DOT
DEPARTMENT OF TRANSPORTATION

Basic Surveying

Inspector
Qualification
Series

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INTRODUCTION

This manual is intended only as a guide for training purposes and is not meant to replace the CDOT Survey Manual and in all cases, the CDOT Survey Manual has precedence over this manual when matters of policy and procedure are of concern. The CDOT survey manual can be found at www.codot.gov/business/manuals/survey

CHAPTER 1: CONSTRUCTION SURVEYS

Construction surveying is the translation of construction plans into physical points on the ground that can be used as a basis for the actual construction. The results of construction surveying are seen in almost any urban, suburban, and rural setting. Almost any roadway, building, or other man-made improvement probably had some amount of construction surveying involved. Construction surveying provides not only the horizontal location of new improvements, but also the vertical information required to ensure that surfaces drain or pipes flow as required.

PREPARATION
To successfully perform construction staking and layout, preparation is a major part of the operation.

Study:
- Contract plans
- Special Provisions
- Standard Specifications
- Plan Quantities
- Construction Manual
- CDOT Surveying Manual
- Contractor's Proposal

Take appropriate measures to protect existing monuments.

RESPONSIBILITIES
Contractor Surveying - When the bid schedule contains pay item 625, Construction Surveying, the Department will provide control points and bench marks as described in the Contract. The Contractor shall furnish and set construction stakes establishing lines and grades in accordance with the provisions of Section 625. Per Section 105.12(a) the Engineer may order additional surveying which will be paid for at the rate established by the contract.

Department Surveying - When the bid schedule does not contain pay item 625, Construction Surveying, the Engineer will furnish one set of construction stakes and marks establishing lines and grades as described below for proper prosecution of the work.

CHAPTER 2: CONSTRUCTION STAKING

Survey stakes are the survey party's primary means of communication. Survey stakes are normally set to establish and designate a work point or reference point on the ground. Appropriate information is written on the stake instructing construction personnel as to the work to be performed. Because these stakes are the actual physical basis for construction, it is essential that they be set at the correct location with the data written on them in a legible and understandable manner.

TYPICAL SURVEY STAKES
Although other sizes are available, the survey stakes most frequently used in construction are the wooden 1" x 2" x 18" stakes, 1" x 1" x 12" oak hubs, and 1 ½" x 48" lathe.

1" x 1" wooden stakes (called Hubs) in 6" to 12" lengths or 60d nails (6" long) are often used to mark important survey points, work points, or reference points, which are to remain in place for future use. Hubs are normally driven flush with the ground after which a survey tack is set in the top of the hub to mark the exact survey point. The 60d nails are also driven flush with the ground but with flagging tied on them. Both hubs and nails are driven flush to make them less susceptible to damage and a "guard" or "witness" stake may be used to mark its location. The guard stake will usually have sufficient information written on it to identify the point.
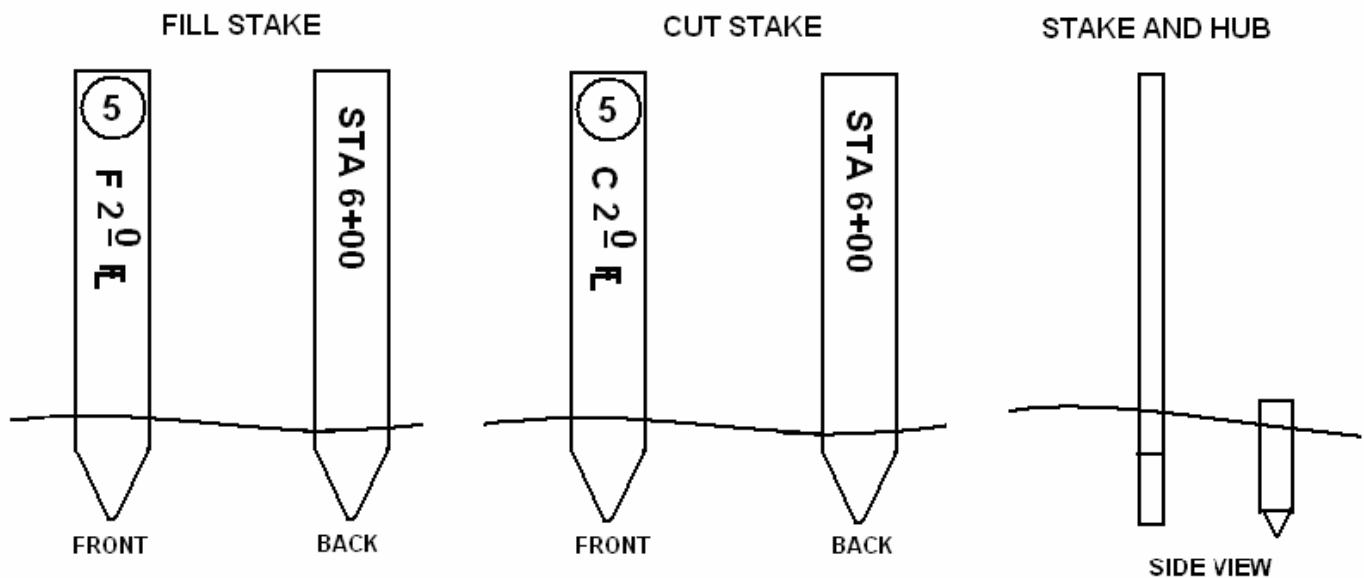
Figure 2-1 Typical construction stakes

MINIMUM STAKING REQUIREMENTS
The surveyor is required to perform all staking indicated on the survey tabulation sheet in accordance with the Standard Specifications for Road and Bridge Construction and in accordance with the CDOT Survey Manual. Minimum staking requirements for the various construction items are described in detail in the CDOT Survey Manual. An example of minimum staking requirements for typical survey items is listed below.

Centerline Staking - The maximum staking interval for the project centerline shall be 100 ft on tangents and 50 ft on curves or as specified on the survey tabulation sheet.

Clearing and Grubbing - Stakes should be set at 50 ft intervals and meet the Minimum Construction Horizontal and Vertical Accuracy Tolerance. The vertical tolerance may be waived by the engineer.

Removal of Structures and Obstructions - Staking should meet the tolerance and interval specified on the plans or specifications. The appropriate tolerance and interval varies depending on the item.

Reset Items - Staking is usually not required for the removal of a reset item but may be required to place items that are to be reset such as light poles, signs and minor structures as the item may not be put in the same place it occupied prior to construction.

Excavation and Embankment - Slope stakes shall be set at a maximum 50 ft spacing interval. Grade stakes for the subgrade shall be set at a maximum 50 ft interval or at the interval shown on the survey tabulation sheet.

FLAGGING COLOR CODE

It is desirable to have a uniform color code system throughout the state so the Contractor's personnel will be able to readily recognize the work item referenced. Whenever flagging is necessary on the project, the following flagging color code should be used.

Type of Stake and/or Monument	Color Flagging, Paint, Etc.
Primary Control, Right of Way (ROW), Boundary, Public Land Survey System (PLSS)	Orange
Secondary Control, Structure Control	Yellow
Benchmarks (Primary and Secondary)	Blue
Easements (Permanent and Temporary)	Florescent Lime or Green
Alignment Centerline (Permanent and Temporary)	Red
Alignment Reference	Red and White
Slope Stakes	White
Structure Reference (Major and Minor)	Yellow and White
Test Holes (Geotechnical)	Pink
Utility Locates	White
Selective Thinning (To be tied around tree at eye level)	
Trees to be Removed	Orange
Trees to Remain	Blue
Clearing and Grubbing	White

Figure 2-2 CDOT Standard flagging color

CHAPTER 3: MEASUREMENT OF DISTANCES

In surveying, the distance between two points typically refers to the horizontal, or level, distance between those two points. Construction plans are prepared showing distances as horizontal distances. Horizontal distances are ordinarily determined in the following ways: Pacing, Taping or Electronic Distance Measuring (EDM).

PACING
Pacing is one of the most valuable things learned in surveying because it has practical applications for everybody and requires no equipment. Pacing is very useful when a rough approximation is needed.

The length of a person's pace must first be determined. This is best done by walking with natural steps back and forth over a measured level course a minimum of 100 ft long, and then averaging the number of steps taken. An accuracy of 1 ft. per 100 ft. is suitable for pacing.

TAPING
Taping consists of measuring between two points with a tape calibrated in feet to the nearest one-hundredth of a foot.

EACH FOOT IS MARKED IN TENTHS AND HUNDRETHS
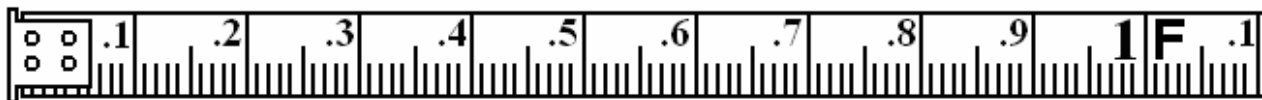
Figure 3-1 Gradations on typical tape

Steel or fiberglass tapes are typically used, although cloth tapes can be used where high accuracy is not important. The tape is often incorrectly referred to as a "chain" and is usually 100 feet in length.

The term "*chain*" derives from a device commonly used for land measurement in the past. The "*Gunter's Chain*" being the most common was 66 ft. long and had 100 links. Each link was about eight inches (0.66') long, made of heavy gauge wire with a loop at each end. The links were joined end to end to create the chain by rings between the links. Another type of chain, the "*Engineer's Chain*" was 100 ft. long and had 100 links each 12 inches long. The term "*taping*" is gradually being used more exclusively and is used in place of "*chaining*" in this text. See figure 3-2.

SURVEYOR'S CHAIN

TYPICAL 100-FT SURVEYORS TAPE
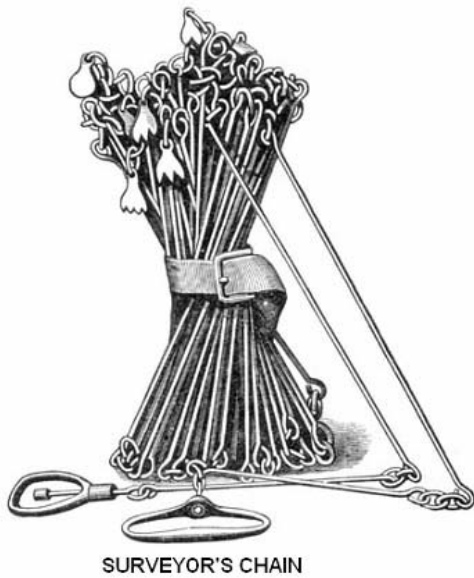
Figure 3-2 Survey chain and modern survey tape

TAPING PROCEDURES

Two methods are commonly used to measure the horizontal distance between two points using a tape. See figure 3-3.

The first method is to measure the distance by holding the ends of the tape on the same horizontal line between the two points. This method requires the use of plumb bobs to transfer the distance to the ground.
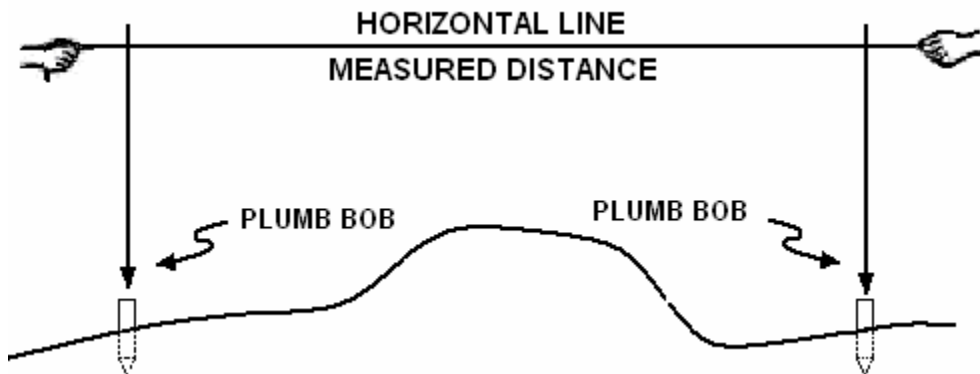
Figure 3-3 Direct distance measurement

The second method called breaking tape is used when it is not possible to pull a full 100 ft. because of the slope of the ground. A point is set at a convenient number of whole feet from the back point. This method also requires the use of a plumb bob to transfer the distance to the ground. See figure 3-4.
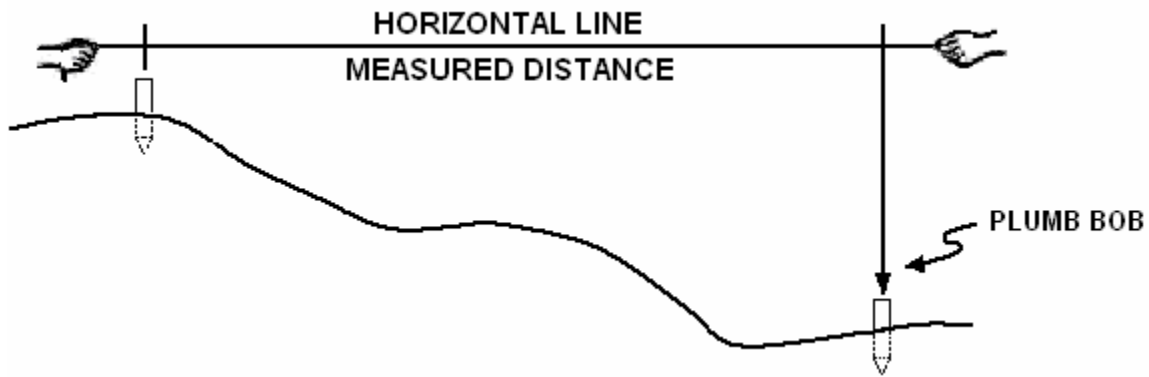
Figure 3-4 Breaking tape

Tape measurements are not usually made with the tape held directly on each point. Normally, each end is held above the point and is located vertically over the point by means of a plumb bob and string. The proper way to hold the plumb bob is to have the thumb and forefinger pinch the string against the top of the tape. Normally one should not use the hand controlling the plumb bob to apply tension to the tape.

The importance of having both ends of the tape at the same elevation when measuring a horizontal distance cannot be overemphasized. One of the most common errors in taping is failure to hold both ends of the tape at the same level.

Figure 3-5 below shows how errors in determining horizontal distances can occur as a result of failure to keep both ends of the tape level.
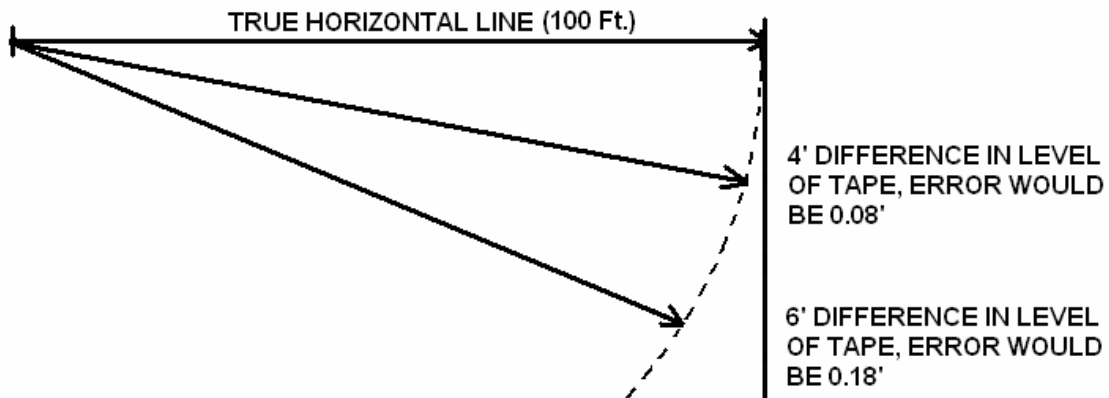
Figure 3-5 Error in measuring when tape is not horizontal

Horizontal measurement with a tape and plumb bob is a process which requires skill and care. It takes considerable practice and experience to tape accurately and efficiently.

EDM (Electronic Distance Measuring)
When a distance is measured using an EDM instrument, an electromagnetic wave is transmitted from the instrument towards a reflector where part of the transmitted wave is returned to the instrument. Electronic comparison of the transmitted and received signals allows for

computation of the distance. Today most EDMs will be found as an integral part of a Total Station. A Total Station is a combination of an EDM, electronic transit and a microcomputer.

ACCURACY AND PRECISION
To many people, accuracy and precision mean the same thing: to someone involved in measurement, the two terms should have very different meanings.

Accuracy – How close to the real value a measurement is.

