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# Earthwork Basics and a Traditional Calculation Method

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**A. Introduction**

This course is developed to identify the basics of earthwork and to explain a “traditional” method of performing earthwork analysis via hand calculations. This study is for those who are not experienced with earthwork, earthwork calculations and earthwork equipment. Additionally it is intended to be a helpful a refresher and source to anyone who has worked in Civil Engineering and/or Land Development looking for a resource discussing earthwork basics. Earthwork analysis is an important topic for any Civil Engineer involved in roadway and land development to understand associated with their required design. This course will focus more on site analysis than on the analysis required to economically determine the elevation of highways through mountainous regions.

This course will also expose the student to the basic equipment used in the construction field associated with earthwork.

**B. Basics and Concepts Defined**

**1. Background:**

In order to develop any piece of property, the earth will invariably need to be moved. This could be as limited as stripping away topsoil in order to pour a sidewalk, and it can be as involved as over excavating 20’ below a proposed building pad footprint in order to remove contaminated fill, and import and install select clean fill that will accommodate the building. Earthwork analysis is a valuable part of the Land Development process. While many authorities having jurisdiction may have minimal interest in the volume of earthwork required on a site, the cost associated with the minimization of earthwork has a construction value that an owner should expect to be minimized by a competent engineer.

The parameters associated with development of a site will be influenced by many things including the required drainage design, as well as the constraints of the grading design. While the drainage and grading are critical to the functionality of the site, earthwork analysis helps the engineer confirm that the most efficient use of the existing geotechnical resources is realized.

Earthwork analysis in general is not a required subject within many Civil Engineering curricula, and as such, often times the entry level engineer must learn earthwork analysis on the job. This is less difficult than in the past as modern tools of analysis on



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the computer have made this process easier. In the past traditional methods of earthwork analysis were all that was available to the engineer.

This course will identify the basics, and upon completion of this course the student should have a confident understanding of earthwork analysis.

It is worth noting that presently most earthwork analysis can be performed by software that is very accurate. This course will present a “traditional” hand calculation method of performing earthwork analysis which can still be useful in conceptual planning to determine the best elevation to set the proposed site.

## 2. Existing & Proposed Conditions

When preparing to perform an earthwork analysis of a site, the engineer must first be provided with a document that defines the existing conditions, including the topography. This document is typically referred to as the Topographic Survey or “survey”. If the survey is received with adequate information for the purposes of re-grading a site by design, it will identify the existing surface features, spot elevation or spot grades, and contour lines.

In order to complete an earthwork analysis, the existing conditions need to be compared with the proposed conditions. The graphical depiction of the proposed conditions and elevations of the site is typically reflected in a Grading and Drainage Plan. The fundamentals of site grading is beyond the scope of this course, however a study on the fundamentals of site design is useful in making sure the proposed grading plan is functionally most appropriate.

This course assumes the engineer has a basic understanding of the fundamentals of site, grading, and drainage design and is fluent in the associated terminologies. The Proposed Grading Plan will also need to identify the proposed surface features, spot grades, and contour lines.

## 3. Soil types

The moving of earth (soil, rock, etc.) is referred to a re-grading and/or earthwork. At a high level, soil types have various properties and conditions. Soil typically is generally quantified as consisting of a combination of Silt, Sand, and Clay and these properties may have expansive and/or contractive properties. For the purposes of the methods presented in this course, we will assume in the analysis that relocated soil upon



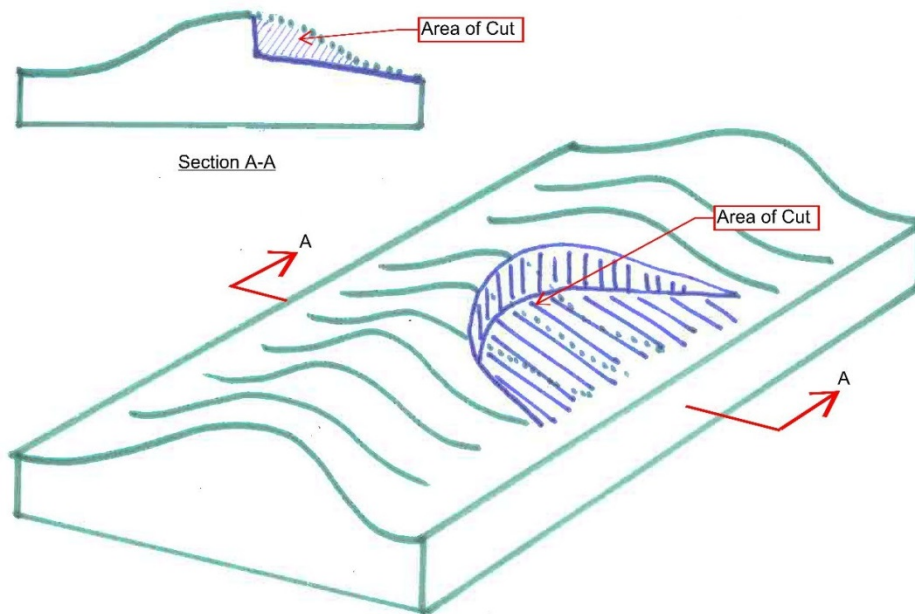
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compaction will occupy the same volume in the proposed condition as it does in the existing. The competent site engineer will consult with a geotechnical engineer and/or report to confirm if any soil expansion/contraction should be accounted for in the earthwork analysis.

#### 4. Cut/Fill & Import/Export

In the locations where soil is excavated or removed is referred to as the “cut”. The location where soil is moved to or placed is referred to as “fill”.

Figure F-1 provides an isometric depiction of a cut scenario.



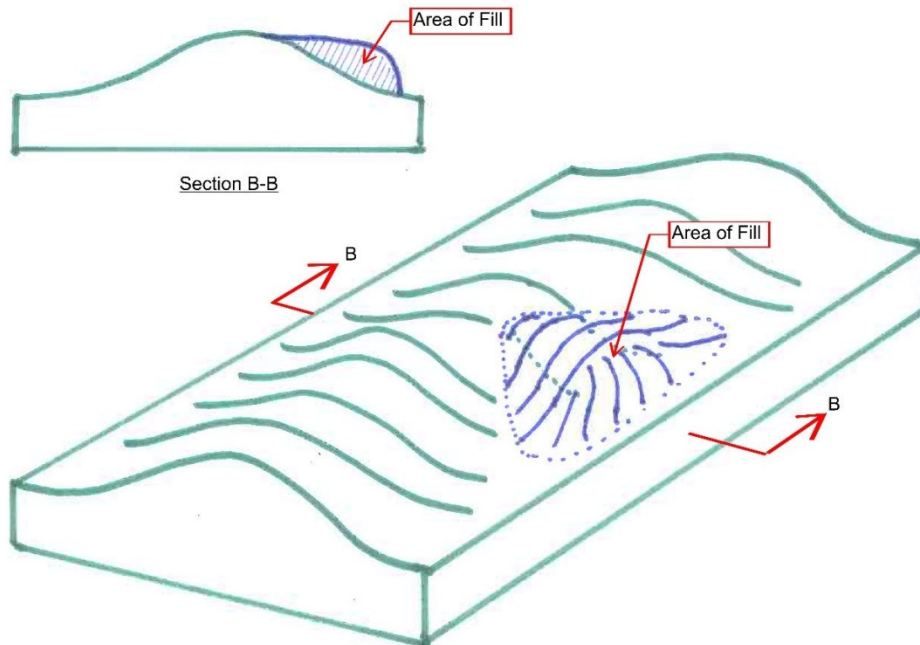
**Figure F-1**  
**(Isometric depiction of “cut”)**

Depending on the amount of soil being moved, the contractor that excavates and places it may use heavy equipment in order to do so. Section E of this course discusses the basic equipment that contractor have at their disposal in order to complete the tasks associated with site work. When soil is placed in a new location, it should be done in accordance with the requirements of the geotechnical / soils report which defines the placement parameters through the analysis of the existing soil on site by a competent geotechnical engineer.



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Figure F-2 provides an isometric depiction of a fill scenario.



**Figure F-2**  
**(Isometric depiction of “fill”)**

Although the parameters of the geotechnical report and recommendations are beyond the scope of this course, a few basics will be discussed throughout. It is worth noting that the site engineer (in their specifications) should either make reference to the requirements / recommendation of the soils report, and/or they should interpret these recommendations and reflect those requirements on the plans.

