
Chapter 5

Construction Surveying and Quantity Computations

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Chapter 5

Construction Surveying and Quantity Computations

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645.0500 Introduction

Construction surveying is required to:

- layout work to ensure correct placement, size, and geometry of the conservation measure being installed
- verify that the work is being constructed to the limits shown on the drawings
- stake work limits and access road boundary lines

Additionally, payment quantities for some items are computed based on groundline surveys that are made when the work is staked; thus, construction surveying typically includes surveying and note keeping necessary for obtaining groundline data for computing quantities.

To make use of the construction surveying portion of this chapter the reader must understand basic surveying principles, techniques, and procedures of engineering surveying and note keeping. Guidance in the use of basic engineering surveying and note keeping principles, techniques, and procedures is provided in National Engineering Handbook (NEH) Part 650, Engineering Field Handbook (EFH), Chapter 1, Engineering Surveys, hereafter referred to as EFH, chapter 1.

Accurate quantity computations are required for making progress payments and final payments. To make use of the quantity computations portion of this chapter the reader must have a working knowledge of basic mathematics.

The purpose of the construction surveying portion of this chapter is to provide quality assurance (QA) personnel with information needed to:

- verify construction staking is performed and recorded as specified
- assist with construction staking and note keeping when staking is performed by NRCS personnel
- verify surveys obtain data needed for accurate quantity computations

- verify work is being constructed within reasonable tolerances to the limits shown on the drawings

The purpose of the quantity computations portion of this chapter is to provide QA personnel with information needed to:

- select the applicable method for performing specific quantity computations
- perform accurate linear, areal, and volumetric quantity computations based on groundline survey data and/or specified neat lines
- record quantity computations in a clear, concise, and accurate manner and reference the source of basic data used in making the computations
- verify contractor performed final quantity computations comply with the specifications

Appendix D of this handbook contains sample notes and calculations to illustrate basic note keeping and quantity computations for construction of some typical NRCS conservation engineering measures.

645.0501 Construction surveying

The complexity required for construction surveying for conservation engineering measures ranges from simple staking such as that for a pit-type pond to more complex staking such as that required to construct a zoned embankment for a flood retarding structure. NRCS personnel may assist landowners with staking and checking of the construction of on-farm engineering measures or the landowner may rely on the contractor to perform construction staking. Historically, NRCS personnel performed staking for more complex structures installed under Federal or Contracting Local Organization (CLO) contracts. NRCS personnel in some locations may continue to perform staking for contract work, but it is more common today for contracts to include a bid item for surveying that requires the contractor to perform construction staking. Regardless of who performs the staking, QA personnel are to verify correct placement, size, and geometry of the measure being installed. This means that whether they actually perform staking, assist with staking, or they inspect staking performed by others, QA personnel must have a working knowledge of construction surveying.

When a construction contract includes a bid item for construction staking, the work is specified according to NEH, Part 642, Specifications for Construction Contracts, Construction Specification (hereafter referred to as "Spec.") 7, Construction Surveys. The QA inspector must verify that surveys, measurements, and computations performed by the contractor comply with Spec 7 requirements when applicable. This requires the inspector to verify:

- adequacy and accuracy of surveying equipment and materials
- quality of work is as specified
- accuracy of primary control
- construction surveys reference the specified primary control
- adequacy and accuracy of initial layout and staking
- adequacy and accuracy of initial groundline surveys
- adequacy and accuracy of checking and interim staking
- adequacy and accuracy of as-built and final surveys
- surveying notes and records meet specification requirements
- the transfer of complete notes and records to the engineer within the specified time frame

(a) Equipment and materials

Surveying equipment includes equipment such as surveying instruments and measuring devices used to determine the horizontal and vertical position of a point on the ground. Surveying materials include all materials such as stakes and notebooks necessary to stake a point and record survey notes.

Inspectors need not be as concerned about the contractor's surveying equipment as they are about the product derived from the use of that equipment. It is good practice for a QA inspector to spot-check staking early to determine if there are repetitive errors in staking that would indicate possible inaccuracy of equipment. When an electronic data collector is used, the inspector should verify that the data collector is functioning properly and is accurately recording and storing survey data before or at the time initial groundline surveying begins.

The inspector will need to care for and maintain surveying equipment that is issued to him or her. The inspector must periodically check surveying instruments for accuracy and either adjust or have adjusted any inaccurate equipment so that it is accurate to within an acceptable tolerance of error. EFH, chapter 1 describes procedures for checking accuracy of surveying instruments.

The materials used for staking generally include short 1-inch by 2-inch wooden stakes, 2-inch by 2-inch wooden hubs, and 2-inch survey lath. Markings are generally made on stakes and lath with a waterproof marker. Colored pin-flags and survey ribbon are sometimes used for marking general limits such as work limits and clearing limits. EFH, chapter 1 and appendix

D of this handbook describe standard markings to be used on stakes and lathes when staking engineering measures.

Engineering notebooks are available in loose-leaf and hardbound form. Spec 7 requires that survey data be recorded in hardbound engineering survey field notebooks. It is not necessary to record detailed survey data in the hardbound field book if it is recorded and stored in an electronic data collector; however, hardbound field notebooks should still be used to record items and make sketches that are needed to better illustrate conditions that are not obvious or adequately conveyed by electronic data.

The inspector's responsibilities related to equipment and materials include verifying:

- surveying equipment and materials are adequate for staking the work
- surveying equipment and materials are adequate for capturing and recording groundline topography if required by the specification
- electronic data collector is functioning properly and is accurately recording and storing survey data
- inspector's surveying equipment and materials are maintained in proper working condition and are adequate for performing staking, checking, and note keeping necessary to inspect the work

(b) Quality of work

The inspector is responsible for verifying that the quality of work is as specified or otherwise appropriate for the job. Quality refers to the level of surveying precision, accuracy, and detail. Surveying precision, accuracy, and detail are briefly described here, but are described in detail in EFH, chapter 1. Additionally, appendix D of this handbook includes sample notes that illustrate the precision and detail commonly required for staking many on-farm engineering measures.

Precision requires a high-quality instrument and refers to the repeatability of results when measurements are made. For example, a precise level may be able to read within 0.01 foot each time a reading is made on the same point where readings obtained with a less

precise instrument, such as a hand level, may vary as much as 0.1 foot each time a reading is made on the point.

Accuracy refers to how close to the actual value the measurement can be made. A precision instrument that is out of adjustment may measure the same results on a point every time, but the value of the measurement would not be accurate.

Survey **detail** refers to the amount and frequency of staking or survey data obtained. The detail must be appropriate for the type of job. For example, when staking a tight curve in a dam, cross sections may be needed for each 25-foot station that falls within the curve; whereas, for a straight dam built on relatively flat ground, less detail (e.g., a cross section on every 100-ft station) might be adequate.

Spec 7 includes precision, accuracy, and detail requirements. If Spec 7 is not a part of the specifications, it is recommended that the Spec 7 requirements or the sample notes in appendix D of this handbook be referenced to determine the precision, accuracy, and detail required for surveying and staking conservation engineering measures.