Precision - The ability of a measurement to be consistently reproduced.
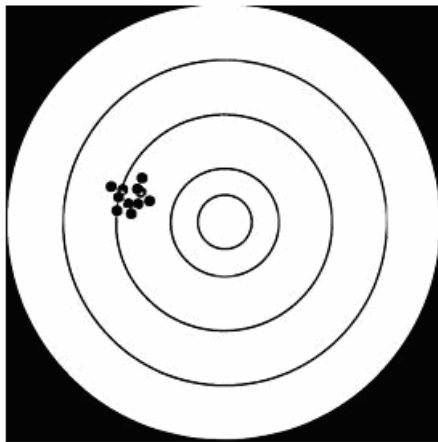
Precise and Inaccurate   Accurate and Imprecise
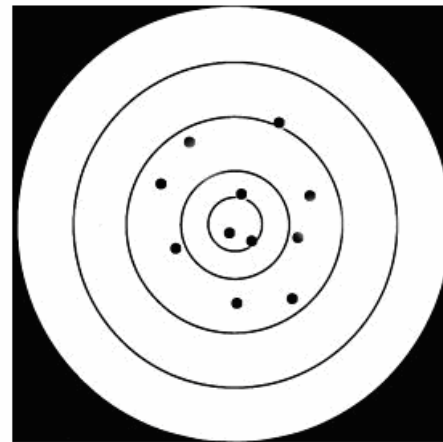
Figure 3-6 Accuracy and Precision

All measurements should be performed with a precision that ensures that the desired accuracy is attained.

CHAPTER 4: COMMON MISTAKES IN READING AND RECORDING LINEAR MEASUREMENTS

An error may be defined as the difference between an observed value and the true value or as the variation in observations, measurements, or calculations of a quantity. This section will discuss some of the principal errors and their effect on the measurements. In general, these errors tend to result in the recorded, or measured, distance being greater than the actual distance.

READING THE WRONG FOOTMARK
This is a careless mistake, which can usually be avoided by alertness and concentration.

TRANSPOSING FIGURES
Sometimes a person may mentally transpose figures before calling them out, or the note keeper may transpose them when recording them. For example, he may call out, or record 42.63 when he should have called out 42.36. Alertness and concentration will usually eliminate this type of mistake.

READING THE TAPE UPSIDE-DOWN
When reading a tape upside down, certain numbers can easily be misread for others. For example, a 6 may be misread as a 9; 86 may be misread for 98, etc. One way to avoid this mistake is to note the adjacent footmarks on both sides of the footmark being used to see that the number is in sequence. However, the best solution is to avoid reading the tape in an upside down position.

TAPE NOT STRETCHED STRAIGHT
Always be sure that the tape is free to be stretched directly between the two points. The tape should not be allowed to bend around trees, bushes, boulders, etc., since this would result in the measured distance being greater than the actual straight line value.
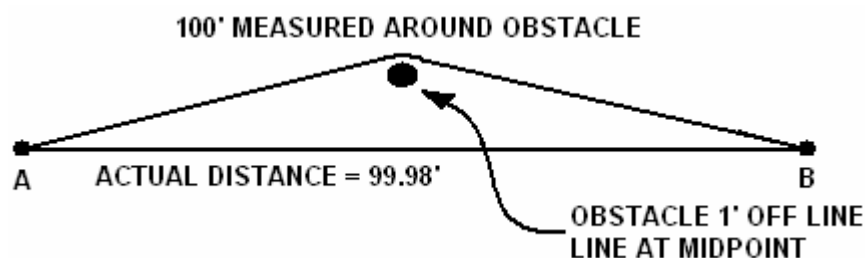
Figure 4-1 Effect of not stretching the chain

One can readily see in figure 4-1 above the effect of this error on the measured distance as compared to the actual distance.

The wind can blow the tape off line, particularly when plumbing, resulting in the same type error as an obstacle, which prevents the tape from being stretched straight between two points. Supporting the tape on line at one or more intermediate points can reduce the magnitude of this type of error.

INCORRECT ALIGNMENT

When measuring distances greater than the length of the tape, or when breaking the tape, the intermediate points must be placed on line by eye or by instrument. Usually, the back person can stand on line and line the front person to within 0.2 feet to 0.3 feet of true line.
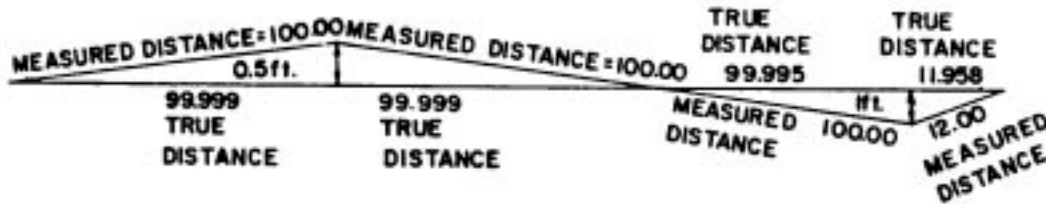
Figure 4-2 Error in measurement from improper alignment of the chain

One can see that if the tape is lined within 0.5 ft. of the true line, the error is insignificant when measuring a full tape length. One can also see that for shorter distances, the alignment becomes more critical. Since this type error is cumulative, it becomes more significant when multiple points are used in measuring a distance. This type of error results in the measured distance being greater than the actual distance.

CARELESS PLUMBING

This error relates to failure to hold the plumb bob tip directly over the chaining point. This type of error is a compensating error in that the measured distance may be greater, or it may be less than the actual distance. Proficient use of the plumb bob requires practice and care. Care should be exercised to ensure that the plumb bob is positioned directly over the point when making a measurement.

TENSION AND SAG

A tape stretches when pulled. Its length changes if the tension changes. For this reason, it should be pulled with the tension for which it is designed. Only at this tension can its actual length be expected to be the same as its calibrated length. The proper tension is normally 20 lb. for a 100-ft. steel tape suspended at the two ends. If the tape is supported throughout its length, as when it is laying on a level sidewalk, the tension should be one-half as much.
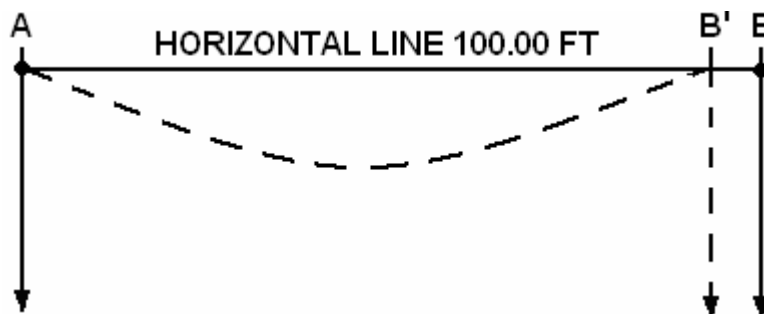
Figure 4-3 Example of sag in taping

CHAPTER 5: DIFFERENTIAL LEVELING

Differential leveling is the process of determining the elevation of a new point from the known elevation of an existing point. The resulting data from leveling is a significant piece of engineering design. This data is also used for mapping and construction projects. Such elevation information is usually given in terms of feet relative to a *vertical datum* such as *mean sea level (MSL)*. Mean sea level is the average height of the sea's surface at all tidal stages over a period of 19 years.

A *benchmark* is an object that has a location, both vertically and horizontally, that is relatively permanent. A point on this object has a known or assumed elevation that is relative to a predetermined datum. Various organizations such as the National Geodetic Survey, the U.S. Geological Survey, and the DOT's Survey Section have conveniently established a network of benchmarks, which are referenced to mean sea level. These benchmarks are the references normally used to establish the vertical control on highway construction projects.

There are different types of levels that can be used to determine the elevation data of points by means of the differential leveling method. The three types discussed in this text are *engineer levels*, *level transits* and *automatic levels*. Levels in each of these categories, though slightly different in design, have a telescope for viewing and establishing line and a means of orienting the line of sight in a horizontal plane. All types of levels are capable of being mounted on a *tripod* and are used to sight a graduated *level rod.*

THE ENGINEER'S LEVEL

The engineer's level or level transit is an instrument designed to project a level line of sight. Basically, the engineer's level consists of a telescope tube designed to impose a set of cross hairs on the image viewed through the telescope. A spirit level vial is attached or incorporated into the instrument to allow the tube to be accurately leveled by manipulating adjusting screws on a footplate. The following figure shows two modern types of engineering levels.

Level   Level Transit

Figure 5-1 Example of engineering Levels

THE SELF LEVELING LEVEL (Auto Level)

The self-leveling level (also called automatic level) is equipped with a small bull's-eye level and three leveling screws. The leveling screws are used to approximately center the bubble of the bull's-eye level. As long as the bubble remains centered, the line of sight automatically remains horizontal. A prismatic device called a compensator makes this possible. The compensator is suspended on fine, nonmagnetic wires. The action of gravity on the compensator causes the optical system to swing into the position that defines a horizontal sight. The horizontal line of sight is maintained despite a slight out of level of the telescope or even when a slight disturbance occurs on the instrument.

Figure 5-2 Example of self leveling level

THE HAND LEVEL

The Hand Level is a device commonly used in construction when a great degree of accuracy is not required. An experienced observer can get satisfactory results with the Hand Level when the distances involved are approximately 50 feet or less. At distances greater than 50 feet, readings with the Hand Level may be questionable.

Figure 5-3 Examples of hand levels

LEVELING RODS

A leveling rod is a graduated pole or stick, used with a surveyor's level to measure differences in elevation. There are many types of leveling rods available, however the rod most commonly used in construction surveying is called the "Philadelphia" rod. Leveling rods can be made of wood, fiberglass or aluminum and come in lengths varying from 12' to 25'.

READING THE ROD

The figure below shows a view of the Philadelphia level rod. The face of the rod is painted white with the graduations painted in black and spaced 0.01 ft. apart. The tops of the black graduations are the even hundredths, and thus the tops of the white graduations are the odd hundredths. The smaller numbers painted black represent tenths of a foot; the large numbers painted red indicate footmarks.
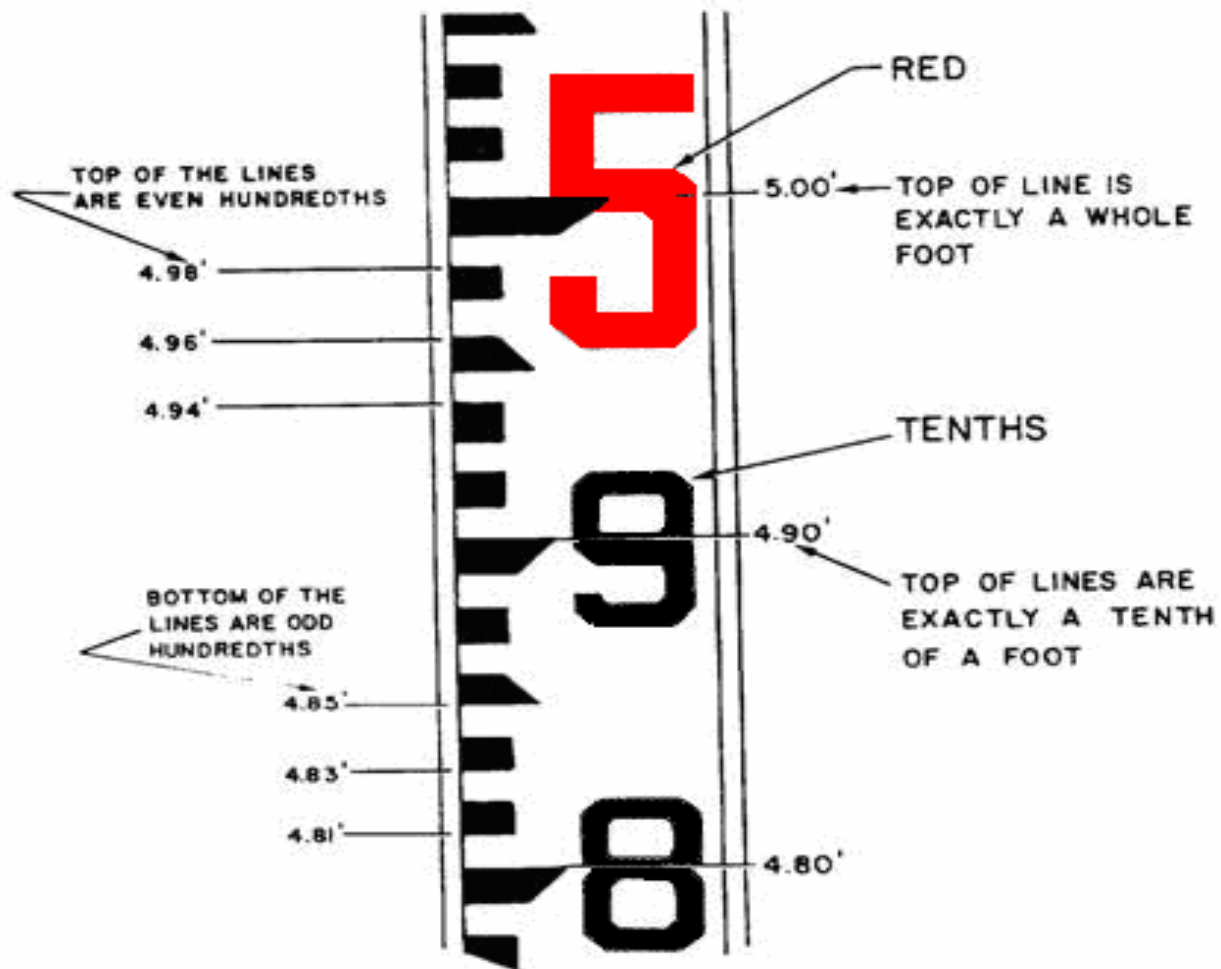

Figure 5-4 Example of Philadelphia rod

HOLDING THE ROD

The level rod must be held vertically for the reading to be correct, a tilted or non-vertical rod will result in a rod reading greater than the correct rod reading. See figure 5-5. Rod levels are available for use as an aid in holding the rod plumb.

Another means of ensuring that the correct rod reading is observed is called "waving the rod." Waving the rod is waving or swinging the rod slowly back and forth toward the instrument, using the base of the rod as a pivot point. The instrument person can observe the lowest reading, which is the true vertical reading.
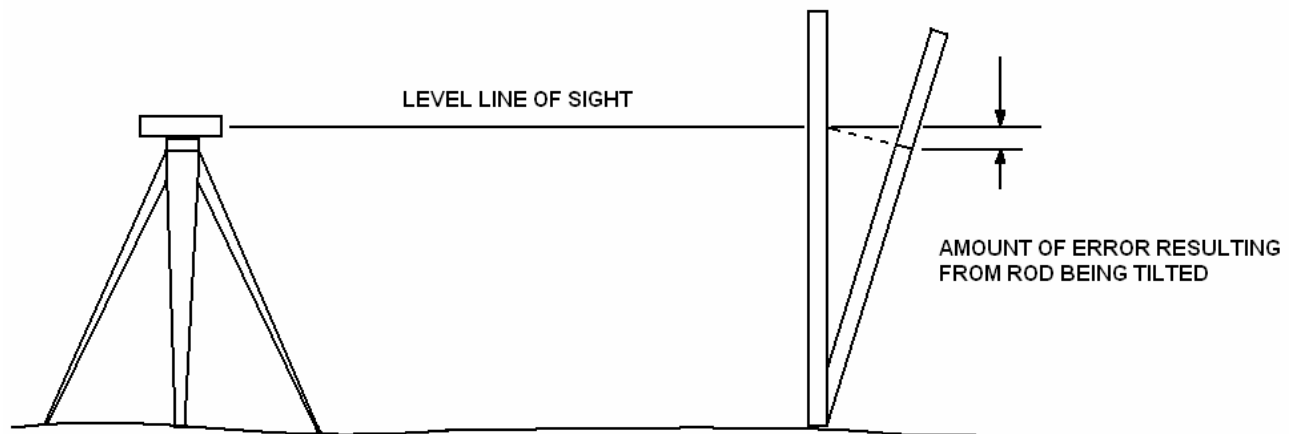
Figure 5-5 Error in reading the rod from being tilted

DETERMINING ELEVATIONS - LEVELING

The leveling process is started from a benchmark of known elevation or from one that has been assigned an arbitrary elevation such as 100.00 ft. In construction surveying any point with a known elevation can be termed a benchmark. The following definitions are of several common terms normally used in leveling.

Benchmark (B.M.) - Monument or point with known elevation.

Elevation - Vertical distance above a reference or datum plane.

Backsight (B.S.) - Rod reading taken on a point of known elevation, sometimes called a plus (+) shot.

Foresight (F.S.) - Rod reading taken on a point to determine the elevation on that point, sometimes called a minus (-) shot.