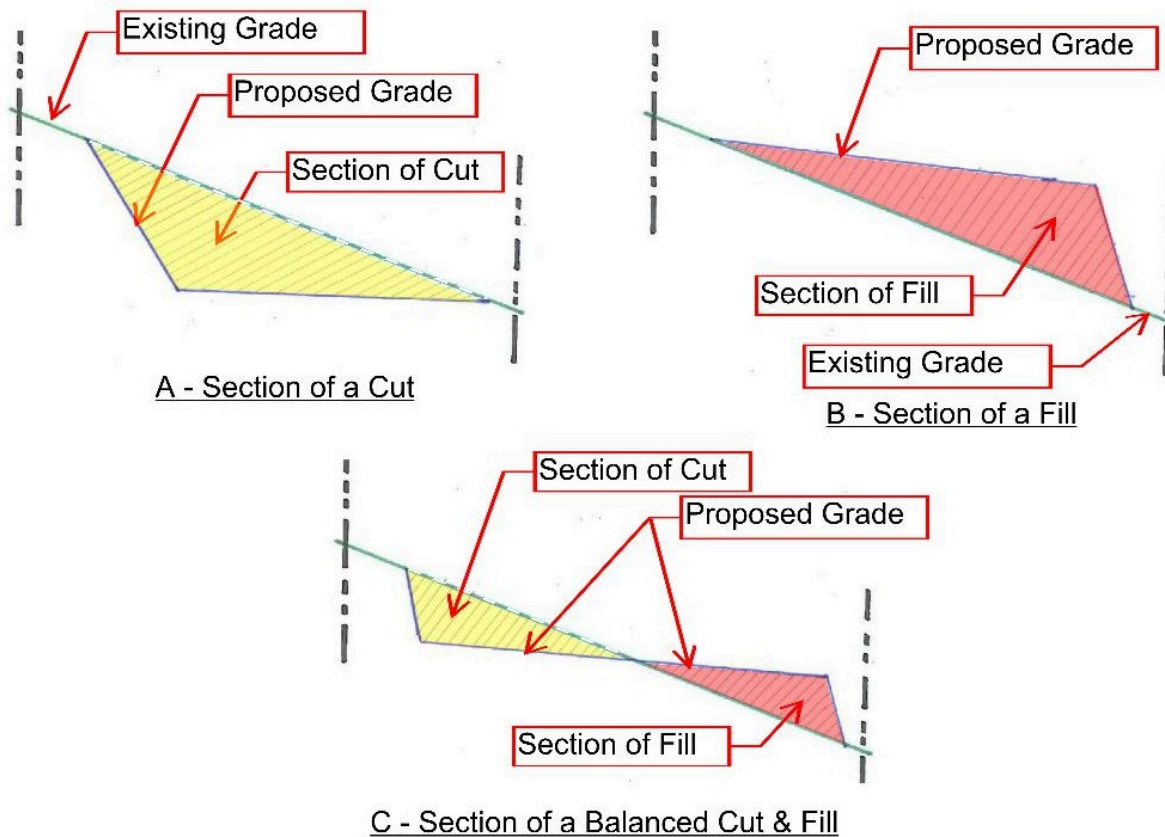
When fill is placed, there is typically geotechnical recommendations associated with the ideal moisture content, the maximum thickness of layers (referred to as “lifts”), and other parameters through which the soils should be placed. The geotechnical engineer may want to witness the completed fill placement by observing a proof roll of the pad or other completed sub-grade installation.

A site design that provides for an equal volume of cut and fill is referred to as “balanced”. It is beneficial to balance the site if possible as there are costs to having to bring soil onto the site or to have to take soil away from the site. Bringing soil to the site is referred to as importing soil. When excess soil needs to be removed / taken away from a site, this is referred to as exported soil. Figure F-3 shows three respective



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sections of a “cut” (A) which theoretically requires export, a “fill” (B) which theoretically requires import, and a balanced section (C) which theoretically requires neither import or export.



**Figure F-3**  
**(Cut, Fill, and “Balanced” sections)**

While the goal of the site engineer should be to minimize earthwork overall, minimizing the import and export is one of the primary goals. Therefore the typical goal of an earthwork analysis is to come up with a net balanced site, and the emphasis associated with minimizing the amount of earthwork that occurs within the site is generally dealt with associated with layout planning and preliminary grading design. Ultimately, the designer must prepare a grading plan that works within the constraints of the site and grading guidelines and standards.





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## 5. Units

In general in the United States, Standard Imperial (SI) units of measure are used. Many other parts of the world use metric units. For the purpose of this course, units will be presented in SI.

When discussing earthwork, the analysis must determine the volume of material being moved. In SI units, volume can be represented with wet volume units (i.e. gallons, quarts, etc.) or dry volume units. The dry volume units are typically cubic measurements of length (i.e. a length in three special dimensions). As a result, SI units for dry volume measurement are cubic inches (CI or in<sup>3</sup>), cubic feet (CF or ft<sup>3</sup>), cubic yards (CY or yd<sup>3</sup>), etc.

Some site materials such as sand or gravel may be sold in terms of weight (i.e. tons), and there are standard conversion factors that can be used by the engineer in the analysis in order to determine the volume that a certain weight of material will occupy. However this topic is generally beyond the scope of this course, and will not be discussed further as most site engineers will need to work with the volume in terms of cubic yards.

When calculating import and export, the engineer will need to consider the volume of the truck load in order to calculate costs. Since various size dump trucks are available, the exact conversion may not be known, but the engineer can make assumptions to estimate the costs.

Often times in the industry the CY is merely stated as “yards” (i.e. (as an example), “our project needs 15 yards of new top soil and we will have to export 200 yards of excess fill material”). This course may use CY and “yards” interchangeably.

It is worth noting (if only barely) that yards in the sense described above is not to be confused with the required setbacks that an engineer may have to deal with associated with planning and zoning analysis. A front yard setback will typically be presented in terms of feet as it is not a volume being considered.

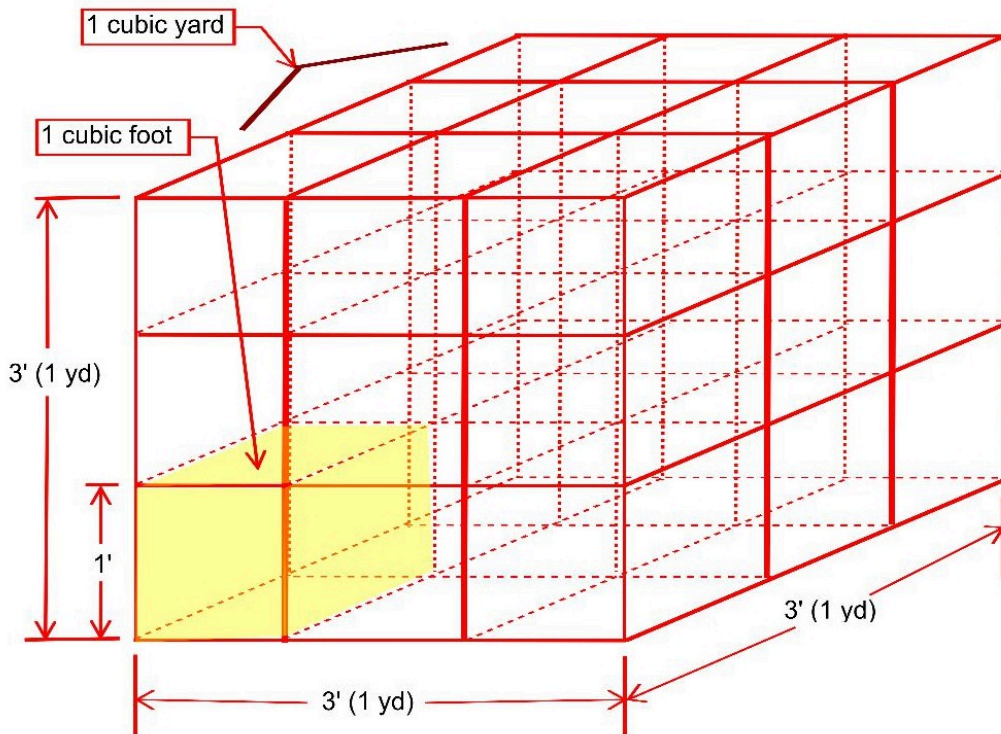
A cubic yard consists of twenty seven (27) cubic feet.





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Figure F-4 depicts a cubic yard of 27 cubic feet.



**Figure F-4**  
**(Cubic yard (NTS))**

**6. Average (Mean)**

In order for an engineer to perform the hand methods of earthwork analysis as defined in the course, the basic concept of averaging (or finding the mean) will be used. An average is the sum of all parts divided by the number of parts. The mathematical definition of average is expressed in Equation E-1:

$$Avg. = \frac{A+B+C+\dots+N}{N} = \frac{\text{(Sum of the Parts)}}{\text{(Number of parts)}}$$

**EQUATION E-1**

A simple example of this calculation is located in Problem P-1



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**P-1)** What is the average of 2, 4, 10, and 16?

Solution:

$$Avg. = \frac{2+4+10+16}{4} = \frac{32}{4} = 8$$

As can be seen from this simple calculation, the average of a group of numbers takes what can be a wide spread in values and simplifies this to a single figure. All engineers are familiar with averaging.

### **C. Surface Cut-Fill Analysis**

#### **1. Modern methods**

Modern methods of earthwork analysis are widely available in software programs that are useful for contractors attempting to perform take-offs of an anticipated project; as well as for the design engineer attempting to balance the site design. The design engineer has tools available in the “Civil 3D” package and/or “Land Desktop” which are the standard tools available with the AutoCAD software package. Highway / Road design tools are also available for the engineer that is tasked with performing that type of design.

Since modern design tools take advantage of contour elevations in design, these modern tools are very useful, and very precise. These tools are able to perform the analysis based on the precise understanding of the existing and proposed elevations and various iterations of analysis can be easily adjusted and re-run based on the whims of the engineer.

In the past, various hand methods of earthwork and cut-fill analysis were developed and used as a standard in the industry for many years. These methods were developed using basic geometry and math, and assumptions were made in order to approximate the amount of earthwork anticipated.

