INTRODUCTORY HIGHWAY ENGINEERING

PART II - INTERMEDIATE

TEXAS HIGHWAY DEPARTMENT
DISTRICT 12

1963

INDEX - SURVEYING II

INDEX - SURVEYING II

INDEX - SURVEYING II

INDEX - HIGHWAY DESIGN II

INDEX - HIGHWAY DESIGN II

INDEX - HIGHWAY DESIGN II

INDEX - CONSTRUCTION INSPECTION II

INDEX - CONSTRUCTION INSPECTION II

INDEX - LABORATORY COURSE II

INDEX - LABORATORY COURSE II

INDEX - LABORATORY COURSE II

SURVEYING II

I. Transit Work

A. Use and Care of the Transit

1. Care of the Transit

The transit is a delicate as well as a costly instrument. It is particularly important that, in learning to use it, one should learn first of all what precautions to take to reduce wear and tear, to avoid accidental damage, and to keep it in good working order. It is often difficult, and sometimes impossible, to restore a damaged part of a transit to its original efficiency. For this reason, the student is advised to review the suggestions for the care of the level, given previously. These suggestions, with slight modifications, apply equally well to the care of the transit. One important modification is as follows: before taking the transit up to carry it, clamp both the upper and lower plates together, tighten the lower clamp just enough to allow the two plates to revolve freely if accidentally hit, point the telescope straight up and clamp lightly so that it is free to turn at the slightest provocation, and make sure that the compass needle is lifted off its point.

2. Setting up the Transit

The transitman aims to do two things in setting up a transit:

a. To "center" it over some given point such as the head of a small nail in the top of a stake.

b. To "level up." The tripod plumb bob and shifting head are used to center the transit, the thumb screws and plate levels to level up. The general procedure may be outlined as follows:

(1) Set the tripod with shoes pressed firmly into the ground, in such a position that when its head is approximately level, the plumb bob will come to rest nearly over the point.

(2) Loosen two adjacent thumb screws and, using the shifting head, bring the point of the plumb bob over the required point. Use the sliding device on the plumb bob string so the point of the plumb bob just clears the stake.

(3) Tighten the two thumb screws previously loosened for shifting and by means of all four screws, level up.

(4) See that the plumb bob still hangs over the center of the tack when the plates are level. If, in leveling up, it has been disturbed, bring the back to the center by using the shifting head, and level up again.

Speed in setting up a transit is worth a great deal, for a slow transitman can delay the work of a whole party. It is true that the knack of setting up a transit comes from practice, but make it intelligent practice from the start.

3. Suggestions for Manipulating Tripod

The following are some suggestions to help you in using the transit tripod.

a. Manipulate the tripod so that its head is approximately level to begin with. The less the thumb screws are used, the better.

b. Spread the tripod legs just far enough to bring the telescope at convenient height. It saves stretching or stooping.

c. Preliminary Setup — Set up the transit at first approximately over the station without any attempt to bring the bob exactly over the tack, the main object being to get the plates approximately level as judged by the eye and the telescope at a convenient height, with the tripod shoes merely resting on the ground. This having been done, lift all three shoes off the ground and move the transit bodily until the bob is over the tack, push the legs into the ground, and proceed to use the shifting head and leveling screws as already explained.

d. Avoid setting a tripod leg on line where it might interfere with stretching the tape in chaining.

4. Suggestions for using Leveling Screws

The following are some suggestions to help you in using the transit leveling screws.

a. Two diagonally opposite screws are worked at the same time, first one pair, then the other, alternating until the plates are level. The thumbs always move toward or away from each other. The knowledge of which way to turn the screws should soon become instinctive. It may be helpful however, to remember that the bubble will move in the direction in which the left thumb is turned.

b. Each plate is placed parallel to a pair of diagonally opposite screws, and first one and then the other pair of screws are manipulated.

When the plate levels are in adjustment, each bubble should remain in the center of its tube when the plate is turned through 360°.

c. Do not try to center one bubble exactly until the other has been approximately centered.

d. In setting up to prolong a straight line, it is well to have one pair of diagonally opposite thumb screws in the line, the other pair at right angles to it.

B. Bearings

1. The Bearing of a Line

The bearing of a line is the direction of that line with reference to a meridian. Let the point C in Figure 1 be one end of a given line CA. A north-south meridian through C forms an angle of 30° with CA. This acute angle is the angle of bearing, taken at C of the line CA. In designating the bearing, it is necessary also to indicate the quadrant of bearing in which the line CA lies, in this case, N 30° E. Bearings are always measured from the north point or the south point, so many degrees east or west.

