4 Distance Measurements

Pacing

Tape

Equipment

Tapes
Markers
Range Poles
Plumb Bobs
Hand Levels

Procedure

Taping Over Smooth, Level Ground
Taping Over Hilly, Sloping Ground
Taping Error

CHAPTER FOUR:
DISCUSSION OF DISTANCE MEASUREMENTS

In surveying, the distance between two points is understood to mean the horizontal distance, regardless of the relative elevation of the two points. Frequently, the lay of the land between the two points is not uniform, or the elevation of the two points is very different. Special equipment and techniques may be needed to obtain an accurate determination of the distance. Various methods of determining distance are available along with special and different types of equipment. The degree of precision required is another factor which is required to be considered before a measurement of distance is undertaken so that the correct type of equipment and method of measurement may be done.

PACING

Pacing is a rapid means of approximately checking more precise measurements of distance. Pacing over rough country may be done with a precision of one in one hundred. In average conditions, a person with some experience should have little difficulty in pacing with a precision of one in two hundred. Obviously, there is not much precision in this method and the procedure provides only an approximation of distance. The natural pace of each individual normally varies from 2 ½ to 3 ft. A convenient relation between the pace and the foot is 40 paces approximately equal 100 ft. Technicians involved in surveying standardize their pace by walking over known distances on level, sloping, and uneven ground.

TAPE

The common method of determining distance is by direct measurement with a tape. The tape is called a "chain" and is usually 100 ft in length. The term "chain" comes from the form of the early tapes which were composed of 100 links, each one foot long. Brass tags were fastened at each ten links and notches in the tags indicated the number of ten link segments between the tag and the end of the tape. Therefore, the early tapes looked like a chain of one hundred links. Chain is also applied to the operation of measuring lines with tapes. The term "taping" is gradually being used more exclusively.

The distance measured with a steel tape is much more precise than the distance obtained by pacing. The precision obtained depends upon the degree of refinement with which the measurements are taken. Ordinarily, taping over flat, smooth ground with a steel tape or chain, divided in hundredths of a foot, provides a precision of one in three thousand to one in five thousand.

EQUIPMENT

TAPES

Tapes (Figure 4-1) are made in a variety of materials, lengths, and weights. Those more commonly used are the heavy steel tape, sometimes called the Engineer's tape or the highway drag tape, and the metallic tape.