This course will explore one of these traditional hand methods. Learning and understanding where we came from as an industry is always useful information to the growing engineer.



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2. A Traditional “Hand Method” of Surface Cut-Fill Analysis

The “hand method” that will be presented in this course can be referred to as a grid method of surface cut-fill analysis. In general, this method can be performed in 1 of 2 ways. The first way is by averaging the quadrant elevations of the existing grid and comparing that to an average of the quadrant elevations of the proposed grid. The other way is to average the differences between each quadrant. Either is effective, and the differences will be explained in the following sections.

In order to perform either method of surface cut-fill analysis, one needs to set up grid over the topographic plan of the existing and proposed conditions. It is worth noting, subsurface considerations will be discussed in later sections of the course.

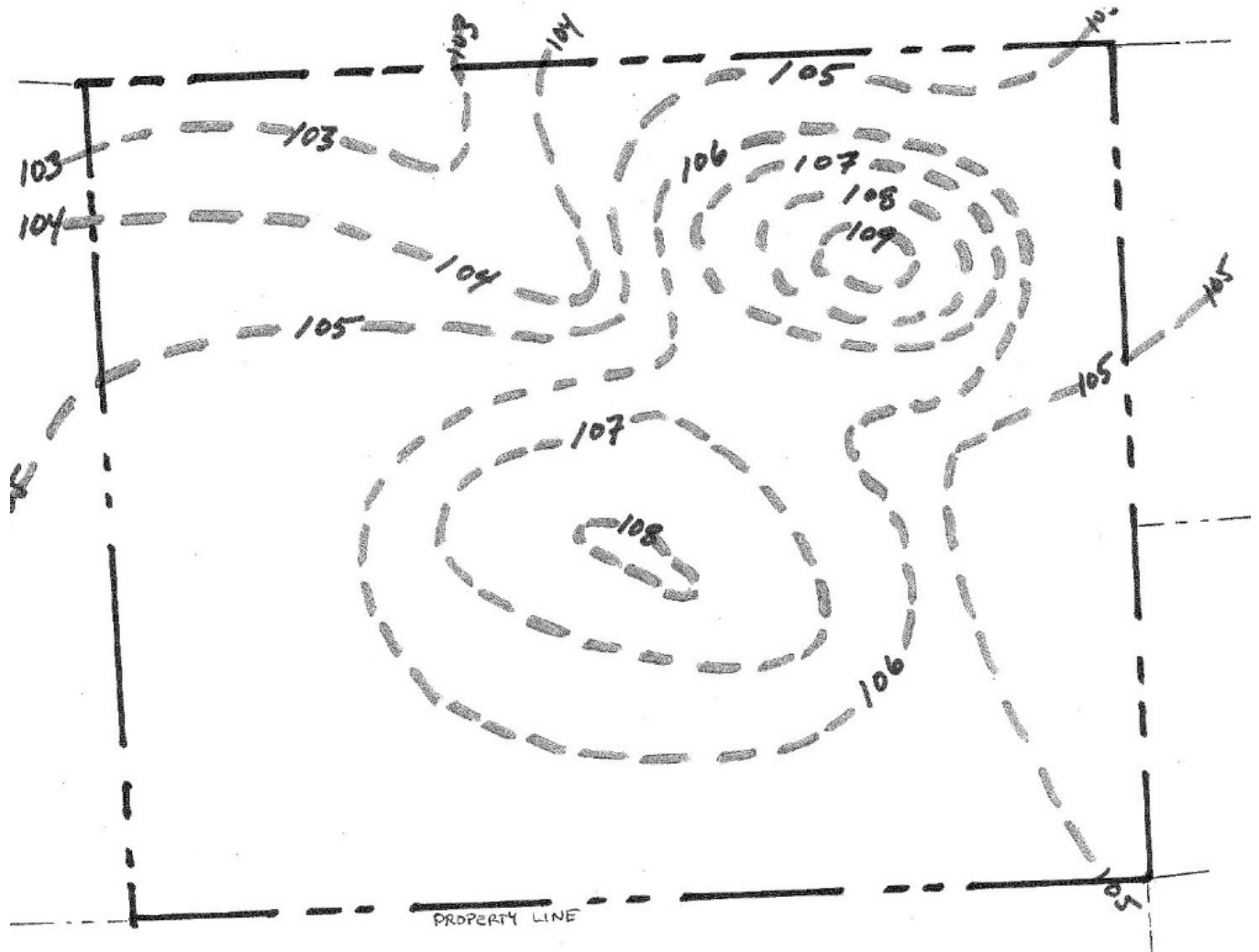
The following sections will walk the student through setting up the grid.

*Setting up the Cut-Fill analysis*

Figure F-5 shows an example of existing topography obtained via a land survey. This will ultimately be overlain with some proposed topography, and a grid overlain on that.



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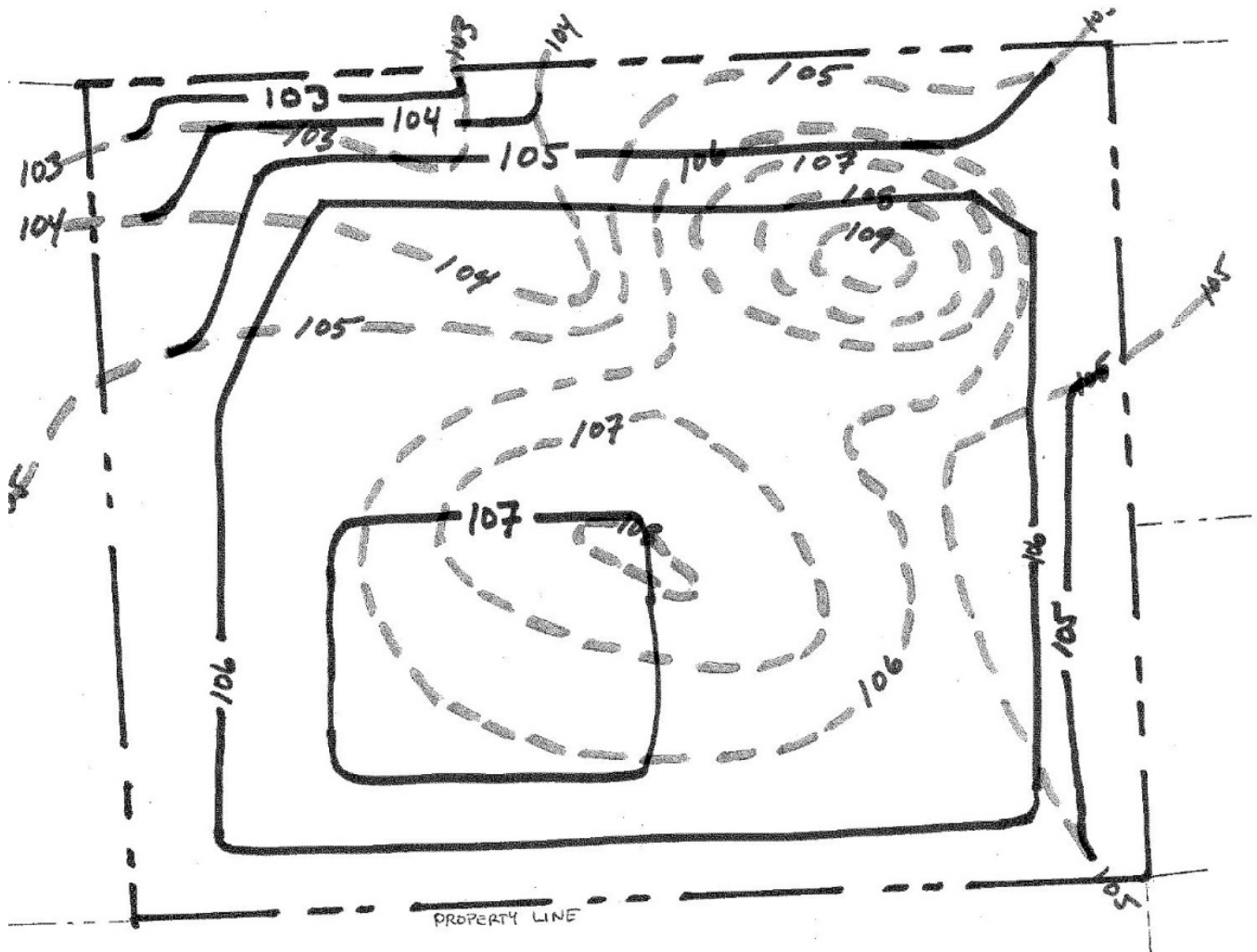


**Figure F-5**  
**(Example of Existing Conditions Grading (NTS))**

Figure F-6 shows an example of a proposed grading design associated with this site. Perhaps the proposed 107 contour is associated with the building pad, and there is site access in the upper right corner crossing the 106 contour.