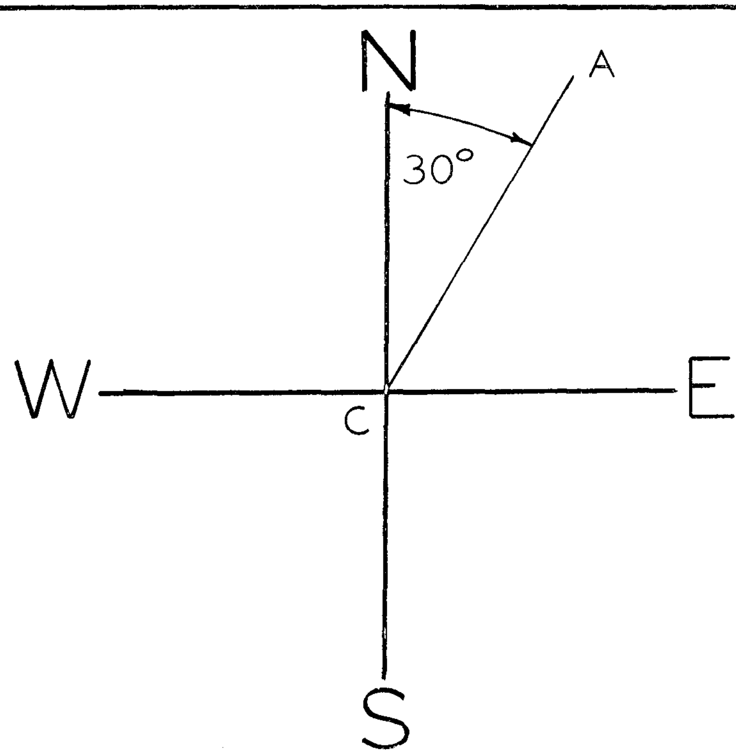


FIG 1

The angle of bearing never exceeds 90°. For example, a line 120° from north, measured clockwise, is <u>not</u> N 120° E, but S 60° E.

2. True Bearing

The bearing of a line with respect to a true north-south meridian.

3. Magnetic Bearing

The bearing of a line with respect to a magnetic north-south meridian. This is the bearing that is read from an uncorrected compass.

4. Forward Bearing and Back Bearing

Every line of definite length has two bearings. If the bearing of any line from one end is NE, it will be SW from the other end or NW and SE. This is an important distinction, because it indicates direction northerly or southerly. The forward bearing of a line is the bearing in the direction in which the survey is being run, the back bearing is that in the opposite direction. The two bearings of a line are numerically equal but with opposite letters. The bearings kept in a survey are normally all forward bearings.

5. Observed and Calculated Bearings

An observed bearing is one obtained by direct observation in the field. A calculated bearing is one that has been derived by computation. For example, if the bearing of one of two intersecting lines is known, the bearing of the second line may be easily calculated from the known bearing of the first and the known angle.

6. <u>Reading a Bearing</u>

The compass box on a transit is attached to the upper plates, and when the telescope is turned sidewise, the compass box must turn with it. When the telescope is right side up, the letter N is directly beneath the front end of the telescope. A line between N and S is always directly beneath the axis of the telescope (or line of sight), no matter in what direction the telescope may be pointing. When the magnetic needle is lowered to its pivot, it will come to rest pointing north, and if the telescope is also pointing to the magnetic north, the north end of the needle will point to the letter N. If, however, the telescope is turned, the letters N, E, S, W, turn with it, and the needle will remain pointing north. Each of its ends will rest between two of the letters. This is the usual condition. To read the bearing of a line, observe whether the telescope is normal or inverted. Do not try to think beforehand whether the bearing is going to be NE, SE, SW, or NW. If the telescope is normal, simply observe between which two letters the <u>north</u> end of the needle rests and how many degrees it is from the letter N, or the letter S.

as the case may be. The south end of the needle is observed, instead of the north end when the telescope is inverted. The north end of the needle is the end without weight.

