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Title FOREST ROAD LOCATION AND DESIGN IN THE DOUGLAS-FIR REGION

Abstract approved William A. Davies
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The purpose of this thesis is to outline the principles involved in the reconnaissance, survey, and design of forest roads in the Douglas-fir Region.

The reconnaissance survey is the most important element in road location. Poor reconnaissance often results in abandonment of the route at considerable expense.

The ground slope affects the type of reconnaissance employed. In level country alignment controls the location of the road and grade is adapted to the topography to balance excavation and embankment quantities. In sidehill country grade controls the location of the road and alignment is adapted to the topography to balance excavation and embankment quantities.

The reconnaissance survey may be separated into extensive and intensive reconnaissance. The extensive survey is the study of an area or drainage to determine the general location of the route. The intensive reconnaissance is a study of the ground adjacent to the general location of the route. The final selection of a route often involves the comparison of one or more alternatives.

A preliminary survey is conducted along the final reconnaissance line to establish horizontal and vertical control and the topography on either side of the line. The precision desired determines the method of survey employed. The staff compass-tape-abney survey is the most widely used method in the Douglas-fir Region.

The road is designed from the data obtained from the reconnaissance and preliminary surveys. These data are studied graphically using the plan, profile, and cross sections of the route or any combination of these graphic aids. Center line of the road will closely follow the final reconnaissance line if the intensive reconnaissance is thorough. Regardless of the method of design used, the final center line is a compromise between optimum alignment and minimum excavation.

FOREST ROAD LOCATION AND DESIGN IN THE DOUGLAS-FIR REGION

by

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INTRODUCTION

The Douglas-fir Region is a narrow strip of land extending from the summit of the Cascade Mountains westward to the Pacific Ocean. It is bounded on the south by the Calapooyo Mountains in southern Oregon, and it extends north into British Columbia. The total acreage in Washington and Oregon exceeds 35,000,000 acres of which approximately 80 percent is classified as forest land (13, p. 352). The timber is predominantly found in the mountainous areas, and to harvest this timber, roads have been pushed farther back into areas heretofore inaccessible.

In the early days of road building, little if any thought was given to proper location, alignment, or grade. Today, logging engineering plays an important part in the formulation of forest management plans of government agencies and private industry. Greater emphasis is placed on locating the road to serve tomorrow's needs, as well as today's. Higher road construction costs are accepted if they result in lower hauling and maintenance costs.

The purpose of this thesis is to outline some of the basic principles for choosing the best route and for the survey and design of this route. The methods discussed in the following pages are by no means the only methods in use today. Each engineer develops his own methods or modifications through experience and experiment. The method used will depend upon the standard of road desired and the terrain encountered.

THE RECONNAISSANCE SURVEY

Road reconnaissance begins when the forest management and logging plans are evolved. At this time the standards of roads that will serve the drainage are established. Generally, there will be one or two primary or access roads (depending upon the size of the drainage) and a network of secondary roads branching from the primary roads. Factors that determine the standard of a road are average annual haul based upon sustained yield management, maintenance costs, recreational potential of the area, and additional industries that may evolve with the development of the road system.

The primary road follows one of three general courses; along the stream bottom, along the ridge top, or along the sidehill between the stream bottom and ridge top. The final choice must be determined from the field reconnaissance.

Most of the logging will be accomplished from secondary roads and low standard spur roads. A recent study on the Willamette National Forest (9, p. 82-85) indicates that the most efficient road system for logging consists of nearly level, parallel routes spaced at the economic interval from the stream bottom to the ridge top. These are connected by a road climbing at the maximum grade.

Sidehill Reconnaissance

There is a distinct difference in the method of reconnaissance used in sidehill country and that used in flat country. In sidehill country, grade will control the location of center line, and alignment will be adjusted to fit the topography and balance excavation and embankment. The reverse is true in flat country. Alignment will control the location of center line, and grade will be adjusted to balance excavation and embankment. This section will cover the method of reconnaissance employed in sidehill country.

Extensive reconnaissance. The process of extensive reconnaissance begins in the office with maps, aerial photos, and any other available information pertaining to the proposed project and continues in the field until the area through which the route will pass is selected.

Contour maps are useful for studying the general topography, and with them, it is possible to determine whether the average grade is greater or less than the maximum grade for the standard of the road desired. To do this, the difference in elevation between the terminals is divided by the distance between the terminals. It is best to be conservative when calculating the distance. If the road can be built on the maximum grade using this shorter distance, it can be built on a grade less than the maximum, depending upon the actual distance. The difference between maximum grade and the actual grade, called slack grade, is important in avoiding rock, swamps, and in utilizing the various controls located during the reconnaissance survey. If the grade, as computed by using a conservative distance, is greater than the maximum grade authorized for the standard of road, an alternate route or switchbacks may have to be located. If neither of these solutions is feasible, the excess grade will have to be justified.

With a pair of dividers and a contour map, it is possible to sketch a route at the average grade on the map. Divide the contour interval by the average grade. This gives the number of stations required to go from one contour to another. Using the map scale, this distance is set off on the dividers. Set one leg of the dividers on the beginning of the project and swing the other leg of the dividers until it intersects the next contour. A fraction of this distance is used to locate the intersection with the first contour if the beginning of the project lies between two contour lines. The intersection of the grade line and each contour line is located with the dividers, and a line is drawn connecting these points. This does not represent the location of the road, but it does indicate the general area through which the route may pass. Several routes can usually be sketched on the map giving some indication as to which areas should be investigated in the field.

The limits of the roadway between any two control points may be computed after the average grade has been determined as shown below. Assume that the distance between controls is "D" and the difference in elevation between the controls is "E" and the maximum grade for the standard of road is "G". There are three basic routes which may be followed between the controls. First, it may follow the average grade line between the two controls. A second possibility is to go along the maximum grade until the difference in elevation at "P" is equal to "E" and then continue on a level grade to the other control. The other possibility is to start out level and continue to "B" from which the other control may be reached on the maximum grade. The last two routes form a parallelogram. On long projects, the area bounded by this parallelogram is large and will involve considerable walking and studying before the final route may be selected. If the average grade route and the extremes are sketched on the contour map with dividers, the area to be studied can be more clearly defined.

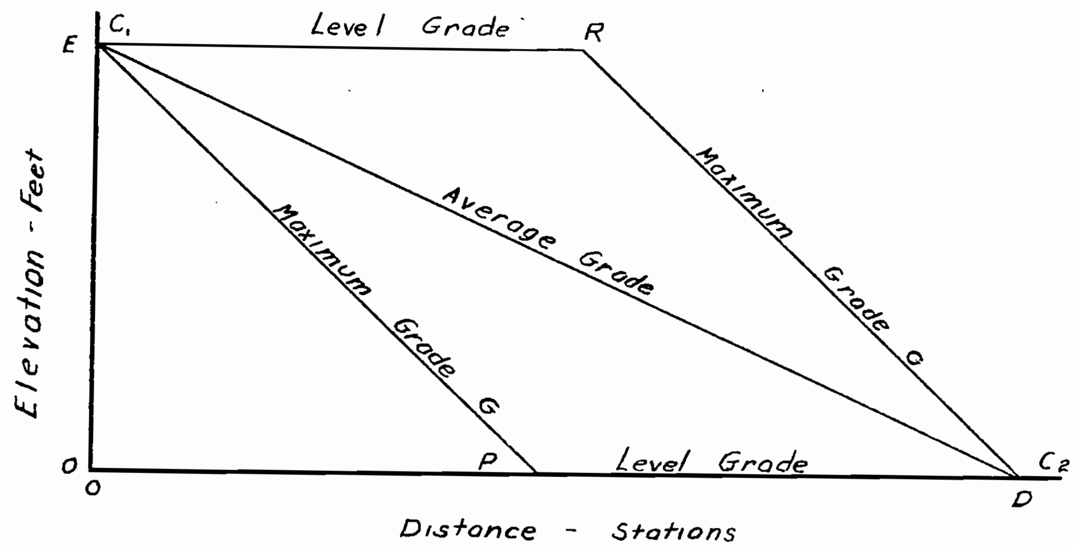


Figure 1. Limits of the Roadway

Aerial photographs are another valuable aid in studying the topography of the area. With the aid of a stereoscope, it is possible to study ridges, draws, rock bluffs, timber density, and species. Although topographic features often stand out quite clearly, they should not be considered controls until they have been investigated in the field. Aerial photos are exaggerated vertically and tend to make the topography appear steeper than it actually is.

With practice and experience, it is possible to obtain relative elevations of the prominent topographic features. With the elevations of these points, it is possible to compute the average grade between them. There will, undoubtedly, be other points located during the field reconnaissance.

The first step in the field work is to become acquainted with the area through which the road will pass. To do this, the engineer should take advantage of any fire lookout towers or exposed vantage points which overlook the area. The process of orientation is relatively simple and involves comparing what is on the ground with what is on the maps and photos. Each ridge and draw seen on the map is located in its natural position as seen from the vantage point. Locating the change in timber type is often easy even at a distance, and this also helps in the orientation.

The next step is to walk through the area on the average grade to become familiar with the terrain. To follow the average grade line, it is necessary to carry a barometer to determine relative elevation and to record pacing. A barometer reading is taken at the beginning of the project, and based upon the average grade, the elevation of a point ten stations from the beginning is computed. The difference in elevation is equal to the average grade times the distance paced, which in this case is ten stations. This value, added to or subtracted from the original reading, gives the grade elevation ten stations from the beginning. A barometer reading is taken every ten stations from the beginning, and the engineer moves up or down hill to the computed elevation.

This is continued over the entire route. Tags may be fastened to a tree every ten stations with the stationing and elevation noted for future reference. Tags should also be used at critical stream crossings, passes, and other features that may be of future interest. The stationing and elevation are also marked on each tag.

Major controls are often located on the first trip through the area, dividing the project into smaller sections. When a rock bluff is encountered, the elevation on top and at the base are recorded because the road, in most cases, will go on top of the bluff or below it. There is no sharp distinction between a rock outcrop and a rock bluff. The standard of the road, rather than the size of the outcrop or bluff, determines whether it must be avoided. Thus, on a lower class road the alignment and/or grade are changed to avoid blasting rock, while on a higher standard road large volumes of rock may be blasted to achieve the desired grade and alignment.

When a prominent draw is encountered, it is desirable to take time to walk up and down the stream bed to locate several possible crossings. Timber types should be noted since the size, species, and location of the timber will affect the clearing and grubbing costs and the location of the road. Possible rock quarry sites should be noted, and rock samples should be collected so that an analysis may be made to determine their suitability for base and surface material. Each time an important topographic feature is noted, it is helpful to locate the point on the map or photos. This gives an accurate location on a map of the route followed in the field, and it also aids in orientation. If funds permit, an aerial view of the area is extremely helpful after the initial field inspection.

Notes should be kept during this initial trip through the area describing what is encountered. They should be as brief as possible without omitting any important information. The notes will generally include stationing, elevation, and a brief description of the feature noted.

After walking through the area and taking general notes, the major topographic features may be plotted on a profile drawing of the route. With the features plotted at their relative elevations along the route, the entire area may be studied to determine which sections or areas need further investigation. The topographic features are analyzed to determine which will be controls and which will not. When the controls have been determined, the grade lines joining them may be drawn on the profile. A sample reconnaissance profile is included in the Appendix.

When there is doubt as to which route to follow, an estimate of construction and hauling costs can be made from the reconnaissance notes. Construction costs are broken down into clearing and grubbing costs, excavation costs, and surfacing costs. Usually, the clearing and grubbing costs and the surfacing costs will not vary appreciably throughout the area so these will be proportional to the length of the road. Excavation costs vary with the volume of excavation, type of excavation, and ground slope.

Hauling costs vary with the distance, grade, alignment, and sight distance. Hauling costs can be obtained from past experience and cost records, or an estimate may be made from compiled tables and graphs (1, p. 40-50). The construction cost or total road cost may be considered as the present value of a terminating series of regular payments. The regular payment may be considered as the annual road cost. On this assumption the annual cost for construction may be computed by the following formula:

$$\text{Annual Road Cost} = \frac{\text{Total Road Cost}\,[p(1 + p)^n]}{(1 + p)^n - 1}$$

p = interest rate

n = number of years before abandonment or major reconstruction is necessary

The sum of the annual hauling cost, annual maintenance cost, and annual road cost are added together to give the total annual cost of the route. The total annual cost is computed for each alternate route, and the route with the lowest total annual cost is the most economical route.

There are other factors that cannot be reduced to a cost basis. Each route should be compared from the standpoint of the overall road system for the drainage or drainages, serving the logging needs of the drainage, fire protection offered, snow removal and subgrade drainage, soil erosion and stream siltation, and rights-of-way transactions. Rights-of-way transactions often involve monetary compensation and commonly reciprocal rights-of-way. Many companies will avoid such transactions, if possible, by seeking an alternate route.

All these factors will affect the final decision as to which route to follow. If a decision still cannot be reached, each route must be tagged and more detailed estimates based upon intensive reconnaissance must be made.

Intensive reconnaissance. Up to this point, the reconnaissance has been concerned with determining the area through which the route will pass. It is now necessary to adjust and fit the route to the topography of the area. This is known as the intensive reconnaissance. When performing this reconnaissance, a tag line is run between selected control points. The tag line is studied and adjusted until it represents the desired route.

The tag line is run at the selected grades using an abney and pacing and is marked with tags fastened to a tree at a point eye level above grade. Although eye level varies with the individual, it generally is not an important discrepancy. The average eye height is 5½ feet and this may be used as a constant for the job. Thus, a tag is considered 5½ feet above grade. Any exceptions should be noted on the tag. Stationing need not be placed on each tag but should be placed at least every two to four stations and at every prominent topographic feature. There is no specific or optimum spacing of tags, but they should be close enough on curves to approximately define the curvature.

Ground slopes, in general, are steeper adjacent to creeks and streams. In some cases, this is not a major factor, but steep sidehill construction should be avoided whenever it is practical. In order to reduce the length of steep sidehill construction, the road should descend into the creek on a minus grade, cross the creek, and then ascend on the other side of the creek on a positive grade. Consider the situation shown in the figure below. Suppose point A is on the point of the ridge where the side slopes are beginning to increase. If point A is 150 feet above the creek, and the grade of the creek is -20 percent and the grade of the road is +5 percent, the road will intersect the creek at point B, 10 stations from point A.