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**Figure F-6**  
**(Example of Proposed Conditions Grading (NTS))**

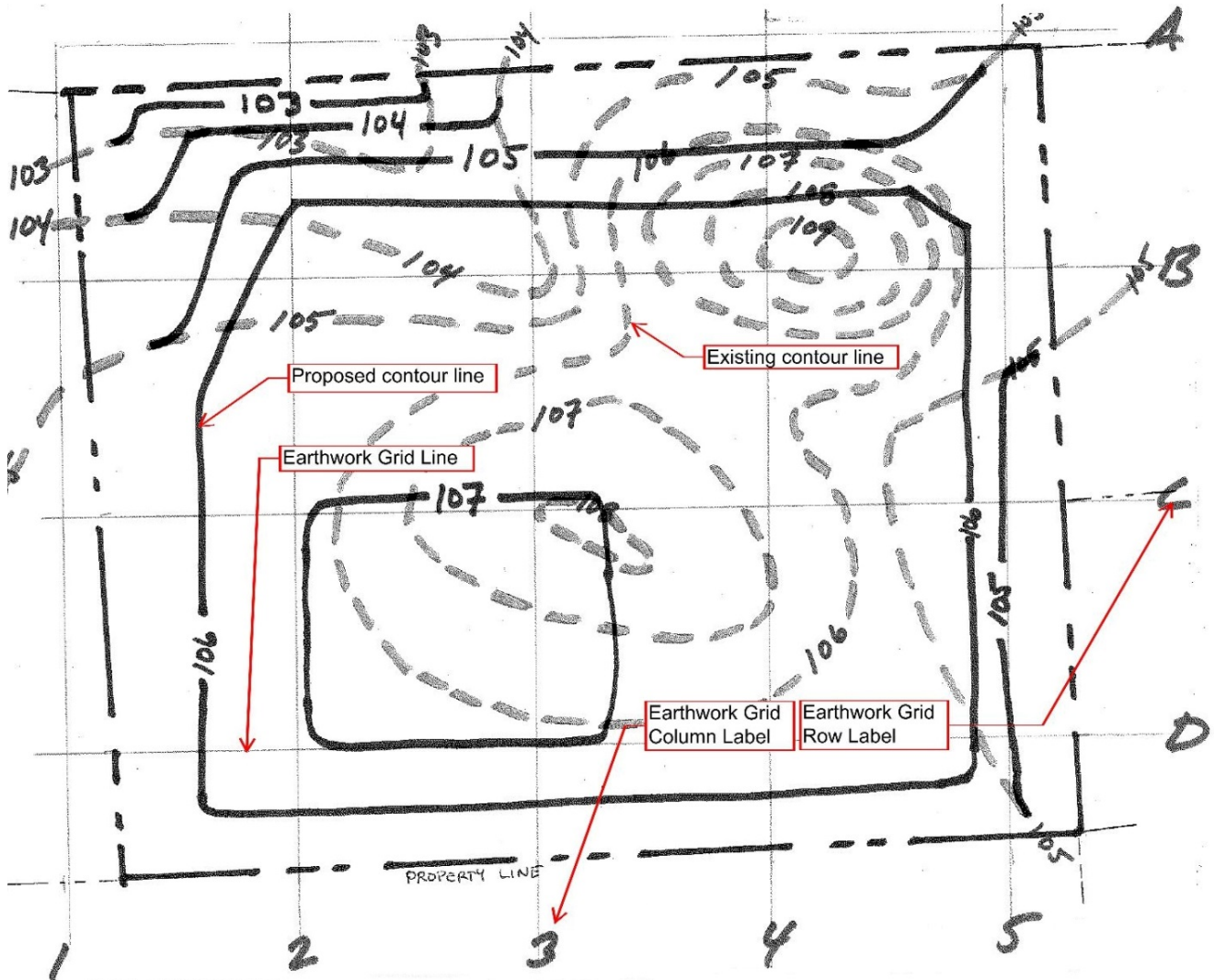
Figure F-7 shows an example of an earthwork analysis grid hand drawn over top of the proposed grading plan overlay. As can be seen, the Grid can be spaced as is convenient for the engineer associated with how detailed they would like the analysis to be. Let's assume for this example, the grid lines have been spaced at 200'. It is typically appropriate to set up the grid so that there is an outside row and column that is beyond the limit of disturbance. This way the outer ring of intersecting nodes will have





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the same elevation in the existing and proposed conditions. In this case, and assumed "Row 6" would be needed in the calculations.

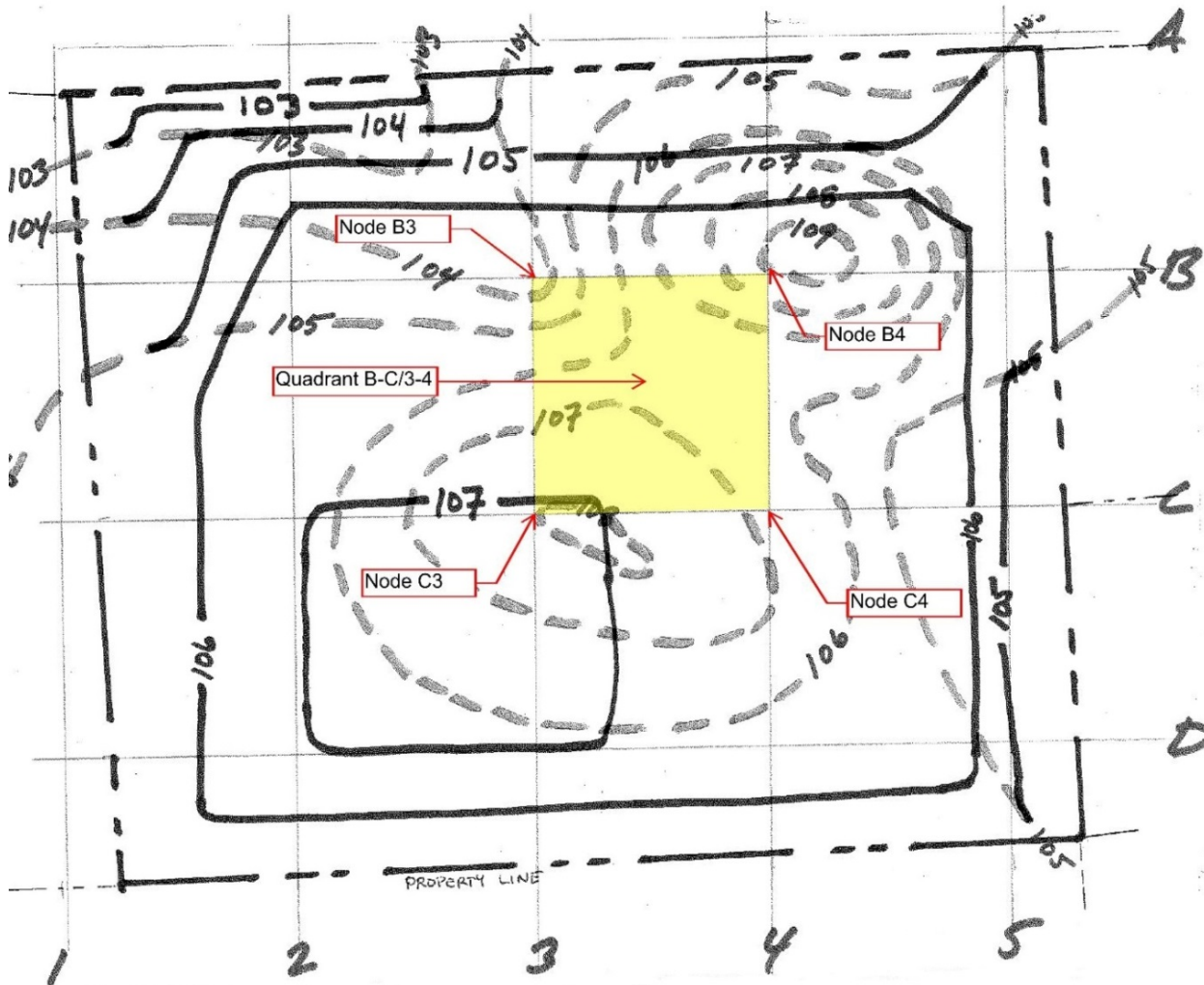


**Figure F-7**  
**(Earthwork Grid Overlay (NTS))**

In order to understand the two methods of analysis described above, (averaging the quadrant elevations vs. averaging the differences of the nodes), let's take into consideration one of the quadrants, for example Quadrant B-C/3-4. This quadrant is highlighted in Figure F-8.



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**Figure F-8**  
**(Highlighted Quadrant B-C/3-4 (NTS))**

It is worth noting, the area of each Quadrant depends on the spacing of the grid (which has not yet been defined in our example). Each Quadrant on the grid is made up of four nodes. In the case of Quadrant B-C/3-4, the nodes are as follows: Node B3, Node B4, Node C3, and Node C4.

Each node can be depicted as having an existing elevation and a proposed elevation. In the following table, Table T-1, we identify the existing and proposed elevations at each Node associated with Quadrant B-C/3-4. The engineer must use engineering judgement and interpolation skills in order to determine the value of each existing and proposed Node elevation.





