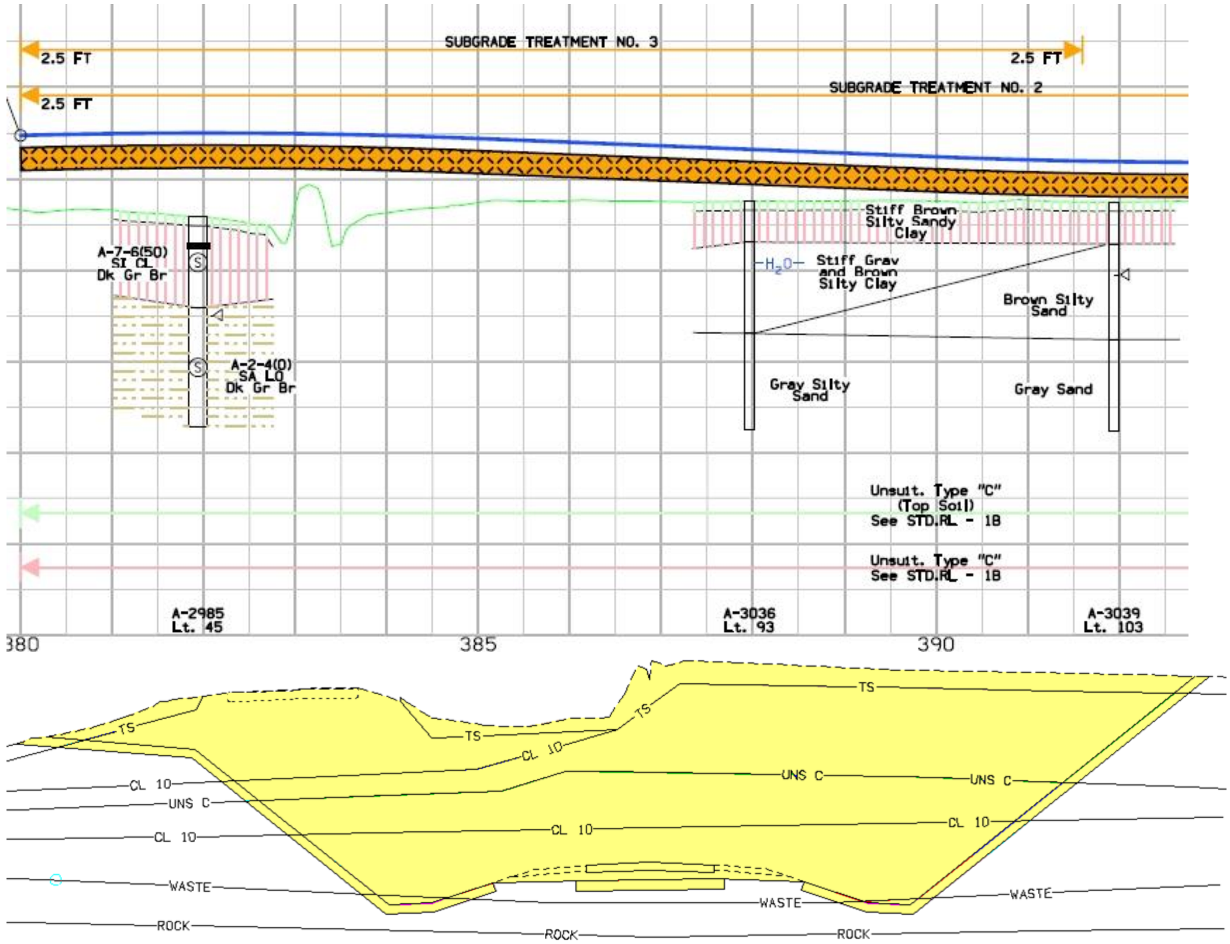

Figure 1: Soil profile (top) and classification lines (bottom).

Soil Classifications

To provide a common language and a general guide to their engineering behavior, soils are classified using either the Unified Soil Class System (USCS) (ASTM D 3282), "Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes" or the AASHTO Classification System (AASHTO M 145), "Standard Specifications for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes". The Soils Design Section typically uses the AASHTO classification system. This system classifies soil into seven major groups: A-1 through A-7. Soils classified as A-1 through A-3 are granular type materials and soils classified as A-4 through A-7 are silty clay type materials. Soils available for embankment construction in Iowa generally range from A-4 soils, which are very fine sands and silts that are subject to frost heave, to A-6 and A-7 soils, which predominate across the state. The A-6 and A-7 groups include shrink/swell clayey soils. In general, these soils rate from poor to fair in suitability as subgrade soils. Because these are marginal soils, it is critical that the embankments be constructed with proper compaction and moisture content, and in some cases, stabilization (see pages 1 through 10 in Section 6D-1 of the SUDAS Design Manual).