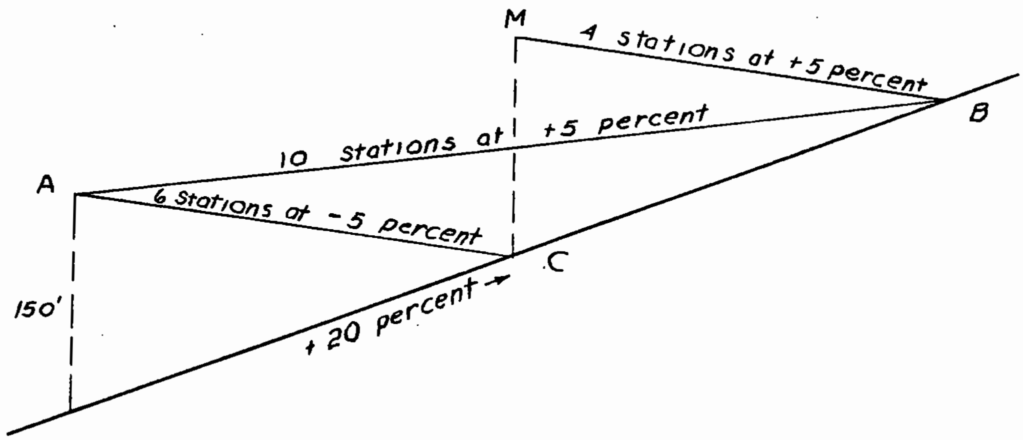


Figure 2. Adjusting the Tag Line

Suppose at point A the grade of the road is -5 percent. Then the road will intersect the creek at point C, six stations from point A. It is evident that the descending grade will intersect the creek in the shortest distance. In order to go from point C to point D (not shown), which lies along the point of the ridge on the other side of the creek, an ascending grade is used. This method can only be used when there is sufficient slack grade between point A and the next control. This can be demonstrated by continuing the +5 percent grade from point B for four stations to point M which is directly uphill from point C. The difference in elevation between points M and C is equal to (5 x 10) + (5 x 4) - (-5 x 6), or 100 feet. In order to have the road pass through point C, a +5 percent line between point A and the next control must either have 100 feet of slack elevation, or a grade in excess of +5 percent must be used.

Sometimes the average grade line goes through rough, undesirable terrain. When it becomes apparent that this line is not practical, the route is abandoned by rodding up or down hill to by-pass the rough terrain. The point at which the route is abandoned is referenced on the ground indicating the stationing, grade of the line up to the referenced point, and the vertical distance up or down to the new line. The point where the grade line resumes is also referenced indicating the stationing, the vertical distance set up or down, and the grade of the new line. Grade changes are also referenced to indicate the station at which the grade changes, the grade up to the reference, and the new grade. The most common form of reference is a tag fastened to a tree. The information on the tag should also be recorded in the notes.

Notes taken along the tag line should include all topographic features above and below the line that may affect the location of the road. Other features that should be noted are the location of possible quarry sites, timber types, and average ground slopes above and below. These notes will duplicate, to an extent, the notes taken during the extensive reconnaissance but they should be more detailed.

When the tag line is completed, a profile is drawn and the topographic features above and below the line are plotted in their respective positions. The profile is studied and any necessary grade changes can be determined and drawn on the profile. If it was necessary to set up or down along the route, a new grade line must be computed or scaled from the profile and run in the field. A sample abney profile is included in the Appendix.

Any changes in the grade line drawn on the profile must be checked in the field to determine if they fit the topography better than the original line. This is one phase of adjusting the tag line. Another phase consists of adjusting the tag line in draws and at the point of ridges so that the line more closely follows the curvature desired at these points. It may be noted that the first case involves adjusting grade, while the second involves adjusting alignment.

Since there will usually be two or more tag lines run before the final route is accepted, each line should have a separate marking. Tags along the first line may be marked "A" and those on the next line "B", and so on for as many lines as are necessary. The lines can then be referred to as the "A" line or the "B" line; and when a tag line is encountered in the field, it can be identified by the letter on the tags. Other markers that are commonly used are colored tags, paint, blazes, strips of cloth, and colored plastic tape.

When the average grade line between two major controls is greater than the maximum for the standard of the road, additional distance may be gained by taking advantage of spur ridges and side canyons or by locating switchbacks. A switchback is a change in direction on the same slope with a corresponding change of sidehill. Thus, if the uphill slope is to the right of the line at the PC, it will be to the left of the line at the PT. Although switchbacks are best suited for slopes below 30 percent, it is up to the engineer to determine whether it is practical to attempt a switchback on steeper slopes.

The most common form of switchback has a central angle very close to 180 degrees. Assuming that the central angle is 180 degrees, the difference in elevation between the PC and PT may be computed in the following manner. If the average ground slope in percent is "s" and the radius of the switchback in stations is "r" and the grade of the road around the switchback in percent is "g" and the length of the switchback in stations is "l", the following relations may be computed. The difference in ground elevation between the PC and PT = 2rs. The difference in elevation between the PC and the PT along the switchback equals gl. The sum of cut and fill at the PC and PT is equal to 2rs - gl. This means that if the center line cut at the PC is zero and the grade of the road is (plus, minus), the (cut, fill) at the PT will be 2rs - gl. In actual practice there would be cut at one of the points and fill at the other. The diagram below shows the roadway cross sections of the PC and PT of a switchback. The central angle is 180 degrees.

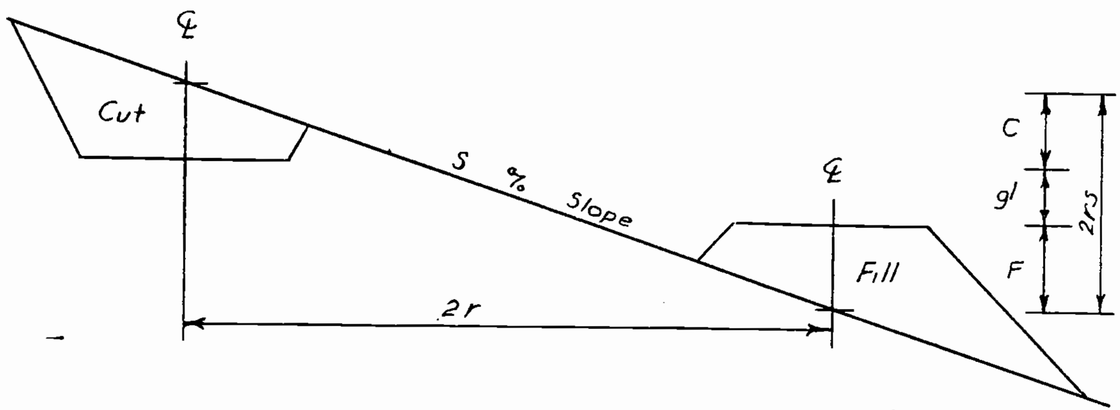


Figure 3. Cut and Fill on Switchbacks

r = radius of switchback in stations

l = length of switchback in stations

g = grade of switchback in percent

s = slope of ground in percent

C = cut at C_L in feet

F = fill at C_L in feet

Then:

$$C + F = 2rs - gl$$

Since the length of the switchback "l" corresponds to the length of a semicircle with a radius "r", the term "gl" may be replaced by "πrg". For rapid field calculations, "π" may be considered equal to 3 and the term becomes "3rg". Factoring out "r" leaves:

$$C + F = r(2s - 3g)$$

If the central angle varies considerably from 180 degrees, the term "2r" must be replaced by the long chord of the curve. The long chord of a curve equals 2r times (sine $\frac{I}{2}$), where "I" is the central angle of the curve. The formula may be rewritten:

$$C + F = 2sr\ (\text{sine}\ \frac{I}{2}) - gl$$

Some proposed roads may lie adjacent to trails. This is a distinct advantage because the trail can be used as the control line. An abney traverse is made over the trail and the profile is drawn. Working from this profile, controls above and below the trail can be noted and tied in accurately. In running a trail traverse, abney shots are taken every 100 feet. The abney reading then gives the difference in elevation between the stations. This traverse can be run almost as fast as the men can walk, and several miles may be covered in a day.

An inspection of the profile will enable the engineer to eliminate certain sections of the trail. Additional tag lines must be run to cover the discarded sections of the trail. The main disadvantage of a trail control line is that the engineer may rely too heavily on the trail and overlook important controls.

A similar method can be used when an existing road is to be improved or when the proposed road follows part of an old road. An abney traverse is run in the same manner as with the trail traverse, and a profile is drawn. Most changes in alignment can readily be seen by walking or driving along the road. Grade changes are not as apparent and must be determined from the profile. By driving along the road and studying the profile, the engineer can decide what sections of the road can be retained and which sections are to be abandoned. Again, with an existing road, the engineer may tend to overlook important controls.

Level Reconnaissance

Flat ground poses many more problems than exist on sidehill reconnaissance. Alignment controls the final selection of the route, and grade is adjusted to fit this location. There are usually no prominent topographic features. Visibility is poor, making it difficult to get oriented even with maps and aerial photos. It is difficult to locate points on either maps or aerial photos. With no prominent topographic features, there are no major controls. The road may lie anywhere within the limits of the maximum grade, and on flat ground this covers a wide area. Grade lines are meaningless, as they meander aimlessly over the area. All these factors make it necessary to employ another method of field reconnaissance to locate the most desirable route.

Extensive reconnaissance. Extensive reconnaissance in level terrain is concerned with establishing horizontal control, rather than vertical control as in the case of sidehill reconnaissance. This is accomplished by determining from a map the bearing of the tangent joining the two terminals and running this line in the field with a hand compass and pacing. Tags are placed along this line so that the line may be referred to in the future. Notes will usually be brief because there is little to note except timber types and possibly swamps. Sometimes it is impractical to run a single tangent between the terminals. Such is the case if a lake or swamp lies along the line joining the terminals. When an obstacle is encountered, the line is run around it using measured bearings rather than following contours. When the bearing of the control line is changed, a reference point is set indicating the stationing, the bearing up to the reference, and the new bearing. This information is also recorded in the notes. Any long sections of excessive grade should be included in the notes. Small, swampy areas need not be avoided with the control line, but it is important to record the distance left and right of the line to the edge of the swamp.

When the control line is completed, a plan is drawn and any features noted in the field are located on the plan. This plan is the base map or control map for the intensive reconnaissance.

Intensive reconnaissance. The next step is to study the area on either side of the control line to locate possible control points. This involves considerable walking and can be accomplished by walking parallel routes on either side of the control line, or by meandering back and forth on either side of the line. In either case, any control points located should be tied to the control line. When the area has been thoroughly studied in the field, the control points are plotted on the plan. The plan is studied and the desired route is selected. This route is then located and tagged in the field, using a compass and pacing. Grade readings may be taken when excessive grade is encountered. This route is adjusted to eliminate any excessive grade and to improve alignment. If the route meets the desired specifications and appears to be the most economical, the preliminary survey may commence. If there are two widely separated routes of seemingly equal desirability, each should be surveyed and perhaps designed to determine the final route. If there are two or more routes close together, it would be best to survey the most direct route and measure the topography 300 feet on either side of the line. This will give ample room to move center line while designing.

Before spending too much time on the field reconnaissance, the engineer should give serious thought to making a topographic map of the area with two or five foot contours. The added time spent on the mapping may more than pay for itself in time saved in the intensive reconnaissance and preliminary survey.

THE PRELIMINARY SURVEY

The purpose of the preliminary survey is to establish accurate horizontal and vertical control over the selected tag line. This may be accomplished either by using a transit, tape, level, and level rod, or by using a staff compass, tape, percent abney, hand level, and level rod. The transit survey is more accurate (1/3000 to 1/5000), but it is much slower than the compass survey. For surveys involving numerous rights-of-way problems and surveys in flat ground where it is desirable to employ long tangents, the transit is more practical. However, on ordinary logging roads where there are few or no rights-of-way involved and an accuracy of 1/300 is sufficient, the compass survey is more practical since it is faster and requires fewer personnel than the transit survey. For a discussion of the transit survey, the reader is referred to any standard surveying text.

Horizontal Control

A compass preliminary survey can be run by two men, but it is faster and more desirable to use three or four men. If the survey is run by two men, they should set stakes and brush the line one day and go back and survey that portion of the line the next day. With a three or four man party, the brushing and surveying may proceed simultaneously.

Stakes should be set along the tag line every 100 feet along tangents and every 25 to 50 feet along curves. These are arbitrary maximum distances between stakes. A more realistic method is to place a stake wherever it is needed to define a change in alignment, topography along the line, or topography to either side of the line.

Bearings. A compass bearing is taken at each turning point. These readings should be taken to the nearest one-fourth degree. Since there is always a possibility of local attraction, backsights should be read at each stake. This gives the same effect as turning angles. Some engineers set the compass on an even degree and have the head chainman move the stake in line. This makes it easier to plot the traverse.

Distance. Distances are measured with a tape 100 to 500 feet in length. The 200-foot tape is probably the most commonly used in the Douglas-fir Region. Level taping is slow and cumbersome with this type of survey because of the steep topography encountered. The slope distance and the percentage of slope are measured; and with the aid of slope correction tables, the true horizontal distance is determined. Calder's (2, p. 4-11) slope tables, or other similar tables, may be used. To make plotting easier the stake may be moved ahead or back to the nearest even foot. Thus, if the slope distance is 57 feet and the correction due to slope is 0.7 feet, the horizontal distance is 56.3 feet. The stake can be moved ahead 0.7 feet, making the horizontal distance 57.0 feet.

Vertical Control

There are two common methods of securing vertical control. The difference in elevation between two stations can be computed from the slope distance and the percent slope, or it can be determined by using a hand level and a level rod.

Hand level and rod elevations. The hand level and rod-method involves a separate trip over the line but gives more accurate results than the abney elevations. The hand level may be steadied by supporting it in the crotch of a forked stick. Rod readings are taken at every P-stake and at any spot where topography is needed. The rod should be read to the nearest 0.1 feet. It is not necessary to use every stake as a turning point. Instead, turning points may be selected so that after the height of the instrument (HI) has been established, rod readings may be taken on several stakes before selecting a new turning point. Bench marks should be set every five to ten stations to serve as check points during the location survey. Before rodding down into a deep draw, a bench mark may be set. When the other side of the draw is reached, a sight is made on the bench mark to eliminate the possibility of making an error in the draw. All bench marks should be referenced on the ground and recorded in the notes.

Abney elevations. This method is rapid and involves no additional time or effort since an abney reading is necessary to convert slope distance to horizontal distance.

To eliminate the possibility of errors in reading, both the head chainman and the instrument man take abney readings. It is important that each man sights on a part of the other person's body that is the same height above the ground as his own eye. To determine what spot to sight on, the two men should stand on level ground about 10 feet apart with their abneys on zero and sight on each other. This is the spot they will sight on when they are working together. When measuring the distance between two stakes, it is equally important that the men hold the tape the same distance from the ground at each end so that the tape is parallel to the abney sight. Both men should keep notes and each night these notes should be compared. Any discrepancies may be checked in the field the next day. Discrepancies of 0.5 percent are within the tolerance of an abney and may be ignored.

The abney reading gives the rise in feet for 100 feet of horizontal distance. The difference in elevation between two stations can be found by multiplying the horizontal distance in stations by the grade in percent. Most errors with this method involve the wrong numerical sign, rather than an error in reading the abney. This is the reason for having the head chainman keep a separate set of notes.