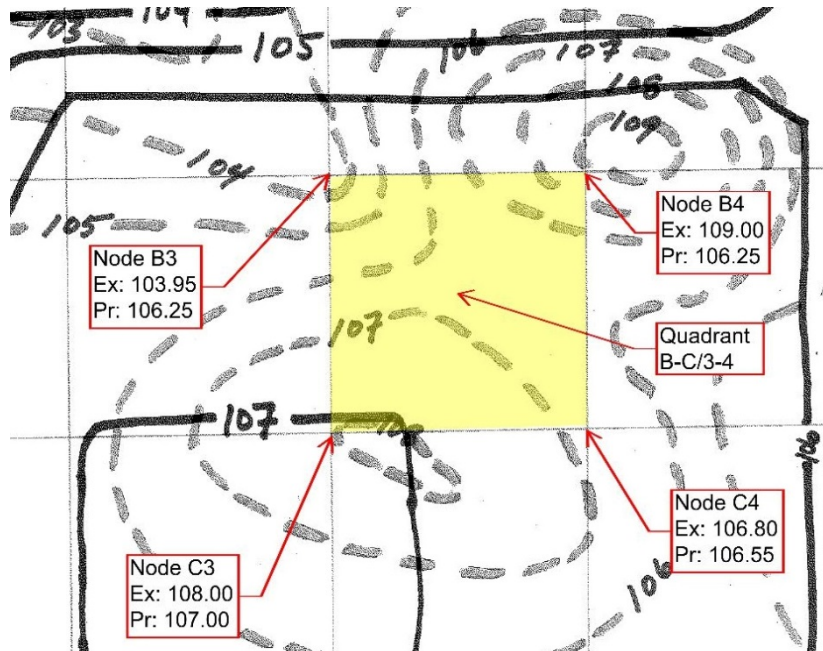
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**Quadrant B-C/3-4**

<b><u>Node</u></b>	<b><u>Existing Grade</u></b>	<b><u>Proposed Grade</u></b>
B3	103.95	106.25
B4	109.00	106.25
C3	108.00	107.00
C4	106.80	106.55

**Table T-1**  
**(Node Elevations on Highlighted Quadrant B-C/3-4)**

The values defined in the table can be reflected on the plan, but typically the engineer marks up the plan and then transfers the information to a table or spreadsheet. Figure F-9 shows the elevations as interpolated and then reflected on the plan.



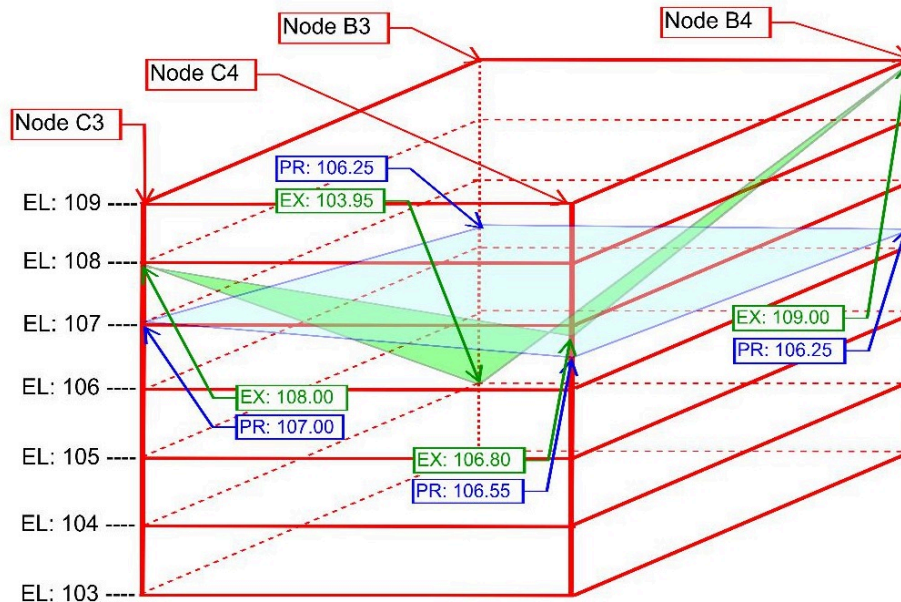
**Figure F-9**  
**(Quadrant B-C/3-4 with elevations at nodes defined (NTS))**

To help show what is being observed, Figure F-10 reflects an isometric of the quadrant. Please note, since the analysis being performed is limited to the nodes being analyzed, the isometric does not show actual existing and proposed topography, it only shows a “flat” plane between the nodes. The existing plane appears to be a “v-shaped” swale



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between Node C4 and Node B3. This figure is not important to be developed to perform the analysis, it is just provided to reflect what is being considered.



**Figure F-10**  
**(“Plane” Isometric of Quadrant B-C/3-4 (NTS))**

As can be seen, the points in view are still fairly complex in terms of an ability to analyze the volume of earthwork being moved and determining the net volume for the quadrant. Some points of the existing quadrant are above the proposed, and some are below. As a result, the analysis will use averaging in order to determine the approximate cut or fill needed in the quadrant.

Method 1 (Averaging the Quadrant Elevations)

As noted previously in the narrative above, there are two (2) methods of averaging the elevations in a cut-fill analysis. The first that will be explained is averaging the quadrant elevations. In order to complete this method, each quadrant will have the existing nodes averaged to define an average existing quadrant elevation, and the proposed nodes will also be averaged in order to define an average proposed quadrant elevation.

Table T-2 shows the calculation to define an average of the existing and proposed plane elevations of Quadrant B-C/3-4.



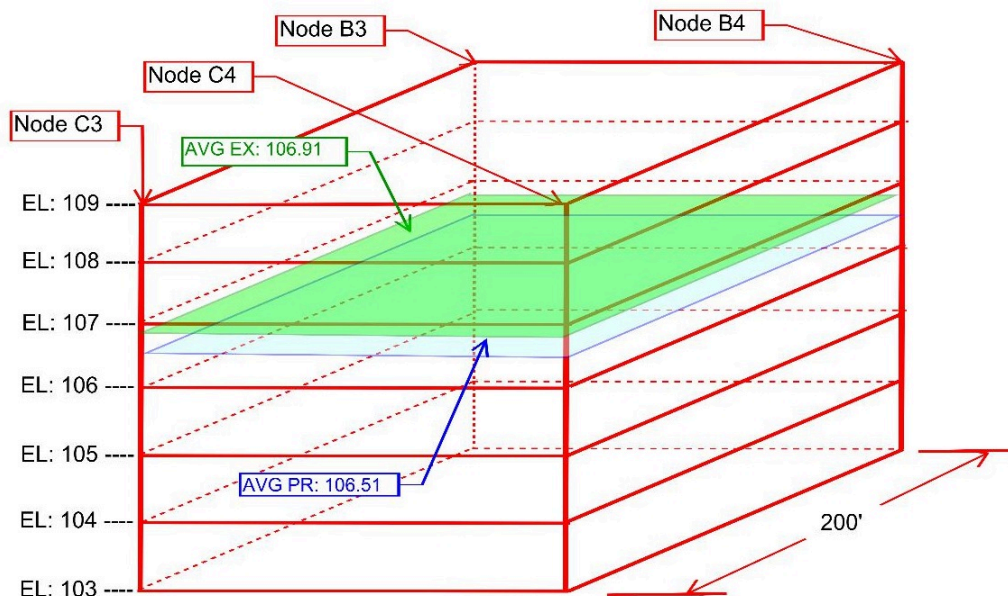
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**Quadrant B-C/3-4**

<b><u>Node</u></b>	<b><u>Existing Grade</u></b>	<b><u>Proposed Grade</u></b>
B3	103.95	106.25
B4	109.00	106.25
C3	108.00	107.00
C4	106.80	106.55
Total	427.75	426.05
Average	<b>106.9375</b>	<b>106.5125</b>

**Table T-2**  
**(Average Elevations of Quadrant B-C/3-4 (NTS))**

Figure F-11 provides a graphic representation of the average change in elevations as developed in the above calculation.



**Figure F-11**  
**(Isometric of Average elevations across Quadrant B-C/3-4 (NTS))**

The difference in elevations can be multiplied by the area of the quadrant to give the net cut or fill of the quadrant depending on if the existing or proposed average elevation is higher. In the case of the quadrant above, the quadrant results in a net cut.



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As was noted above, if we assumed that the grid lines were spaced at 200' apart, then the quadrant is an area of 200' x 200', or 40,000 SF. The volume of cut for the quadrant is defined as the difference of the two elevations times the area of the quadrant.

The earthwork calculation for Quadrant B-C/3-4 under Method 1 is developed in Problem P-2:

**P-2)** In yards, what is the calculated net earthwork requirement for a 200' x 200' quadrant that has an existing average elevation of 106.94 and an average proposed elevation of 106.51?

Solution:

$$106.94 - 106.51 = 0.43'$$

$$0.43' \times 200' \times 200' = 17,200 \text{ CF}$$

$$17,200 \text{ CF} / 27 \text{ CF/CY} = 637.04 \text{ CY}$$

**Answer:** Approximately 637 yards of cut

Method 2 (averaging the differences of the nodes)

The second method that will be explained is averaging the differences of the nodes. In order to complete this method, the difference of each node's elevation is determined and then the calculated differences are averaged to define the approximate net change in elevation across the node. In this method, to determine the difference, the existing elevation will be subtracted from the proposed elevation.

Table T-3 shows the Method 2 calculation to define an average of the existing and proposed plane elevations of Quadrant B-C/3-4.