The inspector's responsibilities related to quality of work include verifying:

- stakes are accurately placed and clearly marked to define the work for construction to the specified lines and grades
- survey detail is adequate to accurately represent the groundline or feature surveyed

(c) Primary control

Primary control refers to benchmarks and reference markers used to determine the horizontal and vertical location of the instrument or alignment points to be used for staking. Benchmarks and reference markers on a construction site are usually temporary and have been set or established specifically for primary control to be used for the construction surveying. These may include nails driven in trees, iron pipe or rebar driven into the ground, or other items that are securely set and clearly identified.

All benchmarks and reference markers should be identified on the drawings. A description of each benchmark and reference marker must be provided with enough detail so that it can be positively identified. Elevations of each benchmark and coordinates of each horizontal reference marker must be given on the drawings. The inspector must verify that primary control is available at the beginning of construction surveying and maintained throughout the performance of the work.

The inspector must verify that the proper benchmarks and markers are referenced by the surveyor when staking and laying out the work. The construction surveyor may establish other benchmarks and reference markers in locations that are convenient to specific work. The inspector should verify that all benchmarks and reference markers established from primary control are accurate within the specified or otherwise acceptable degree of error. This degree of error is described in EFH, chapter 1 and specified in Spec 7.

The inspector's responsibilities related to primary control include verifying:

- primary control is available and maintained during the performance of the work
- the proper benchmarks and markers are referenced
- all benchmarks and reference markers established from primary control are accurate within the specified or otherwise acceptable degree of error

(d) Staking and quantity surveys

When the contractor performs surveys and computations for final payment quantities, Spec 7 requires software identification, vendor's name, version number, and other pertinent data be provided to the engineer before beginning survey activities. Regardless of who performs the surveying (contractor, landowner, or the NRCS), it is prudent to have a surveying plan. This plan should list all of the items to be staked and those items for which quantity surveys must be recorded. The date by which each item must be staked and surveyed along with who will perform the staking and data collection should be clearly identified on the plan. The plan should be updated, if needed, to keep

aligned with the most current construction schedule. It is incumbent upon the QA inspector to verify that all items have been submitted as required. It is also important that the inspector be knowledgeable of the survey plan and elevate any concerns about the plan to the contracting officer's representative/government representative (COR/GR) or engineer and the contractor's quality control personnel.

Staking—Slope stakes are typically 1-inch by 2-inch wooden stakes placed at the intersection of the specified slope and groundline. Additional stakes called reference stakes or offset stakes are typically set a short distance from the slope stakes because slope stakes are often destroyed during construction. It is common to place a lath next to reference stakes. The inspector must verify that slope stakes, reference stakes, and lath are legibly marked and the markings are complete and accurate. Markings generally include station numbers, required cut or fill, slope ratio, and horizontal distance from the centerline or other control line. Markings on reference stakes should also include the offset distance from slope stake to the reference stake. EFH, chapter 1 and appendix D of this handbook describe markings in detail. Damage to stakes is common throughout the performance of the work; the contractor is responsible for replacing damaged stakes. The QA inspector must verify stakes are being maintained as specified and promptly replaced by the contractor when damaged.

The number of stakes must be adequate to layout or define the work on the ground so the engineering measure can be constructed to the specified lines and grades. Spec 7 requires that stakes be located at 100-foot stations or closer for sharp curves or where there are breaks in the ground surface. The inspector must verify that the number and location of stakes are adequate to accurately define the work and to meet Spec 7 requirements when applicable.

Quantity surveys include surveys of the specified pay limits necessary for computing volume, area, and linear quantities for payment. There are two types of quantity surveys: interim quantity surveys and final quantity surveys. Interim quantity surveys are those surveys made to estimate quantities for progress payments. Final quantity surveys are those made to compute final quantities for payment. The difference in the two types of quantity surveys is a matter of detail and precision. Interim surveys do not have to be as de-

tailed or precise as surveys for final quantities because quantities computed from interim survey data will not affect the final payment amount. Summing interim quantities to determine final quantities for payment is not allowed.

Linear measurements for pay quantities for items such as fences, roads, and pipelines are generally made during staking or after the items have been installed. Area surveys such as those for determining the limits of clearing or clearing and grubbing will likely require surveys of before and after conditions. Area surveys for vegetation typically only require surveys of the boundary of the vegetated area, not surveys of the area before it is vegetated.

For earthwork volume quantities, the pay limits include lower, lateral, and upper limits. For example, the upper limit of excavation may be specified to be the original ground surface as it exists prior to the start of construction and the lower and lateral limits specified as the true surface of the completed excavation. Thus the final quantity surveys would include both the groundline survey made prior to excavation and a survey of the groundline after excavation is completed. If the specified payment limits are the original ground surface (upper limit) and the neat lines and grades shown on the drawings (lower and lateral limits), only the original ground surface as it exists prior to the start of construction would be needed for computing excavation quantities for payment. The QA inspector must understand what survey information is needed to compute final quantities for payment as specified in the measurement and payment section of the applicable construction specification. The inspector must be aware of all items that must be surveyed for computing final quantities and verify that quantity surveys are made at various stages of the work to adequately define the limits needed to compute final payment quantities.

When volume quantities are to be computed by the average end-area, prismoidal, or composite method, it is common for the groundline topography to be captured at the time of staking. Survey points will be recorded at the centerline of the work at points where the cut or fill intersects the ground (at toe stakes) and at points between the centerline and toe stakes necessary to accurately depict the groundline. The inspector should verify that stakes are placed and survey points recorded at a frequency and at locations that result in

an adequate groundline survey as well as that needed to define the work on the ground.

The inspector must verify the frequency and location of stakes are adequate to define or layout the work so that it can be built to the specified neat lines and grades. Surveys to capture the groundline for the purpose of computing quantities may be made at the time of staking or any time near and prior to beginning construction. Where the ground is steep or undulating, it is common for a surveyor using electronic equipment and data collection to randomly capture some groundline data at the time of staking and download the data to a computer in the field to verify the number and location of survey data points adequately represent the topography. The inspector should review the data with the surveyor to verify the adequacy of the data.

The inspector's responsibilities related to staking and quantity surveys include verifying:

- any submittals that must be submitted prior to surveying have been submitted prior to beginning construction surveying operations
- the surveying plan seems reasonable and is revised, as needed, to align with the current construction schedule
- stakes are legibly marked and the markings are complete and accurate
- stakes are being maintained and promptly replaced by the contractor when damaged
- the number and location of stakes is adequate to define the work
- all quantity surveys necessary for computing final pay quantities are adequate to thoroughly and accurately define the specified pay limits

(e) Checking, interim staking, and interim quantity surveys

Checking—For many measures, it is important for the work to be constructed within acceptable tolerances to the specified line and grade as the work proceeds rather than having to later trim and fill high and low spots to attain the specified line and grade. Thus, during the performance of the work, the construction surveyor must check line and grade of the measure

being constructed. Quality control (QC) personnel are frequently tasked with checking line and grade and QA inspectors will perform periodic checks to verify QC personnel are doing an adequate job of checking line and grade.