Turning Point (T.P.) - An intermediate reference point used when it is necessary to move the instrument ahead while running a line of levels.

Height of Instrument (H.I.) - The elevation of the level line sight projected by the instrument, when properly set up.

PROCEDURE

The level should be set up at some convenient distance from the benchmark. A good rule of thumb to follow in leveling is to keep all observations to within 300'. Observations in excess of 300' may introduce errors. The instrument person should be careful to set up the instrument at a point that is neither too high, nor too low. Usually a quick check with a hand level before setting up will verify whether the rod can be seen from a particular point

Once the instrument is set up, the instrument is ready to take a rod reading on the benchmark:

- This reading is called a backsight (B.S.).
- From the Figure 5-6, the rod reading on B.M. "A" is 10.63.
- The backsight (10.63) is added to B.M. "A" elevation (100.0) to calculate the height of instrument (H.I.).
- The height of instrument (H.I.) = 100.0 + 10.63 = 110.63.
- Remember backsights are always added.
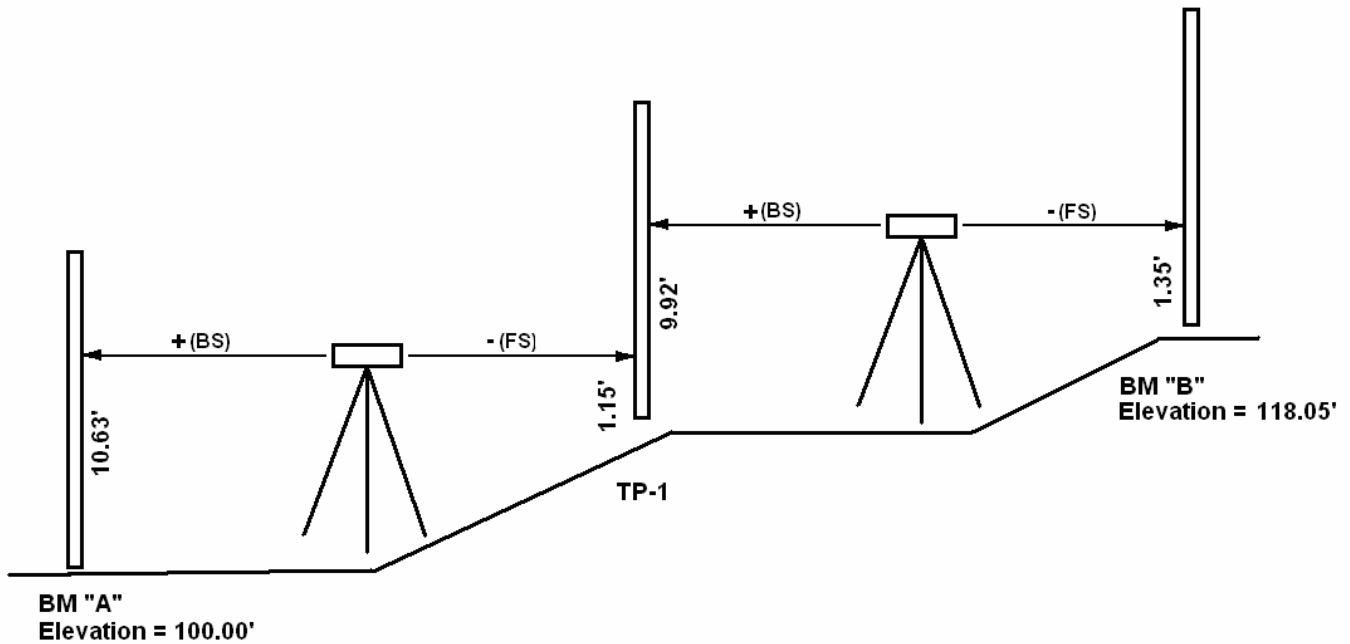
Figure 5-6 Differential leveling

LEVEL NOTES

Sta.	+B.S.	H.I.	-F.S.	Elev.
BM A	10.63	110.63		100.0
TP-1			1.15	109.48
TP-1	9.92	119.40		
BM B			1.35	118.05

Figure 5-7 Typical notes

Once the height of instrument is known, the elevation of other points can be determined from that set up as long as a rod reading is visible on the point. If the instrument person is unable to observe a rod reading on the point due to difference in elevation, distance limitations, physical obstructions, etc., it will be necessary to establish one or more turning points (T.P.) in order to progress to the required points.

A turning point should be a solid, clearly defined point, such as a stake or embedded rock, which is not likely to change in elevation during the leveling process. It should also be of such configuration that the elevation of the bottom of the rod would not change when the rod is faced in different directions.

To determine the elevation of a turning point (T.P.):
- This reading is called a foresight (F.S.).
- The foresight (1.15) is subtracted from the H.I. (110.63) to determine the elevation of T.P.1
- Elev. T.P.1 = 110.63 – 1.15 = 109.48.
- Foresights are always subtracted from the H.I. to calculate elevations.

Once the elevation of T.P.1 is determined, the level can then moved ahead and the entire process is repeated.

Whenever a line of levels is run involving two or more set ups, the field work should always be checked by running a line of levels back to the original B.M. or to another B.M.

NOTE KEEPING
In construction surveying, level notes are kept in bound level books. As with all field notes, level notes should be written with a 3H pencil or harder, and with no erasures. Erroneous entries should be lined through and initialed. Also, for each day's operation, the date, party members, and the weather should be recorded. It is also a good idea to make a copy of the days work. Field books occasionally get left on work truck toppers, in the field, etc. Having a second copy of previous notes can be invaluable.

LEVEL NOTES

STA.	(+) B.S.	H.I.	(-) F.S.	ELEV.	B.M. ELEV.	
BM₁	8.24	100.50			92.26	BM₁; BRONZE DISK SET IN CONC MARKER 56' RT. STA. 254+21
TP₁	7.35	105.60	2.25	98.25		₵ GRADE STAKE STA. 257+00
TP₂	8.78	112.96	1.42	104.18		
TP₃	2.25	104.45	10.76	102.20		
BM₂			8.11	96.34	96.36	BM₂; RR SPIKE SET IN CONC. MARKER 65' RT. STA 265+25

Figure 5-8 Typical surveying level notes

CHAPTER 6: COMMON SOURCES OF ERRORS AND MISTAKES IN DIFFERENTIAL LEVELING

INSTRUMENT OUT OF ADJUSTMENT
If an instrument is out of adjustment, the line of sight is not truly level. The error can be eliminated or minimized by taking backsights and foresights at 180° to each other and at approximately equal distances from the instrument.

BUBBLE NOT CENTERED WHEN TAKING ROD READING
The instrument person should always check the bubble when making a rod reading.

ROD NOT HELD PLUMB
The Rodman can "balance" the rod between his fingers if the wind is not blowing. Rod levels may be used. The Rodman can use the horizon, building lines, trees, or other references to hold the rod plumb. The instrument person can use the vertical hairline to assure that the rod is plumb in one direction. "Waving the rod," as discussed earlier in the text, is an effective means of eliminating this type of error, particularly when reading high on the rod.

TURNING POINTS
Turning points should be solid, well defined points that are not apt to change in elevation while the instrument person moves ahead. A marked spot on pavement, a stake firmly set, or embedded rocks are some examples of items that can be used as turning points. It is very important that the foresight and backsight be taken on exactly the same spot on a T.P.

ERRONEOUS ROD LENGTH
New rods should be checked with a steel tape to verify that the face is properly graduated. However, the most common error relating to rod length is failure to clamp the top sections of the rod at the proper place when using the "high rod." The Rodman should always extend the rod fully before clamping it, and he should periodically check to see that the rod does not slip from its fully extended position when using the high rod.

OTHER MISTAKES AND ERRORS
Some of the more frequent mistakes include: reading the wrong foot-mark; reading the wrong tenth-mark; entering the F.S. in the B.S. column of the field book, or vice versa; adding the F.S. or subtracting the B.S. when computing the notes. Concentration on individual job tasks is probably the most effective means of reducing mistakes.

CARE OF EQUIPMENT
As with any other precision measuring equipment, the level should be carefully handled. When being transported in a vehicle, the instrument should be in its box or case.

The instrument should be handled carefully when transferring it from the tripod to the box or vice versa. In the field, the instrument is normally carried over the shoulder with the tripod legs pointing forward. However, in close quarters, thickly wooded areas, entering doorways, etc., the instrument head should be held forward to avoid striking it on objects. Special care should be exercised to avoid striking or jolting the instrument, as this can result in the instrument being out of adjustment.

The instrument should not be allowed to get wet, but in case of a quick rain shower, all metal parts should be wiped dry before storing the instrument. When cleaning the telescope lens, care should be exercised to avoid scratching the glass. A special lens cloth is typically provided with each level and should be available for cleaning the lens.

The level rod should be used and stored in such a manner as to prevent damage to the graduated face.

CHAPTER 7: SLOPE MEASUREMENTS

In some cases, it is faster and more accurate to measure a distance at an angle to the horizontal and to calculate the horizontal distance than measure it with several horizontal steps. The angle up or down from the horizontal is called the *slope angle*, and the distance is called the *slope distance*. The slope distance is always longer than the corresponding horizontal distance.

Two methods of making a slope measurement and calculating the horizontal distance are described here.

METHOD 1
The horizontal distance can be calculated by measuring a slope distance from a point of known elevation to another point of a different known elevation. The Pythagorean Theorem can be used directly. See figure 7-1.

$$H = \sqrt{L^2 - d^2}$$

where

L = slope distance
d = difference in elevation
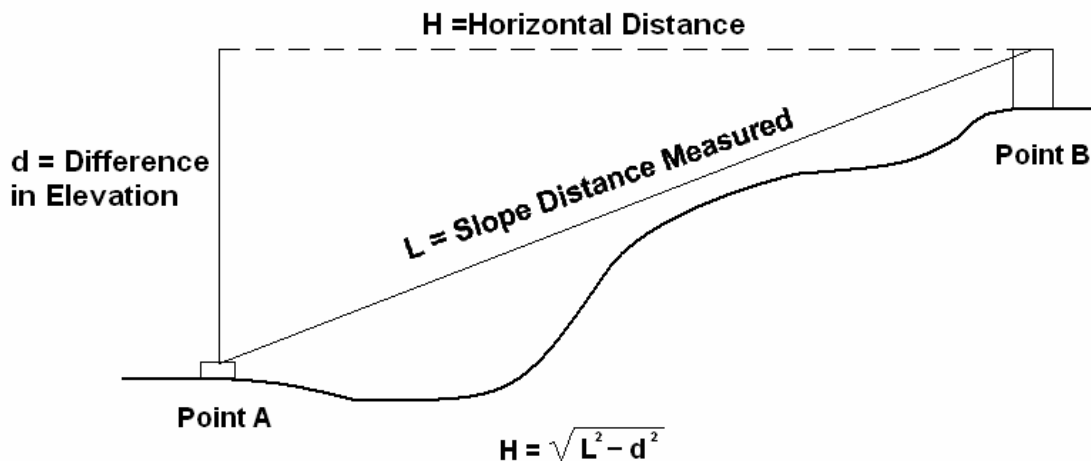H = horizontal distance

Figure 7-1 Determining horizontal distance from slope distance and elevation difference

Suppose one needs to determine the horizontal distance between Points A and B. The difference in elevation between Point A and Point B is 8.26 feet and the slope distance is measured to be 73.84 feet.

Using the formula above: $\sqrt{73.84^2 - 8.26^2} = 73.38$

METHOD 2

The most frequently used method of slope measurement in construction surveying involves measuring the slope distance, determining the slope angle, and calculating the horizontal distance. The horizontal distance can be calculated by multiplying the slope distance by the Cosine of the slope angle. See figure 7-2.

$$\text{Cos } \alpha = \frac{H}{L}$$

where

α = slope angle
L = slope distance
H = horizontal distance

H = Horizontal Distance

L = Slope Distance Measured

Point A

Point B

α

$$\text{Cos } \alpha = \frac{H}{L}$$
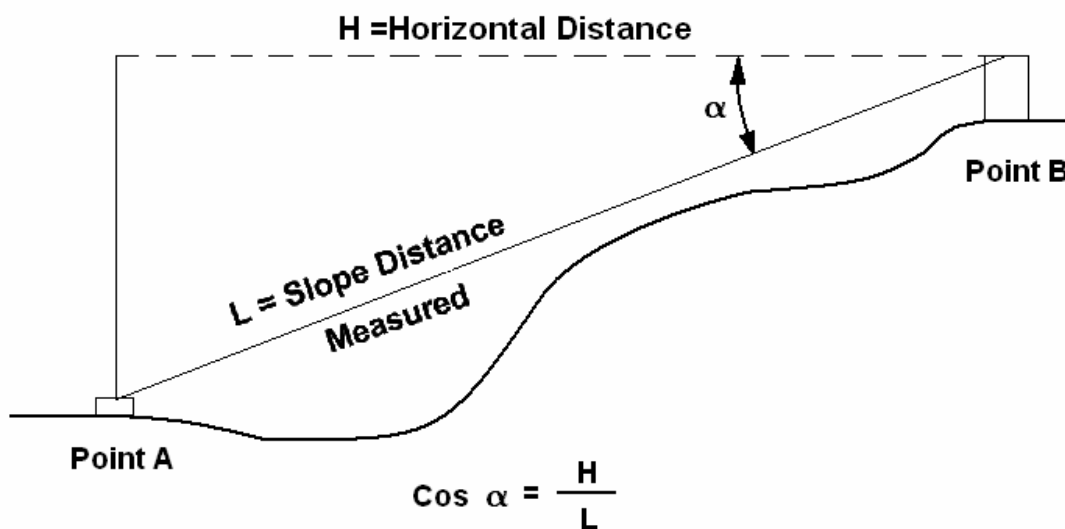
Figure 7-2 Determining horizontal distance from slope distance and slope angle

Suppose one needs to determine the horizontal distance between Points A and B. Using a slope angle of 6° 25′ 21″ and a slope distance of 73.84 feet.

Using the formula above:

$$\text{Cos } 6° 25′ 21″ = \frac{H}{73.84}$$

$$(73.84) \text{ Cos } 6° 25′ 21″ = H$$

$$(73.84) \; 0.9937 = 73.38$$

∗ Angles used in this equation must first be converted from DMS to DD.

CONVERTING FROM DEGREES MINUTES SECONDS (DMS) TO DECIMAL DEGREES (DD)

To convert from DMS to DD manually, use the following equation:

$$D + \frac{M}{60} + \frac{S}{3600}$$

For example convert 54° 30' 45" to DD

1. $54 + \frac{30}{60} + \frac{45}{3600}$

2. 54 + 0.5 + 0.0125

3. 54.5125

CONVERTING FROM DECIMAL DEGREES (DD) TO DEGREES MINUTES SECONDS (DMS)

To convert from DD to DMS manually, use the following method:

For example convert 54.5125° to DMS.
1. Subtract the whole degrees: 54.5125° – 54° = .5125°
2. Multiply the remainder times 60 to get the number of minutes: .5125° × 60 = 30.75'
3. Subtract the whole minutes: 30.75' – 30' = .75'
4. Multiply the remainder by 60 to find the number of seconds: .75' × 60 = 45" (If there is a decimal remainder, round.)
5. Thus 54.5125° = 54° 30' 45".

EXERCISES

Solve the following using one of the methods described above.