C. Angles

1. Measuring a Horizontal Angle

If a horizontal angle, as AOB (Figure 2), is to be measured, the transit is set up over O, as described above. The upper motion or plate is clamped, and by means of the upper tangent screw, the vernier plates are set at 0^{o}. The telescope is sighted approximately to A, the lower motion is clamped, and by turning the lower tangent screw, the line of sight is set exactly

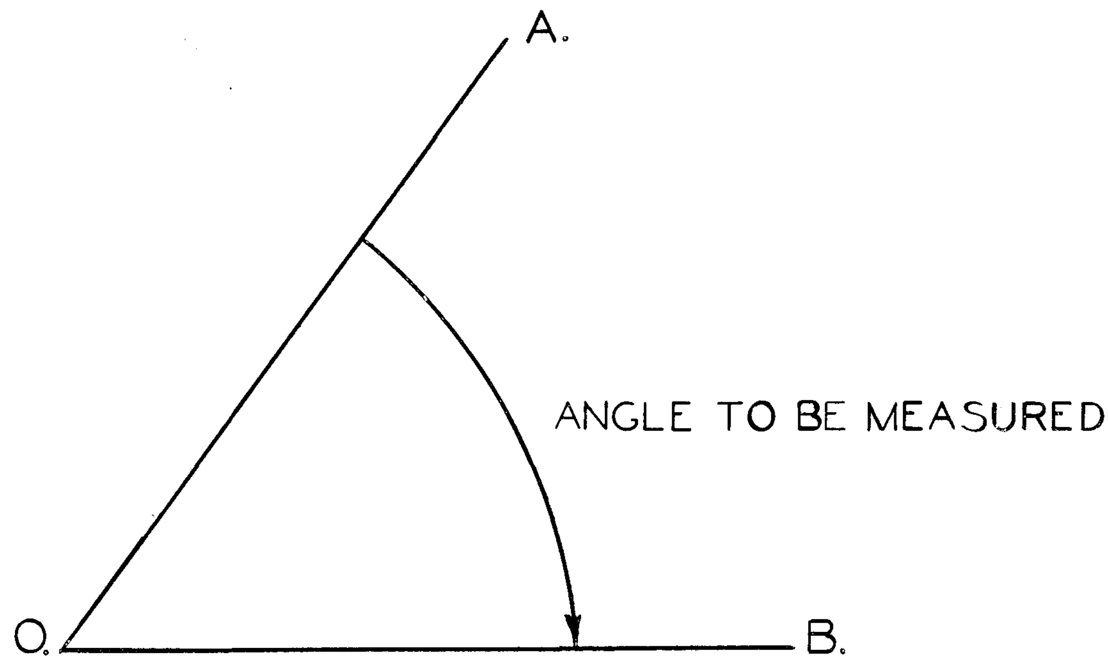


FIG 2

on a range pole or other object marking the point. The upper clamp is loosened, and the telescope is turned until the line of sight cuts B. The upper clamp is tightened, and the line of sight is set exactly on B by turning the upper tangent screw. The reading of the plates, which were initially set at 0°, gives the value of the angle.

2. Reading Angles

There are three distinct steps in reading the angle on a transit.

a. Reading the plate.

b. Reading the vernier

c. Combining the two readings.

3. Reading the Plate

No matter in which direction the plate carrying the indicator revolves, there are always two readings for an angle. One is the value of the angle measured clockwise from the backsight, and the other is the value measured counterclockwise from the same backsight. Their sum is 360°.

a. Plate Readings for Angles to the Right

Consider the indicator to have moved clockwise (it is immaterial whether it did or not). Observe which row of graduations increases clockwise and use this set of graduations to determine the plate reading (Figure 3).