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**Quadrant B-C/3-4**

<b><u>Node</u></b>	<b><u>Existing Grade</u></b>	<b><u>Proposed Grade</u></b>	<b><u>Elevation Difference</u></b>
B3	103.95	106.25	2.30'
B4	109.00	106.25	-2.75'
C3	108.00	107.00	-1.00'
C4	106.80	106.55	-0.25'
		Total	-1.7'
		Average	<b>-0.425'</b>

**Table T-3**

**(Node Elevation Differences and Net Average of Quadrant B-C/3-4)**

The earthwork calculation for Quadrant B-C/3-4 under Method 2 is developed in Problem P-3:

**P-3)** In yards, what is the calculated net earthwork requirement for a 200' x 200' quadrant that has an average change in elevation of -0.425 across its 4 nodes?

Solution:

$$-0.425' \times 200' \times 200' = -17,000 \text{ CF}$$

$$-17,000 \text{ CF} / 27 \text{ CF/CY} = -629.63 \text{ CY}$$

**Answer: Approximately 630 yards of cut**

As can be seen each method yields a very similar result.

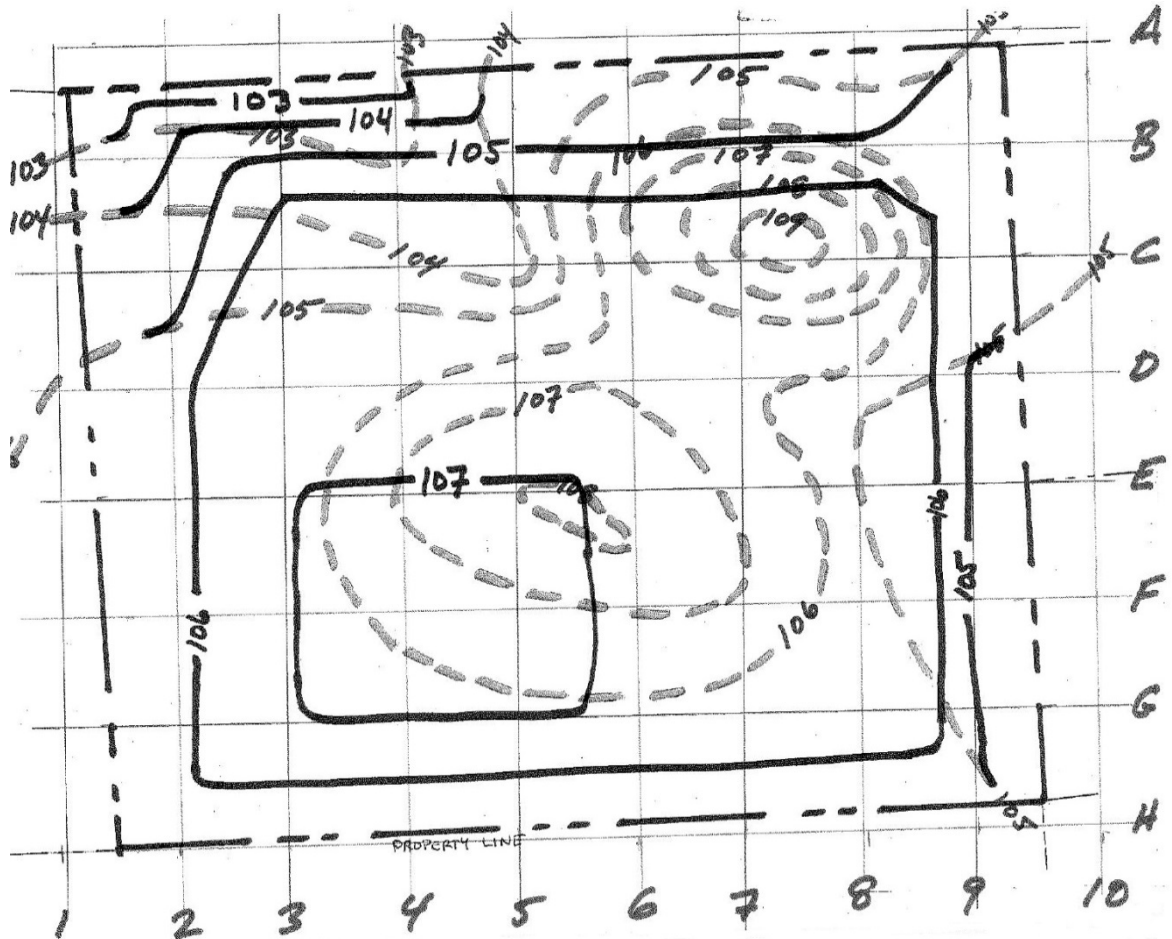
The more frequently spaced the grid is laid out, to more accurate the results will be. The engineer must use discretion to determine how accurate the results are needed based on the purposes of the analysis. A conceptual grading plan might be analyzed with a very loosely spaced grid, while a final plan might be analyzed with a much more tightly spaced grid in order to confirm the truly anticipated earthwork volume.





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Figure F-12 shows an overlay grid with a spacing of 100' between gridlines. It is worth noting, with the more frequent spacing of gridlines, the outer nodes of this layout are now beyond the limit of disturbance, and will now have the same elevation in the existing and proposed condition.



**Figure F-12**  
**(Earthwork Grid Overlay with more frequent 100' spacing (NTS))**

As can be seen, the Quadrant that was analyzed previously as Quadrant B-C/3-4 would in this example be defined as Quadrant C-E/5-7 and is now seen to be made up of four (4) smaller quadrants

An earthwork calculation for Quadrant C-E/5-7 is shown in Problem P-4:

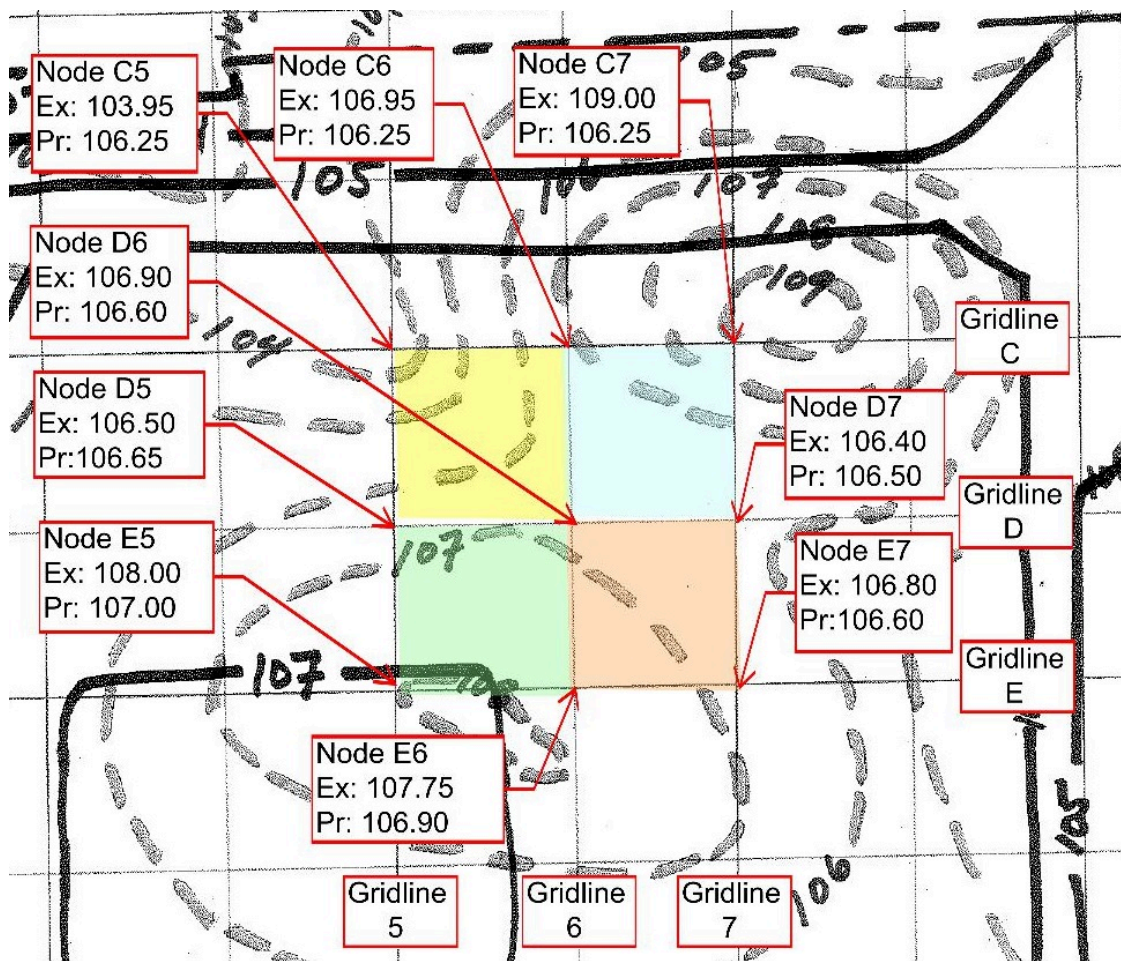


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**P-4)** Using Method 2 (*averaging the differences of the nodes*), what is the calculated net earthwork requirement for the 200' x 200' Quadrant C-E/5-7 as reflected in Figure F-12?