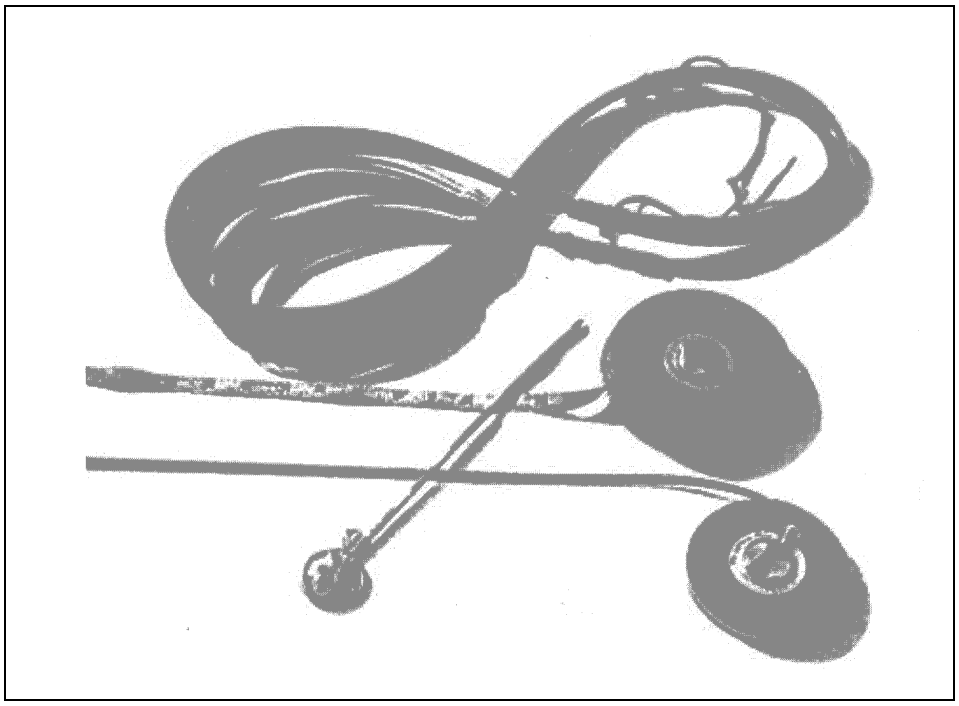

Figure 4-1. Tapes

The metallic tape is a ribbon of waterproof fabric into which small brass or bronze wires are woven to prevent stretching. This tape may be 50 or 100 ft long and graduated in feet, tenths, and half-tenths. Cloth tape is another name that more correctly describes the tape. This type of tape is used principally for earthwork cross-sectioning or in similar work where a light, flexible tape is desired and where small errors in length are not critical. Due to the metallic wires woven into the fabric, a cloth tape conducts electricity and is used carefully near power lines.

The steel highway tape is generally used for the direct linear measurement of important survey lines. The length most commonly used is 100 ft. Longer tapes of 200 and 300 ft are common for some contracts. The steel highway tape has graduations every foot, and only the end foot is graduated in tenths and hundredths of a foot. Some tapes have an extra graduated foot at one or both ends. The steel highway tape most commonly used is a one hundred and one foot tape with the extra foot graduated in hundredths. Rawhide thongs are attached through the rings at each end of the tape to allow for ease of handling during measurement and also for storing and fastening the tape when not in use. Tapes are usually very close to the correct length when subjected to a given pull at a given temperature. The conditions of support are important. For example, a 100 ft tape is the correct length at 68° F under a pull of 10 pounds with the tape horizontal and fully supported throughout the entire length of the tape. All tapes are standardized so that the actual length is known under various conditions of support, at various temperatures, and under a known amount of tension.

MARKERS

Steel chaining pins are used to mark the end of the tape during the chaining process between two points which are more than a tape length apart. These pins are used only as temporary points. The pins are usually 10 to 14 in. long and a full set consists of 11 pins. Pins are more of a convenience and not a required item of equipment. Road nails or P-K nails are other types of markers used on hard surfaces. These nails may be marked with keel, pencil, or even spray paint. A short piece of adhesive tape may also be stuck to the pavement or hard, smooth surface, and a point marked on the tape with a pencil or ball point pen. More commonly, a wooden stake or hub, usually 2 in. x 2 in. x 18 or 24 in. in length, is driven into the ground to mark the more permanent points along a surveyed line.

RANGE POLES

Range poles are wooden, metal, or fiberglass poles usually 8 ft in length. These poles are used as temporary markers to indicate the location of a point or the direction of a line which is required to be seen from a relatively long distance. Range poles are painted with alternate bands of one foot red and white sections. The range pole is not used to provide a precise indicator of line, especially in a short distance. They are intended to provide a foresight or backsight which does not require constant attendance.

PLUMB BOBS

A plumb bob (Figure 4-2) is a brass weight with a pointed end which is suspended by a string 5 to 6 ft long. The plumb bob is used to vertically project a point and may be used at one or both ends of the tape to keep the tape horizontal. The technique required for the proper use of a plumb bob is learned through considerable field experience. Where to stand with relation to the line, how to stand so that the plumb bob is stable and steady, and how to keep the proper tension on the tape at the same time is only learned through practice.

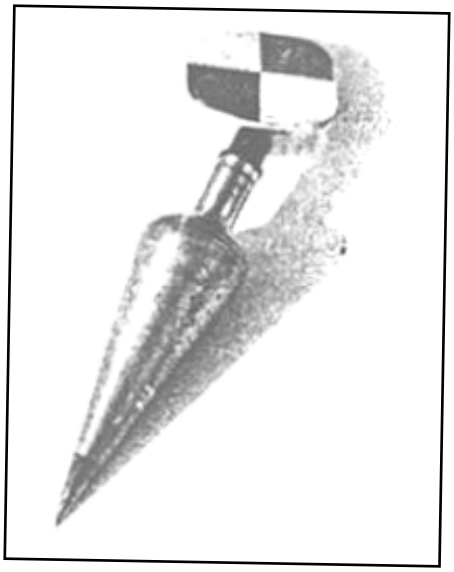

Figure 4-2. Plumb Bob

HAND LEVELS

The hand level (Figure 4-3) is a small sight tube of low magnification with a bubble level which may be held in the hand. This level may provide a level line of sight over a short distance and may be used to help accurately determine how much one end of the tape is raised to make the tape horizontal. The hand level is never used to determine the elevation of the top of a stake or even some significant ground elevation. The hand level may be used, however, to check the slope of a fill section and set slope stakes. Both of these procedures require little accuracy. If some point of known elevation is handy, the hand level is a very convenient tool for checking or setting soil grades.