Since 0.25 percent is the approximate limit of accuracy for adjusting an abney, each 100-foot sighting can result in an error of ± 0.25 feet. This error is cumulative. The abney may be read to the nearest 0.50 percent and can result in an error of ± 0.50 feet per 100-foot sighting. In a mile, the error due to adjustment is ± 0.25 times 52.8 or ± 13.2 feet. If 53 readings are taken per mile (approximately 100 feet per sighting), an error of $\pm 0.50\sqrt{53}$, or ± 3.6 feet may be expected. The sum of these two probable errors is ± 16.8 feet per mile. When hand levels are run over a survey that already has abney elevations, this point is easily demonstrated. If a hand level is used and read to the nearest 0.1 foot, the probable error will be approximately $\pm 0.10\sqrt{53}$, or ± 0.7 feet (7, p. 31).

The abney elevations also can be used as a check on the hand level elevations. As mentioned previously, the turning points for the hand level survey are selected so that rod readings may be observed on several stakes from one turning point. If the rod was read incorrectly at one of the intermediate stakes, there would be no way to detect this error without the abney elevations until the location survey. Such an error will have adverse effects if the road is designed on maximum grade, or if the ground slopes in the area are too steep to support fill.

Topography

The final center line will not exactly follow the P-line. At some points it may be uphill and at others it may be downhill. Since there is no way of knowing the exact location of center line when the P-line survey is run, there must be some information of the topography above and below the P-line. This is accomplished with a hand level, a level rod, and a tape, or by using an abney and tape or pacing.

Hand level topography. The hand level method is best adapted to flat or moderately sloping terrain with numerous changes in slope. The distance is measured at right angles to the P-line, or along the bisection of the angle at the turning points to the important breaks in topography. Rod readings are taken using the hand level at these points. A strip 100 feet wide on either side of the P-line is usually sufficient. The HI is subtracted from each rod reading to give the difference in elevation between the P-stake and the break in topography.

Abney topography. In steep country an abney and tape or pacing is more practical. One man stands at the P-stake with an abney, while the other man takes the end of the tape and walks out to the break in topography. The man at the P-stake takes an abney reading and reads the slope distance. The slope distance is reduced to horizontal distance, and it is recorded in the notes along with the percent of slope.

A more common method is to take abney sights and pace out to any major break in topography within 50 feet of the P-line. Topography beyond the first 50 feet is not usually critical if the reconnaissance was thorough. When using this method, it is difficult to get an accurate slope reading because there is no target to shoot at and eye level must be guessed. However, even an error of five percent in the slope reading will not affect the design or earthwork quantities appreciably. This method is fast and requires only one man to measure and record the topography.

Reference Points

In many cases the P-line survey is completed long before the road is designed and constructed. In order to relocate the line, permanent references should be set. The easiest reference is a metal tag stapled to a tree facing the P-stake with the station of the P-stake being referenced, the difference in elevation between the reference and the stake, and the distance from the reference to the P-stake. A more permanent reference is a bench chopped into a tree with the exposed face facing the P-stake. The information written on the reference point is also recorded in the notes along with the size and species of the tree. Since only one reference point is set at any stake, it is important that the reference be as close to the stake as possible to reduce the error in relocating a lost stake. References made on Douglas-fir, true fir, spruce, and pine have a tendency to pitch over or mildew and make it difficult to read the reference data. When referencing on these trees, the information should also be scribed on a metal tag and fastened to the tree. References should be set every three or four stations.

Small trees, up to six inches d.b.h., can be used as P-stakes. The advantage of using trees is that they are permanent and references need not be set. The disadvantage of using trees is that the compass must be set up along side of the tree, and in sighting back or ahead, the cross-hair must sight on a point that is the same distance from the stake as the compass is from the tree. It is difficult to judge this distance accurately and errors may arise. Another disadvantage is that trees cannot be moved back or ahead to an even foot, and a correction must be made on the next stake. Metal tags should be used on any tree which is likely to pitch over or mildew.

On steep sidehills there is often considerable difference in elevation between the uphill and downhill side of the stake. In order to relocate grade when the slope stakes are set, grade must be referenced on the P-stake. This can be done by making a distinct mark on the stake and recording, on the stake, the elevation of the mark above grade.

Notes

Each individual will devise his own method of note keeping, but essentially, the data recorded will be the same regardless of the method used. This includes bearing and distance between stakes, the stationing of the stakes, the abney reading, hand level elevations if used, and some type of topography notes. The left hand page is used for recording the data, and the right hand page is used to add any descriptive information to clarify or explain the data recorded. This information is quite useful when designing center line. Besides being accurate, the notes must be neat so that any person can pick them up and interpret them. A sample of the notes used by the Gifford Pinchot National Forest is included in the Appendix.

THE ROAD DESIGN

Before the design work can begin, certain criteria must be reviewed. Maximum favorable and adverse grade, width of road, and alignment are determined during the formulation of the logging and forest management plans. Such factors as slash disposal and clearing specifications should be determined during the field reconnaissance or preliminary survey, since they depend not only on the standard of road, but also on the size and species of timber. Two other factors of prime importance that should be considered before the design begins are the type of equipment to be used and the allowance to be made for shrinkage and loss in earthwork computations. Shrinkage factors will be discussed later in connection with earthwork computations.

Plotting Data

When the field work is finished, the survey data must be interpreted so that it may be studied to determine the location of center line. Three graphic aids are used to interpret and study the data. These are the P-line plan, P-line profile, and cross sections. A fourth graphic aid, the mass diagram, will also be included in this paper. This diagram is plotted and studied after the center line has been located on the plan.

P-line plan. The P-line plan is a graphic representation of the horizontal control of the P-line. The scale used for plotting the P-line plan is generally one inch equals 100 feet of horizontal distance. The P-line plan may be plotted by coordinates, with a drafting machine, or with a protractor. The use of coordinates usually results in plotting accuracy greater than the accuracy of the field work. Use of the drafting machine or a protractor often give rise to a constant error. Thus, if one course is plotted wrong, all subsequent courses will be in the wrong position even though they will be correct relative to each other. On long surveys drafting errors may be avoided by computing coordinates and plotting points about every one-fourth mile along the P-line. Between these points, the traverse may be plotted with a drafting machine. This way no error can accumulate for more than one-fourth mile. The coordinates act as a check on the plotting; and the plotting in turn acts as a check upon the coordinates. Lines at right angles to the P-line or bisecting the angles at the turning points may be drawn in lightly. These lines represent places where topography was taken and are used as guides for measuring the offset from the P-stake. Other features that should appear on the plan are streams, rock outcrops that might affect the alignment, section corners, A device used in connection with the cross sections is a roadway template. The template is cut from acetate or similar material and represents the roadway perpendicular to the center line. There are three roadway sections: the through cut, the through fill, and the sidehill section. Each of these may be further modified by changing the base, the back slope, or the fill slope. If the template is cut to represent a sidehill section, it may also be used for through cut and through fill sections by turning it over. A separate template must be cut for each roadway width and combination of back slopes and fill slopes.

Center Line Design

In order to explain the procedure of center line design, a short section of road will be designed based upon the P-line notes in the Appendix.

The road used as an example in this paper has a subgrade width of 20 feet with three additional feet allowed for a ditch. This is, for all practical purposes, equivalent to the U. S. Forest Service EE standard road, which is considered a one lane road. Back slopes and fill slopes will be 1:1 and 1 1/2:1 respectively unless otherwise indicated. A shrinkage factor of 25 percent will be used for earthwork computations, and the road will be built with a bulldozer having a freehaul distance of 200 feet. The timber is being hauled uphill to the road junction at station 0 + 00.

The P-line plan, P-line profile, and cross sections for the example are shown in Figures 4, 5, 6, and 7. A turnout is desired on the right side of the road in the vicinity of P 2 + 91 and P 3 + 60. Tentative balance points for excavation and embankment are desired near P 2 + 00 and P 5 + 00. The road design and earthwork quantity sheets used (Figures 8 and 16) are standard U. S. Forest Service Region Six forms. They were used because they were readily available. Other forms could have been used to achieve the same results.

<u>Trial grade line</u>. After the plotting is completed, the next step is to draw the trial grade line on the profile. It is important to review an important point discussed in the first section of this paper.

On steep slopes, grade is the controlling factor, and center line is adjusted to fit the topography. The tag line was run in the field between controls and the P-line accurately defined this line. The trial grade line should be drawn on the P-line profile between those same controls. It is not necessary to balance excavation and embankment with the trial grade line. This can be done by adjusting center line to fit the topography and grade line.

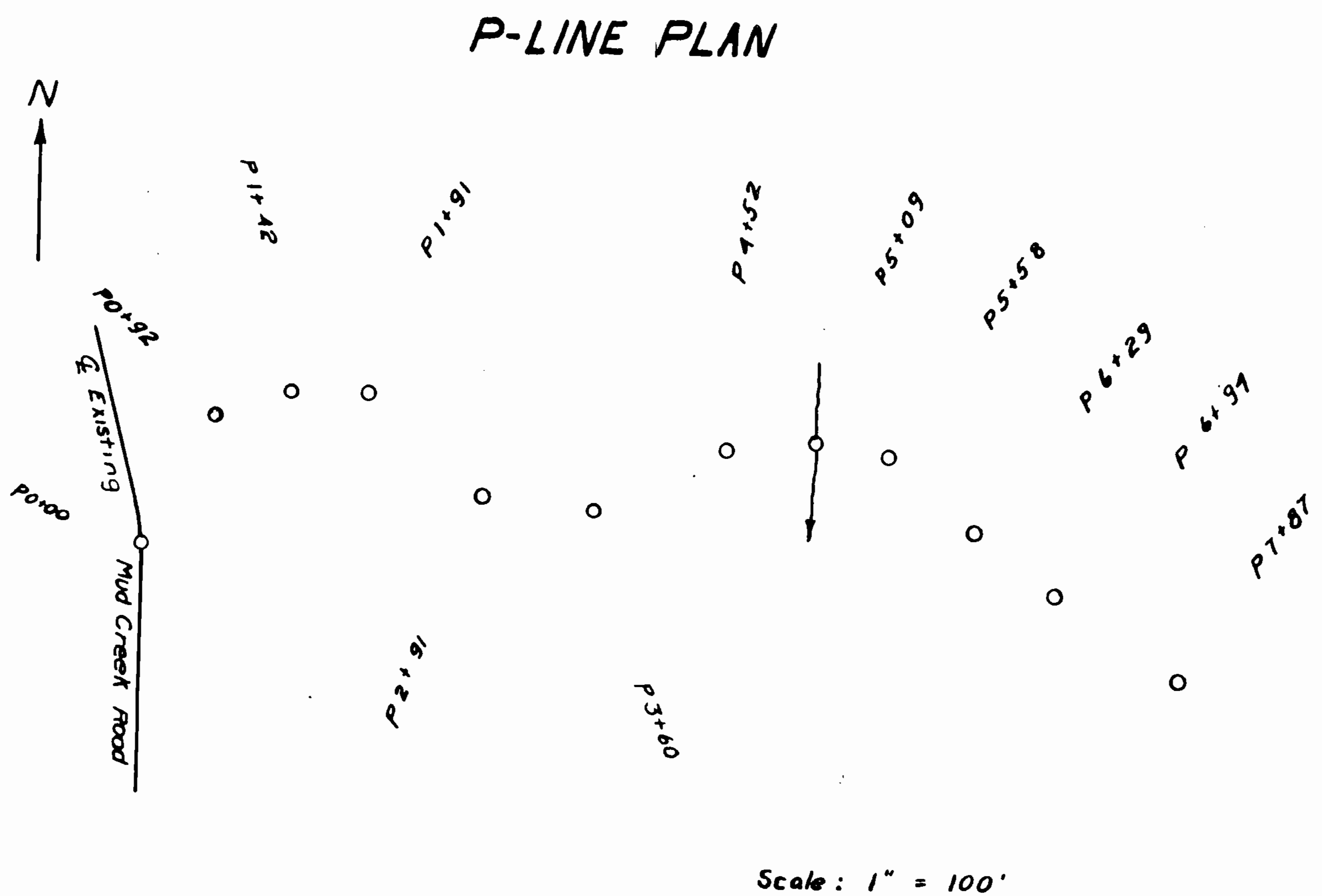

P-LINE PLAN
N
P0+00
P0+92
℄ Existing
Mud Creek Road
P1+42
P1+91
P2+91
P3+60
P4+52
P5+09
P5+58
P6+29
P6+91
P7+87
Scale: 1" = 100'

Figure 4.

P-LINE PROFILE & TRIAL GRADE

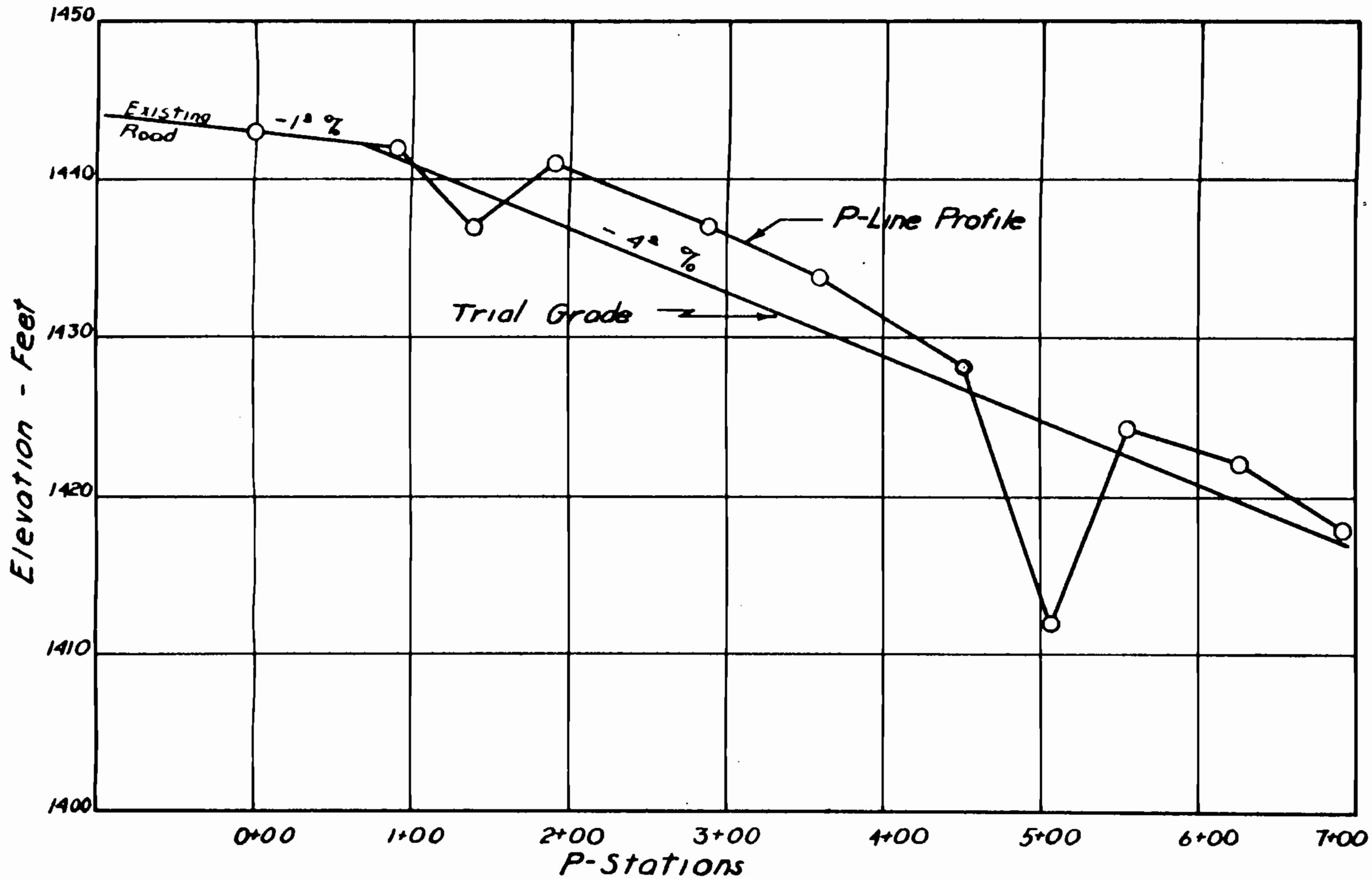


Figure 5.