1. BM #1 = 7556.68, BM #2 = 7521.50, slope distance of 128.35';
   horizontal Distance =_____.

2. BM #1 = 7569.55, BM #2 = 7527.67, slope distance of 98.50';
   horizontal Distance =_____.

3. Slope Angle of 7° 30' 30", slope distance of 125'; horizontal distance =_____.

4. Slope Angle of 9° 35' 48", slope distance of 225'; horizontal distance =_____.

5. Convert 45° 25' 32" to Decimal Degrees; _____.

6. Convert 45.5069 to Degrees Minutes Seconds; _____.

CHAPTER 8: SLOPE STAKING

Slope stakes are set to mark the intersection of the proposed side slope and the original ground or *"catch point."* Slope stakes may be placed prior to the contractor clearing and grubbing as a way to establish the clearing limits. The slope staking procedure should be discussed with the contractor and the earthwork superintendent prior to beginning earthwork operations so all personnel are aware of how the slope stakes are marked and read.
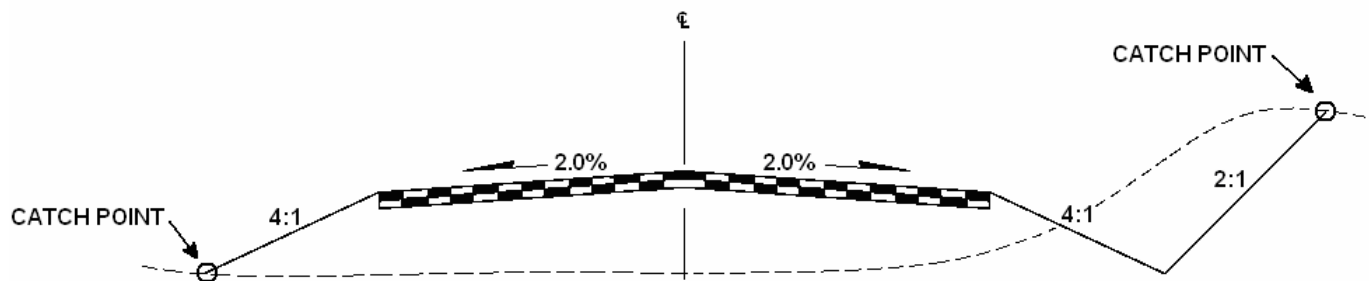

Figure 8-1 Catch points

The minimum information needed to set slope stakes is:

- The profile grade for each station
- Typical cross section for each station
- Original cross section with elevations

EQUIPMENT

Modern techniques for setting slope stakes generally involve the use of a *Total Station*, G*PS,* or an *Auto Level.* To gain a basic understanding of the slope staking process we will assume the use of a level instrument, level rod, and a tape. This method is best suited to relatively flat or rolling terrain where it is possible to run the centerline profile, cross sections, and set the slope stakes with only a few additional instrument setups. The slope staking interval should be a maximum of 100 ft. on tangents and 50 ft. on curves or as specified on the survey tabulation sheet.
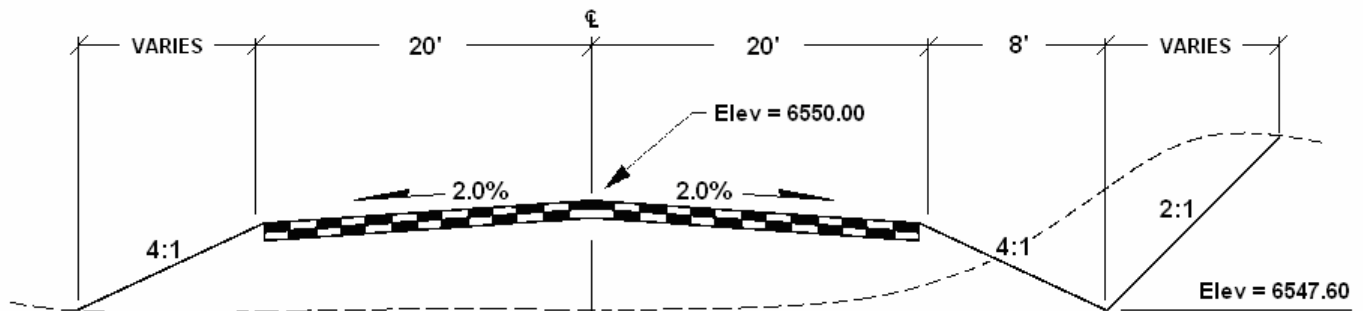
SLOPE STAKING PROCEDURES

Figure 8-2 Roadway Typical Section

In this example we are going to slope stake the 2:1 backslope on the right side of the typical section shown in figure 8-2.

First the elevation at the toe of the slope we are staking must be determined. These elevations are typically determined prior to going out in the field. Performing these calculations beforehand will greatly speed up the slope staking process once in the field. The process is as follows:

1) To calculate the elevation at the *toe of slope* we must first determine the elevation at centerline. Centerline elevations are determined by using the plan and profile sheets. For this example, we will assume a centerline elevation of *6550.00* and use the typical section in figure 8-2.
   a) First, convert the *-2.0%* cross slope to decimal form by dividing by *100, -2.0% / 100 = -0.02 ft./ft.*
   b) Next calculate the difference in elevation between the centerline and the shoulder by multiplying the horizontal distance by the *-0.02 ft./ft., 20 ' x -0.02 ft./ft. = -0.40*
   c) Subtract this difference from the centerline elevation to calculate the elevation at the shoulder. *6550.00 – 0.4 = 6549.60.*
   d) Repeat this process from the shoulder to the toe of the slope.
      i.   *4:1* slope is equal to *1* divided by *4* or *0.25 ft./ft.*
      ii. The *0.25* slope multiplied by an *8'* horizontal distance equals a *2.0* difference in elevation from the shoulder to the toe of the slope.
      iii. This *2.0* difference subtracted from the shoulder elevation equals the elevation at the toe of the slope. *6549.60 – 2.0 = 6547.60.*

2) Once the toe of slope elevation is determined we are ready to set up the level and begin slope staking.
   a) First set up the level in a convenient location where a backsight to an existing benchmark can be seen as well as the probable location of the catch point.
   b) Then determine an H.I See figure 8-3.

Figure 8-3 Determine an H.I.
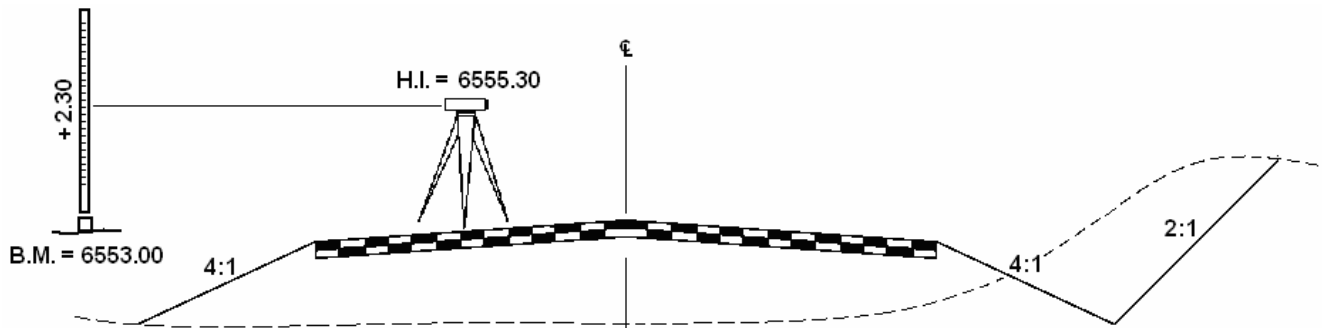
3) Once an H.I. is determined, calculate the difference between the H.I. and the finished grade at the toe of slope. *6555.30 – 6547.60 = 7.7.* This difference is called the *Grade Rod*. <u>This calculation is done only on paper and is not actually a shot taken with the level.</u> Figure 8-4 shows a graphical representation of a Grade Rod. By determining a *Grade Rod* we will be

able save time by using the difference in rod readings to slope stake rather than having to convert them to elevations first.
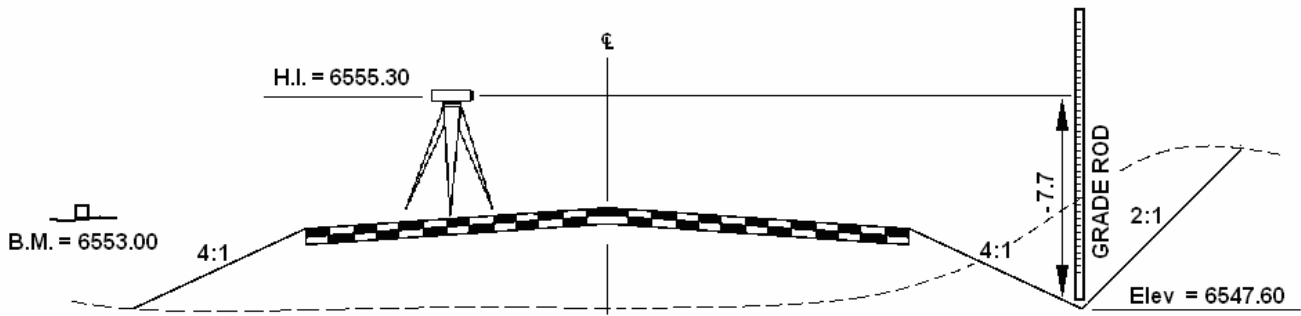

Figure 8-4 Calculate the *Grade Rod*

4) Once the G*rade Rod* is determined we can begin taking shots in the approximate location of the catch point, several attempts may be necessary.
5) While measuring the distance from centerline, take a F.S. in the approximate location of the catch point. This is called the *Ground Rod.* For our first attempt we read a *-3.2* on the level rod at a distance of *35'* from centerline. See figure 8-5.
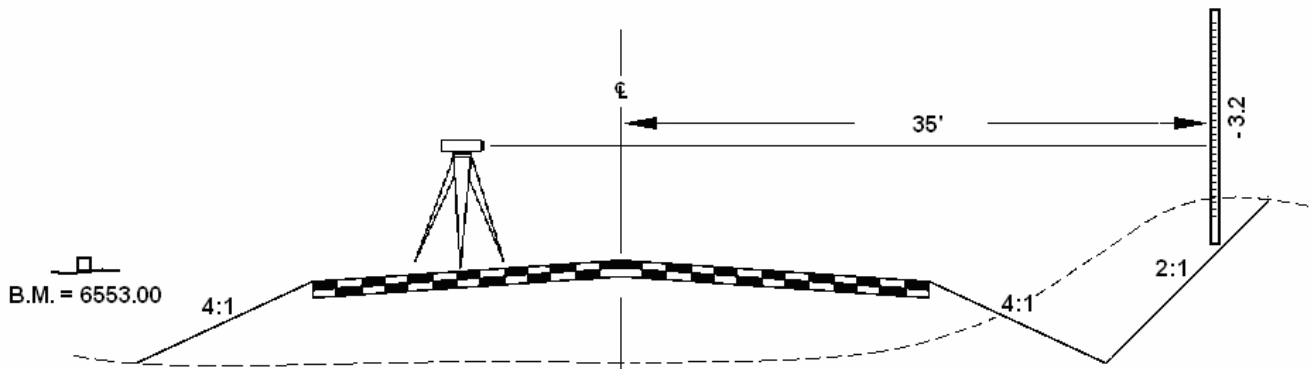

Figure 8-5 First attempt, try 35'

6) The difference between the G*rade Rod* and the *Ground Rod* will either be a cut or fill. This cut or fill is multiplied by the *slope* and added to our *reference offset* to determine the horizontal distance from centerline.

$$\text{Distance} = \text{Reference Offset} + (\text{Grade Rod} - \text{Ground Rod}) \times \text{Slope}$$

The *Reference Offset* is the horizontal distance from centerline of the roadway to the beginning of the slope being staked. This offset represents the horizontal distance that remains unchanged regardless of where the catch point is staked. In some cases this distance may remain the same between several typical sections. In our example, it is the toe of slope on the right side 28' from centerline. This offset See figure 8-6 below.
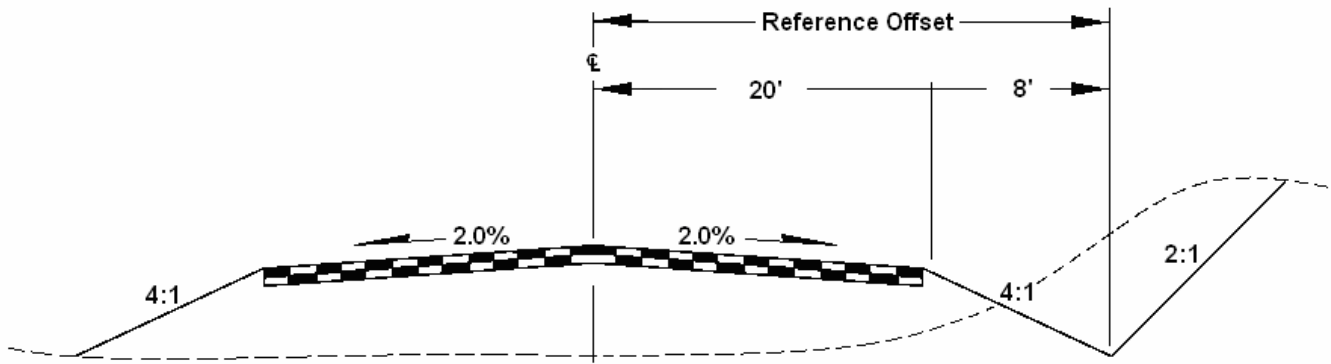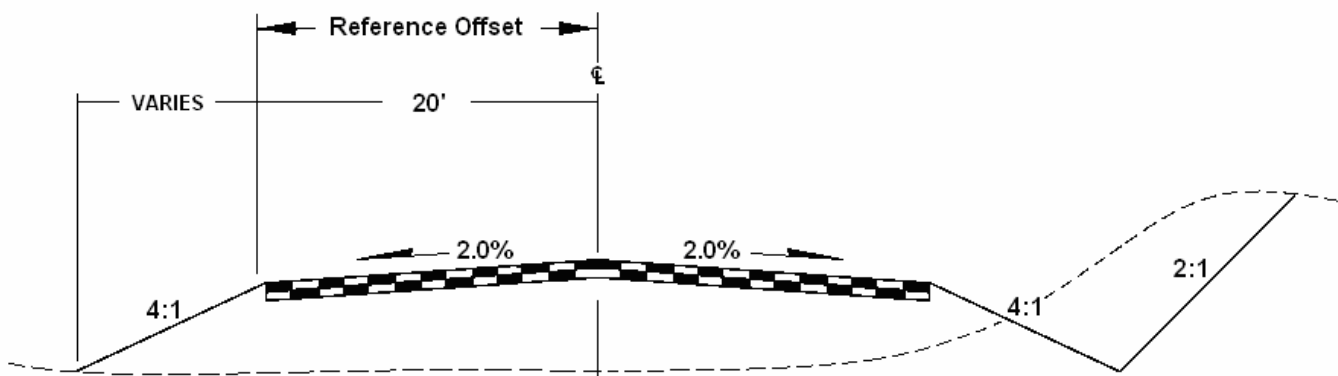
Figure 8-6 Reference Offset right side

Figure 8-7 Reference Offset left side

7) Using the formula above, we can perform the calculations for our first attempt as follows:
   a) First calculate the cut or fill. For our example *7.7* is subtracted from *3.2* this equals a fill of *4.5*.
   b) Next calculate our distance by multiplying the fill by the side slope. *4.5 x 2 = 9.0.*
   c) Then add this distance to the *reference offset*. *28' + 9.0' = 37.0'.*
   d) Our calculated distance is then compared to the actual distance we measured. Our measured distance of *35'* is not equal to our calculated distance of *37'*. If they were the same, a slope stake would be set. But, since they are not, the process is repeated at a new distance from centerline until the measured distance matches the calculated distance.

8) For our second attempt we will move further out from centerline and repeat the process. Try a rod reading of -2.3 at a distance of 40' from centerline. See figure 8-8.
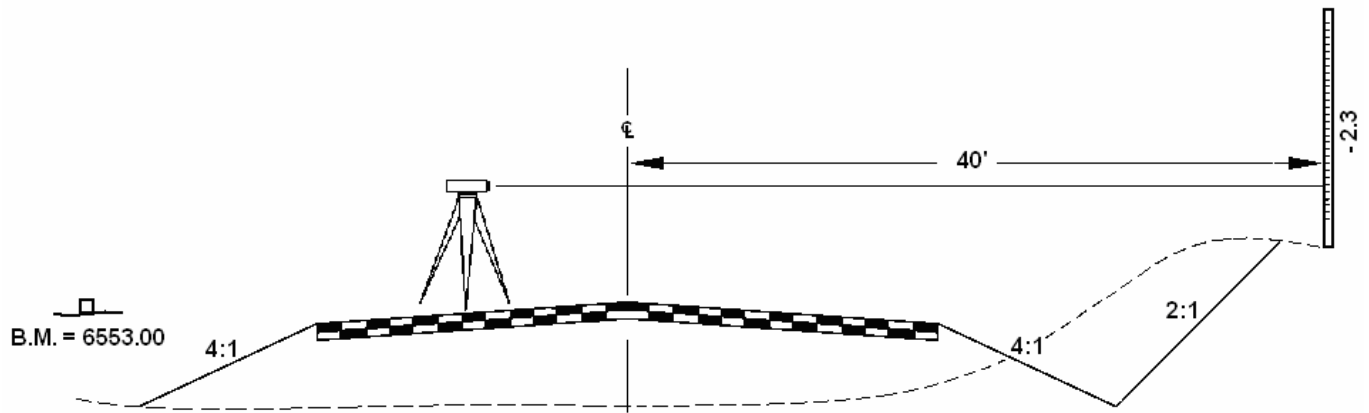
Figure 8-8 Second attempt, try 40'

    a) *28' + (7.7 - 2.3) x 2 = 38.8'*, this is not equal to *40.0'*, try moving closer.