The importance of understanding different soil types cannot be overemphasized. Certain soil types classified as unsuitable material have to be placed in the proper location because of their engineering characteristics. Standard Road Plans EW-101, EW-102, and EW-103 (discussed later in this section) show proper placement of these materials.

Roadway and Borrow Excavation Classifications

The Iowa DOT Standard Specifications divide Roadway Borrow and Excavation into different classifications based on the level of effort required to excavate the material. Class 10, Class 12, Class

13, and Borrow (Embankment-in-Place and subgrade treatments) are the major classifications and are described as follows.

Class 10

This classification includes all normal earth materials such as loam, silt, gumbo, peat, clay, sand, and gravel Class 10. Material is further divided into Suitable Soils and Unsuitable Soils. These are described in more detail later in this chapter.

Unsuitable soils are further divided into Type A (UNS A), Type B (UNS B), Type C (UNS C) and Slope Dressing (Peat/Muck). They may be used in embankments according to Standard Road Plan EW-102.

Class 12

This classification is commonly referred to as Rock Excavation. Excavation requiring ripping, blasting, or other methods to remove granite, quartzite, chert, limestone, sandstone, shale and slate is considered Class 12 Excavation. Boulders that may be removed or handled along with the soil in which they are embedded, without special handling, will be not be included in Class 12 excavation. Should the Engineer decide that boulders encountered on the project require special handling, then they will be included in the Excavation, Class 12, Boulder/Rock Fragment pay item and bid as such.

Class 13

This classification is commonly referred to as Unclassified Excavation. Class 13 includes all materials listed under the definitions of Class 10 and Class 12, and any other materials encountered regardless of nature. The contract documents will specify the limits of Class 13 excavation. Excavation within these limits will not be classified as Class 10 or Class 12. This material is not commonly handled in the earthwork calculation spreadsheet.

Embankment-in-Place

When the quantity of material required for the roadway embankment is not available within the limits of the roadway cross sections, it will need to come from another location. Refer to Section 5B-3 for bidding information. Also refer to Chapter 6.40 of the Construction Manual for requirements of Contractor furnished and Contractor acquired borrow areas.

Select Treatment Material

Select Soils used for subgrade treatment must meet the following criteria, except Proctor, if a Proctor test was not taken.

Cohesive Soil (Select Loam)

Meet the requirements of Article 2102.02, D, 1, a of the Standard Specifications.

Granular Soil (Select Sand)

Meet the requirements of Article 2102.02, D, 1, b of the Standard Specifications.

Earthwork Standard Road Plans

Standard Road Plans EW-101, EW-102, and EW-103 demonstrate the proper excavation, placement methods, and treatment of the different soil types that may be encountered during the design and construction of a project. These standards provide details for the construction of roadway embankments, allowable placement of unsuitable materials, subgrade treatments, moisture and density control, topsoil spreading, plowing and shaping, and special compaction requirements.

Standard Road Plan EW-101 – Embankment and Rebuilding Embankments

This standard illustrates the normal construction procedures for the excavation and rebuilding of embankments, and excavation of peat, muck, or other material not to be used for the construction of embankments. The key difference between each of the typical cross sections for rebuilding of embankments is the location of the natural ground line. The intent is to excavate a uniform layer down to existing embankment line, or a distance “D” below finished grade line, whichever is higher. Likewise, the excavation of peat, muck, or other material not to be used for the construction of embankments should be removed according to the typical cross section shown in this standard. The detailed project design cross sections should reflect the intent of these typical cross sections shown in this standard. Excavation material may be quantified as Plowing and Shaping during the earthwork calculation process.

The dimension "D" will be defined in Tabulation 107-31.

Standard Road Plan EW-102 – Allowable Placement of Unsuitable Soil in Embankments.

Unsuitable Soils

As previously discussed, unsuitable soils are classified as Type A (UNS A), Type B (UNS B), and Type C (UNS C) and should be placed in embankment construction as outlined in EW-102. Table 2102.02-1 in Article 2102.02, D, 3 of the Standard Specifications defines the various types and uses of unsuitable soils. The table is arranged from highest quality to lowest quality soil. The Type A, Type B, and Type C placements of Table 2102.02-1 correspond to the Type A, Type B, and Type C placements shown on EW-102.