CROSS SECTIONS

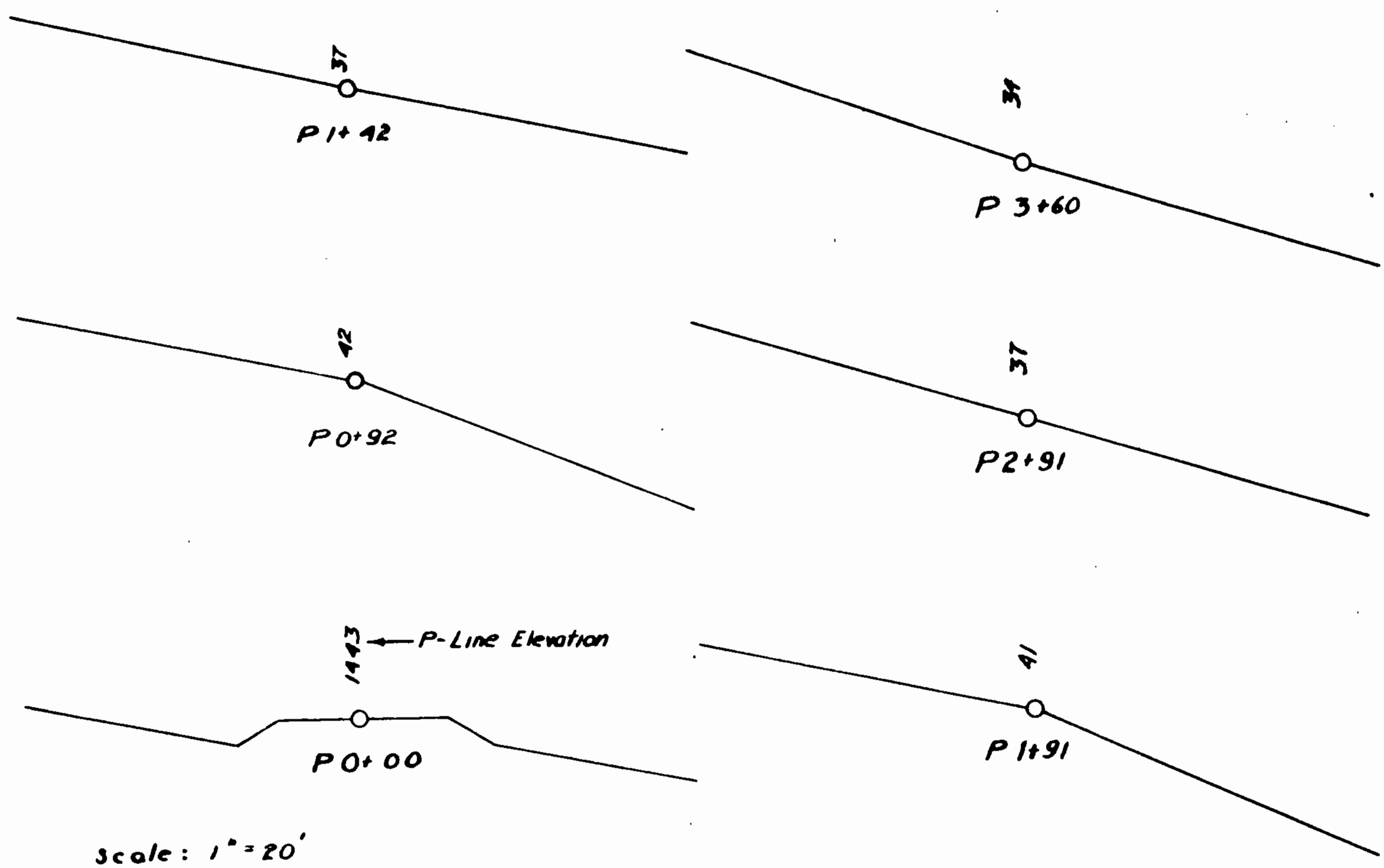


Figure 6.

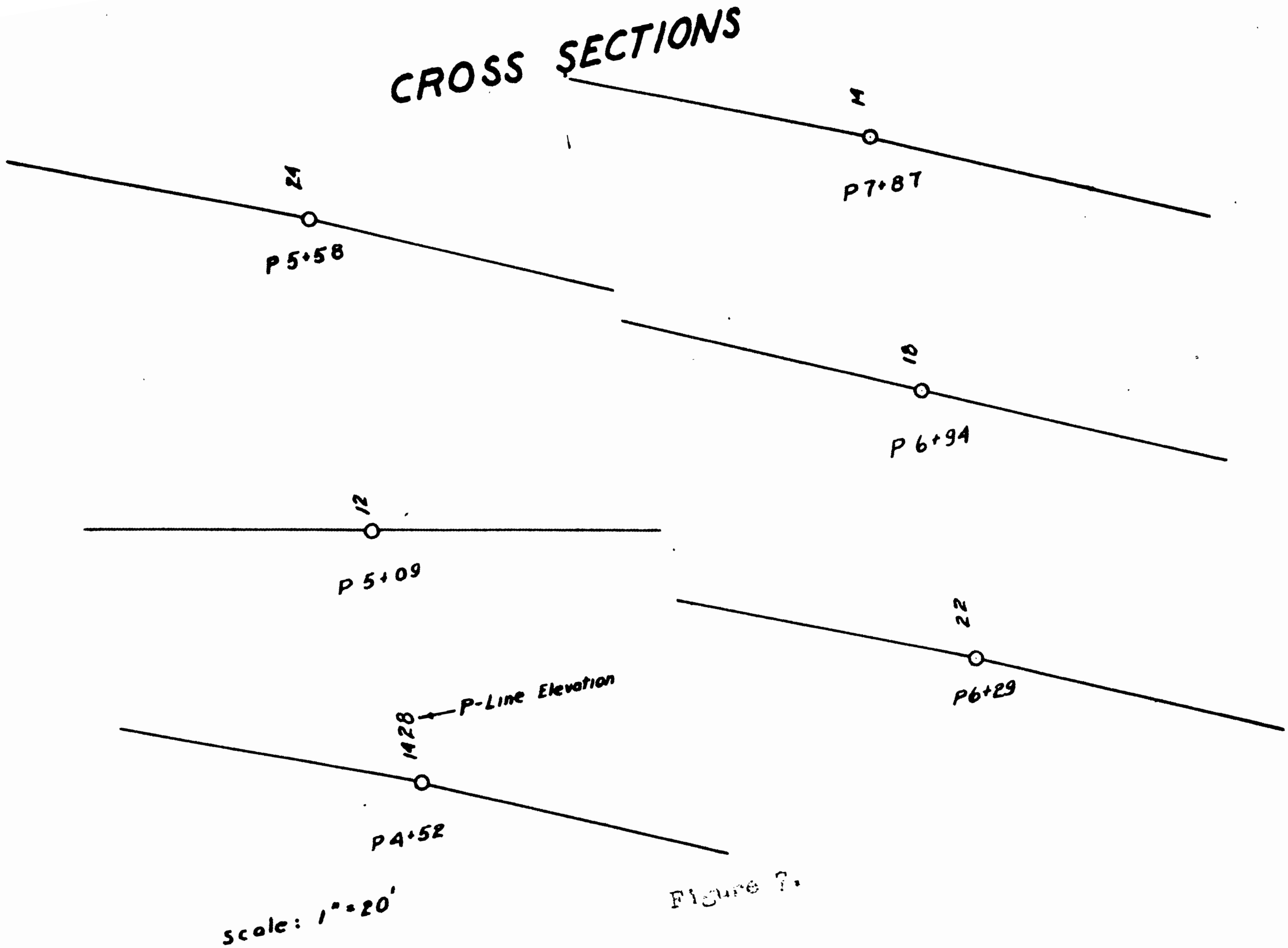

CROSS SECTIONS
14
P 7+87
24
P 5+58
18
P 6+94
12
P 5+09
22
P6+29
1428
P-Line Elevation
P 4+52
Scale: 1" = 20'

Figure 7.

On flat slopes, alignment is the controlling factor, and grade is adjusted to balance excavation and embankment. It is important to locate the culverts on the profile at this time. Culverts often become controls because grade must be high enough to clear the culverts. Trial grade is often drawn between culverts. Volume of excavation is a function of cut or fill at center line, back slope, fill slope, and percent of ground slope. As the ground slope approaches zero, volume becomes more and more a direct function of cut or fill. Therefore, excavation and embankment quantities may be roughly balanced in flat country by balancing cut and fill ordinates with the trial grade line on the P-line profile.

The trial grade drawn on Figure 5 was determined by drawing a straight line to the base of the rock bluff at station P 80 + 00 (see Abney Profile in Appendix). It is interesting to note that the trial grade line was not drawn through station P0 + 00, because two diverging roads must remain on the grade of the existing road until the roadways are entirely independent of each other.

Trial offset points. The trial grade elevation for each section is recorded on the design form in Figure 8, and also on the cross sections. The roadway template is moved horizontally along the trial grade on the cross section until a visual balance of cut and fill area is determined. The area of cut should exceed the area of fill to account for shrinkage and loss. In this example the area of cut should exceed the fill area by $\frac{1}{1-0.25}$, or $\frac{1}{0.75}$.

The center line of the balanced section is marked on each cross section as shown in Figures 9 and 10. The trial offset left or right of the P-stake is recorded on the design sheet. After this operation is completed for each stake, the offsets are transferred to the plan.

Sometimes it is impossible to obtain a balance between cut and fill areas. When it is no longer feasible to fill because of steep slopes, the center line must be moved into the hill at least one-half the subgrade width from the point where grade intersects the surface of the ground. An asterisk is marked on the plan indicating that center line must pass through this point or be farther into the hill.

Center line. A line on the plan joining these trial offset points represents the center line of a completely balanced road. The dashed line on the plan in Figure 11 represents the balanced road for the trial grade. Such a road is impractical because it would have very poor alignment. Tangents and curves are drawn to fit these points as closely as possible.

Figure 8.

Form R6 - E9
REV. FEB. 1956

ROAD DESIGN FORM

PROJECT .... NO. .... SECTION .... CLASS .... PAGE ....

FOREST .... Designed by .... Date .... 19 ....

"P" LINE	TRIAL GRADE ELEV.	TRIAL OFFSET LT.	TRIAL OFFSET RT.	"L" LINE	℄ OFFSET LT.	℄ OFFSET RT.	GROUND ELEV. PROJTD. LINE	PCT. GRADE	TANGENT GRADE EL.	VERTICAL CURVE DIST.	VERTICAL CURVE ORD.	VERTICAL CURVE ELEV.
0+00	1443	℄		0+00	℄		1443^{2}	-1%	1443			
0+92	41^{5}	1		0+95	℄		42^{2}	-1%	40^{2}			
1+42	39^{4}	10		1+46	2		37^{5}		38^{1}			
1+91	37^{1}		8	1+97		6	38^{2}		36^{1}			
2+91	33^{3}		5	2+94	8		39^{5}		32^{8}			
3+60	30^{5}		7	3+66	3		35^{1}		30^{2}			
4+52	26^{8}		2	4+56		11	23^{2}		26^{1}			
5+09	24^{5}			5+11		4	11^{2}		24^{2}			
5+58	22^{1}		3	5+53		9	20^{2}		22^{2}			
6+29	19^{2}		4	6+24		4	20^{2}		19^{5}			
6+94	17^{2}		2	6+88		2	17^{2}		17^{2}			

TRIAL BALANCE ROADWAY

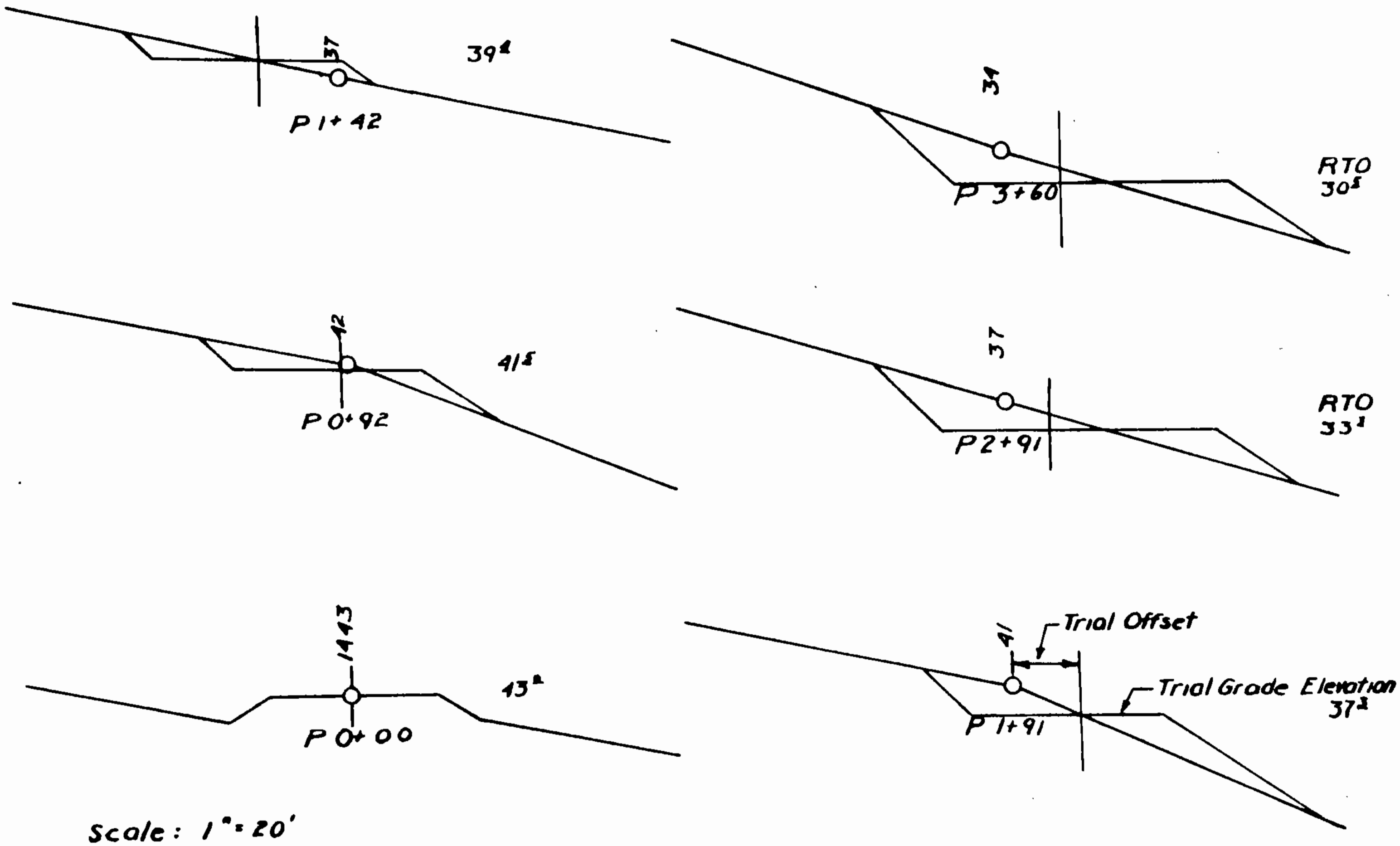


Figure 9.