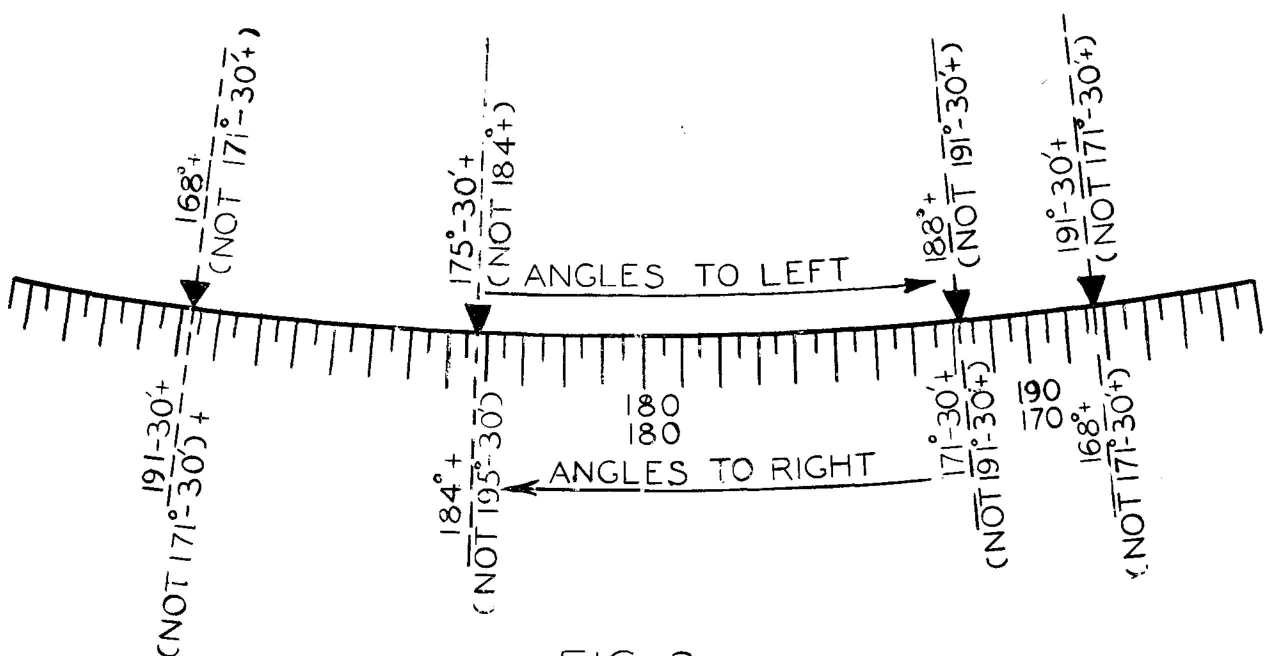


FIG. 3

READINGS IN PARENTHESIS INDICATE COMMON MISTAKES.

b. Plate Readings for Angles to the Left

Proceed as above, but consider indicator to have moved counterclockwise, and use the row in which the graduations increase counterclockwise (Figure 3).

4. Verniers

Generally, if a vernier is divided into ten equal spaces between numbers as shown in Figure 4, it reads to minutes, i.e., each space is called a minute, though it really covers nearly a degree. This is termed the "least count." The least count, as determined by inspection, should be verified when using any vernier for the first time. The following rule usually applies. Divide the value of the smallest division on the limb by the number of parts of the vernier.

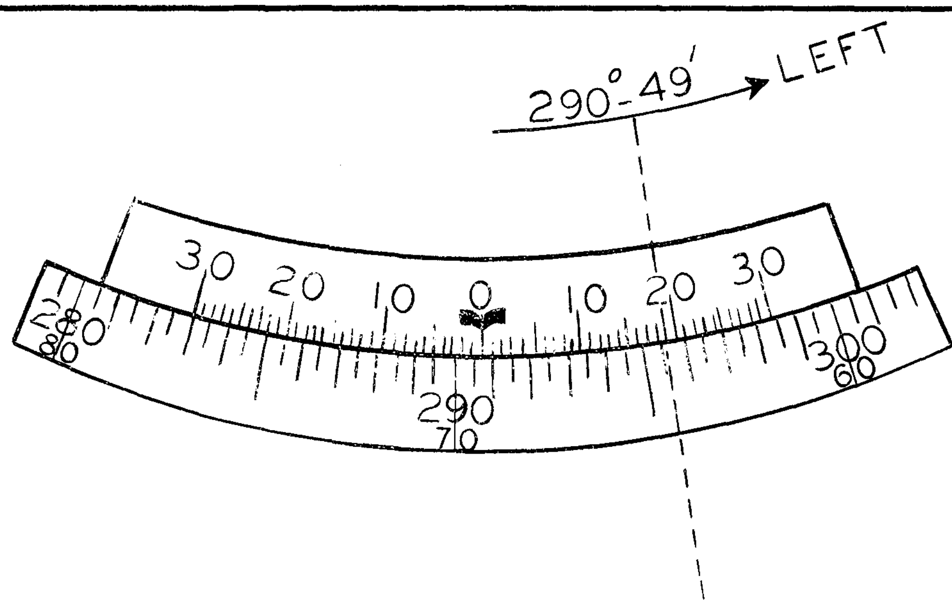


FIG. 4

5. Setting the Vernier

A preliminary step in measuring an angle is to set the vernier.

a. Loosen the upper and lower clamps, and turn either the upper or lower plates, or both, until the zero mark of one of the verniers is so nearly opposite the zero mark of the graduated circle, that a turn or two of the tangent or slow motion screw will bring the two zero marks into coincidence. Clamp the two plates together with the upper clamp and do not touch this clamp again.

b. By means of the upper tangent screw, bring the two zero marks exactly opposite.