Solution:

*First define the existing and proposed elevations of each node:*



*Next determine the differences of the elevations and determine the average net change per sub quadrant. Using a table of spreadsheet, calculate the differences.*





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**Quadrant C-D/5-6 (Yellow)**

<u>Node</u>	<u>Existing Grade</u>	<u>Proposed Grade</u>	<u>Elevation Difference</u>
C5	103.95	106.25	+2.30'
C6	106.95	106.25	-0.70'
D5	106.50	106.95	+0.45'
D6	106.90	106.60	-0.30'
		Total	+1.75'
		Average	<b>+0.4375</b>

**Quadrant C-D/6-7 (Blue)**

<u>Node</u>	<u>Existing Grade</u>	<u>Proposed Grade</u>	<u>Elevation Difference</u>
C6	106.95	106.25	-0.70
C7	109.00	106.25	-2.75
D6	106.90	106.60	-0.30
D7	106.40	106.50	+0.10
		Total	-3.65
		Average	<b>-0.9125'</b>

**Quadrant D-E/5-6 (Green)**

<u>Node</u>	<u>Existing Grade</u>	<u>Proposed Grade</u>	<u>Elevation Difference</u>
D5	106.50	106.95	+0.45'
D6	106.90	106.60	-0.30'
E5	108.00	107.00	-1.00'
E6	107.75	106.90	-0.85'
		Total	-1.7'
		Average	<b>-0.425'</b>

**Quadrant D-E/5-6 (Orange)**

<u>Node</u>	<u>Existing Grade</u>	<u>Proposed Grade</u>	<u>Elevation Difference</u>
D6	106.90	106.60	-0.30'
D7	106.40	106.50	+0.10
E6	107.75	106.90	-0.85'
E7	106.80	106.55	-0.25'
		Total	-1.3'
		Average	<b>-0.325'</b>

Next calculate the net cut and fill associated with each quadrant:

Yellow:  $+0.4375' \times 100' \times 100' = 4,375 \text{ CF}$  or  $\sim 162.0 \text{ CY}$  Fill

Blue:  $-0.9125' \times 100' \times 100' = 9,125 \text{ CF}$  or  $\sim 338.0 \text{ CY}$  Cut

Green:  $-0.4250' \times 100' \times 100' = 4,250 \text{ CF}$  or  $\sim 157.4 \text{ CY}$  Cut

Orange:  $-0.3250' \times 100' \times 100' = 3,250 \text{ CF}$  or  $\sim 120.4 \text{ CY}$  Cut

Next calculate the net cut and fill the total analysis:

$$162.0 - 338.0 - 157.4 - 120.4 = -453.8 \text{ CY}$$

**Answer: 453 CY Cut required for Quadrant C-E/5-7**



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As can be seen, the “tighter” analysis of spacing the earthwork grid at 100’ x 100’ vs. 200’ x 200’ has yielded a more accurate result of only 453 CY cut required vs. 629 CY cut as was projected in the earlier analysis.

The closer the grid spacing used by the engineer, the more accurate the results will be.

### 3. Cut-Fill Analysis Spreadsheet File Summary

As can be seen in Problem P-4, an earthwork analysis can be quite extensive when performed with a hand method. It is worth pointing out that there is a significant amount of overlap in the calculations required in terms of the data obtained and the calculations performed. For example, the difference at Node D6 was calculated for each quadrant. As a result, it can be understood that for an entire site analysis, the calculation at each of the node points is used in four quadrant calculations.

The sample software / spreadsheet file provided with the course utilizes Method 1 as outlined in the above material. As a result, if using this sort of tool, the engineer only needs to set up the number of columns and grids, insert the grid spacing, and insert the values of the existing and proposed elevations at each grid location.

The spreadsheet then completes all of the calculations for each quadrant and the net cut or fill result is found automatically. It is worth noting that the spreadsheet must be manipulated by the user depending on the number of rows and columns needed for the analysis.

The engineer should take care to confirm that all formulas properly function if the spreadsheet as provided is modified to suit a specific project.

It is worth noting that the spreadsheet also simplifies the naming of quadrants by merely naming each quadrant after the name of the node in the upper left corner of the quadrant. For example, Quadrant B-C/3-4 used in the above example would be referred to as quadrant B3 since that is the node in the upper left corner of the quadrant.

Sample data is also included in the file which can just be over written by the user when the project specific data is inserted.



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## **D. Ancillary Conditions Analysis**

### **1. Background**

The above sections define the difference between the surface grades. However, there are often several ancillary items associated with a site that need to be incorporated into the analysis. These “corrections” can be applied to the surface cut-fill analysis after they are completed. This is related to sub-surface conditions that change the amount of soil available and or needed in the post constructed condition.

### **2. Some Considerations and Assumptions**

#### *Topsoil*

One common assumption that needs to be made is that topsoil is not a suitable fill material. As a result topsoil is typically stockpiled on site and reused as possible in the proposed condition. If additional topsoil is needed to achieve the design parameters, this should be taken into consideration.

#### *Suitability of Existing Soil*

Another assumption that is often made is that the soils on site are suitable and are not contaminated. The engineer should always consult with the soils / geotechnical and any available environmental reports to glean any information possible associated with the site.

For example, there might be some geotechnically unsuitable and/or contaminated fill that needs to be exported, outside of what was determined by the surface cut-fill analysis. This would not only require the expense associated with export and disposal at an appropriate receiving facility, but it may also require the import of clean/suitable fill if the site is not adequately cut to the proposed grade or appropriate clean fill is not available on site to comply with environmental parameters of the authorities having jurisdiction.

#### *Rock Ledge*

Another consideration is the possibility that there is rock ledge just a few feet down on portions of the site, which may change significantly the grading approach of the project.

In general some of these topics are beyond the scope of this course, but it is definitely something that the engineer should be aware of and considering as they approach the design. The thorough and experienced site engineer will document his requests for



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information and materials to support his ability to perform due diligence in these regards.

If a formal earthwork calculation is developed (especially to be presented for review), the assumptions should be clearly stated and documented.

### 3. Subsurface Conditions

Notwithstanding the situations noted in the assumptions section above, the subsurface conditions need to be considered after the surface cut-fill analysis is completed. For example, the existing conditions may have a building slab and driveway, while the proposed conditions may have a new building, a parking lot, and an underground detention basin.

Certainly the engineer has the freedom to attempt to incorporate these assumptions into the surface cut-fill analysis by identifying the spot grades at the quadrants as those of the subgrade, but that method is slightly more difficult to document. The strategy being explained in this course separates the surface analysis from the sub-surface assumptions.

As a result and expanding on the statement above, after completion of the surface cut-fill analysis, it needs to be understood that in order to have been at the existing elevation as assumed by the topographic survey, additional soil would have been needed for the volume of the topsoil, the slab, and the driveway. This represents additionally “assumed fill” to be at the existing grade. So the volume of topsoil, volume of the building slab, and the volume of asphalt and stone associated with the existing driveway should be calculated.

Additionally, the volume of the existing constructed features should be calculated. This volume is an amount of soil “not needed” in order to get to the proposed surface grade as determined by the surface cut-fill analysis. This represents additionally “assumed cut” in order to achieve the proposed surface grade.

Problem P-5 and P-6 will help describe this aspect of the process:

**P-5)** An existing site has a 24,000 SF concrete slab that is 1’ thick on top of 6” of  $\frac{3}{4}$ ” clean stone.



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How much fill is needed to bring the site to the existing grade once the slab and base are removed?

Solution:

$$20,000 \text{ SF} \times 1.5' = 30,000 \text{ CF}$$

$$30,000 \text{ CF} / 27 \text{ CF/CY} = 1111.11 \text{ CY}$$

*Answer: Approximately 1111 CY of fill*

**P-6)** If a surface cut-fill analysis determined that 555 CY of fill is needed, and the existing constructed subsurface features account for 223 CY of material while the proposed constructed subsurface features account for 778 CY of material, what is the net volume of soil import/export needed on site?

Solution:

$$555 \text{ CY Fill} + 223 \text{ CY assumed fill} - 778 \text{ CY assumed cut} = 0 \text{ CY}$$

*Answer: None, the site is generally balanced.*

The engineer should always take into account the subsurface conditions when performing an earthwork analysis.

Problem P-7 will reflect how import/export can be calculated:

**P-7)** Assuming a site that requires 1110 CY of export is needed, how many trips to the disposal location will be needed if 20 yard dump trucks will be used to export the fill.

Solution:

$$1,120 \text{ CY} / 20 \text{ CY per trip} = 56 \text{ trips}$$

*Answer: 56 trips required*



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## **E. Earthwork Equipment**

This section of the course will expose the student to the heavy equipment used in earthwork in the construction industry. The basic pieces of equipment that will be reviewed are as follows: Dump Trucks, Scrapers, Front Loaders, Bulldozers, Excavators, Backhoes, Rollers, and Graders. Of course there are many other “tools” that will not be discussed such as hand held rakes, shovels, hoes, tamping plates and hand compactors, etc., as these are for smaller scale work, although also used on many large project as well.

### **Dump Trucks / Haulers**

Dump trucks are vehicles used to transport materials, including soil, over longer distances and are used when the soil being excavated is moved by loaders. Virtually all standard dump trucks utilize hydraulics to raise the bed which allows the material being transported to slide off. Later in this section of the course will be a review of scrapers which can load and transport soil themselves. Dump trucks range from small standard dump trucks to semi-trailer dump trucks as well as side and bottom dump trucks. A standard dump truck employed for the purpose of transporting earthwork will typically consist of a Dump Truck with at least six (6) wheels.