TRIAL BALANCE ROADWAY

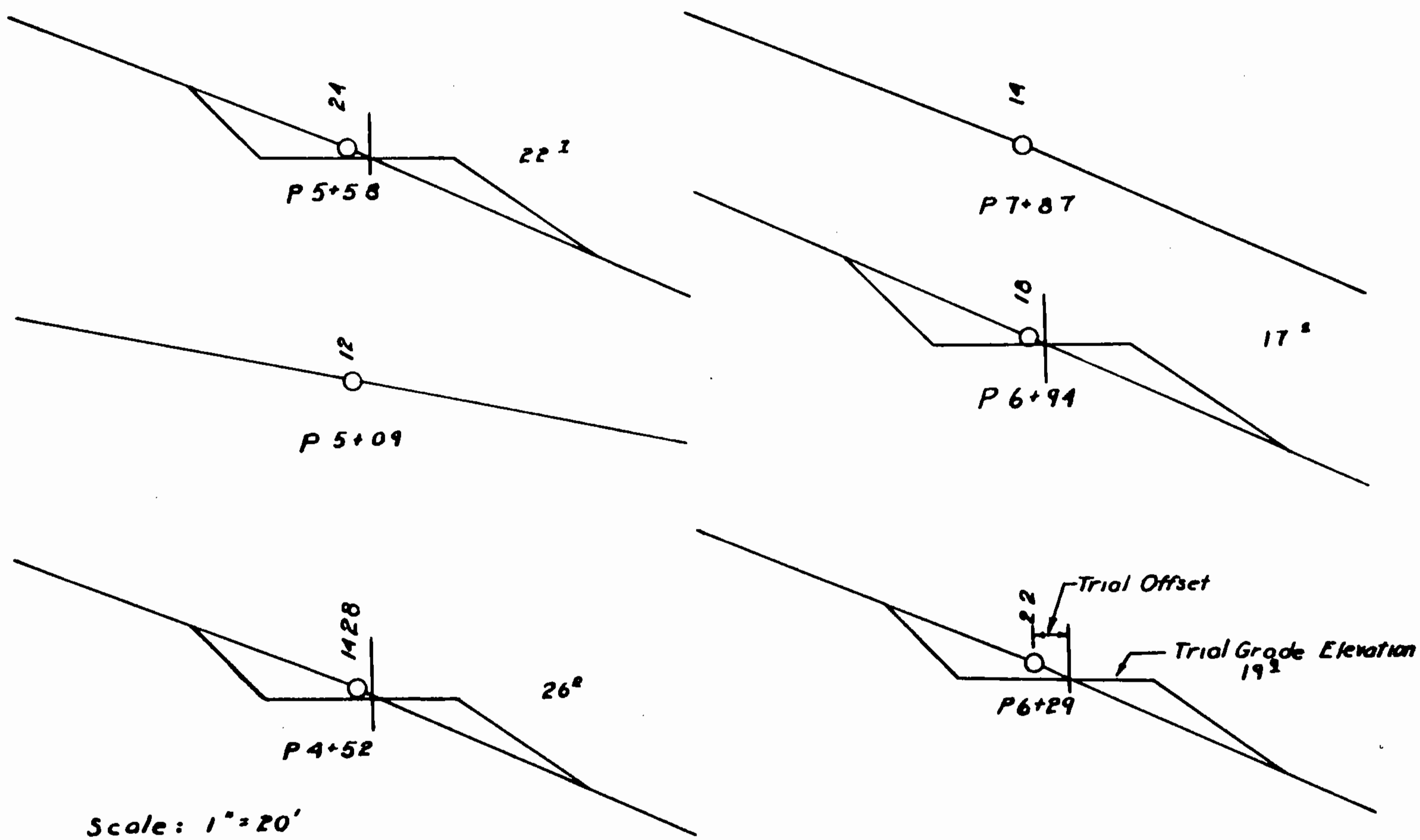
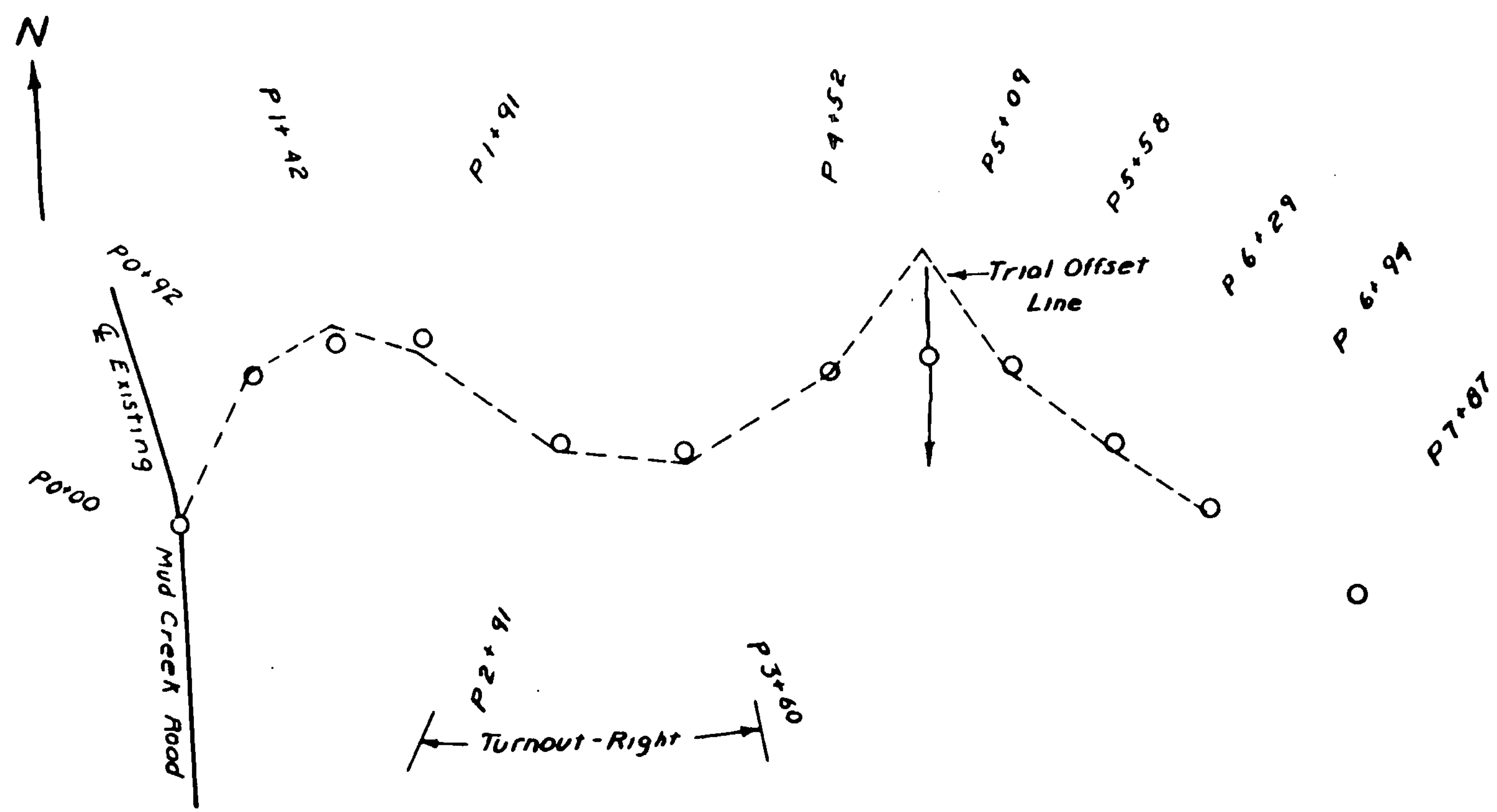


Figure 10.

TRIAL OFFSET LINE



Scale: 1" = 100'

Figure 11.

To determine the desired combinations of tangents and curves requires considerable study on the part of the designing engineer. One important point to remember is to maintain adequate sight distance on curves. The distance required for a vehicle to stop is expressed by the formula (1, p. 85):

$$d = 4.4v + \frac{v^2}{30f}$$

d = distance required to stop in feet

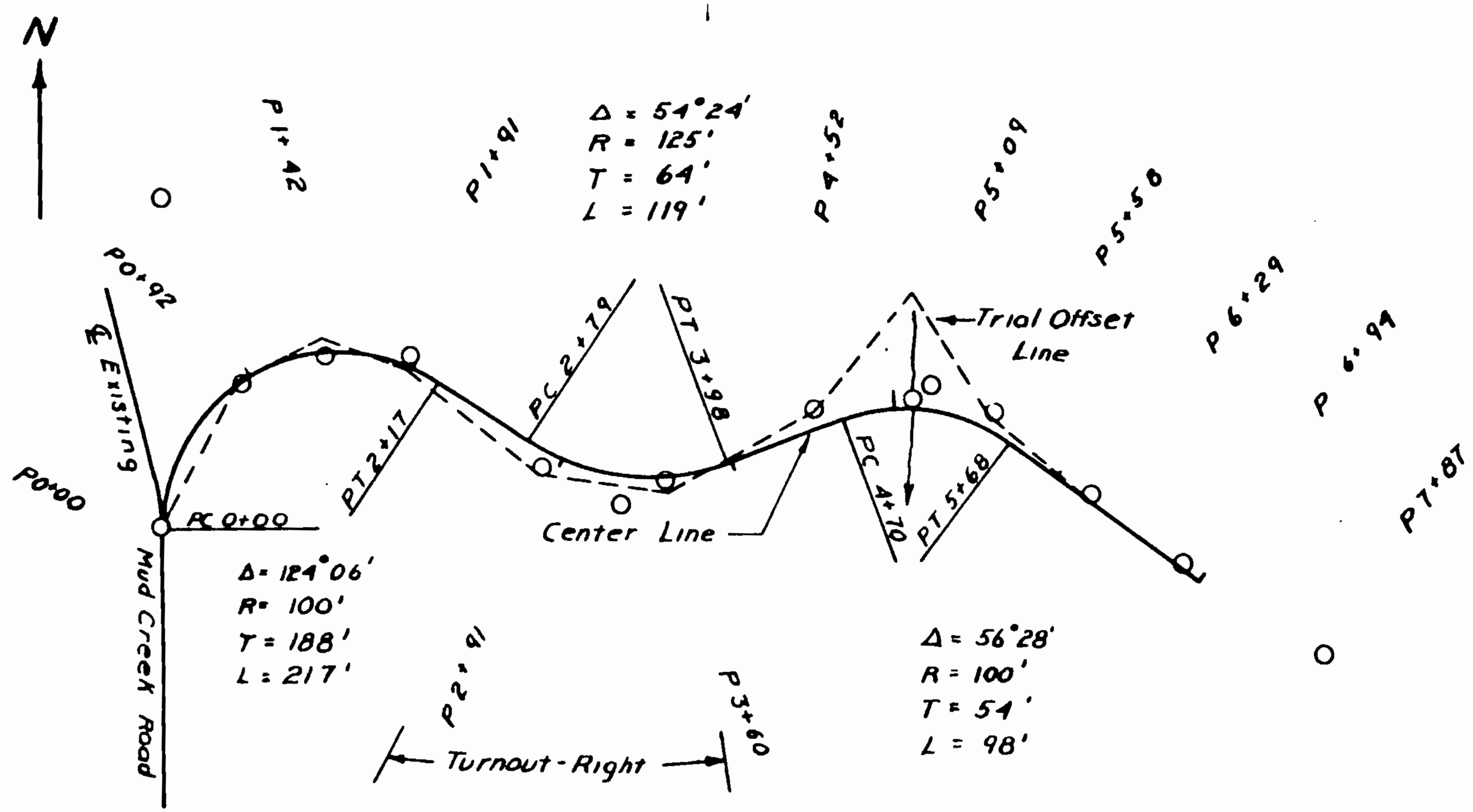
v = speed of the vehicle in miles per hour

f = coefficient of friction of the tires against the road

On a single lane road, two oncoming vehicles require twice this distance to stop. This is referred to as the double stopping distance. The sight distance should be checked at each curve. If it is less than the double stopping distance, the road should be widened to allow two vehicles to pass. The widening should extend until the sight distance equals or exceeds the double stopping distance.

When designing a road along a sidehill, curves should be designed first and then the tangents drawn to join the curves. The reason for this is that the road must conform with the contour of the terrain and in sidehill locations, curves fit the contours better than tangents. On flat ground the tangents are drawn first because long tangents

CENTER LINE



Scale: 1" = 100'

Figure 12.

P-stationing is determined and entered on the design form opposite the P-station. The offset from the P-station to the corresponding L-station is measured and recorded on the design sheet. When this has been completed for the section, the information is transferred to the cross sections as shown in Figures 13 and 14. The L-stationing is placed directly under the P-stationing at each cross section. The center line offset is located on the cross section and the ground elevation at this point is recorded on the design sheet. This elevation is a projected value based upon the general topography of the sidehill. It does not account for minor irregularities in the topography. The actual elevation must be determined in the field.

The projected center line profile is shown in Figure 15. The grade line is drawn to fit the profile. In the example, the grade line is the same as the trial grade line. Vertical curve data are computed and the curves are drawn to connect the grade lines. The grade elevation is determined for each station and recorded on the design sheet.