Fill Areas Greater than 20 Feet High

In new embankments greater than 20 feet in height, only Select, Suitable Class 10, or Type 'C' Unsuitable material will be allowed below that 20 foot depth.

Boulders

Boulders that have been classified as Class 12 excavation may be placed into the embankment according to Article 2102.03, C, 3 of the Standard Specifications, or with the Engineer's approval, may be placed according to Article 2102.03, C, 4 of the Standard Specifications.

Standard Road Plan EW-103 – Embankment Subgrade Treatment, Moisture Density Control and Special Compaction

This standard illustrates the details of embankment subgrade treatment, moisture and density control, and special compaction. Each of these items impacts the amount of excavation and embankment required to complete this type of work. The overall impacts to excavation and embankment are shown in the table associated with each of the typical treatment cross sections.

> The Iowa DOT currently specifies only standard width (pavement width plus shoulder width) treatment areas, while counties or cities may use trench width (pavement width plus 3.0 feet on each side).

Earthwork Pay Items and Tabulations

Division 21 of the Standard Specifications explains the Method of Measurement and Basis of Payment for the many items related to earthwork construction for roadways. The type of materials encountered determines the Tabulations required for a project. The placement of Class 10, unsuitable soils, select backfill, and special backfill materials may have both moisture and density limit requirements. Check with the Soils Design Section prior to beginning earthwork calculations to determine if moisture and density control will be required on the project, and which of the following tabulations are required for the project. More information on how to determine which bid items are needed can be found in Section 5B-3.

The earthwork pay items required will depend on whether the project balances, has excess (waste) material, or requires a borrow source. The Iowa DOT master pay items list contains the excavation bid items below. Refer to the English Bid Item Descriptions for a complete list of items associated with Division 21.

Class 10 Excavation and Embankment-In-Place

Pay Items:

- EXCAVATION, CL 10, RDWY+BORROW
- EXCAVATION, CL 10, UNSUIT/UNSTABLE MAT'L (This item is not normally used)
- EXCAVATION, CL 10, WASTE
- EXCAVATION, CL 10, CHANNEL

- EMBANKMENT-IN-PLACE
- EMBANKMENT-IN-PLACE, CONTRACTOR FURNISHED
- EMBANKMENT-IN-PLACE, STOCKPILE

Tabulations:

- Tab 103-7 Shrinkage Data
- Tab 107-5 Template Quantities
- Tab 107-7 Shoulder Material Availability Areas
- Tab 107-29,30 Tabulation of Template Quantities and Adjustments
- Tab 107-31 Plowing and Shaping

Class 12 Excavation

Pay Items:

- EXCAVATION, CL 12, BOULDER/ROCK FRAGMENT
- EXCAVATION, CL 12, RDWY+BORROW

Tabulations:

- Tab 107-25 Rock Splitting

Class 13 Excavation

Pay Items:

- EXCAVATION, CL 13, RDWY+BORROW
- EXCAVATION, CL 13, WASTE
- EXCAVATION, CL 13, CHANNEL

Tabulations:

- Tab 112-9 Shoulders

Topsoil

Pay Items:

- TOPSOIL, FURNISH AND SPREAD
- TOPSOIL, SPREAD
- TOPSOIL, STRIP, SALVAGE AND SPREAD
- TOPSOIL, STRIP AND STOCKPILE

Select Materials

Pay Items:

- SELECTED BACKFILL
- MODIFIED SUBBASE

Use of Select Materials may require the use of the following tabulations:

- Tab 103-1 Embankment with Moisture and Density Control
- Tab 103-3 Proposed Subgrade Treatment
- Tab 103-6 Embankment with Moisture Control

Special Backfill

Pay Items:

- SPECIAL BACKFILL
- SPECIAL BACKFILL MAT'L, PLACE ONLY
- MODIFIED SUBBASE

When Embankment-in-Place is specified, payment is based on one of two methods:

1. Plan quantity agreement.

2. Cross Sections obtained *after* placement.

Compaction Requirements

Pay Items:

- COMPACTION W/MOISTURE AND DENSITY CONTROL
- COMPACTION W/MOISTURE CONTROL

Granular Blankets

Pay Items:

- GRANULAR MATERIAL-BLANKET AND SUBDRAIN

Granular blankets are typically used to develop a drainage layer in areas where the soil has a high moisture content and poor stability. Information on location, depth, and type of material used for granular blankets is to be included on Tabulation 104-5C.