Figure 4-3. Hand Level

PROCEDURE

TAPING OVER SMOOTH, LEVEL GROUND

When the ground is fairly smooth and the ground cover vegetation is light and low, the effort required to measure the distance between two points or to set a point ahead of some required distance is very minimal. Careful taping under these conditions by two experienced individuals results in measurements with the precision of one in five thousandths.

There is a definite procedure to be followed in measuring the distance between two points. The person moving ahead or away from the instrument is called the head chainman. The head chainman takes the zero end of the tape or the end of the tape with the graduated foot, and moves on the line toward the distance point. The person remaining behind to hold the end of the tape on the last established point of beginning is called the rear chainman. The rear chainman does not handle the tape as the head chainman moves ahead. During this time, the rear chainman is responsible for keeping the head chainman on line. The rear chainman also watches the movement of the tape to make sure the tape does not snag or kink which could result in damage to the tape. As the hundred foot end of the tape reaches the rear chainman, he should call ahead to the head chainman to tell him he has gone far enough. This warning, generally, is one word such as CHAIN, GOOD, or STOP. The next step requires a general lining-in procedure. Both chainmen check to make sure that the tape is straight, not twisted, and is more or less on line. Again, the major responsibility of the rear chainman is to observe that the tape is not twisted and there is a continuous reflection of light off the surface. If the reflection is broken, there is a twist in the tape. Obviously, the graduations on the face of the tape should be up at both ends. After the

initial lining-in, both rear and head chainmen kneel off the line and face the line with their bodies parallel to the proposed survey line. Both the head and rear chainman are on the side of the tape so that the hand holding the tape is at the extreme end of the tape. When the tape is straight and on line the rear chainman holds the 100 ft mark on the established point.

The head chainman repositions himself so that he is perpendicular to the line, facing the instrument. The tape is pulled taut with a tension of 10 to 15 pounds. The stake or pin are held upright with the zero mark of the tape centered and low on the stake or pin. The instrument operator tells the head chainman to move the stake left or right to come precisely on line. As the stake is moved on line, the instrument operator continues to check that the tape is straight, taut, and at the proper distance. The rear chainman continues to hold steady his mark with the end of the tape. He calls out to the head chainman while watching his mark, saying GOOD, SET, or MARK, as long as the stake or pin is steady on the mark. When the instrument operator indicates the stake is exactly on line and the rear chainman continues to call that all is good, the head chainman sets his pin or begins to drive his stake. If he is driving a 2 in. x 2 in. wooden stake, some technique and experience is necessary to do a proper job with the least amount of effort. After a few blows, the head chainman setting the stake looks at the instrument operator to verify that the stake is being driven straight. The zero mark falls near the center of the stake as the stake is being driven. When the stake is solidly set, at least ¾ of the length in the ground, the top of the stake is marked for line and distance. A point is then established on the stake by the head chainman. A check of the point is made. If the head chainman is satisfied with the point, he says ALL RIGHT or GOOD. The rear chainman releases the 100 ft end of the tape, and the head chainman takes the zero end of the tape, moves forward as before, and repeats the process.

If an odd distance is to be measured between two points, the head chainman holds the zero end of the tape approximately on the forward point. The rear chainman pulls the tape somewhat taut and checks to see where the rear point intersects the tape. The tape is then pulled so that the smaller graduation of the tape is on the point, and then this number is called out to the head chainman. The head chainman then pulls the tape with the proper tension and reads the fine division of the extra foot on the tape. The graduation held by the rear chainman on the new point added to the graduation read by the head chainman on the forward point gives the measurement between the two points in hundredths of a foot.

Example:

1) The distance between two stakes is less than 100 ft.

2) The tape is pulled so that the head chainman is holding zero very close to the forward point, and the rear chainman pulls the tape and finds that the point is between the 63 and 64 graduations on the tape.