Dump trucks do not load the soil, they only transport the soil. Standard dump trucks can travel on public roads on speeds comparable to the speed limits, but are limited to relatively flat, dry areas of transport.

It is worth noting that often the geotechnical engineer will specify / recommend that the installation of soil be “proof rolled”. This is often defined as observing the soil under the rolling weight of a fully loaded rubber tire dump truck.

The skilled dump truck driver can off-load and place fill relatively close to the location needed.





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Figure F-13 shows a pictures of dump trucks.



**Figure F-13**  
**(Standard Dump Truck)**

Off highway dump trucks, also known as “haulers”, are made to handle the terrain on an excavation site. Haulers are most commonly used in the mining industry or at sites with heavy dirt and rock hauling needs. Although similar, they are rarely referred to as “dump trucks”. Haulers come in rigid frame and articulated styles.





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Figure F-14 shows pictures of an Off Highway Dump Truck / Hauler.



**Figure F-14**  
**(Hauler)**

Scrapers

A scraper is a machine used on site for the purpose of moving earth across shorter distances and across relatively smooth terrain. These are ideal on a site where the soil is suitable to be reused on site and merely needs to be relocated to another area on site, but not across steep grades. These are used extensively in highway construction. The scraper accomplishes the job of rough grading.

Scrapers have a blade that cuts into the soil. This blade is referred to as the apron. When the apron is opened, the soil is captured in a bowl, or hopper, or wagon. When the bowl is full, the apron is closed and the soil is taken to the location where it will be placed. In order to release the soil, the apron gate is opened, and an ejector plate pushes the soil out to release it.

There are several configurations of scrapers available that have differing benefits depending on the specifics of the application it is being used in. Some scrapers utilize an auger to load the material into the hopper. This can remove the need for a bulldozer or similar pushing machine which is typically required on a “push-pull” style scraper.



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Figure F-15 shows pictures of a scraper.



**Figure F-15**  
**(Scraper)**

Front Loaders

A front loader is a “tractor type” piece of equipment that is used to move relatively small amounts of soil short distances without having to push it along the ground. This machine is typically on wheels, although they are also manufactured on tracks.

A wide bucket is connected to the front of the vehicle with two hydraulically operated booms or arms that allow the bucket to be raised and rotated. Front loaders can be used to load loose soil into a dump truck or create a stock pile on site. A front loader is sometimes referred to as a wheel loader, a scoop, or a shovel.



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Figure F-16 shows pictures of front loaders.



**Figure F-16**  
**(Front Loader)**

**Bulldozers**

A bulldozer or dozer is a piece of equipment that consists of a substantial plate or blade on a machine equipped with continuous tracks to drive the machine. The tracks provide a bulldozer with excellent mobility on rough and steep terrain. Often, dozers are also equipped with a claw like device on the rear known as a ripper. The purpose of the ripper is to loosen densely compacted materials.

Bulldozers are also available on wheeled equipment, but wheeled dozers do not have the same capacity to move as much dirt as efficiently as a tracked dozer.

Dozers are ideally used to move soil relatively shorter distances by pushing it along the ground. Dozers are also good for rough grading.

The elevation of the blade can be raised and lowered by moving the hydraulic arms. The blade can come in an assortment of configurations depending on the application needed. "S blades" have no lateral curve nor side wings and are good for fine grading. "U Blades" are tall and have a lateral curve and side walls and are used for moving more material.



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The dozer may be equipped with hydraulics that allow the angle of the blade to be varied while moving.

Most bulldozers will come with a “ripper” in the rear that can consist of one or more shanks. The ripper can be raised and lowered to tear up hard soil that can be later moved by the blade more easily.

Figure F-17 shows pictures of a bulldozer.



**Figure F-17**  
**(Bulldozer)**

Excavators

An excavator is a large machine used for digging, demolition, grading, and heavy lifting site work. The excavator is typically manufactured on tracks. The machine has a boom, stick, and bucket head, all configured on a rotating platform.

The rotating platform allows for a dump truck to be located directly behind the machine from where the excavation is taking place. These machines can navigate very difficult terrain.

Modern excavators come in a wide variety of sizes. An excavator is sometimes referred to as a “track hoe” presumably by comparison to a backhoe.





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The bucket head can be interchanged with a variety of other useful tools such as augers for coring, breakers (jacks) for hammering and demolishing materials such as concrete, and grapples for picking up debris from above.

Figure F-19 shows pictures of excavators with a bucket head installed.



**Figure F-18**  
**(Excavator)**

Backhoes

A backhoe is a smaller machine that contains the features of a front loader and an excavator within a single machine. The front bucket is a wide bucket located very similarly to a front loader, while the rear of the machine has a boom, arm and bucket head mounted for excavating and digging trenches and the like.

The seat inside the cab rotates to allow the operator to perform either the front bucket operation and driving, or the excavator functionality.

A backhoe is equipped with outriggers that can be extended to provide safety and stability during use of the rear boom. The rear boom is limited on a backhoe in that it cannot rotate 360 degrees, so the operator may have to reorient the entire piece of equipment in order to perform the excavations desired.



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Figure F-19 shows pictures of a back hoe.



**Figure F-19**  
**(Back Hoe)**

Rollers

There are many variations of rollers used in site work construction. The two that will be discussed here are “sheep foot rollers” and smooth drum “vibratory rollers”. The purpose of rollers is to compact soil that has been placed or otherwise achieve the required additional compaction.

Sheep foot rollers have “hoof like” structures protruding from the drum. These protrusions create pinpoint pressure. Smooth drum rollers apply pressure in a more uniform way. Traditionally the smooth drum rollers were vibratory, but manufacturers now offer both styles of drum on machines add vibration to compact the soil.

Rollers are manufactured as single frame machines or articulating style machines.



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Figure F-20 shows pictures of a smooth drum roller.



**Figure F-20**  
**(Smooth Drum Roller)**





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Figure F-21 shows pictures of a sheep foot roller.



**Figure F-21**  
**(Sheep Foot Roller)**

Graders

A grader is a commonly used piece of construction equipment used to create flat fine graded surfaces. The machine is typically a 6-wheeled / tri-axle vehicle which has a blade mounted below and in front of the cab and the 2 rear axles and behind the front axle setting it near the center of the machine. The front of the blade is referred to as the toe, and the rear is referred to as the heel.



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The front wheels can typically tilt and pivot over mounds of soil in order to allow the blade to remain level as the machine drives over the terrain.

The purpose of this machine is to refine the rough grade to the “finished grade” or finished sub-grade. This machine typically does its work once the scraper and/or bulldozer have completed the rough grading, and adequate compaction is complete.

Figure F-22 shows pictures of a grader.



**Figure F-22**  
**(Grader)**



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Figure F-23 shows pictures of a grader's blade.



**Figure F-23**  
**(Grader Blade)**

There are many pieces of equipment and machines needed in construction. The above examples provide a summary of the primary machines used in earthwork.

Other Machines

A few other vehicles / machines that are worth mentioning are as follows:

- 1) *Water Trucks* – Typically a site or road project does not have utility water available, but water is needed in order to achieve moisture content during the fill placement / compaction process. As a result water truck is needed. Water trucks are merely a tanker filled with water.

The water can be used as needed for achieving the required moisture properties of the soil being placed, but they are also useful for dust control as construction sites often become dry and dusty which fosters wind erosion.



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Figure F-24 shows pictures of water trucks.



**Figure F-24**  
**(Water Trucks)**

- 2) *Cranes* – Although cranes are usually more commonly associated with the building portion of construction (and not earthwork), there are occasions where a crane is used associated with the earthwork portion of the project.

One example is a site where the existing soil could be useful, but it exists in its in situ condition, it does not have adequate compaction and the process of removing and re-placing the soil would be time consuming. In a case like this the geotechnical engineer might be in a position of being able to specify an over-compaction method to achieve the compaction and/or consolidation needed on site. This could consist of a process of using a crane to raise large concrete blocks, several tons in weight, and dropping them repeatedly from a substantial height to over-compact the existing soil. In this case rollers would have been insufficient to the task, and cranes are the earthwork machine that performed the job.

- 3) *Bucket Wheels* – more likely to be seen in the mining industry, bucket wheels can (in conjunction with large conveyor systems) move large amounts of rock and soil, relatively significant distances, very efficiently. While these pieces of equipment have been used on some major developments, they are very large, very expensive, and not in common usage on most general development projects.



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There are many other devices and pieces of equipment that could be mentioned associated with earth moving and road development projects, but these remain beyond the scope of this course.

### **F. Summary and Conclusion**

This course has identified the basics of earthwork analysis, identified some considerations that the engineer should keep in mind when tasked with performing such analysis, and provides for an explanation of a hand method of completing a surface cut-fill analysis.

While there are many modern design tools available for the engineer to utilize, understanding the basics and traditional methods is beneficial to helping the engineer think through how they approach the analysis

This course also exposed the student to the basic tools/equipment available for the contractors to utilize in heavy earthwork projects.

The student of this course should now be able to approaching earthwork and earthwork analysis with confidence that they have been exposed to the basics.