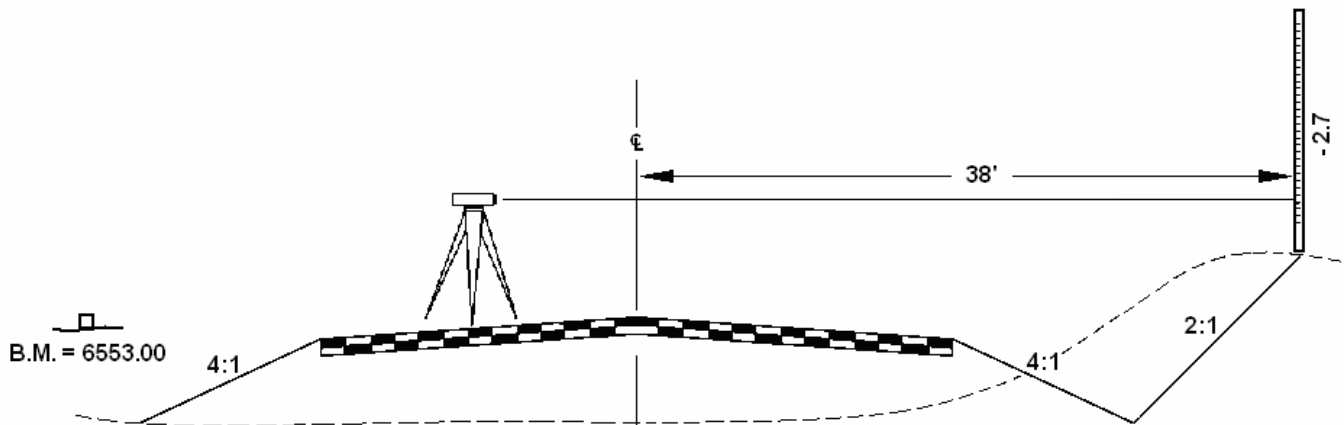9) For our third attempt try a rod reading of *-2.7* at *38'* from centerline. See figure 8-9.

Figure 8-9 Third attempt, try 38'

    a) *28' + (7.7 - 2.7) x 2 = 38'*, this is equal to *38'*. A stake would then be set at this point.

Setting slope stakes is a process of trial and error; several shots at different distances from centerline are generally required to set slope stakes.

SLOPE STAKES
There are several satisfactory methods of showing information on slope stakes. The intent is to provide the workers adequate information of:
- Where to begin a cut or fill
- Which slope to follow
- The depth or height of the cut or fill
- Show additional information, but not to the point of confusion

Figure 8-10 shows the results of the slope stake we set at the catch point in the previous exercise. Note all the calls reference finished grade.

C 5 $\frac{0}{}$ @ 10 $\frac{0}{2}$ ₵ // F 2 $\frac{0}{}$ @ 8 $\frac{0}{4}$ EOP // F 0 $\frac{4}{}$ FG @ 20 $\frac{0}{2\%}$ ₵ ——→

FRONT

STA 10+00   38' RT ₵   ELEV = 6552.60

BACK

Figure 8-10 Slope stake set at catch point

In addition to a stake set at the catch point, slope stakes are typically referenced by an offset stake to prevent the loss of information during construction. The offset stake should contain the same information as the slope stake and include the offset distance and elevation difference to the catch point.

(10) C 1 $\frac{3}{}$ CP // C 5 $\frac{0}{}$ @ 10 $\frac{0}{2}$ ₵ // F 2 $\frac{0}{}$ @ 8 $\frac{0}{}$ EOP // F 0 $\frac{4}{}$ FG @ 20 $\frac{0}{2\%}$ ₵

FRONT

STA 10+00   48' RT ₵   ELEV = 6553.90

BACK

Figure 8-11 10' Offset stake for catch point set 1.3' higher than catch point

STAKING SUBGRADE
Our stakes shown in figure 8-10 and 8-11 show the cuts, fills, and offsets relative to finished grade. Typically slopes stakes will show this information relative to subgrade. To provide slope stake information relative to subgrade, the intersection of the subgrade slope and the shoulder slope must be calculated. This point is known as the *Point of Slope Selection* or *P.O.S.S.* see figure 8-12.
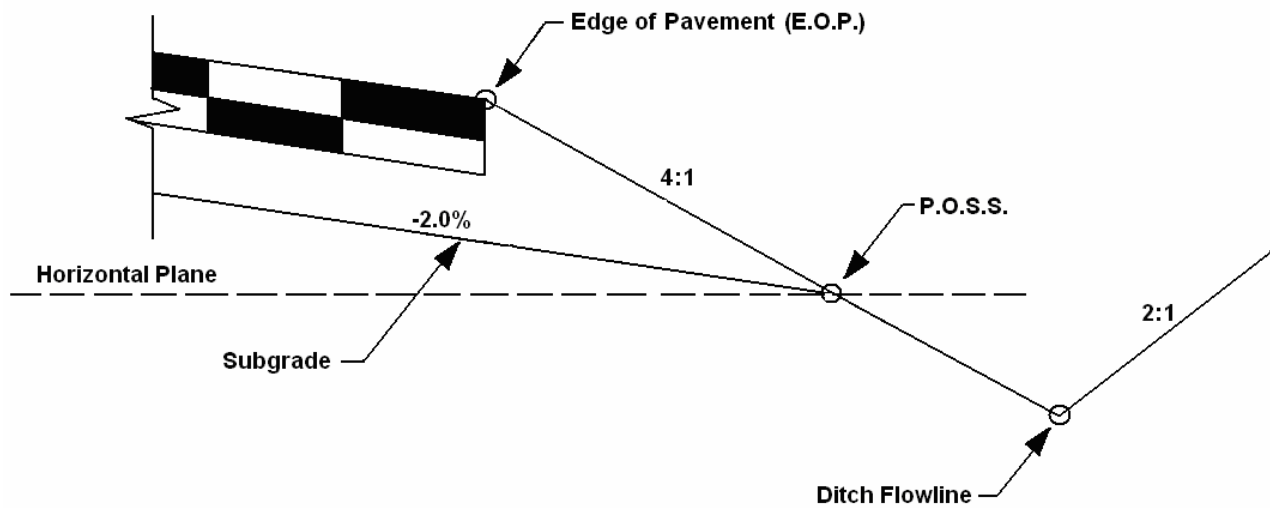
Figure 8-12 Point of Slope Selection (P.O.S.S.)

In this exercise we will write a new slope stake with calls to the *P.O.S.S.* and to the roadway centerline both at subgrade elevation. The first call to the ditch flowline is already known, **Cut 5.0' @ 10.0'**, and will remain unchanged.

The first step is to calculate the horizontal distance from the finished shoulder *(E.O.P.)* to the subgrade shoulder *(P.O.S.S.)*. This is done by dividing the depth of surfacing (pavement + base course) at the edge of pavement by the difference between the shoulder slope and the subgrade slope. See figure 8-13.

Equation: $X = \dfrac{B}{A}$
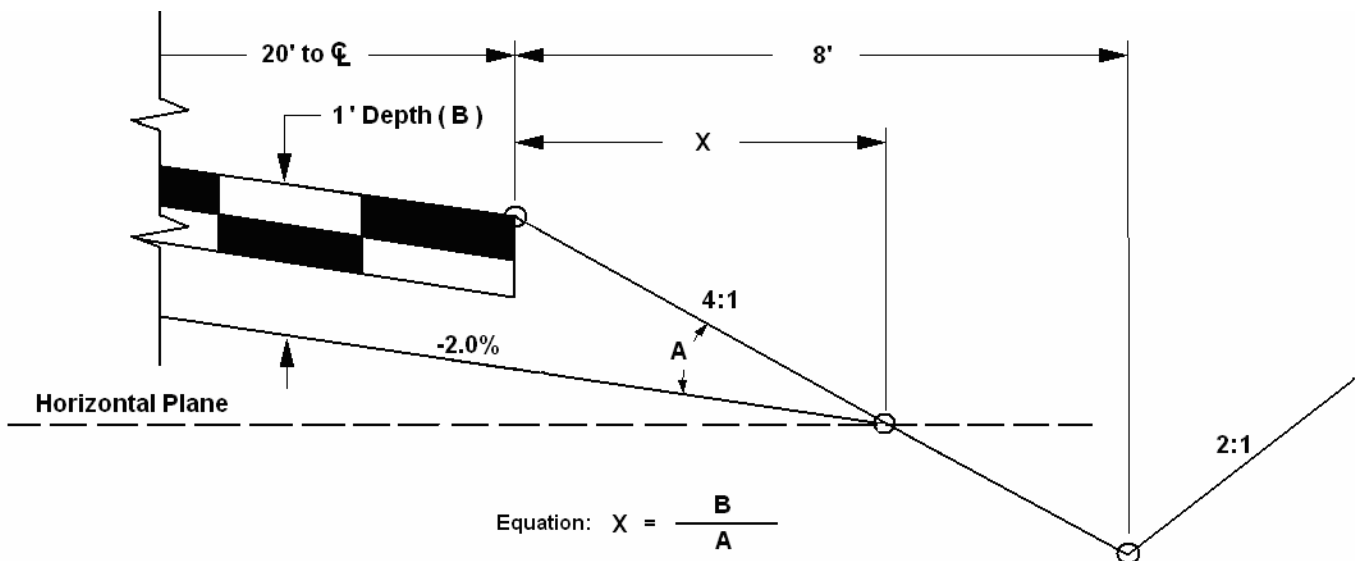
A = Algebraic difference in decimal between the shoulder slope and subgrade slope

B = Depth of surfacing at the edge of pavement in feet

X = Distance from the finished shoulder to the subgrade shoulder in feet

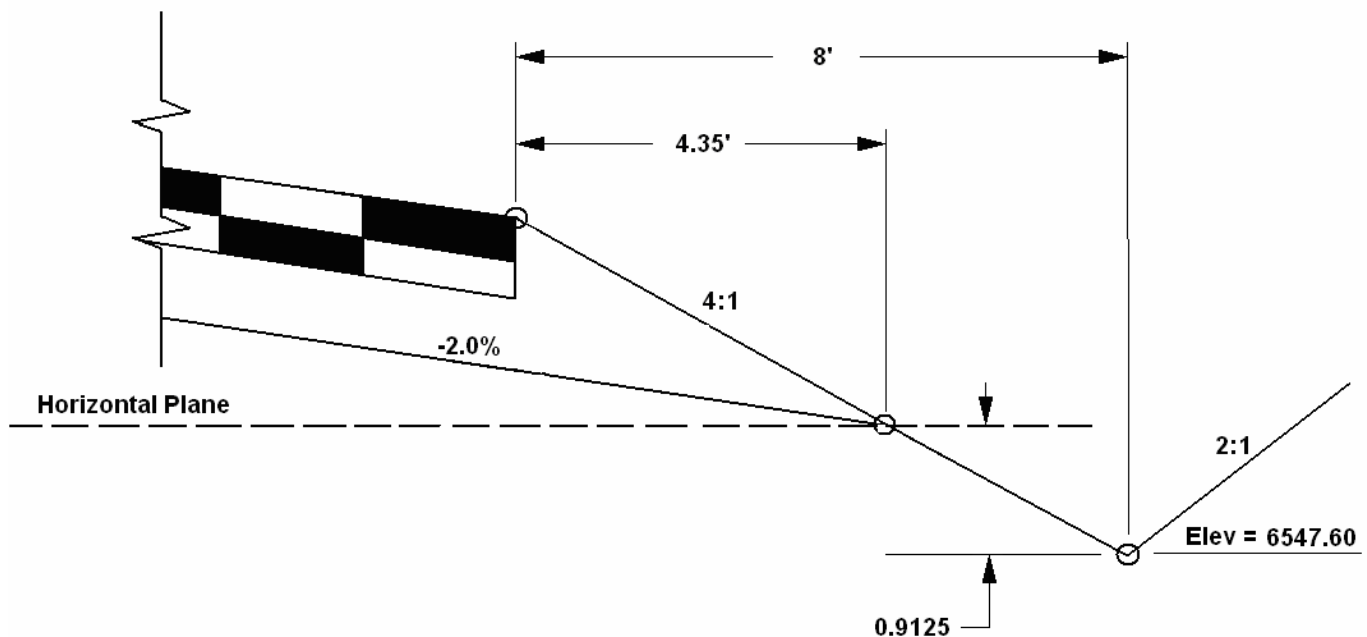**Figure 8-13 Calculating difference in slopes**

Example:
1) First calculate the difference between the two slopes by subtracting the *2% (0.02 ft./ft.)* slope from the *4:1 (0.25 ft./ft.)* slope**.**
    a) *0.25 – 0.02 = 0.23*
2) Then using the equation shown in figure 8-13, determine the offset distance from the *E.O.P.* to the *P.O.S.S.* by dividing the depth of surfacing at the edge of pavement by the difference between the shoulder slope and the subgrade slope.

    a) $X = \dfrac{B}{A}$

    b) $X = \dfrac{1}{0.23}$

    c) $X = 4.35$

3) Now that we have calculated horizontal distance, we can use this to calculate the difference in elevation from the ditch flowline to the P.O.S.S. See figure 8-14.
    a) First subtract the *4.35* from the *8.0, 8.0 – 4.35 = 3.65*
    b) Then multiply by the *4:1* slope *(0.25), 3.65 x 0.25 = 0.91*
    c) This gives us our second call, ***Fill 0.91 at 3.65'***

Figure 8-14 Calculating difference in elevation

4) To calculate the final call to centerline, add the *4.35* we previously calculated to the *20'* from *EOP* to centerline and multiply by the *2%* slope.
    a) *20 + 4.35 = 24.35*

b) 24.35 x 0.02 = 0.49

c) This gives us our final call to centerline, **Fill 0.49 at 24.35'** to finished grade at centerline.

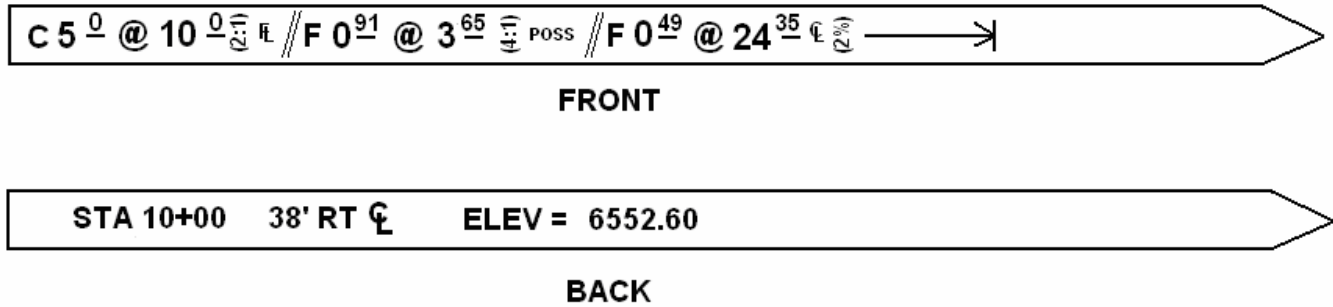5) Now all the calls written together on a slope stake :

C 5 ^{0} @ 10 ^{0} ₵ // F 0 ^{91} @ 3 ^{65} POSS // F 0 ^{49} @ 24 ^{35} ₵ ⟶ ⟶|

FRONT

STA 10+00   38' RT ₵   ELEV = 6552.60

BACK

Figure 8-15 Slope stake at subgrade

CHAPTER 9: GRADE STAKING

After the roadbed is constructed, grade stakes are set for final finishing. Staking will be done for:
*   Subgrade (*Red Tops*)
*   Base course (*Blue Tops*)

Hubs for Subgrade are to be set within *0.02* feet (*6 mm*) of actual grade.
Hubs for Base Course are to be set within *0.02* feet (*6 mm*) of actual grade.

BLUE AND RED TOPS
After completing the embankment, *Red Tops* are set at the top of each sub base layer and *Blue Tops* are set at the top of the base course. There are two primary methods used for setting blue and red tops: level and rod, and total station.

The blue and red tops should be set at the centerline and shoulders. The frequency of red and blue tops should not exceed 50' in tangent and 25' in curves.

The hub should be driven so that the top is at the elevation of the finished grade. The inspector should complete, as a minimum, random checks of the staked roadway. A visual inspection using a string line can catch many problems in the field that could lead to over depth of base course or an HBP mat that would be thin.

The inspector should check grade with a string line between stakes in both the transverse and longitudinal direction. A good grade foreman and grader operator should be capable of finishing the grade to ±0.1 foot before calling for blue tops. Call the grader operator back to finish grading if the grade varies more than specifications allow.