3) The rear chainman then pulls the tape and holds the 63 mark on the rear point.

4) The rear chainman then calls to the head chainman saying HOLDING 63.

5) Both chainmen check to make sure the tape is straight, not twisted, and pulled taut.

6) The head chainman reads 0.58 on the extra foot.

7) The distance between the two points is 63.58 ft.

TAPING OVER HILLY, SLOPING GROUND

If the ground is not too rough and hilly and in general considered as gently rolling, the taping procedure required would be slightly more difficult than that required for taping on flat ground. If the plumb bob is used to keep the tape horizontal, the procedure is more difficult. If the terrain is very rough and the slopes are steep with considerable undergrowth or vegetation, the chainmen is required to break tape in addition to plumbing the tape. A one hundred foot distance may require the setting of many intermediate points before the full distance is successfully measured. In any case, the head chainman and rear chainman responsibilities and the orientation of the tape remain the same as was used for taping over level ground.

Considerable skill and experience is required to achieve the same level of precision which may be achieved and expected when taping over level ground. The tape is generally unsupported over much of the length when measuring between any two points. The tendency for the tape to sag is very great. There is also a tendency for the head chainman to hold his end too low when going down hill. Patience and technique are very important for this type of taping. If the head chainman is moving down hill toward the forward point and the slope is 5 or 6 ft in a hundred, the full 100 ft may be taped in one measurement. The rear chainman holds the 100 ft mark on the rear established point. The head chainman loops the string of

the plumb bob over the zero mark, letting the plumb bob fall so that the tape is approximately level between the two end points when the bob is a few inches off the ground (Figure 4-4). The head chainman holds the end of the tape at approximately chest or chin level. He should be in a comfortable position, his body perpendicular or parallel to the proposed line, whichever is more comfortable, and his feet spread so that he has a stable base. An up and down motion of the hands prevents the plumb bob from swinging.

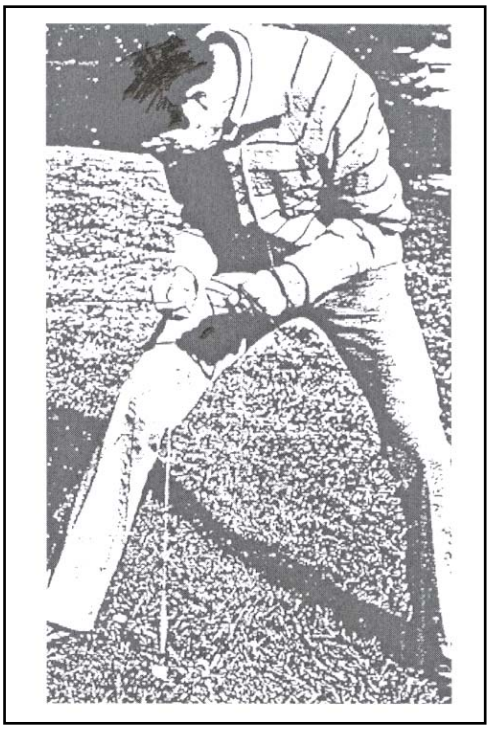

Figure 4-4. Taping Over Hilly Grounds

The rear chainman advises the head chainman of the correct alignment of the tape. The head chainman looks down to see the area where the plumb bob strikes the ground when the tape is on line. He clears this area of loose material and undergrowth before he is ready to set his plumb bob as directed by the instrument operator. The plumb bob is required to be hanging freely an inch or so from the ground with no swing. At this point, the instrument operator gives voice signals so that the head chainman may watch the plumb bob to make sure the plumb bob remains steady as he moves from left to right to bring the plumb bob on line. When the instrument operator determines that the head chainman is on line, he says GOOD and the head chainman sticks the plumb bob into the ground by dropping his hands straight down about 3 to 4 in. The head chainman sets his tape aside, carefully removes the bob, and places the point of stake in the hole made by the plumb bob. He then carefully drives the stake

approximately one-third the length of the stake into the ground, picks up his end of the tape, and with the plumb bob checks the distance and line of the stake. If both are satisfactory to the instrument operator, the head chainman continues to drive the stake into the ground making sure the stake is plumb in both directions. When at least three-fourths the length of the stake is into the ground, the head chainman again picks up the tape with the plumb bob and the stake is marked for distance and line. This point is checked before moving ahead. When the terrain is quite rough, "breaking tape" is the procedure followed to measure the distance.