<u>Earthwork quantities</u>. Turning to Figures 13 and 14, grade elevation is located and the roadway is drawn on each section with the roadway template. The next step is to determine the areas of cut and fill at each section.

ROADWAY OF DESIGNED CENTER LINE

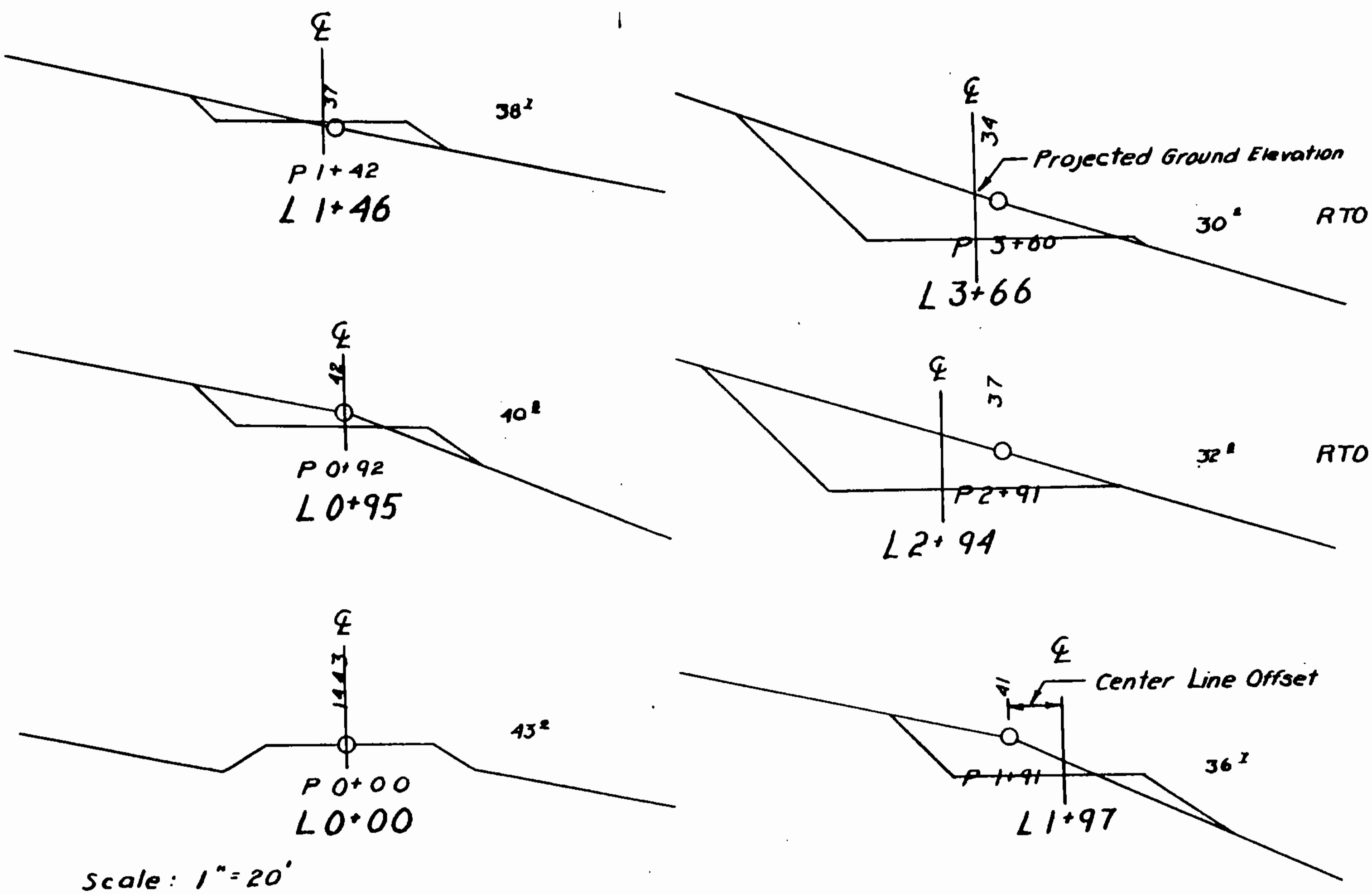


Figure 13.

ROADWAY OF DESIGNED CENTER LINE

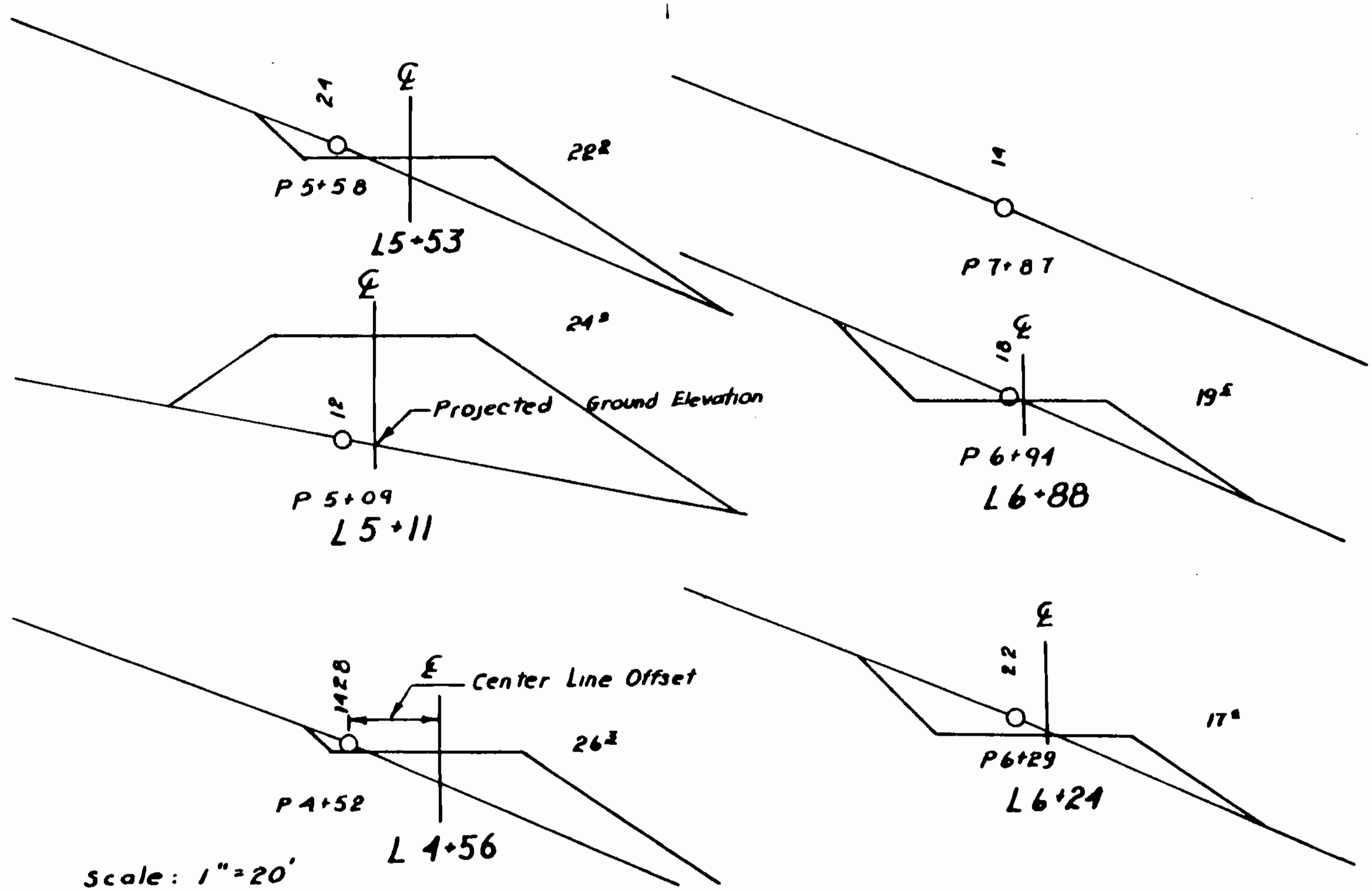


Figure 14.

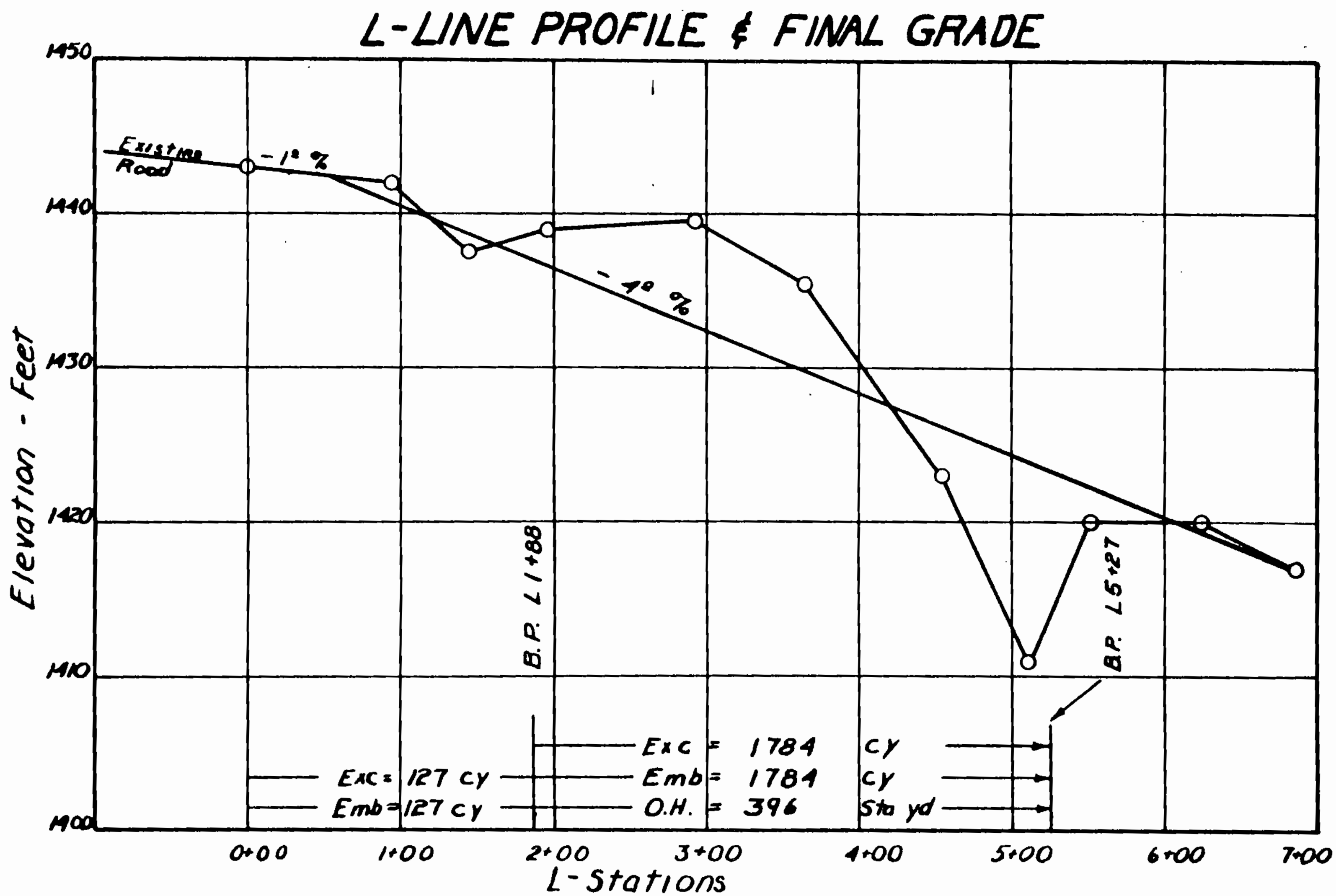

L-LINE PROFILE & FINAL GRADE
Elevation - Feet
1450
1440
1430
1420
1410
1400
Existing Road
-1° %
-4° %
B.P. L1+88
B.P. L5+27
Exc = 127 cy
Emb = 127 cy
Exc = 1784 cy
Emb = 1784 cy
O.H. = 396 Sta yd
0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
L-Stations

Figure 15.

The L-line station of each section, the distance between sections, and the area of cut and fill at each section have been recorded on the earthwork quantity sheet shown in Figure 16 in columns 1, 2, 3, and 5. The end areas of successive stations are added together to give the double end area. These figures are recorded in columns 4 and 6. The double end area is converted to volume and recorded in column 10 for excavation and column 12 for embankment.

Column 10 represents total excavation. This figure is converted to common material and solid rock, depending upon the estimated percentage of rock. In this example there is no rock so the material is all classified as common.

The actual embankment in column 12 is increased by a specified amount to allow for shrinkage and loss. There has long been a disagreement among engineers as to what shrinkage factor should be used in balancing earthwork. To be more specific, this factor is not only shrinkage, but also includes loss. If a cubic foot of soil is carefully removed from the ground, its volume will increase to a value greater than one cubic foot because of an increase in the void ratio. When placed in a fill, its final volume may be greater or less than one cubic foot. In actual practice, a cubic foot of excavation generally occupies a

Form R6 - E3
U. S. F. S. Region 6

U. S. DEPARTMENT OF AGRICULTURE
Forest Service

EARTHWORK QUANTITY SHEET

Sheet No. ....

Project .... No. .... Forest .... Class ....

Computation by .... Date ...., 19 Checked by .... Date ...., 19

Station	Dist.	Areas in square feet: Cut, End area	Cut, Double end area	Fill, End area	Fill, Double end area	Volumes in cubic yards: Excavation, % S. R.	Excavation, Solid rock	Excavation, Common	Excavation, Total	Borrow	Embankment, Actual	Embankment, Swell or shrink	Mass Curve Data, Cut +	Mass Curve Data, Fill −	Mass Curve Data, Mass
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0+00		0		0									0	0	0
	95		45		15			9	9		5	7			
0+95		45		15									9	7	+2
	51		55		50			52	52		47	63			
1+46		10		35									61	70	−9
	51		85		55			80	80		52	69			
1+97		75		20									141	139	+2
	97		337		20			608	608		12	16			
2+94		262		0									749	155	+594
	72		487		0			650	650		0	0			
3+66		225		0									1399	155	+1244
	90		231		209			385	385		115	153			
4+56		6		209									1784	308	+1476
	55		6		851			0	0		867	1156			
5+11		0		642									1784	1464	+320
	42		24		802			1	1		624	830			
5+53		24		160									1785	2294	−509
	71		94		205			124	124		270	360			
6+24		70		45									1909	2654	−745
	64		128		105			152	152		125	166			
6+88		58		60									2061	2820	−759

Figure [illegible].

volume less than one cubic foot in a fill. This may be due in part to the compaction and in part to the loss in the process of excavating, hauling, and placing in the embankment. Another explanation is that some of the material classified as dirt is not dirt at all. The top layer is usually duff made up of twigs and needles in various stages of decomposition. Also, stumps occupy space that has been considered as dirt. The amount of space occupied by stumps varies with the size and number of stumps per unit area, and little is known as to how much this value is. However, many engineers feel that when the area is well stocked, the top foot of soil will be lost in the clearing and grubbing operation. Where there are fewer stumps, the amount lost may only be six inches. The percent of loss varies inversely with the depth of the cut. Thus, the larger the cut, the smaller the percentage of loss due to stumps and duff.