Shrink and Swell Factors

One cubic yard of excavation will rarely occupy exactly one cubic yard of space in the fill. In order to put excavation and embankment quantities on a common basis, a shrink or swell factor is used. Shrinkage and swell are often expressed as “shrink factor” or “swell factor”, which represents the volume change between cut and fill. Shrink\swell factors are a function of the material’s physical characteristics and should be accurately determined prior to beginning earthwork operations in order to estimate the efforts required for hauling, stockpiling, and in-place compaction. Swelling of material usually only applies to hard rock and not the soil on a project. Shrinkage and swell factors of soil or rock can significantly affect the effort and cost of an earthwork project.

Shrink and swell factors are determined by the Soils Design Section and provided to the designer. Typically, a 1.3 shrink factor is applied to Class 10 quantities; however, that may not always be the case. Topsoil used for slope dressing or as a Class 10 material may have a shrink factor as high as 1.5 applied, depending on the type of material encountered and project characteristics.

The use of these factors assumes a homogenous material, since each soil type will have unique factors. When faced with multiple soil types needed for excavation or used for earthwork construction, the designer may have to apply individual factors for each type. This is especially important when using different soil types from a borrow source(s).

Soil or rock volumes can be measured three ways:

- As bank cubic yards – Material in its natural state before disturbance.
- As loose cubic yards – Material that has been disturbed, excavated, or loaded.
- As compacted yards – Material after compaction.

Shrink

Shrinkage is the change in quantity from cut to fill and includes losses from hauling, wind and water erosion, embankment subsidence, and other factors that change the material density. Shrinkage of material will require an increase in suitable fill on the project.

$$\text{Shrinkage Factor} = \frac{\text{Compacted Cubic Volume}}{\text{Bank Cubic Volume}}$$

For example, a volume of 1 cubic yard (3 feet x 3 feet x 3 feet) in its natural state may swell to 1.30 cubic yards after being excavated and loaded onto a truck and then shrink to 0.70 cubic yards after being compacted into the roadway embankment.

Swell

A rock’s swell factor reflects the reality that the volume of material placed by nature in the ground is not the same as the volume of the same mass of rock excavated and placed in the dump truck. The same mass of rock occupies more volume in the truck (loose cubic yards) than it does in the ground (bank cubic yards). The swell factor is an adjustment representing this increase in volume and will decrease the need for fill material on the project.

Physically, the act of excavation breaks up the rock into particles of various sizes. This creates more air pockets and results in an effective increase in the rock's void volume. An increase in volume also results in a decrease in density. This decrease in density and increase in volume varies between rock types and is not proportional due to the initial natural void volume of the in-place rock. The swell factor is calculated as follows:

$$\text{In-Place volume+Swell Factor} = \frac{\text{Loose Cubic Volume}}{\text{Bank Cubic Volume}}$$

For example, if the volume of loose rock is 1.25 times greater than the bank volume it occupied prior to excavation, the rock's swell factor is 1.25.

Calculations for Earthwork

Determining quantities for earthwork items is a multi-step process. Instructions can be found at the provided links.

1. Prepare the Microstation file for Earthwork Processing, see Section 20F-30.
2. Run Cross Sections with Geopak input files using the Process Cross Sections tool.
3. Import data from Geopak .txt files to T Sheet Calculation File, see Section 20J-62.
4. Import data for Manual Plus Cuts and Fills (see below).
5. Interpret data from T Sheet Calculation File to determine bid item Quantities, see Section 1F-20.

Manual Plus Cuts and Fills

When determining earthwork volumes for a roadway, there will be instances where additional volumes will still need to be added to the earthwork spreadsheet quantity to account for areas not included in the average end area calculations. Examples of these areas may be:

- Median crossovers (see PV-500s).
- Rural entrances (see EW-501).
- Safety ramps (see EW-502).
- Maintenance turnarounds (see Road Design Detail 8101).
- Ditch checks (see EW-110).
- Wing dikes (see EW-210).
- Guardrail blisters (see EW-301).

Several methods may be used to calculate volumes for these additional areas:

- Accurate modeling of the corridor using Geopak Corridor Modeler or Geopak Site will provide the means to compare the proposed finished grade with the existing ground line to determine volumes (.tin to .tin volume analysis).
- Manual Calculations – May be sufficient for most cases.