Breaking tape is the measurement of a line when increments less than 100 ft are measured due to the roughness of the terrain. The tape does the adding of the increments to 100 ft. This is done by having the head chainman pull the zero end of the tape completely along the line down the rugged slope until the 100 ft mark is even with the rear chainman. The tape is left lying on the line in this fashion. With the rear chainman holding the 100 ft mark on the rear point, the head chainman backs up on the tape to a graduation which he can plumb comfortably and under which a stake may be set accurately. He proceeds to plumb, line and place the stake at this point on the line. This procedure is repeated until 100 ft are measured. The tape is not moved ahead until the zero mark is reached. The rear chainman occupies the mark that is just vacated by the head chainman as he moves ahead on the line and down the slope. Figure 4-5 shows how horizontal measurements are obtained on steep slopes by the process of breaking tape

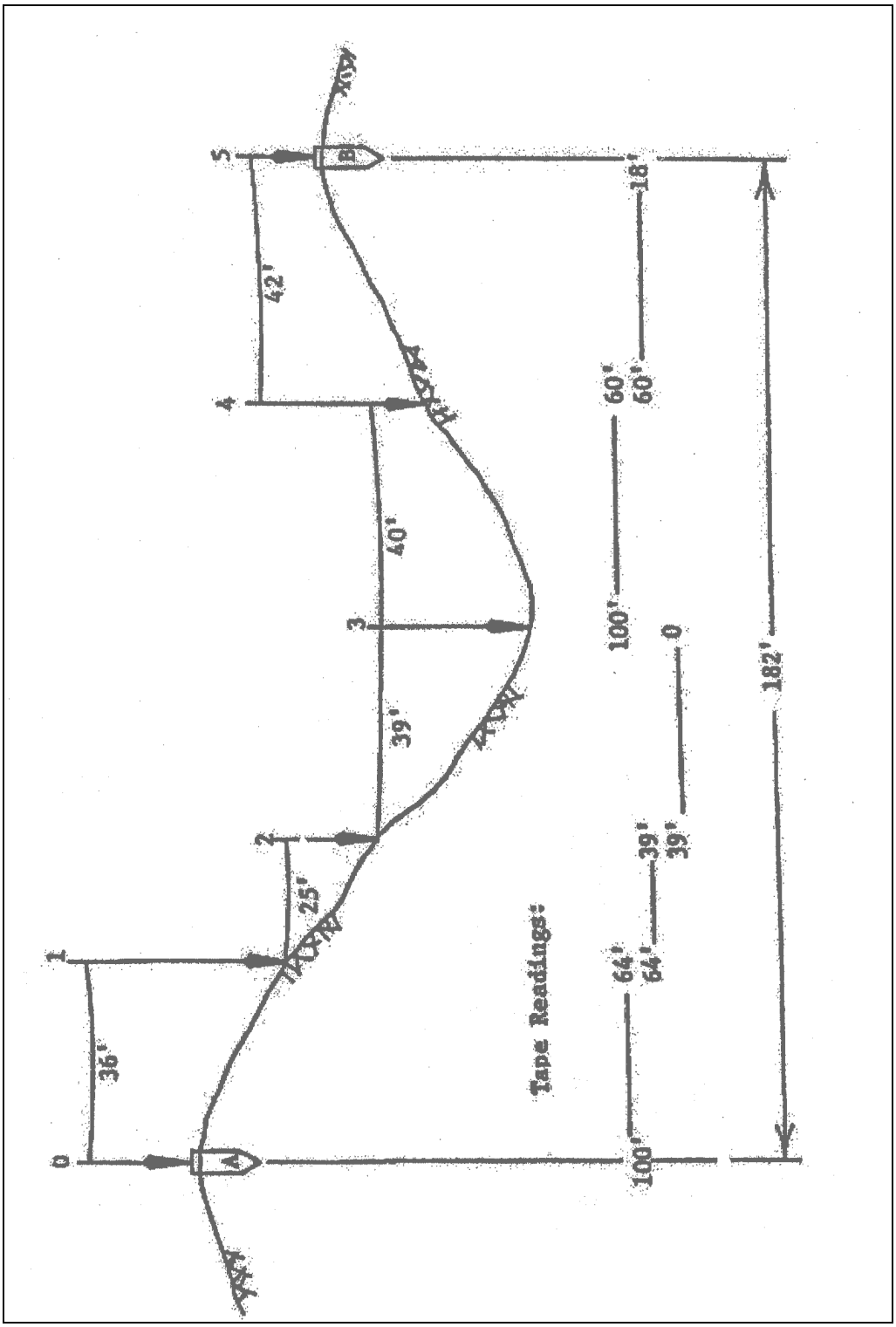

Figure 4-5. Breaking Tape

TAPING ERROR

Error is defined as the difference between the true value and the measured value of a quantity. Errors result from instrument imperfections, personal limitations, and natural conditions affecting the measurement. An error is either systematic or random. A mistake is not considered an error, but is a blunder on the part of the observer such as the failure to record each 100 ft in taping, misreading a tape, forgetting to level the instrument, etc. Errors in taping may also be caused by one or more of the following reasons:

1) The tape is not the standard length. This results in systematic error which may be eliminated by standardizing the tape or comparing the true length of the tape with some permanent standard of length. The tape may be sent to the Bureau of Standards in Washington D.C. for standardization or may be standardized in a local laboratory equipped for this type of work. Generally, errors due to this reason may be offset by varying the amount of tension applied to the tape.

2) Poor alignment of the tape. Both chainmen are required to be constantly aware of the condition of the tape as they move along the line. The instrument operator also helps ensure that the tape is on line over the entire length from point to point. Poor alignment results from sloppy or lazy habits developed by the chainmen. A variable systematic error is produced which may be reduced almost completely if care is exercised in aligning the tape. This is probably the least important of the chaining errors because in 100 ft the error amounts only to 0.005 ft if one end is off line one foot. This type of error tends to make the measured length greater than the true length, therefore, the error is positive.