Interim staking is required to set blue tops for grade control or to provide alignment stakes and offset stakes for structures. Blue tops are short stakes that are set at the time of finish grading. They are set on cut or fill slopes with the top of the stake set at the specified line and grade. The tops are sometimes painted blue or a colored plastic whisker is stapled to the side of the stake extending above the stake so that equipment operators can locate the stake if it is slightly covered during the grading operation. The equipment operator tries to skim the top of the blue top stakes with the equipment blade during the final grading operation; thus, it is common for blue tops to be destroyed before completion of the grading operation. It is incumbent upon QC personnel to ensure adequate blue top stakes are maintained at the specified line and grade until the grading operation is complete. QA inspectors should verify that blue tops are set and maintained to the specified line and grade until no longer needed.

Alignment stakes are interim stakes set for structures such as: pipelines, principal spillway conduits, fences, slabs, gabions, sheet piles, barns, and any other structure to be built to a specified line. Alignment stakes may be offset so that they can be maintained during construction of the structure. It is important that any structure be built to the specified grade as well as specified alignment, so offset alignment stakes are commonly set to an elevation or accompanied by a grade stake set to an elevation to provide a quick reference for checking the grade of the structure at several locations along its alignment during construction. Alignment stakes should be marked with station numbers and elevation. Offset stakes should also be marked with the horizontal offset distance from the stake to the centerline of the structure or to the boundary of the structure if the structure is a slab or building. QC personnel must ensure alignment and grade stakes for structures are set, properly marked, and maintained so that the structure can be constructed to the specified line and grade. QA inspectors should verify that these stakes are set, marked, and maintained as required for the structure to be built to the specified line and grade.

Interim quantity surveys are made during the performance of the work to monitor work progress and determine the amount of work accomplished during a payment period. It is not necessary for interim quantity surveys to be conducted to the level of detail or precision as final quantity surveys since some error can be tolerated when estimating quantities for interim payment. Interim quantity surveys may involve only a centerline survey or a few shots on top of an embankment if the top of the embankment is relatively flat. Interim quantity surveys may only be needed if there is a disagreement between the inspector's records and the contractor's records of quantities installed during the payment period. The QA inspector may conduct interim quantity surveys as a check of the contractor's surveys or may assist with or observe the contractor's interim surveys to verify the surveys are thorough and accurate enough to provide a basis for estimating installed quantities.

The inspector's responsibilities related to checking, interim staking, and interim quantity surveys include verifying:

- QC personnel are checking to verify construction to the specified line and grade
- blue tops are set and maintained to the specified line and grade until no longer needed
- alignment and grade stakes for structures are set, marked, and maintained as required
- interim quantity surveys are adequate for estimating quantities

(f) **As-built surveys**

As-built surveys are made to document any changes in the line and grade of the constructed measure and document that the work of improvement has been constructed within acceptable tolerances to the specified limits. As-built surveys include surveys of the lower and lateral limits of the structure as well as the upper limits or finished line and grade. As-built surveys also include any internal line and grade surveys necessary to show changes from the planned or designed line and grade of internal features. For example, as-built surveys may be needed to describe changes made in the location of an internal drainage system, foundation cutoff trench, principal spillway conduit alignment, embankment zoning, or any change in a dam that will

not be visible following completion of the dam. The QA inspector must keep track of changes and verify that surveys are made of any change to the planned line and grade defining the location of a component of the work. The QA inspector is also responsible for documenting the work is constructed within acceptable tolerances to the lines and grades shown on the drawings. This will require occasional checks of the as-built line and grade of various features such as a chimney drain, conduit, embankment zone limits, and other structural elements. It also requires a clear understanding of construction tolerances. Because tolerances for many components of NRCS engineering measures are generally not specified in the drawings or specifications, it is important for the inspector to be familiar with industry standard tolerances. For more information on tolerances that are considered standard to the industry, see Appendix E, Construction Tolerances, of this handbook.

As-built surveys may also be used for determining limits for computing final payment quantities if the earthwork pay limits include the true surface of completed excavations or the measured surface of the completed earthfill. The inspector must verify that necessary as-built surveys are made to define the specified pay limits. The inspector must also verify that as-built surveys made to define pay limits accurately represent the specified limits necessary to compute accurate quantities for payment.

The inspector's responsibilities related to as-built surveys include verifying they:

- are made where necessary to document changes from the original planned line and grade
- adequately document construction to the lines and grades shown on the drawings
- accurately represent the as-built conditions including any changes from the original plans
- accurately capture and document the specified pay limits

645.0502 Quantity computations

Quantity computations are commonly performed by computer, but hand estimating quantities is always prudent for the purpose of verifying computer performed quantities, and it is not uncommon for the QA inspector to be tasked with manually performing other quantity computations. For example, excavation within the specified payment limits may have been computed before it was learned that additional excavation would be required. In this case, the inspector may be tasked with computing the quantity of any additional excavation beyond the specified payment limits. In doing this, the inspector may survey or oversee the survey required to obtain the data needed to compute the additional quantities, verify the adequacy and accuracy of the survey and resulting data, and perform the computations necessary to determine the quantity of additional excavation. For this and similar tasks, a fundamental knowledge of quantity computations is needed. Even if someone else performs all of the computations, a fundamental knowledge of how to perform quantity computations is needed for the inspector to verify the survey data is adequate for making quantity computations.

There are two categories of quantity computations made in construction work: interim quantity computations and final quantity computations. Interim quantity computations are made to estimate quantities for progress payments. Final quantity computations are made to compute final quantities for payment. Interim computations do not have to be as detailed or precise as final quantity computations, but the inspector should verify they are accurate enough to provide a reasonable estimate of the quantity of completed work.

To ensure adequate survey data will be obtained for final quantity computations, the computations should be set up or planned in detail prior to obtaining the survey data. The person who will perform the final quantity computations should initiate the computation process by selecting the computation method and laying out computations to the point where the amount of detail and required format of the field survey data is determined. This should be done before or near the beginning of construction since quantity surveys are begun early in the job at or near the time of staking.

The necessary detail and presentation format should be conveyed to and understood by the construction inspector and surveyor prior to beginning surveying for final quantity computations.

The limits of payment should be well defined in the specifications or otherwise clearly documented prior to the beginning of work. The inspector should become familiar with the specified limits and verify that quantity surveys and computations are consistent with these limits. For example, the payment limits for earthfill may be defined as the lower limits of excavation and the neat line and grade of the earthfill as shown on the drawings. In this case, the inspector would verify that survey data adequately defining the lower limits of excavation is obtained for computing the earthfill quantity.

Volume, area, and linear computations are made to compute quantities for payment. Some items, such as rock riprap, are sometimes paid on a weight basis, which requires a summary of the delivery ticket weights to compute the quantity for payment. All computations should be performed accurately and presented in a logical order. They must be checked by someone other than the person performing the computations. Computations are not considered to be complete until they have been checked.