CHECKING FINISH GRADE
It is not feasible to set hubs with close enough spacing to notice minor deviations in grade, but the grade still needs to be checked between hubs, both laterally and longitudinally. Several methods exist for checking finish grade against red and blue tops including using a straight edge and string lining.

Straight Edge - Involves using a 10 foot long straight edge to check for deviations in the grade. Simply lay the straight edge on the grade and check for gaps under the straight edge. Check the specifications for allowable tolerances in the grade for the layer being checked. Any gaps outside of the tolerances should be corrected by cutting and/or filling.

String Lining - String lining involves using a string pulled tight between two hubs to check for deviations in grade. Generally the string is not placed directly on top of the hubs while string lining. Typically the string line is tied between two pieces of lathe 1ft. from the bottom end. This allows for a quick check of the finished grade with a tape measure without having to get on your hands and knees. See figure 9-1. A reading of 1 ft. is on grade, anything else is either high or low. This method requires that three people be available to assist. This method allows for quick checking of distances up to 50 foot and can be used to verify hub elevations and grade elevations between hubs.
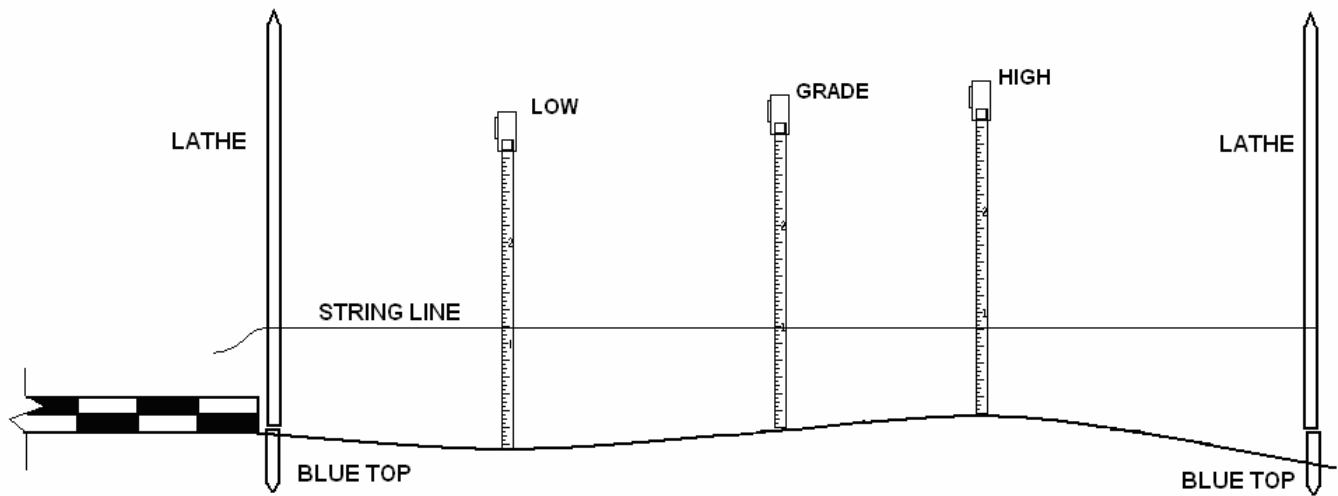
Figure 9-1 Example of checking grade using a string line

CHAPTER 10: PIPE LAYOUT

When construction stakeout is considered, there are two categories of pipeline – pressure and gravity. Liquid or gas that fills a pipeline under pressure flows upward as readily as downhill, and slope is of little importance. Water and natural gas lines are of this type, and it is customary to construct them at a certain depth below the surface without regard to the slope of the pipe. Line is staked at an offset for this type of pipeline, and grade is measured from the ground surface at the edge of the trench.

Gravity pipelines are only partially full of liquid, and the liquid flows from a higher elevation to a lower one. It flows only as far as the pipe continues to slope downward. The steepness of the slope determines the velocity at which the liquid flows and, therefore, the quantity that flows in a given time. The slope is an important factor in the design and construction of these pipelines. Storm drains and sanitary sewers are of this type, and line and grade must be indicated for these pipes without regard to the grade of the ground surface.

There are many types of pipelines that may be encountered on a highway project. Typically a plan and profile sheet is included in the project plans for every pipeline to be constructed or modified. Having the ability to verify pipe grade is critical for inspection of drainage structures.

Following are some uses of survey techniques to check pipe grades and work out solutions for errors in grade.

SAMPLE PIPE PROBLEM #1

A pipe run begins at invert elevation of 8000.00. The horizontal distance of the pipe is 48 LF and slopes at a -5.6%. What is the invert elevation at the other end?

48 LF (RUN)

- 5.6%

8000.0
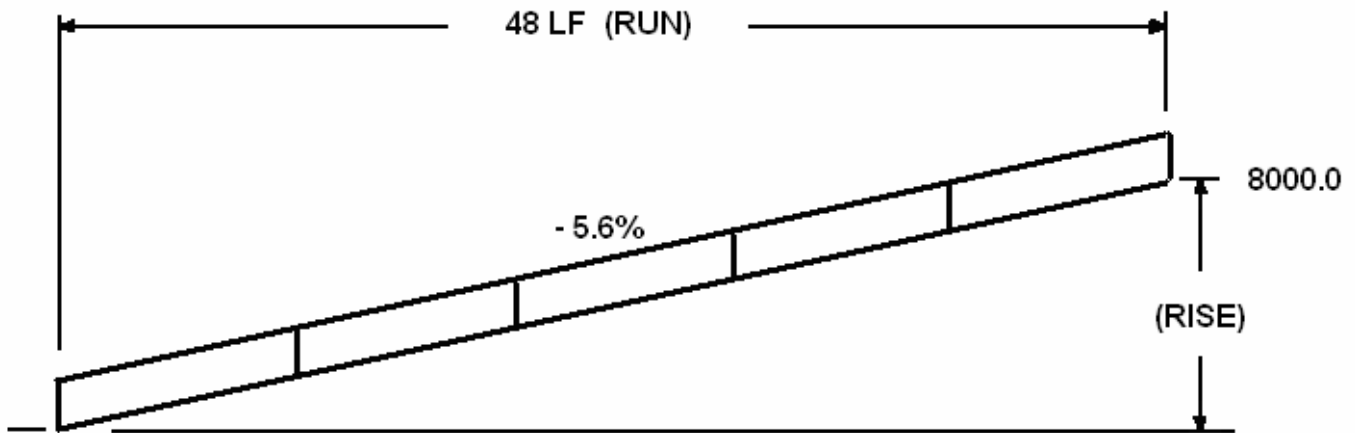
(RISE)

$$SLOPE = \frac{RISE}{RUN}$$

Figure 10-1 sample pipe problem #1

The change in elevation of the pipe is calculated as follows:

$$0.056 = \frac{RISE}{48}$$

$$(48)\ 0.056 = RISE$$

$$2.69 = RISE$$

$$8000 - 2.69 = 7997.31$$

SAMPLE PIPE PROBLEM #2

Contractor has installed 50 LF of pipe (five 10' sections). You use the level to determine that the beginning invert elevation is correct at 7206.70 feet. Using the level you determine that at 50 LF installed, the invert is 7200.00 feet. The plan slope in the pipe is -12.5%. What is the contractors slope on the pipe and how many feet in elevation are they off?
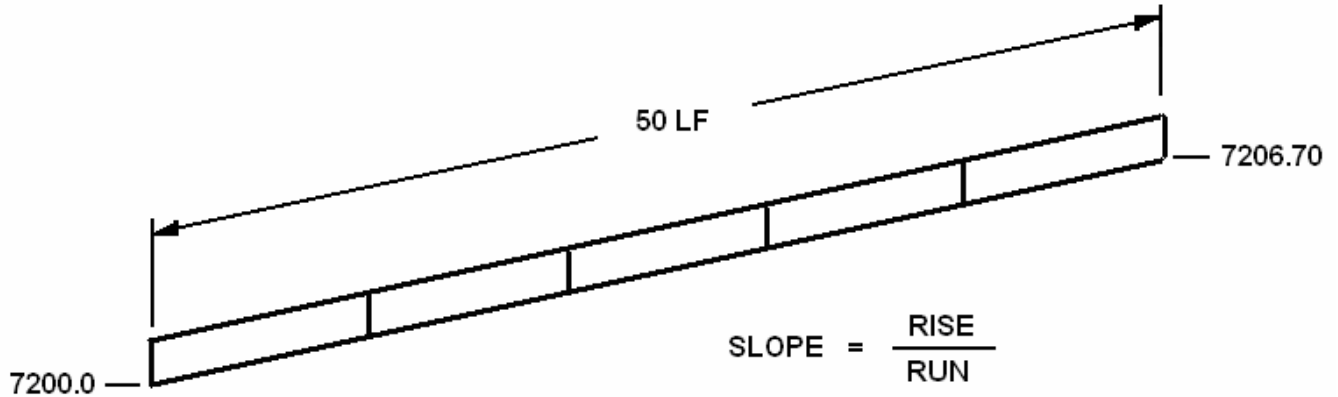

Figure 10-2 Sample pipe problem #2

Before we can use the formula above we must first calculate the horizontal distance of the pipe, see chapter 7 page 22.

$$\sqrt{50^2 - 6.7^2} = 49.55$$

Then, determine what slope the pipe is installed at:

$$SLOPE = \frac{(7206.70 - 7200.00)}{49.55}$$

$$SLOPE = -13.52\%$$

Second, determine what the elevation should be if the pipe were installed at the plan slope. Again, use Slope = Rise / Run:

$$0.125 = \frac{RISE}{49.55}$$

$$(49.55)\,0.125 = RISE$$

$$6.19 = RISE$$

$$7206.7 - 6.19 = 7200.51$$

Error in installation equals plan elevation (7200.51) minus actual elevation (7200.00).
7200.51 – 7200.00 = 0.51 feet low

SAMPLE PIPE PROBLEM #3
From the plans you get the following information for a pipe run:
Pipe run is to be from 0+00 to 1+07 at a 5.7% slope.
Beginning invert elevation is 7550.00.
Final invert elevation is 7556.10.

The Contractor has installed pipe from station 0+00 to 0+68. Using your level, you obtain the following information:
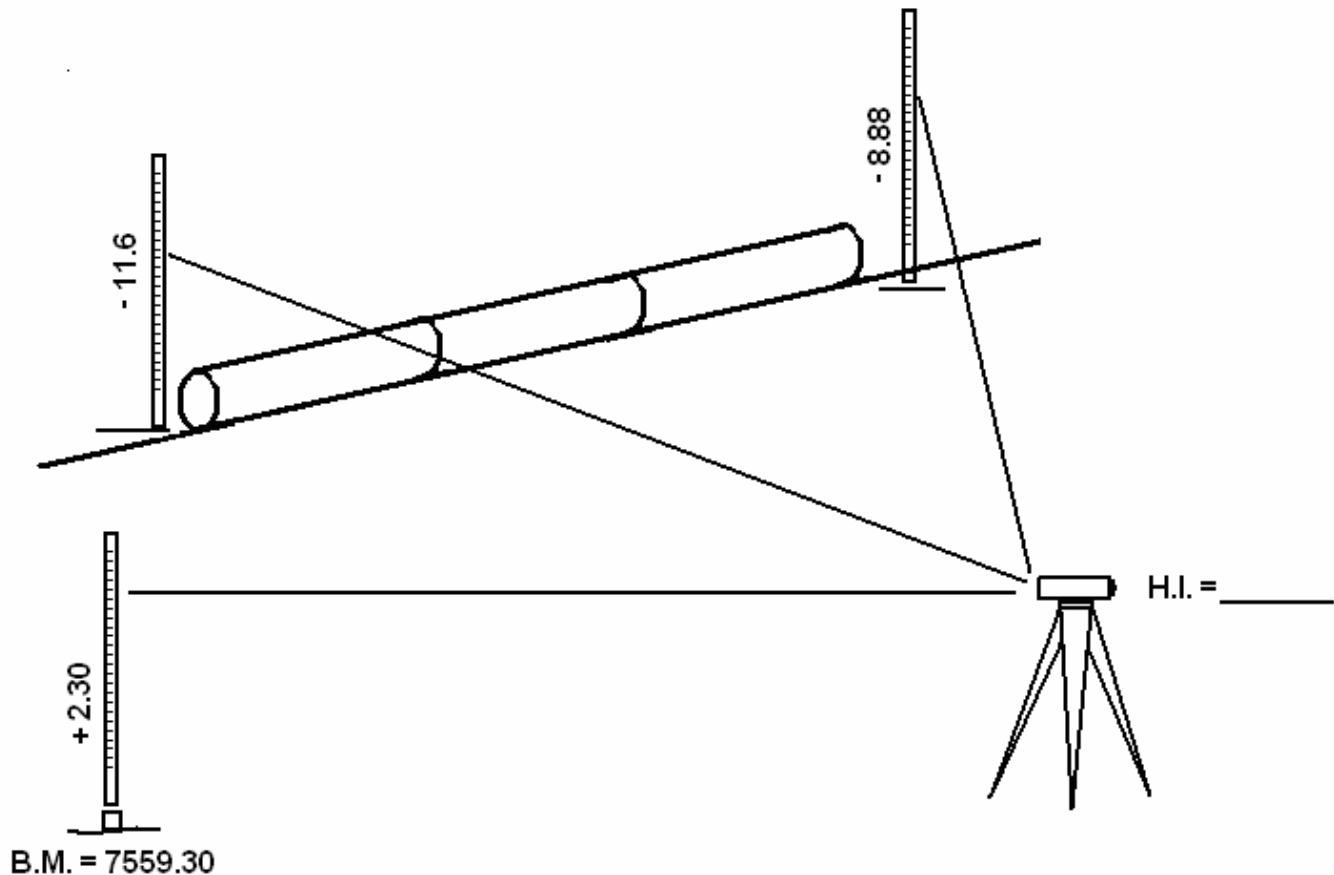

Figure 10-3 Sample pipe problem #3

Determine the following:
- Is the grade correct at the beginning of the run?
- Is the grade correct at station 0+68?
- If the grade is off, what will have to be changed to hit the plan invert at the end of the pipe run?

First, using the information obtained by the level, determine the elevations of the installed pipe.