3) Tape not horizontal. This error produces an effect similar to that due to poor alignment. Once again, this error results from a sloppy procedure and with a little care may be virtually eliminated. Even an experienced chainman probably underestimates the rate of slope. This may be a large source of error and in rough or deceptive terrain, a hand level may eliminate the error.

4) Tape twisted or not straight. When taping through fairly dense undergrowth, when the wind is blowing, over a stubble field, or across a harvested cornfield, keeping all parts of the tape in perfect alignment with both ends is difficult. The error in this case is systematic and variable and has the same effect as that which arises from measuring with a tape that is too short.

5) Human error of observations. There are accidental errors caused by misreading the tape, improper setting of pins and stakes, and errors due to plumbing improperly due to inexperience or sloppy procedure. All accidental errors may be kept to a minimum by exercising care and following proper procedures.

6) Variations in temperature. Materials expand as the temperature rises and contract when the temperature falls. In Indiana the ambient air temperature may vary from 10 or 15° below zero to 100 to 105° F. Daily temperatures may vary from the 40 to 50°F early in the morning to 80 to 90°F by mid-afternoon. These temperature extremes cause the tape to expand and contract. A change in temperature of 15° F will result in a change in length of about 0.01 ft for a 100 ft tape. The formula for the correction for temperature is as follows:

$$C = 0.0000065\ L\ (T_1 - T_2)$$

where:

0.0000065 = coefficient of thermal expansion of steel per 1°F
L = the measured length in feet
T_1 = the temperature of measurement in °F
T_2 = standard temperature of tape in °F (normally 68° F)

7) Variations in tension. A steel tape is elastic and stretches when tension is applied. The amount of pull is most important and is required to be known to make the tape the right length. Again, this type of error is systematic and depends on the methods employed and who is doing the taping. Generally, a pull of 10 pounds is sufficient when the tape is fully supported. A pull of 20 pounds or more is necessary when the tape is unsupported throughout its length. This information is obtained when the tape is standardized.

8) Tape Sag. Error due to sag in the tape is significant if the tape is relatively heavy and unsupported over the length of the tape. This may be a very important consideration when both rear and head chainmen are plumbing over rough ground. The tapes typically used for highway surveying are heavy, and both the head and rear chainmen are required to be constantly aware of the amount of sag in the tape when plumbing. Controlling a plumb bob, when applying a tension of 30 pounds to a 100 ft tape which is fully unsupported, is very difficult. This procedure takes considerable effort and experience to do a good job.