The inspector's responsibilities related to quantity computations include:

- maintaining a fundamental knowledge of quantity computations
- hand estimating to verify computer generated quantity values
- verifying interim computations are accurate enough to provide a reasonable estimate of the quantity of completed work
- verifying the necessary detail and presentation format of quantity surveys is understood by the surveyor prior to beginning quantity computation surveys
- verifying contractor performed quantity computations are consistent with specified payment limits
- verifying all items to be submitted by the contractor are submitted within the specified time frame

(a) Format

The output for computer-generated computations may be adjusted by the user to included information such as job name, item number, etc. Otherwise, the computer output may have to be supplemented to identify the job name, persons computing and checking the computations, contract item number, explanation of what is computed, and origin of data. Checking of computer computations generally entails verifying that the computer program method of computation conforms to the specification, the applicable survey data is input, templates are representative of the work, and output values are reasonable.

Appendix B of this handbook contains worksheets that can be used to record manual earthwork computations. NRCS-ENG-523 Computation Sheet and NRCS-ENG-4 Tabular Computations are not included in appendix B, but are also useful for recording computations.

Items that should be included in the heading of all NRCS computation sheets are:

- the State where the project is located
- project name
- job or contract number
- name of person performing computations
- date of computation
- name of person checking computations
- date computations are checked
- sheet number and number of total sheets

To add clarity, computations should also include sketches and comments that help to explain the computational method. Manual computations should be broken into simple steps that are easy to understand. They should be arranged and entered in such detail as to leave a well-marked trail from the data to the final result.

When performing computations by hand, it is good practice to divide the computation sheet into two columns by drawing a vertical line on the left side of the sheet so that approximately a fifth of the sheet falls to the left of the line. This area is used to record refer-

ences, note the source of data, list conversion factors, explain abbreviations, and provide any other information that will aid in understanding and documenting the computations. The area to the right of the vertical line is for the diagrams, analysis, and the solution to the problem. Draw a horizontal line from margin to margin to separate each step in a series from the step that follows. A line from edge-to-edge of the sheet denotes the end of a complete computation.

There should be four basic parts to each quantity computation:

- detailed description of what is being computed, including bid item name and number as applicable
- origin of data on which computations are based
- specified payment limits
- the solution

Inspectors who are tasked with performing final quantity computations should follow the format established in their State when possible. Otherwise, choose a format that is neat, legible, concise, and well organized, and consistently use this format to promote efficiency and clarity.

The inspector's responsibilities related to computation format include verifying:

- the heading contains sufficient information to:
 - fully identify the project and the computations
 - indicate the name of the person performing the computations and the date performed
 - indicate the name of the person checking the computations and the date checked
- sketches, explanations, and references are adequate to explain the computation method
- the computation is broken down into simple steps
- the computation includes the four basic parts: description, data origin, pay limits, and solution
- State format is used where applicable
- computations are neat, legible, concise, and well organized

(b) Units and precision

All computations must be accompanied by units. It should be clear what units are being used for intermediate computations and final answers. Show the units in which measurements, computations, and conversions are made so that it is clear what is being done. Answers without units are wrong.

Computation precision is limited by the precision of the data on which the computation is based. Neither the data nor computation results should be recorded to indicate a higher level of precision than the data. For example, if a survey instrument is only capable of reading to the nearest tenth of a foot, the reading should be recorded as 6.1 not 6.10 as this would erroneously infer a precision of one hundredth of a foot. Likewise, the result of a computation based on data obtained with this instrument should be shown to a level of precision consistent with the precision of the surveying instrument. Thus, an elevation of 100.3 computed from surveys made with this instrument would be shown as 100.3 not 100.30, as this would infer a precision that is not attainable with the instrument.

It is accepted practice that groundline surveys for earthwork are generally recorded to the tenth of a foot. Results of intermediate computations for computing earthwork volumes are generally carried to the one hundredth of a cubic foot with the final answer; the sum of these intermediate answers, rounded to the nearest tenth of a cubic foot, then converted to the nearest cubic yard. This follows the accepted practice that intermediate computations are made to one decimal place beyond the number of decimal places shown for the final answer.

The sample engineering notes and computations in appendix D of this handbook may be used as a guide to determine the level of survey and computation precision common for many NRCS engineering practices.

The inspector's responsibilities related to units and precision include verifying:

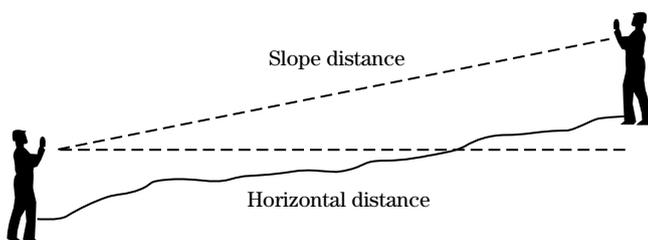
- all measurement, computation, and conversion units are shown
- computation precision is consistent with data precision
- computation precision is consistent with the accepted practice

(c) Linear computations

Linear computations are required for determining payment quantities for such measures as fences, diversions, waterways, terraces, pipelines, etc. The surveyor must know if payment will be made based on the slope distance or the horizontal distance. For example, Construction Specification 92, Field Fence, states, "The length of each type and kind of fence is measured to the nearest foot along the profile of the fence." Thus, the slope distance would determine the pay quantity. Figure 5-1 illustrates the difference between slope distance and horizontal distance. Measurements for each segment of fence are generally made to the nearest tenth of a foot. The computation for final payment would consist of adding up the measured lengths of each segment and rounding the answer to the nearest foot to arrive at the total fence length. A sketch is generally provided to indicate where each segment is located. The length may include or exclude the length of gaps or gates in the fence depending on how payment is specified.

Other linear measurements and computations may be as simple as totaling up the pieces or sections of a string of pipe. Construction Specification 51, Corrugated Metal Pipe, contains a method of measurement and payment that states, "the quantity ... of pipe is determined as the sum of the nominal laying lengths of the pipe sections installed." The computation for final payment would consist of adding up the number of pipe sections that are the same length and multiplying this number by the nominal laying length of each section, then adding to this value the nominal length of other sections, if any, to arrive at the payment quantity.

Figure 5-1 Distance measured as either horizontal or slope distance



The inspector's responsibilities related to linear computations include verifying that:

- linear measurements are made as specified (based on slope distance or horizontal distance)
- linear computations are consistent with specified measurement and payment method

(d) Area computations

Area computations are commonly used to compute payment quantities for such measures as clearing, clearing and grubbing, vegetation, critical area shaping, land leveling, etc. Concrete slabs may also be paid for on an area basis. As with linear computations, it is important to know if slope distance or horizontal distance will be used to compute the area. This will generally not be specified. If payment is made on an acre basis with little relief in the topography, computing the area using either horizontal or slope dimensions would yield similar results, and either method would be acceptable unless otherwise specified. For areas where there is significant relief in the topography, the difference in the area computed using horizontal distances and that using slope distances may result in a significant quantity and price difference for the overall work. For example, slope distances would be used to compute the quantity of a pit-type pond liner because there is significant difference in the slope distance and the horizontal distance across a pit-type pond.

There are various methods for computing areas. A few common area computations, where A = area, are shown in figures 5-2 through 5-5.