Loss occurs in several ways. When a bulldozer pushes dirt, some spills off to the side out of reach of the blade. Some of this is picked up with succeeding passes with the blade, but eventually some will spill over the side and will be lost below the toe of the embankment. When earthwork volumes are computed, it is assumed that the fill is built by placing dirt in layers, beginning at the lower slope stake and building the fill up to grade.

This is the recommended practice (11, p. 94) and (3, p. 381-382), but too often the dirt is pushed over the side of the fill and keeps going until the downward force due to the weight of the dirt is overcome by the force of friction between the dirt and the ground. On steep slopes the dirt often continues down the slope well below the slope stake, finally coming to rest in the timber or in the creek bed. One method of reducing the amount of dirt that runs below the lower slope stake is to mark the lower clearing boundary above the lower slope stake. This practice should be limited to spur roads over which a relatively small volume of timber is hauled. There are several disadvantages of using this method on higher standard roads. The size of the clearing is smaller and less sunlight will reach the fill. Snow will stay later in the year. This means that the fill cannot dry out or drain properly, thus becoming unstable. Another disadvantage is that it is difficult to compact this type of fill.

Excavation for the pioneer road accounts for some loss; but if the pioneer road is placed at the lower slope stake, it can be utilized as a bench upon which a fill can be constructed. In this way the loss is reduced to the material from the pioneer road.

A method to reduce loss, and at the same time reduce excavation, is by using a retaining wall to hold material in place. The most common use of retaining walls is around bridge abutments. They may be used in places where the toe of the fill is subject to erosion by a stream or river. Another use, more in line with saving material, is in a steep, chute like draw where grade cannot be lowered and it would be too expensive to move the center line into the hill. Such a structure is expensive but provides better alignment. The use of retaining walls on steep slopes to eliminate loss of material is not likely to become a popular or economic method for logging roads in the Douglas-fir Region.

The shrinkage factor will generally increase with the percent of slope until the slope reaches some value between 50 percent and 70 percent. When the slope approaches these values, very little of the road will be on fill, and there will be an excess of material. The value also depends upon the type of soil and amount of compaction. The Gifford Pinchot National Forest uses a 25 percent shrinkage factor and does not consider the top foot of material when computing earthwork quantities. Experience should govern in making the decision, rather than assuming an arbitrary value.

When rock is excavated, the void ratio greatly increases and a swelling rather than a shrinkage occurs. Some engineers assume that this swelling is offset by loss, and the material excavated will occupy approximately the same volume in the embankment (12, p. 11).

A shrinkage factor of 25 percent has been used in this example. The sum of the embankment and increase is shown in column 13 of the quantity sheet.

The next step in the earthwork computations is to compute the mass diagram data. A mass diagram is a graphic representation of the algebraic sum of the cumulative volumes of excavation and embankment. Columns 14 and 15 are added algebraically to obtain the mass ordinate at each station shown in column 16. Mass curve data are valuable to the engineer even if the mass diagram is not drawn, since by looking at the yardage in the mass curve column, the excess or shortage of material at any station can be determined. In plotting a mass diagram, the abscissa is the L-line stationing and the ordinate is the cumulative volume of earthwork as shown in column 16.

The mass diagram for the example is shown in Figure 17. The curve lies very close to the zero ordinate from stations 0 + 00 to 1 + 88. This means that the excavation and embankment quantities balanced at each cross section. The curve rises at station 1 + 88 indicating that excavation exceeds embankment. The curve continues to rise until station 4 + 56. Then it drops off rapidly, indicating heavy filling. The curve crosses the zero ordinate at approximately station 5 + 27. At this point, cumulative excavation equals cumulative embankment. If any horizontal line intersects the curve, excavation and embankment between the points are equal. The horizontal line drawn between station 2 + 96 to 4 + 96 equals the free-haul distance stated on page 38. This line is 600 cubic yards above the zero ordinate. This represents the overhaul volume. Overhaul is material moved beyond the free-haul distance. It is a function of volume and distance, and it is most commonly measured in terms of station-yards. The average haul distance equals the distance between the center of mass of the excavation and embankment volumes. This distance is approximately equal to the width of the overhaul area at mid-height. The average haul shown on the diagram by the dashed line is 266 feet. The overhaul distance equals 266 - 200, or 66 feet. The overhaul is equal to (0.66)(600), or 396 station-yards.

In addition to determining overhaul, the mass diagram is used to determine borrow, waste, and the direction that the material will be moved. The balance point at station 1 + 88 indicates that the material required to construct the fill beginning at station 4 + 56 lies between stations 1 + 88 and 4 + 56. If the curve is concave upward, material is moved from right to left. If

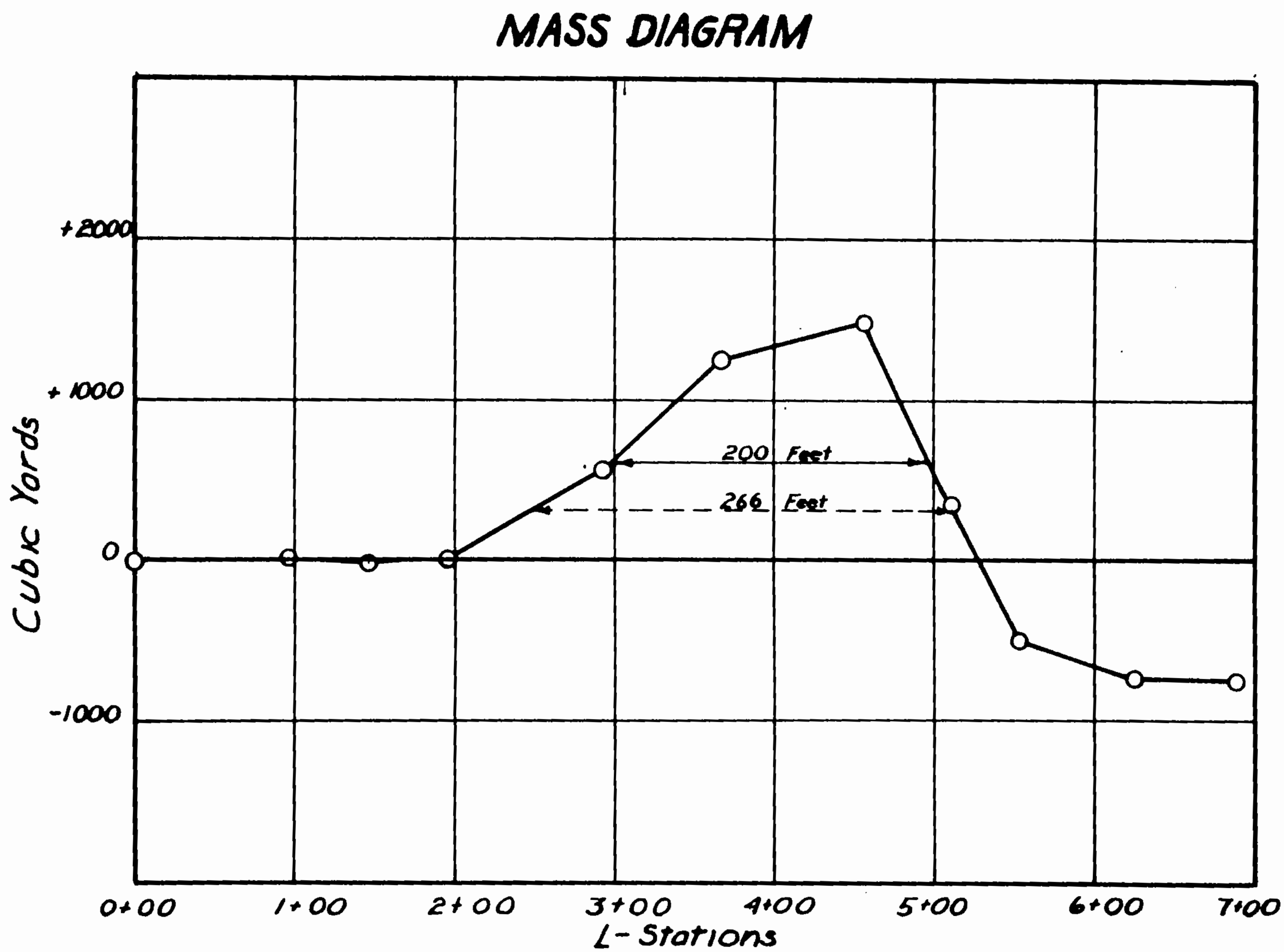

MASS DIAGRAM
+2000
+1000
0
-1000
Cubic Yards
200 Feet
266 Feet
0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
L-Stations

Figure 17.

the curve is concave downward, the material is moved from left to right.

The haul schedule is shown on the L-line profile in Figure 15. The haul schedule shows the volume of material, the direction it will be moved, and where it is to be placed.

Full Bench Design

Considerable mileage of road in the Douglas-fir Region is constructed on ground slopes too steep to support any fill and the road must be completely benched. The material excavated is generally wasted by side casting. Since there is no embankment, the designer is not confronted with the problem of balancing cut and fill volumes. A design procedure well adapted to side cast construction is discussed here. This method does not utilize the plotting of cross sections.

The P-line plan, P-line profile, and trial grade are plotted as described previously. Assuming that the road is to be completely benched, each P-station is analyzed as follows. The center line must be moved "x" feet from the P-stake to obtain a full benched roadway.

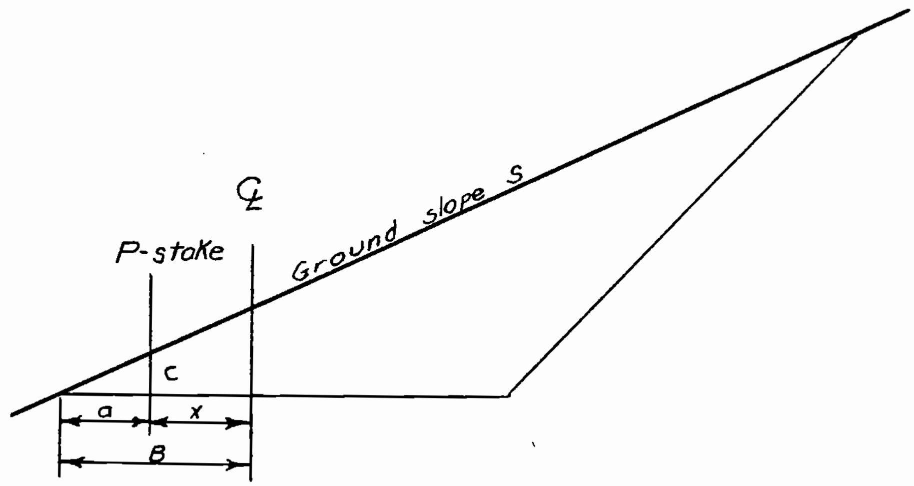


Figure 18. Offset for Full Bench Road

$$a = \frac{c}{S}$$

$$x = B - \frac{c}{S}$$

Where:

x = the offset to center line for a full benched road

B = the width of the road from center line to the shoulder of the road

c = the cut or fill as determined from the trial grade

S = the ground slope from the topography notes

If the value of "x" is positive, the offset is uphill. If "x" is negative, the offset is downhill. If the trial grade line is above the P-stake, the value of "c" is negative and the formula becomes:

$$x = B - \frac{(-c)}{(S)}$$

$$x = B + \frac{c}{S}$$

The values of "x" are recorded in the trial offset column for each station and then transferred to the plan. These points are considered controls because center line cannot be downhill from them without lowering the grade line. Curves and tangents are drawn to fit these control points. Curve data are computed and the road is stationed. The center line offset is scaled from the plan and recorded on the design form.

The difference in elevation between the P-stake and the corresponding L-station is equal to the product of the center line offset and the ground slope. This value is added to or subtracted from the P-stake elevation to arrive at the projected center line elevation. This figure is recorded on the design form.

The L-line profile is plotted from the projected center line elevation, and the grade line is drawn. The grade line must be low enough so that the road will be completely benched. The cut at any point must be equal to or greater than the product of the ground slope and the width of road from the center line to the shoulder.

Excavation quantities are computed, but it is not necessary to plot the mass diagram as it serves no purpose with a full bench road design. By changing grade frequently, excavation may be reduced, but this may increase hauling cost. If the timber is being hauled uphill, the grade should be held constant so that time will not be lost by constant shifting of gears.

Grade Contour Design

The grade contour is an imaginary line formed by the intersection of grade with the ground slope. The grade contour design is similar to the full bench design because neither utilize cross sections. They differ in that the grade contour design can be used to balance excavation and embankment quantities. The offset to the grade contour is located as shown in Figure 19.

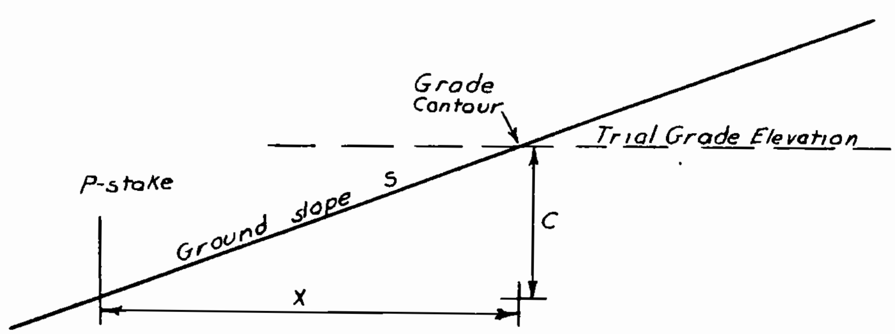


Figure 19. Offset to the Grade Contour

The offset "x" to the grade contour equals $\frac{c}{S}$, where "c" is the difference in elevation between the P-stake and the trial grade elevation and "S" is the ground slope.

This offset is recorded on the design form and plotted on the plan for the corresponding P-station. When this has been completed for each stake, the points are joined with straight lines. This line is the grade contour, and it may be considered the center line of the balanced road.

Curves and tangents are drawn to fit the grade contour, curve data are computed, and the road is stationed. The projected ground elevation is determined as shown in the full bench design and the L-line profile is plotted.

The grade line is drawn on the L-line profile and the projected center line cut is measured and recorded on the design form. Since cross sections have not been drawn, the end area of cut and fill at each station must be computed from the projected center line cut and the topography notes. This involves considerable work without the use of earthwork tables.

An earthwork table may be compiled to show the cubic yards per station of excavation and embankment for any cut or fill, combination of back slope and fill slope, and percent of ground slope. The table is constructed for the width of subgrade desired. Such a table is time consuming to compile; but once it has been compiled, it greatly facilitates this method and the full bench method of design.