In judging the exact coincidence of the two zero marks, it will be helpful to observe the nearest vernier mark on either side of the zero mark. The vernier mark on one side should be as far from the nearest mark on the graduated circle as the mark on the other side from the corresponding mark on the circle; that is, the two vernier marks should be symmetrical with respect to the zero lines as judged by the marks on the circle. In finely graduated circles and verniers, such as those reading to 20", it is well to examine for symmetry two or three vernier marks on either side of the zero marks.

6. Reading a Vernier

Keeping in mind the value of the smallest division on the vernier, it is an easy matter to get the vernier reading. If the zero or indicator exactly coincides with a mark on the plate, the angle is read without using the vernier; otherwise, find the mark on the vernier which is exactly opposite some mark on the plate. It is immaterial what the mark on the plate is, as the mark on the vernier determines the vernier reading. The plate reading to which the vernier must be added is determined separately, as explained above.

Remember these rules:

a. Always read that side of a double vernier which is ahead of the zero or indicator, the direction in which the latter moved having been assumed in reading the plate.

b. When reading the plate, estimate at a glance, the approximate vernier reading. This not only saves time by indicating where to look on the vernier for the line of coincidence, but it often saves blunders such as reading the wrong side of a double vernier.

c. Form the habit of looking at one or two marks each side of the vernier mark you think is in coincidence.

d. When there are two verniers 180° apart, use the one under the eye end of the telescope

e. Use a reading glass.

7. <u>Measuring Angles by Repetition</u>

To measure an angle by repetition, the single value of the angle is read as pointed out above. The plate setting is left unaltered, the instrument is turned on its lower motion, and a second sight is taken to the first point as A. The upper clamp is loosened, and the telescope is again sighted to B. The angle has now been doubled. The process is continued the required number of times. The plates are read, and the value of the angle is determined by dividing the reading by the number of times the angle was turned. To eliminate mistakes, this value is compared with the angle observed at the completion of the first letter.

I. Horizontal Curves

A. Definitions: (Refer to Figure 5)

1. P.C. - Point of Curvature

This is the point at which the curve begins.

2. P.T. - Point of Tangency

This is the point at which the curve ends.

3. P.I. - Point of Intersection.

This is the point of which two straight lines (tangents), intersect.

4. Tangent Length

Distance measured along the tangents from the PI to the PC or PT. The distance from the PI to the PC is always equal to the distance from the PI to the PT.