Irregularly shaped areas

It is commonly understood that the area of a square or rectangle is computed by multiplying length by width and the area of a triangle is equal to half the base width times the height. However, most areas measured for payment are irregularly shaped and require additional computations. The rectangular coordinate method is often used to compute the area of an irregular shape.

The rectangular coordinate method can be used to compute irregular shapes which can be defined by linear boundary segments. Figure 5-6 is an example of such a shape. The irregular area is defined by rect-

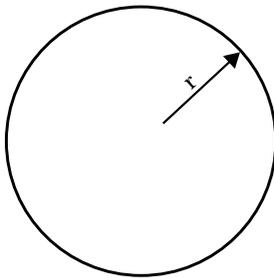
Figure 5-2 Rectangle



$$A = l \times w$$

(eq. 5-1)

Figure 5-3 Circle



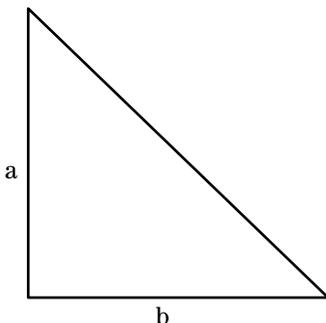
$$A = \pi r^2$$

(eq. 5-2)

where:

$$\pi \approx 3.1416$$

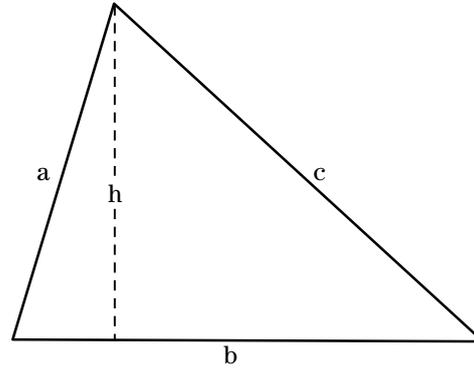
Figure 5-4 Right triangle



$$A = \frac{1}{2} a \times b$$

(eq. 5-3)

Figure 5-5 General triangle



$$A = \frac{1}{2} h \times b$$

(eq. 5-4)

or:

$$A = \sqrt{(s(s-a)(s-b)(s-c))}$$

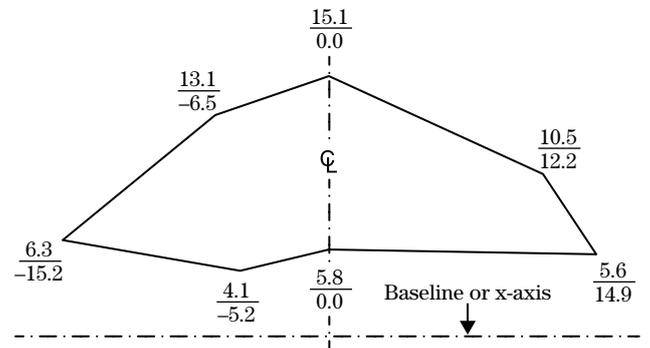
(eq. 5-5)

where:

$$s = \frac{1}{2}(a + b + c)$$

(eq. 5-6)

Figure 5-6 Irregular shape defined by rectangular coordinates in feet



angular coordinates that are all in the same plane. The rectangular coordinates are shown in feet with the *numerator* being the y-value over the x-value *denominator*. For example 15.1/0.0 denotes a point on the area boundary that is 15.1 feet above the baseline or x-axis and 0.0 feet from the centerline or y-axis. Since all of the points in figure 5–6 are above the baseline or x-axis, all of the numerators or vertical distances are shown as positive numbers; otherwise, they would be shown as negative numbers if located below the baseline or x-axis. All of the denominators or horizontal distances left of the centerline or y-axis are shown as negative numbers, and the denominators to the right of the centerline or y-axis are shown as positive numbers. It is important to pay attention to the location of each point and assign the proper positive or negative value to each denominator and numerator.

Begin the rectangular coordinate method of computing the area by setting up the coordinates as shown below beginning at any point and ending on the same point. The numbers can be recorded in either clockwise or counterclockwise order from the beginning point. Include a positive and negative sign on each side of each denominator, and reverse the signs after each zero denominator as shown below.

$$\begin{array}{cccccccc} \frac{6.3}{-15.2+} & \frac{13.1}{-6.5+} & \frac{15.1}{0} & \frac{10.5}{+12.2-} & \frac{5.6}{+14.9-} & \frac{5.8}{0} & \frac{4.1}{-5.2+} & \frac{6.3}{-15.2} \end{array}$$

Multiply each numerator by the denominator of the adjoining coordinate, and draw a line through the two numbers to keep up with the numbers that have been considered. If there is a negative sign between the two numbers being multiplied, the product of those two numbers will be recorded as a negative value.

$$\begin{array}{cccccccc} \cancel{6.3} & \cancel{13.1} & \cancel{15.1} & \cancel{10.5} & \cancel{5.6} & \cancel{5.8} & \cancel{4.1} & \cancel{6.3} \\ \cancel{-15.2+} & \cancel{-6.5+} & \cancel{0} & \cancel{+12.2-} & \cancel{+14.9-} & \cancel{0} & \cancel{-5.2+} & \cancel{-15.2} \end{array}$$

$$\begin{array}{l} 6.3 \times -6.5 = -41.0 \\ 13.1 \times 0.0 = 0.0 \\ 15.1 \times 12.2 = 184.2 \\ 10.5 \times 14.9 = 156.5 \\ 5.6 \times 0.0 = 0.0 \\ 5.8 \times -5.2 = -30.2 \\ 4.1 \times -15.2 = -62.3 \\ 6.3 \times 5.2 = 32.8 \\ 4.1 \times 0.0 = 0.0 \\ 5.8 \times -14.9 = -86.4 \end{array}$$

$$\begin{array}{l} 5.6 \times -12.2 = -68.3 \\ 10.5 \times 0.0 = 0.0 \\ 15.1 \times 6.5 = 98.2 \\ 13.1 \times 15.2 = \underline{199.1} \\ \text{Sum} = 382.6 \end{array}$$

Divide the sum by 2 to obtain the area.

$$A = 382.6 \div 2 = 191.3 \text{ ft}^2$$

Other methods for computing the area within irregularly shaped boundaries include the *planimeter* method, computer aided design (CAD) methods, and other electronic methods. These are described in the EFH chapter 1.

The inspector's responsibilities related to area computations include verifying:

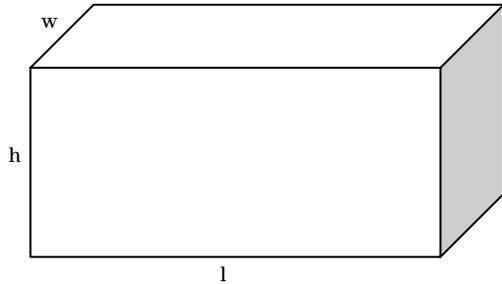
- area measurements are made as specified (based on slope distance or horizontal distance)
- the correct equation or mathematical process is applied to arrive at the answer

(e) Volume computations

Volume computations are used to compute quantities of earthfill, excavation, concrete, rock riprap, etc. Some volumes are defined by common geometric shapes; formulas for these are given here. Other volumes are defined by irregular boundaries and must be computed by methods such as the average end-area method or grid method, which are described later in this section.