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 LEVEL  NOTES
```

Sta.	+ B.S.	H.I.	- F.S.	Elev.
BM	2.30	7561.60		7559.30
Beg. FL			11.60	7550.00
End FL			8.88	7552.72

Figure 10-4 Sample pipe problem #3 field notes

Second, determine what the plan elevation is at 68 LF of pipe installed and compare to the surveyed elevation.

$$0.057 = \frac{RISE}{68}$$

$$(68)\ 0.057 = RISE$$

$$3.88 = RISE$$

$$7550.00 + 3.88 = 7553.88$$

The surveyed elevation is 7552.72.

$$7553.88 - 7552.72 = 1.16\ LOW$$

Third, to determine how the problem can be fixed, calculate the slope needed to end at the correct elevation. Perform the following calculations and contact the Project Engineer and discuss how the problem should be fixed.

Pipe remaining to be installed: **0+68 to 1+07 = 39 LF**
Difference between current elevation and final elevation: **7556.10 – 7552.72 = 3.38 feet**
Slope between current pipe and final pipe grade: **3.38 / 39 = .0867 or 8.67%**
The slope could be adjusted for the remaining pipe to 8.67%. This solution should be discussed with the Project Engineer who may have other concerns about the change in grade.

SAMPLE PIPE PROBLEM #4

While installing 24 inch RCP it is determined that the slope of the pipe needs to be changed by 3% to get back on the plan grade. Can the next joint of pipe be changed by 3% without kinking the pipe? Assume that the tolerance for the spigot of the pipe is only allowed ½ inches of play inside the bell.
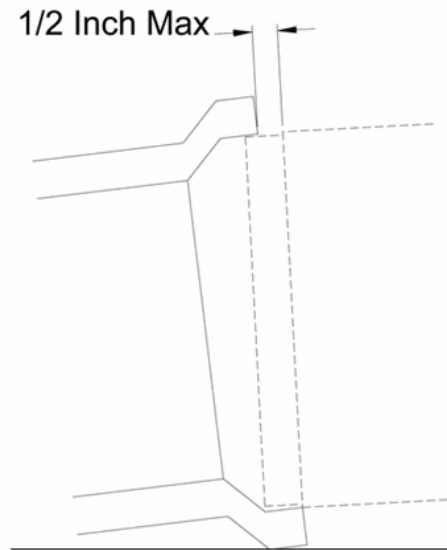

Figure 10-5 Pipe deflection

Given the ½ inch tolerance and 24 inch RCP, the percent change allowed per joint is easily calculated by Slope = Rise/Run.

$$Slope = \frac{1/2"}{24"}$$

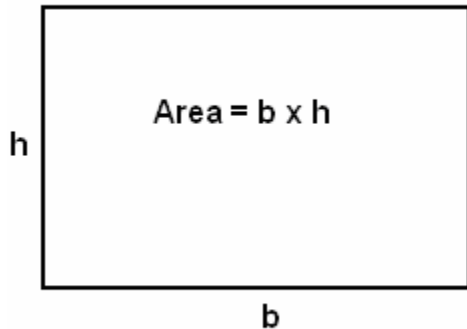$$Slope = 0.02 \text{ or } 2\% \text{ Change Allowed}$$

This situation requires 3% change in slope. The change will have to be made over 2 joints instead of just 1.

In the previous example, the pipe was incorrectly installed at a 4% grade; 7552.72 – 7550.00 / 68 = .04. To correct this problem, a revised slope for the remainder of the pipe was calculated to be 8.67%. Using this example, a maximum change of 2% is all that is allowed. So, the next stick of pipe could only be installed at a 6% (4% + 2%) grade, the next stick at an 8% grade, and the next at an 8.67% grade.
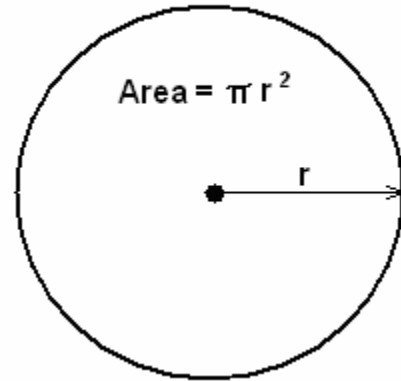
CHAPTER 11: AREA AND VOLUME CALCULATIONS

Calculating the area of simple geometric shapes is often required to determine the pay quantity for a particular item. There are many items that are measured and paid by the square foot (SF) or square yard (SY). Area calculations are also required to calculate earthwork volumes using the *Average End Area Method*.
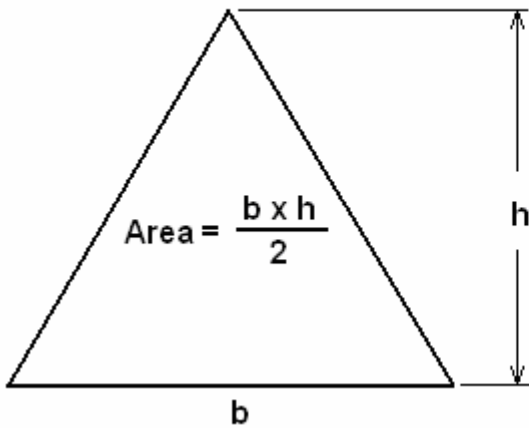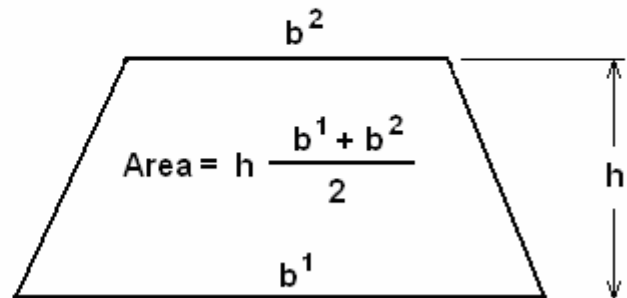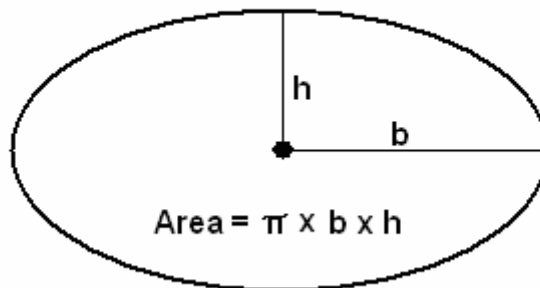
Rectangle

$$\text{Area} = b \times h$$

Circle

$$\text{Area} = \pi\, r^2$$

Triangle

$$\text{Area} = \frac{b \times h}{2}$$

Trapezoid

$$\text{Area} = h\,\frac{b^1 + b^2}{2}$$

ELLIPSE

$$\text{Area} = \pi \times b \times h$$

PRACTICE EXERCISES
1. What is the area of a square with equal sides of 112'? Area = _____ SF

2. Solve the area of a circle with a 23' radius in SY. Area = _____ SY

3. Calculate the area of a triangle with a height of 5' and a base of 21'? Area = _____ SF

4. Trapezoid with a 'b^1' of 25', a 'b^2' of 29' and a 15' height. Area = _____ SF

5. Ellipse with a 'b' of 4' and 'a' h of 3', calculate area in SF. Area = _____ SF

EARTHWORK VOLUMES
Earthwork volumes are typically calculated from original ground cross sections and final grade cross sections. The volume between cross sections is approximately equal to the average of the two end areas multiplied by the distance between them. This approximation is called the *Average End Area Method* and is accurate enough to be the most common way of determining volume of earthwork for payment to a Contractor who is being paid by the cubic yard.
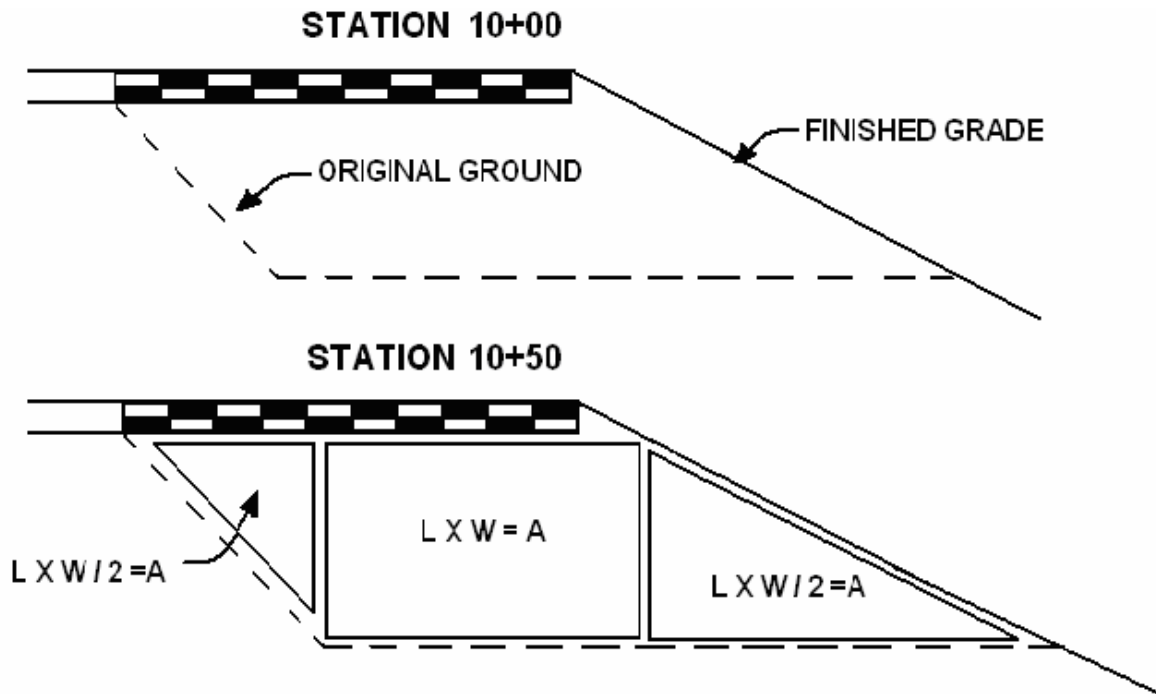

Figure 11-1 Cross sections

PROCEDURE

If the cross sections are rather simple they can be divided into rectangles, trapezoids and triangles, and the areas can be determined mathematically. See figure 11-1. To calculate the volume between the two stations in figure 11-1, assume the area at station 10+00 is 75 SF and the area at station 10+50 is 125 SF. Use the following formula:
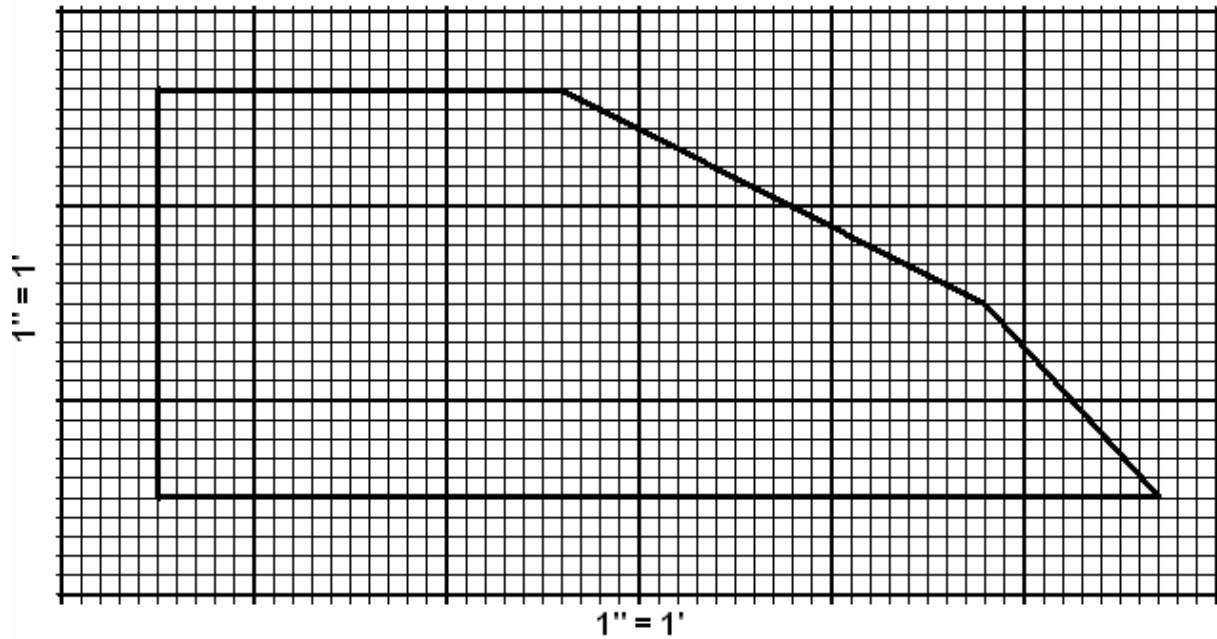
$$\text{VOLUME} = \frac{(\text{AREA}^1 + \text{AREA}^2)}{2} \times \text{LENGTH}$$

$$\frac{75\text{ SF} + 125\text{ SF}}{2} (50\text{ FT}) = 5000\text{ CF} \qquad \frac{5000\text{ CF}}{27\text{ CF/CY}} = 185.185\text{ CY}$$
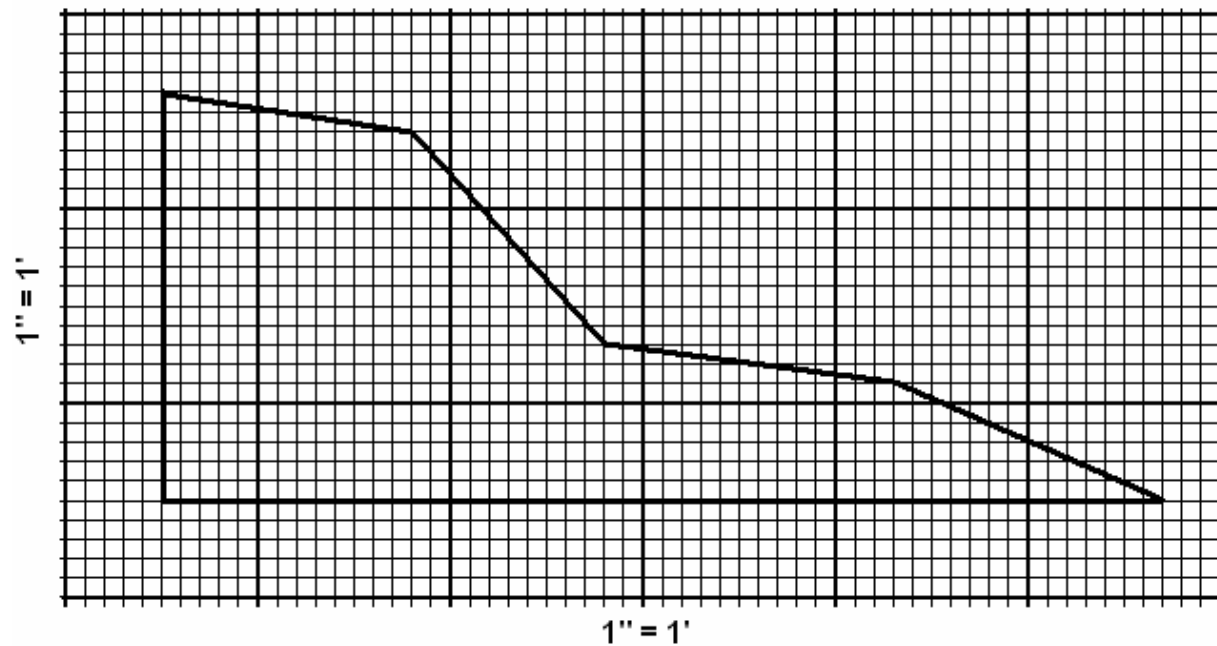
Figure 11-2 Cross section equation and calculations

SAMPLE EARTHWORK PROBLEM #1

STA 10+50

1" = 1'

1" = 1'

STA 10+00

1" = 1'

1" = 1'

Calculate the area of each cross section:
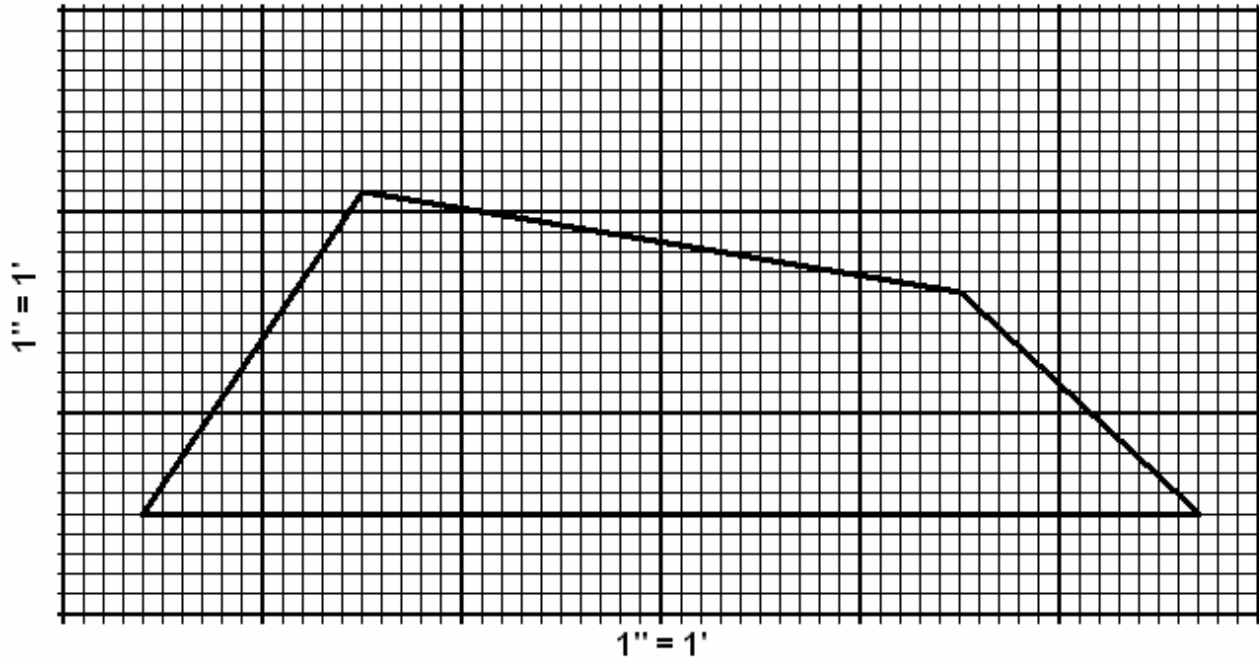
Area at 10+00 = _____ SF

Area at 10+50 = _____ SF

Calculate the volume between station 10+00 and 10+50 in cubic yards:

Volume between 10+00 and 10+50 = _____ CY

SAMPLE EARTHWORK PROBLEM #2

STA 9+50

1" = 1'

1" = 1'

STA 9+25

1" = 1'

1" = 1'

Calculate the area of each cross section:

Area at 9+25 = _____ SF

Area at 9+50 = _____ SF

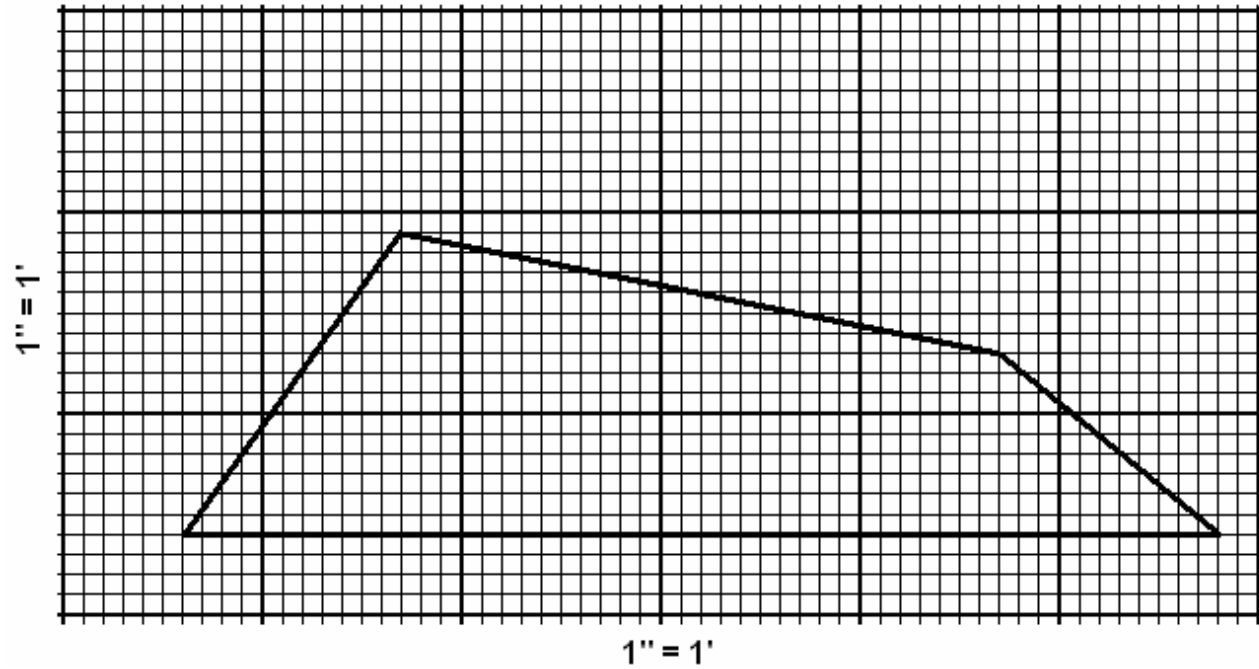Calculate the volume between station 9+25 and 9+50 in cubic yards:

Volume between 9+25 and 9+50 = _____ CY

SAMPLE EARTHWORK PROBLEM #3

STA 10+00

1" = 1'

STA 9+50

1" = 1'

STA 9+25

1" = 1'
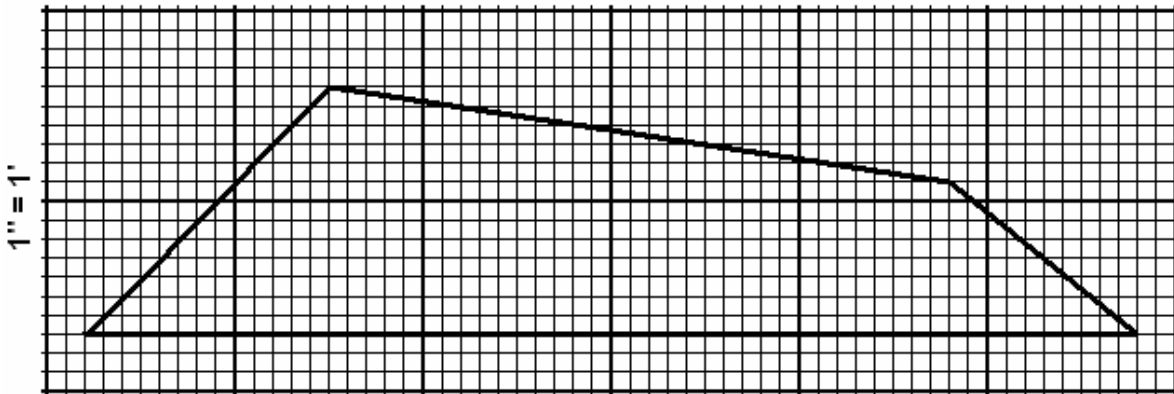
Calculate the area of each cross section:

Area at 9+25 = _____ SF

Area at 9+50 = _____ SF
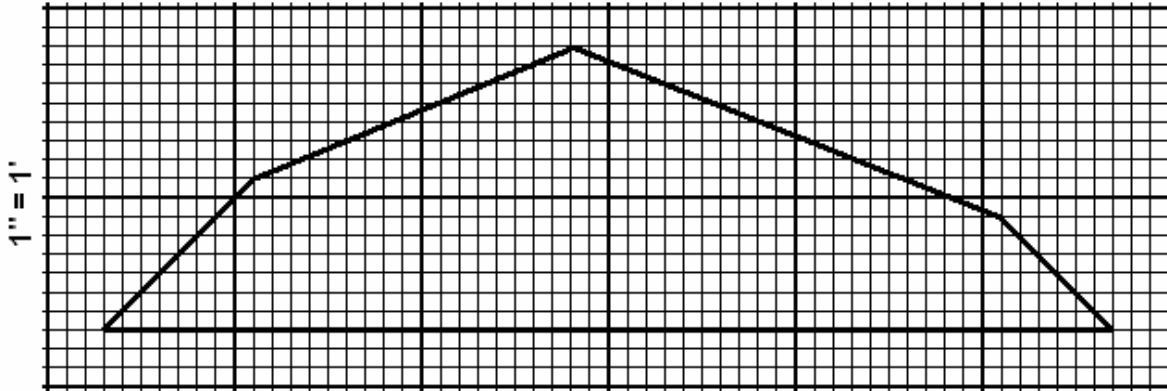
Area at 10+00 = _____ SF

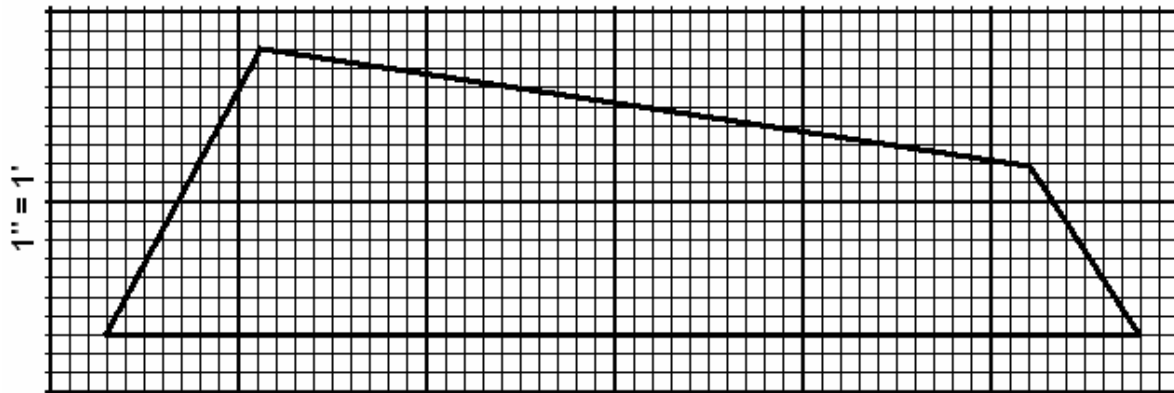Calculate the volume between station 9+25 and 9+50 in cubic yards:

Volume between 9+25 and 9+50 = _____ CY

Volume between 9+50 and 10+00 = _____ CY   Total: _____ CY

SAMPLE PROBLEM #4 (USE CHAPTER 10 & 11)