The remaining design is similar to the cross section design. A mass diagram is plotted and the haul schedule is shown on the L-line profile.

THE CONSTRUCTION SURVEY

The location survey is conducted to transfer the center line data from the plan and profile to the ground. There are two basic methods to accomplish this. The first is to run a new survey, using the bearings and distances as computed or scaled in the office from the plan and profile. This method is not too popular since it involves brushing a new line, and it is considerably slower than the offset method.

The offset method involves offsetting the center line at right angles to the P-line, or along the bisection of the angle at each P-stake. The horizontal offset from the P-stake to the center line and the difference in elevation between these two points have already been recorded on the design sheet. This method, however, also needs revision because the P-stake and the center line stake both generally lie within the clearing boundaries and will be destroyed during the clearing and grubbing operations. In order to insure permanence of the control data, bench marks or reference stakes should be set 10 to 20 feet beyond the edge of the upper clearing. The most permanent reference is a bench chopped into a tree close to the ground level. The references are set at right angles to the L-line when the upper slope stake and clearing boundary are located. The data recorded on the reference are the corresponding center line stationing, the distance from the reference to the center line, and the vertical distance from the reference to grade. In addition to these data, the distance from the reference to the upper slope stake is determined since the upper slope stake marks the place to begin excavation.

The reference can be located by rodding uphill at right angles to the P-line without locating the center line stake. The horizontal distance from the P-stake to the center line stake has already been scaled from the plan and recorded in the design form as the center line offset. This value is added to or subtracted from the horizontal distance between the P-stake and the reference to give the horizontal distance from the center line stake to the reference. The difference in elevation between grade at center line and the P-stake can be determined from the design form. This value is added to or subtracted from the difference in elevation between the P-stake and the reference to give the vertical distance from the reference to the grade of the road.

If the direction of the L-line does not closely parallel the direction of the P-line, the reference stake cannot be set by rodding uphill perpendicular to the P-line. This can be explained by referring to Figure 20.

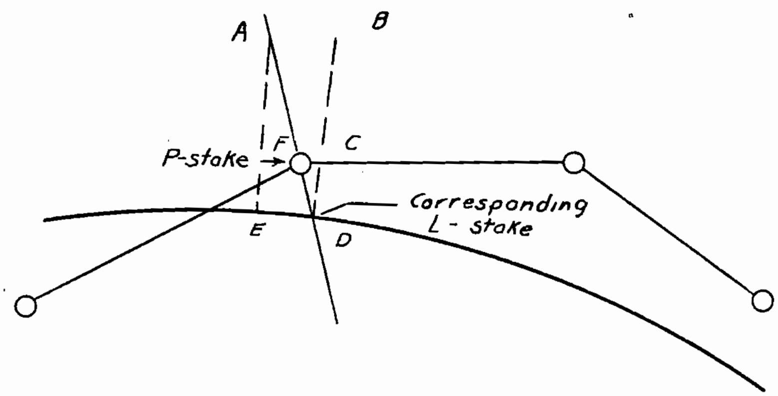


Figure 20. L-line Reference

Point "A" represents the reference located along the bi-section of the P-line. Since the reference is to be at right angles to the L-line, "A" represents the reference to point "E" on the L-line instead of point "D". There are two ways of setting point "B". The first is to measure along the bisection of the turning point to the L-line. Then proceed uphill along bearing DCB to point "B". The other method involves locating point "C" along the P-line and proceed uphill along the bearing of DCB to set point "B". The distances FD, FC, and CD and the bearing DCB may be measured on the plan. The P-stake is used as a back-sight for elevations in both methods.

The upper slope stake is located either on the way up to the reference or else it is located by rodding down from the reference. If cross sections have been drawn, a close approximation can be made of the location of the upper slope stake by scaling the horizontal distance from the P-stake to where the back slope intersects the ground level. If the data recorded in the topographic notes are accurate, this should coincide quite closely with the upper slope stake. However, errors in topography or local ground variations will affect the location of the slope stake. Unless the error is appreciable, this method can be used to find the approximate location of the slope stake faster than rodding up from the P-stake or down from the reference.

Except on flat ground or through cuts, it is generally unnecessary to locate the lower slope stake. Perhaps if more care were taken in construction of fills, it would be desirable to locate the lower slope stake. However, the fills in the majority of cases are built by side casting material over the slope until it builds up to the desired height of fill. The material will run down past the lower slope stake and will not stop until its momentum is checked by friction or the lower clearing edge. This results in an unstable roadbed that will eventually settle and require additional man hours to repair. In the future more emphasis will undoubtedly be placed on proper construction and compaction of fills. At this time the lower slope stake will become a necessary item to be located in the field.

The upper edge of clearing should be set at least 10 feet beyond the upper slope stake so that no trees are undermined by the excavation. The lower clearing boundary is set about 10 feet below the lower slope stake. Since the lower slope stake is seldom located, the lower clearing boundary can be determined by measuring the distance from the P-stake to the intersection of the fill slope with the ground (as shown on the drawn cross section) and then adding 10 feet. If cross sections are not used, the lower clearing boundary may be established by assuming that the distance from center line to the lower clearing boundary equals the distance from center line to the upper clearing boundary. In steep country this can result in a wide right-of-way, but the damage to trees on the lower side from rocks and debris usually necessitates their removal anyway. Also, this wide right-of-way will allow more sunlight to reach the road, drying it out faster and removing snow earlier. Clearing boundaries should be smooth. This often means that the clearing will extend more than 10 feet beyond the upper or lower slope stakes.

The location of balance points, as determined by the mass diagram, can also be located and marked with tags on trees on the edge of the clearing. This will show the construction crew which way the excavation material is to be moved. Culverts are also tentatively located. Usually a tree is marked or a stake is set on the edge of the clearing above the proposed location of the culvert. The stationing of the culvert and its diameter and length are recorded on the tree or stake.

When the right-of-way has been cleared and grubbed, the upper slope stakes and center line stakes can be set from the data recorded on the reference. The cut or fill at center line is recorded on the stake. At this point grade and alignment can be checked and adjusted for any minor errors.

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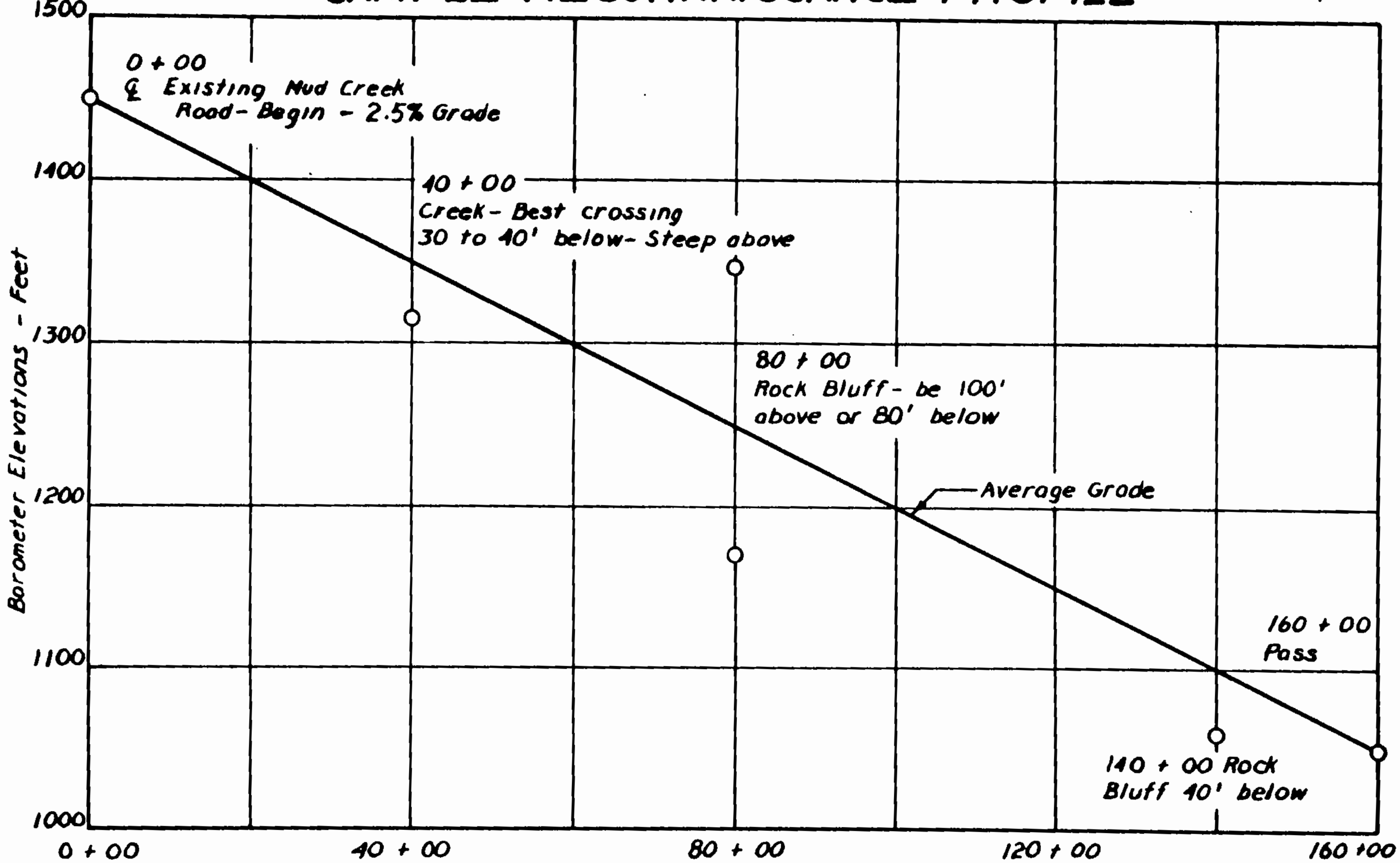
APPENDIX A

Mud Springs Road — Page 1

STA	DIST	BEAR	GRADE	TOPO L	TOPO R	Notes
7+87				+40/100	-45/100	P 7+87 Enter D5 ≡
	93	S57E	-4			
6+94				+45/100	-45/100	
	65	S53E	-6			
6+29				+40/100	-45/100	
	71	S50E	-3			
5+58				+40/100	-45/100	
	49	S80E	+25			
5+09				+20/100	-20/100	P 5+09 12" culvert
	57	N85E	-30			
4+52				+40/100	-45/100	
	92	N65E	-6			
3+60				+35/100	-35/100	
	69	S85E	-4.5			
2+91				+30/100	-30/100	
	100	S50E	-4			
1+91				+20/100	-45/100	
	49	East	+8			
1+42				+25/100	-20/100	
	50	N70E	-10			
0+92				+20/100	-40/100	
	92	N30E	-1			
0+00				+20/100 -60/5 0/10	0/10 -60/5 -20/100	P 0+00 = ℄ Exist Mud Creek Road

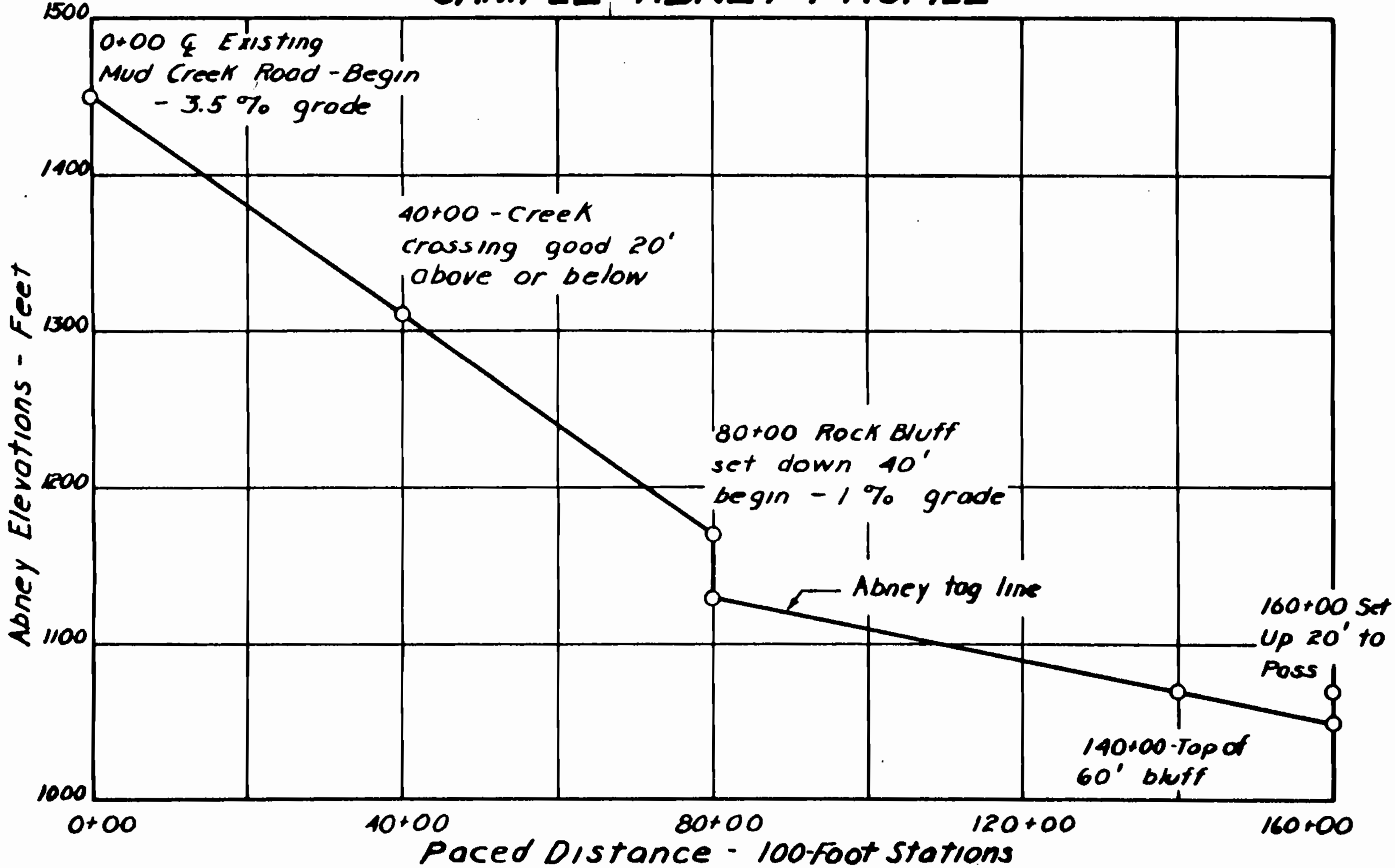
SAMPLE P-LINE NOTES

SAMPLE RECONNAISSANCE PROFILE



APPENDIX B

SAMPLE ABNEY PROFILE



APPENDIX C