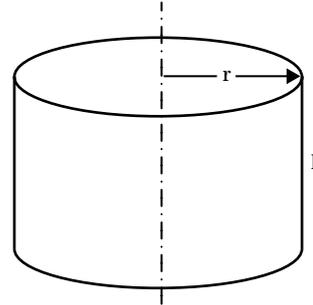
Figures 5–7 through 5–10 show volumes (V) of common geometric shapes applicable to conservation engineering work.

A prismatoid (fig. 5–8) has a top and bottom that are in parallel planes. A rectangular pit-type pond constructed on relatively flat horizontal ground is an example of a prismatoid. The prismoidal formula shown is used to compute the volume of a prismatoid.

Figure 5-7 Rectangular prism

$$V = lwh$$

(eq. 5-7)

Figure 5-9 Cylinder

$$V = \pi r^2 h$$

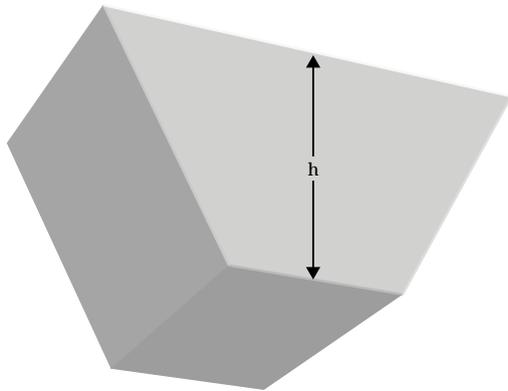
(eq. 5-9)

where:

V = volume

r = radius

h = height

 $\pi \approx 3.1416$ **Figure 5-8** Prismatoid

$$V = \frac{h}{3} (B + T + \sqrt{B \cdot T})$$

(eq. 5-8)

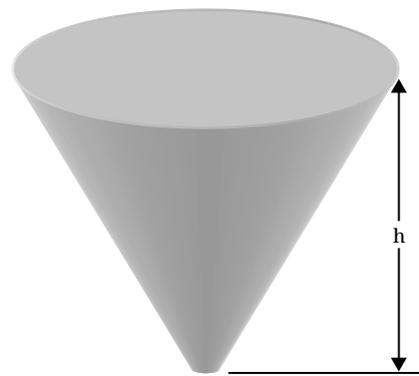
where:

V = volume

B = area of bottom

T = area of top

h = height

Figure 5-10 Frustum of a cone

$$V = 0.2618h (D^2 + Dd + d^2)$$

(eq. 5-10)

where:

V = volume

d = diameter of bottom

D = diameter of top

h = height

Irregularly shaped volumes

Many conservation engineering practices require computing volumes of irregular three-dimensional shapes. For linear projects, such as a roadway, dam, diversion, waterway, etc., the average end-area method is commonly used for computing volumes.

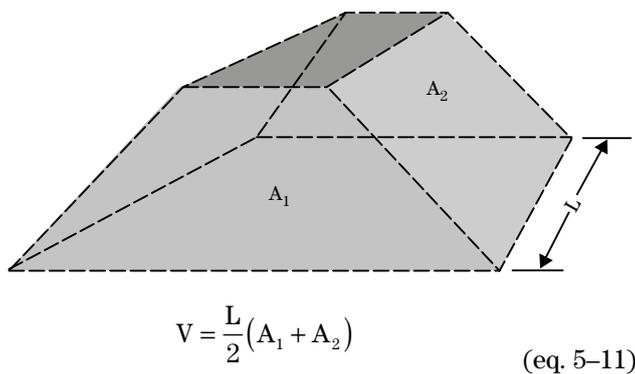
Average end-area method—The average end-area method computes the volume between two areas in parallel planes such as shown in figure 5–11.

The average end-area method is performed to determine the volume between various stations along the centerline of a dam, channel, or other linear project. If the end-area varies only slightly from one station to the next, the average end-area volume computed in this manner will be accurate. Conversely, the accuracy of the method decreases as the difference between the end-areas being averaged increases. It is for this reason that several cross sections are required in those areas where the end-area changes considerably between stations.

Correction for curvature—A correction for curvature, or curve correction, is made when computing the volume of a curvilinear project. Sections are taken radially through the curve. If a section in a curve is

symmetrical (i.e., the area to the left of the centerline is the same as the area to the right of the centerline as shown in figure 5–12), no curve correction for that section is needed. However, when the section is asymmetrical as shown in figure 5–13(c), a curve correction must be made when using the average end-area method to determine the true volume between two sections in a curve.

Figure 5–11 Volume between two parallel ends



where:

- V = volume
- A₁ = area 1
- A₂ = area 2
- L = distance from A₁ to A₂

Figure 5–12 Symmetrical section

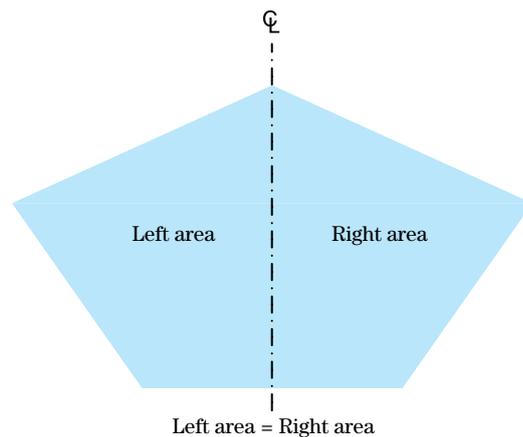
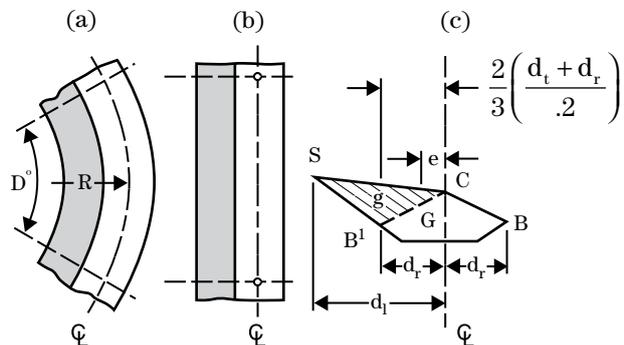


Figure 5–13 (a) Representation of volume corrected for curvature
(b) Representation of volume not corrected for curvature
(c) Asymmetrical section



The true volume (V_{true}) between stations located in a curve is that represented in figure 5-13(a). Figure 5-13(b) represents the volume computed without correction for curvature (V_{computed}).

The curve correction (C_c) is the difference between these volumes:

$$C_c = V_{\text{true}} - V_{\text{computed}} \quad (\text{eq. 5-12})$$

The curve correction is computed by equation 5-13:

$$C_c = \frac{AeD^\circ}{1,550} \text{ yd}^3 \text{ per station per 100 linear feet} \quad (\text{eq. 5-13})$$

where:

A = cross-sectional area in ft²

e = eccentricity as depicted in figure 5-13(c). It represents the horizontal distance from centerline to the centroid of the area. The value of e is positive on the outside of the curve and negative on the inside of the curve.