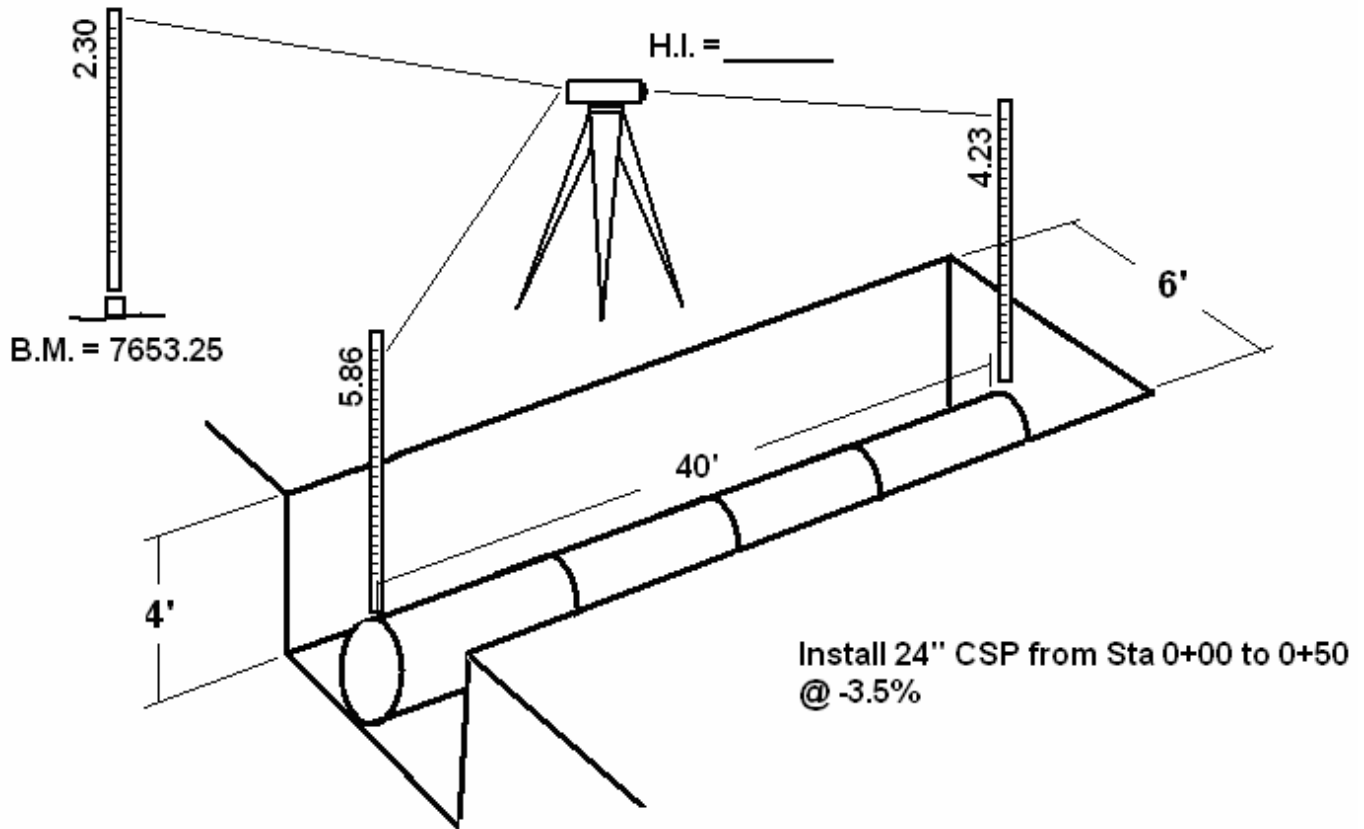
Figure 11-3 Sample problem #4

Using the figure above, solve for the following:
1. At what percent slope is the pipe installed? _____.
2. What is the difference between the actual flowline elevation at 40' vs. the plan elevation? _____.
3. What needs to be done to the remaining 10' of pipe to end at the correct elevation? _____.
4. Calculate the volume of flowfill in cubic yards required to fill the trench after the last piece of pipe is installed. _____.

CHAPTER 12: MODERN SURVEY TECHNIQUES

Today, most measurements for laying out work are done using various electronic instruments such as Total Stations, and GPS. These instruments still perform the same basic functions as a manual survey but have eliminated much of the error. On a project, the student should expect to see many types of instruments used and a basic understanding of each is beneficial. The intent of this section is to not have the student be able to run these instruments but instead for the student to know what the instrument is and what it can be used for.

TOTAL STATION

The Total Station combines several instruments into one, an EDM, electronic transit, and a microcomputer. It can measure horizontal and vertical angles, slope distances, horizontal distances, and perform numerous calculations using these measurements. The onboard microcomputer typically has a limited set of functions; more complex functions are available by utilizing an external data collector running some type of surveying software. Most surveys are completed using total station systems. Benchmarks are required for the instrument to determine its location. Once the instrument knows its location and orientation, points can be quickly laid out for construction. The instrument may need to be moved from time to time to maintain line of sight and to stay within the parameters needed for accuracy.

GPS (GLOBAL POSITIONING SYSTEM)

The Global Positioning System, usually called GPS (the US military refers to it as NAVSTAR GPS - Navigation Signal Timing and Ranging Global Positioning System), is a satellite navigation system used to determine one's precise location and provide a highly accurate time reference almost anywhere on Earth or in Earth orbit. It uses a satellite constellation of at least 24 satellites. A basic GPS receiver uses radio signals broadcast from multiple satellites to determine how far away the satellites are using a process called multilateration or hyperbolic positioning. Using these calculated distances the receiver then calculates its position by trilateration.

The accuracy of the GPS signal itself is about 5 meters (16 ft) as of 2005 and has steadily improved over the last 15 years. Using differential GPS and other error-correcting techniques, the accuracy can be improved to about 1 cm (0.4 in) over short distances.

Differential correction requires a second GPS receiver, a base station, collecting data at a stationary position on a precisely known point (typically it is a surveyed benchmark). Because the physical location of the base station is known, a correction factor can be computed by comparing the known location with the GPS location. This correction factor is then broadcast to the GPS receiver in the field (RTK) or used when post processing the data back at the office.

Use of GPS in surveying is beneficial because line of sight to the control points is not required. As long as enough satellites can be seen by the instrument, surveying can be done around corners, over hills, and through trees. In some locations though, such as in areas with steep, tall mountains, enough satellites cannot be seen to obtain the accuracy required by survey and GPS cannot be used.

SUMMARY

After studying this text, the student should have a basic understanding of the measurement of horizontal distances (taping), the measurement of vertical distances (leveling), slope staking, and grade checking for embankment and pipe, and modern survey techniques. The only way to become proficient in making these measurements is through experience, and hopefully working in the field. With practice, the student will become proficient in these techniques. With this basic understanding, the student should be able to communicate with the Contractor's staff and the Engineer. The student should expect to find different methods of slope and grade staking and should be able to adapt to each as required. Ask the Contractor or the Project Engineer for assistance with reading the information in the field to insure that the student has the correct information and can inspect these stakes and rely on their information. The serious student would do well to secure a textbook on surveying for more detailed study.

CREDITS

CDOT would like to give the credit to the following Organizations for their contribution to this paper, portions of the text were used with their permission:

Principles of Surveying / Charles A. Herubin, Fourth Edition,

Georgia Department of Transportation

Washington Department of Transportation

Alaska Department of Transportation

Colorado Department of Transportation's Survey Manual which can be found at

www.codot.gov/business/manuals/survey

ANSWER KEY

Chapter 7 Exercises
1. 123.43
2. 89.15
3. 123.93
4. 221.85
5. 45.4256
6. 45°30'25"

Chapter 11 Practice Exercises
1. 12544 SF
2. 184.66 SY
3. 52.50 SF
4. 405 SF
5. 37.70 SF

Sample Earthwork Problem #1
Area at 10+00 = 5.42 SF
Area at 10+50 = 8.27 SF
Volume between 10+00 and 10+50 = 12.68 CY

Sample Earthwork Problem #2
Area at 9+25 = 4.92 SF
Area at 9+50 = 5.59 SF
Volume between 9+25 and 9+50 = 4.87 CY

Sample Earthwork Problem #3
Area at 9+25 = 5.79 SF
Area at 9+50 = 4.71 SF
Area at 10+00 = 4.87 SF
Volume between 9+25 and 9+50 = 4.86 CY
Volume between 9+50 and 10+00 = 8.88 CY
Total Volume = 13.74 CY

Sample Problem #4 (Use Chapter 10 &11)
1. 4.08 %
2. Low 0.23
3. Installed at -1.20%
4. 38.63 CY