The accuracy of the calculations depends on the accuracy of the end areas. Therefore, each time the geometry of the entrance changes, a new end area should be calculated. Figure 2 illustrates needed end areas for an entrance.

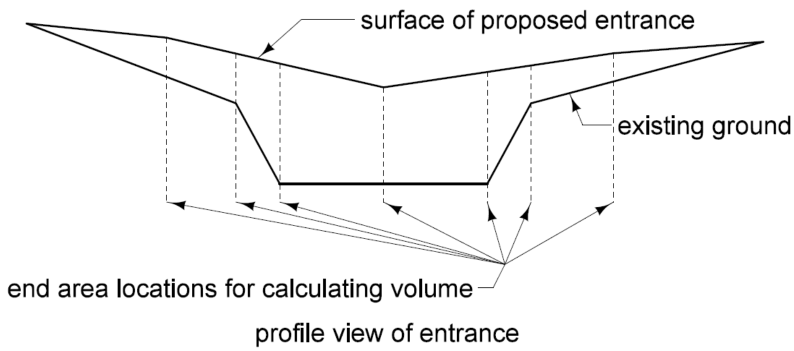

Figure 2: Needed end areas for calculating volume at an entrance.

The areas of ditch checks, safety ramps, entrances, etc. may be calculated manually by using the areas in Figures 3 and 4.

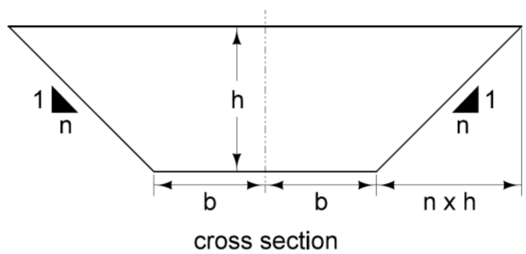

Figure 3: End area for ditch checks, entrances, etc.

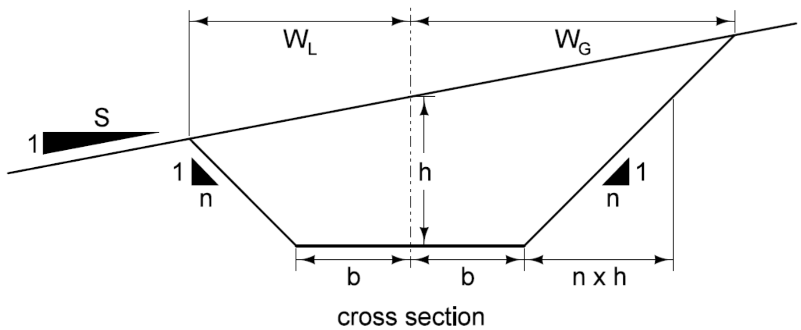

Figure 4: End area for ditch checks, entrances, etc. with a sloping ground line.

Assuming a cut (or fill) such as the one in Figure 3, the cross sectional area is given by:

$$\text{Area} = 2bh + nh^2 = h(2b + nh)$$

Assuming a cut (or fill) such as the one in Figure 4, the cross sectional area is found first by calculating W_L and W_G:

$$W_L = \frac{S(b+nh)}{(S+n)} \quad \text{and } W_G = \frac{S(b+nh)}{(S-n)}$$

$$\text{Total Area} = \frac{(h+\frac{b}{n})(W_L+W_G)}{2} - \frac{b^2}{n}$$

Depending on the level of accuracy required, the volumes of these areas may be summed using the average end area formula, or if more accuracy is required, the prismoidal formula. The following Average End Area formula is defined as follows:

$$V = \frac{A_1+A_2}{2} \times L$$

Where:

V = Volume
A_1 = Cross section area of first side
A_2 = Cross section area of second side
L = Length between the two areas

If one end area has a value of zero, the earthwork volume can be considered a pyramid and the correct formula would be:

$$V = \frac{AL}{3}$$

A more accurate formula is the prismoidal formula, which takes out most of the error accrued by the average end area method.

$$V = \frac{L(A_1 + 4A_m + A_2)}{6}$$

Where:

V= Volume
A_1 **=** Cross sectional area taken at beginning of proposed element
A_m= Area of a plane surface midway between the two cross sections
A_2 = Cross sectional area taken at end of proposed element

Chronology of Changes to Design Manual Section:

005A-002 Earthwork Essentials

6/25/2019	Revised Updated hyperlinks. Updated header logo and text.
8/5/2016	NEW New.