D° = degree of curvature in degrees as depicted in figure 5-13(a)

The sign of C_c is positive when the excess area of a cross section is on the outside of the curve and negative when the excess area of a section is on the inside of the curve.

Equation 5-14 is used to determine the curve correction between two stations that are L feet apart:

$$C_{c(\text{sta 1 to sta 2})} = \frac{L}{100} \left(\frac{C_{c\text{sta1}} + C_{c\text{sta2}}}{2} \right) \text{ yd}^3 \quad (\text{eq. 5-14})$$

The volume correction for curvature is made by the equation 5-15:

$$V_{\text{true}} (\text{yd}^3) = V_{\text{computed}} + C_c \quad (\text{eq. 5-15})$$

Computation of the true volume between two stations located in a curve is a nine-step process.

Perform steps 1 through 7 on both asymmetrical sections to determine the area (A) and curve correction (C_c) for both sections.

Step 1 Divide the section into component geometric shapes that will facilitate computing the centroids and areas of each component.

Step 2 Compute the area of each component.

Step 3 Determine the eccentricity of each component (i.e., the location of the *centroid* of each component relative to the survey centerline of the asymmetrical section).

Step 4 Sum the products of the area of each component multiplied by eccentricity of the component.

Step 5 Sum the component areas to determine the total area of the asymmetrical section (A).

Step 6 Compute the eccentricity (e) of the asymmetrical section by dividing the sum of the products determined in step 4 and by the total area of the asymmetrical section (A) determined in step 5.

Step 7 Compute the curve correction for the first station, then repeat steps 1 through 7 for the subsequent section.

Steps 8 and 9 complete the process of determining the true volume between stations located in a curve.

Step 8 Determine the curve correction between stations ($C_{c(\text{sta to sta 2})}$).

Step 9 Compute the volume assuming no curvature (V_{computed}) and correct for curvature by adding the curve correction from step 8 to determine the true volume (V_{true}) between the two stations located in a curve.

See appendix D of this handbook for a sample problem labeled Correction for Curvature, which shows computing the eccentricity of two asymmetrical sections, determining the curve correction for each section, and computing the true volume between the sections on a curve.

Grid method—The grid method is typically used for volumes such as cut and fill volumes for land leveling or excavation volume of a borrow area. For this method, the depth of cut or fill is determined at several equally spaced points and multiplied by the area represented by each point. For example, if the points are spaced 100 feet apart on a square grid pattern, such as those shown in figure 5-14, the cut or fill at each point

is multiplied by 100^2 (i.e., $10,000 \text{ ft}^2$) to arrive at the volume of cut or fill represented by that point. Then the volumes computed for each point are summed to determine the total volume.

The volume of cut in cubic yards is computed as follows:

$$\begin{aligned} 0.2 \text{ ft} \times 100^2 \text{ ft}^2 &= 2,000 \text{ ft}^3 \\ 0.3 \text{ ft} \times 100^2 \text{ ft}^2 &= 3,000 \text{ ft}^3 \\ 0.5 \text{ ft} \times 100^2 \text{ ft}^2 &= 5,000 \text{ ft}^3 \\ 0.6 \text{ ft} \times 100^2 \text{ ft}^2 &= 6,000 \text{ ft}^3 \\ &16,000 \text{ ft}^3 \end{aligned}$$

$$16,000 \text{ ft}^3 \div 27 \text{ ft}^3/\text{yd}^3 = 593 \text{ yd}^3$$

Earthwork areas are typically irregular and require cuts or fills in fringe areas that are different than the normal area represented by a grid point. This is depicted in figure 5-15, which shows two fringe areas on the edge of an excavated area. The depth of cut is shown in each fringe area.

The volume of cut in cubic yards is computed as follows.

$$\begin{aligned} 0.2 \text{ ft} \times 100^2 \text{ ft}^2 &= 2,000 \text{ ft}^3 \\ 0.3 \text{ ft} \times 100^2 \text{ ft}^2 &= 3,000 \text{ ft}^3 \\ 0.5 \text{ ft} \times 100^2 \text{ ft}^2 &= 5,000 \text{ ft}^3 \\ 0.6 \text{ ft} \times 100^2 \text{ ft}^2 &= 6,000 \text{ ft}^3 \\ 0.15 \text{ ft} \times (100^2/2) \text{ ft}^2 &= 750 \text{ ft}^3 \\ 0.25 \text{ ft} \times 100 \text{ ft} \times (100+50)/2 &= 1,875 \text{ ft}^3 \\ &20,500 \text{ ft}^3 \end{aligned}$$

$$20,500 \text{ ft}^3 \div 27 \text{ ft}^3/\text{yd}^3 = 690 \text{ yd}^3$$

Figure 5-14 Area to be excavated represented by four points and the depth of cut at each point

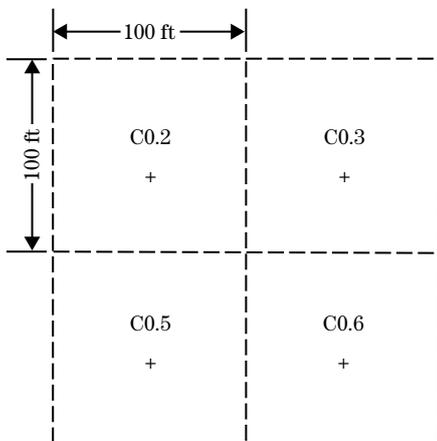
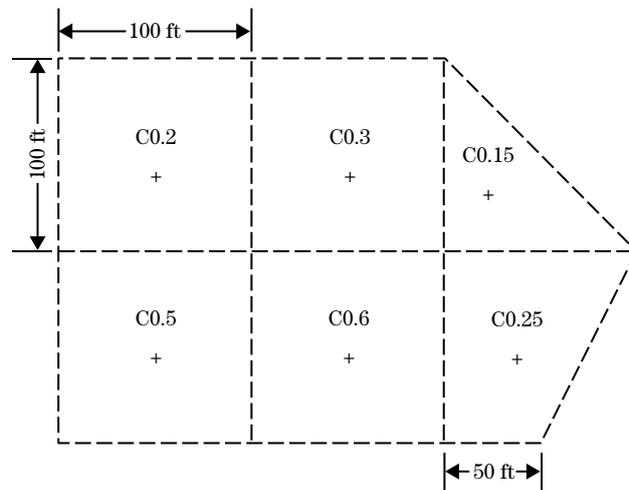


Figure 5-15 Area to be excavated represented by six points and the depth of cut at each point



Other methods—Other methods for computing volumes include methods such as the prismoidal method and composite methods that are used in computer programs. Description of these methods is beyond the scope of this handbook; however, the inspector should be aware that there are other methods that are commonly used to compute volume.

The inspector's responsibilities related to volume computations include verifying:

- the specified or otherwise correct equation or mathematical process is applied to arrive at the answer
- surveys for determining sections for average end-area and other volume computations are representative of the groundline
- the frequency of surveyed sections complies with specifications
- curve corrections are made when applicable

(f) Weight computations

Some quantities such as rock riprap and drain fill may be paid for on the basis of weight. The weight is generally determined from a statement of delivery ticket provided by the contractor. The ticket shows the tare weight and loaded weight of the delivery truck with the difference being the amount of material delivered. These values are generally specified to be shown on the delivery ticket to the nearest 0.1 ton.

The inspector is responsible for obtaining a copy of all of the delivery tickets for materials delivered to the site which are to be paid for on a weight basis. These should be filed in the contract file folder labeled quantities. Delivery of these materials, with reference to the applicable contract item, should be noted in the job diary with a quantity shown for materials delivered during any reporting period. Cumulative values of quantities delivered should also be noted in the diary to facilitate verifying quantities delivered for progress payments.

Payment may be made for materials delivered to the site but not installed. If such partial payment is to be made, the inspector is responsible for verifying the quantity of materials delivered and the quantity installed. It is good practice to record both delivered and installed materials on a separate line in the diary section entitled "Estimated Quantities of Pay Work Accomplished." These should be recorded showing both daily (or per reporting period) and cumulative delivered and installed quantities.

See appendix C of this handbook for a sample diary entry documenting materials delivered and installed.

The inspector's responsibilities related to weight-based computations include:

- obtaining a copy of all delivery tickets for items to be paid on a weight basis
- submitting all delivery tickets to be filed in the contract "quantities" folder
- documenting quantities in the job diary showing delivered and installed quantities for each day or reporting period along with cumulative delivered and installed quantities

(g) Computations performed by the contractor

Whenever the contract requires the contractor perform final quantity computations, they must be mathematically correct and neatly recorded. Quantity computations must reference the applicable bid item and include a record of individuals who performed and checked the computations and the dates they were performed and checked. Computer based computations must also include "performed by" and "checked by" names and dates. Spec 7 requires the engineer be provided software identification, vendor's name, version number, and other pertinent data before beginning survey activities.

The inspector's responsibilities related to final quantity computations performed by the contractor include verifying:

- when quantity computations are to be performed with computer software, survey activities do not begin until software identification, vendor's name, version number, and other pertinent data has been provided to the engineer
- all quantity computations are performed and presented in the specified manner
- computations are submitted within the specified time frame

645.0503 Records

(a) Engineering notes

Survey data (*engineering notes*) will be recorded by hand in an engineering field notebook (field book), on a worksheet dedicated to recording notes for a specific practice, or recorded electronically and in a field book or on a worksheet. For Federal or CLO contract work, standard hard-bound engineering survey field notebooks are required. When surveys are not recorded electronically, all of the data collected during the survey will be recorded in a field book or on a worksheet. When surveys are recorded electronically, the electronic data must be cross referenced to a field book or worksheet. Additionally, notes and sketches that are needed to better illustrate items encountered during surveying should be provided in the field book or on the worksheet. Detailed guidance on recording survey data and keeping notes is provided in the EFH, chapter 1. Examples of common survey notes are included in appendix D of this handbook.

The inspector must review contractor's survey records to verify that all notes, sketches, and other data are presented as specified, are complete, and are neatly recorded and organized so that they are easily understood and referenced to the applicable portion of the work. The inspector must also observe note keeping throughout the performance of the work to verify compliance with specifications and any other contract requirements.

The inspector must verify that the contractor's survey records are transmitted to the COR/GR within the specified time frame. It is imperative that the person performing the quantity computations or checking the quantity computations performed by the contractor have the opportunity to study the notes and request additional survey data as needed to compute quantities. Early transmittal of notes will afford this person the opportunity to request additional survey data, if necessary, before the area surveyed is disturbed or covered up.

The inspector's responsibilities related to construction engineering notes include verifying:

- all notes, sketches, and other data are presented as specified
- all engineering notes are transmitted to the COR/GR within the specified time frame

(b) Interim quantity records

Interim quantities are computed for the purpose of estimating the amount of work performed during a payment period. The cumulative quantities (total quantity performed to date) are also estimated by summing all interim quantity computations for an item of work such as earthfill. Interim quantities should never be summed to determine final quantities for payment.

Interim quantities should be legible and recorded in an orderly fashion that makes sense and can be independently checked by others. They are commonly performed by the inspector and kept with the inspector's records, not filed as a part of the permanent contract records. The inspector should keep interim computations until the contract has been finalized.

The inspector's responsibilities related to interim quantity records are to:

- verify interim quantities are an accurate approximation of the quantities performed
- verify interim quantities are recorded in a legible and orderly fashion
- keep interim quantity records until the contract has been finalized

(c) Final quantities

Final quantity computations should be identified by contract number, job name, and contract item number with a clear description of what is being computed (e.g. Item 8—Excavation, overexcavation in bottom of core trench at Dam CL Sta. 12+15 to 12+38). Reference should be made to the origin of the data on which the computations are based (e.g., survey made by Bacon and Rice on 3/17/2011 recorded in Engineering Field Book #3), and the computations should be neatly recorded using a standard format.

The inspector is usually not tasked with computing final quantities; they are often computed by a civil engineering technician, engineer, or other agency

employee. When the contractor performs final quantity computations, the inspector should verify and document that specified information is provided to the engineer within the specified time frame. Final quantities are to be filed with the permanent contract records.

The inspector's responsibilities related to contractor performed final quantity records include verifying:

- all final quantity records are identified according to specification requirements
- all final quantity records are submitted to the engineer within the specified time frame

(d) As-built records

As-built drawings (also known as as-built plans, red-lined or record drawings) refer to all plans and specifications that have been altered during construction. A field copy of as-built drawings depicting the actual as-built conditions of the completed construction is to be maintained by the construction inspector. The final copy of as-built drawings is completed by the project engineer. It is common practice for the field copy to be transferred to a final paper or electronic copy. The inspector may be tasked with making the final copy or the field copy may be submitted for others to develop the final copy.

The final as-built drawings are labeled and signed by the engineer according to agency policy set forth in the National Engineering Manual (NEM). The field copy need not follow the same labeling requirements, but should be neat and legible and clearly show all changes in enough detail so that the change can be fully understood. Additional written documentation of a change may be needed so that the change, limits of the change, and reason for the change can be fully understood.

Of particular importance is any change to the project that will not be visible following completion of the project. Changes in the limits of excavation or a drainage system are examples of items that should be shown on the as-built drawings. Changes to the specifications also need to be documented. Reference to specification changes should be made on the as-built drawings and the changed specifications filed in the permanent project records. The inspector is responsible for making sure all changes are recorded during

construction and presented to the engineer in the manner requested so that the as-built records can be finalized to comply with agency policy.

Some contracts require the contractor to develop the as-built drawings. The inspector should verify that all changes have been documented by the contractor and the as-built drawings comply with specified requirements.

The inspector's responsibilities related to as-built drawings include:

- maintaining a neat and legible field copy of as-built drawings
- verifying that all changes have been included in the as-built records
- verifying all as-built records are submitted to the engineer
- when the contractor is responsible for producing as-built drawings, verifying the as-built drawings meet specification requirements

645.0504 References

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