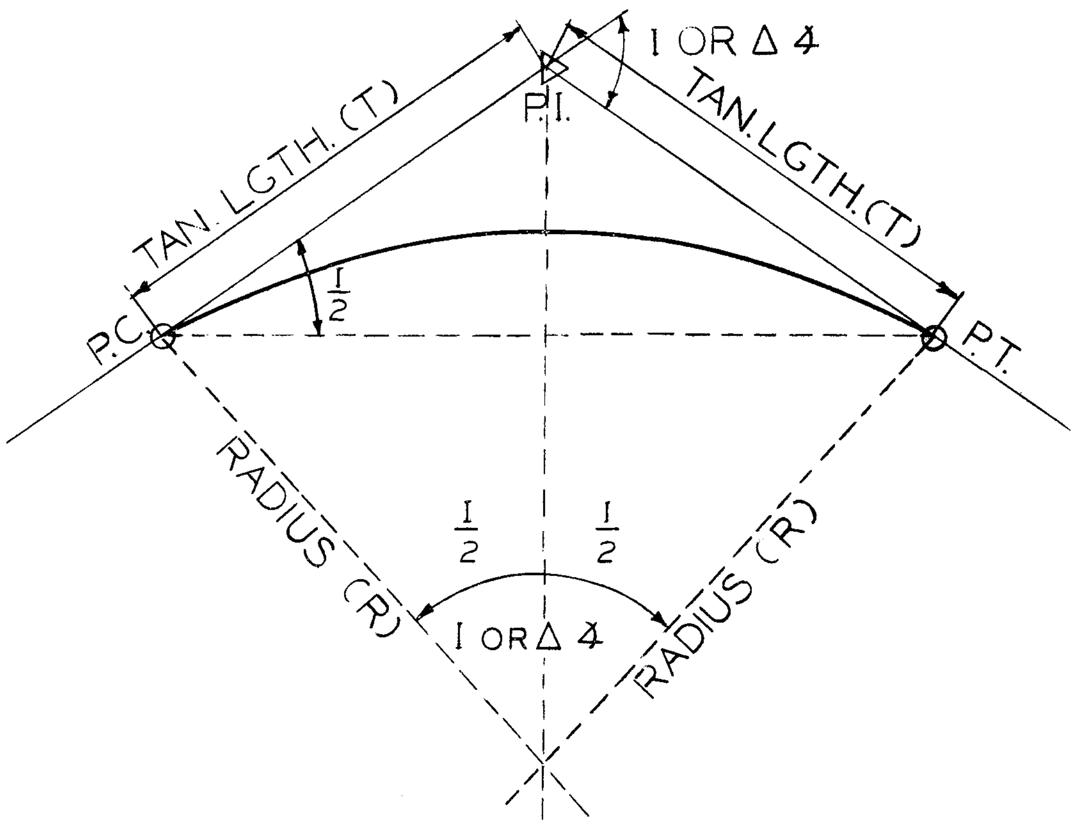


FIG. 5

This length is sometimes called "semi-tangent."

5. Degree of Curve

The degree of curve defines the "sharpness" of the curve. Since a horizontal curve is simply a portion of a circle, obviously an infinite number of curves may connect the tangents. The actual definition of "degree of curve" will be given later.

6. Length of Curve

The distance, measured around the curve from the PC to the PT. This measurement is impossible to actually make on the ground. It can be approximated by measuring a series of straight lines or chords.

7. I. Angle - The Intersection Angle

This is the deflection angle that occurs at the PI. This angle is also called the "delta angle" or central angle.

8. Radius

The radius of the circle selected to form the horizontal curve. This then, bears a direct relationship to the degree of curve, as will be shown.

B. Formulae

1. General

We will now develop various formulae to be used in calculating the components of a horizontal curve. These derivations are all based on the basic trig functions given in Session IV.

2. Degree of Curve

While this value is usually selected by the designer, it is well to understand the mathematical relationship it bears to the radius (refer to Figure 6). The degree of curve is actually the angle subtended at the center of a circle by a 100-foot chord. As you can see

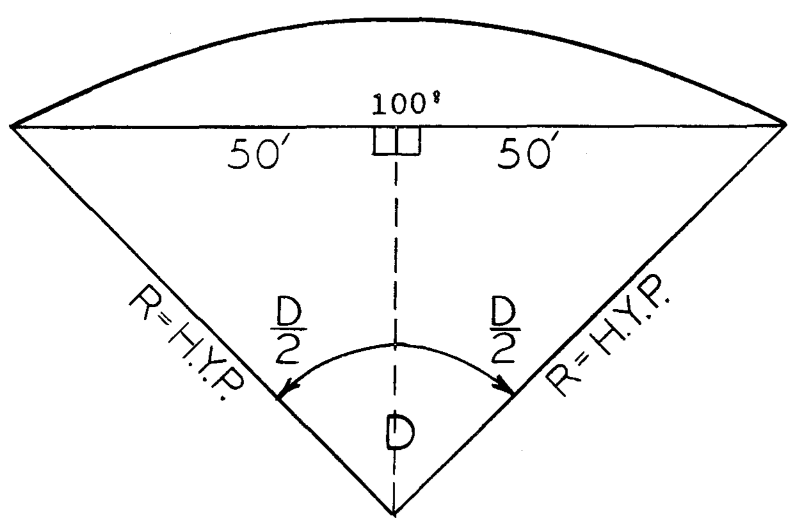


FIG. 6

from Figure 6, it is possible to draw a perpendicular line from the center of the circle to the 100' chord, thus creating two equal right triangles. By assigning symbols to the various values, it is possible to solve for the mathematical relationship.

Let the Radius	=	R
Degree	=	D
1/2 Degree	=	D/2
Then Sin of D/2	=	50/R (Opposite side/hypotenuse)
Then R	=	50/sin D/2

3. Tangent Length (Figure 5)

You will note in Figure 5, that two right triangles are formed when you connect the PC, PI, and PT to the center of the circular curve. Since the whole angle at the center is equal to the central or I. Angle, then each of the two small angles are equal to 1/2 I. By using the trig function, the tangent length may be found.

$$\text{Tan } 1/2\ I = T/R$$

$$T = R(\text{Tan } 1/2\ I)$$

This length may be looked up in tables for a 1° curve, then divided by the degree of curve used.

4. Length of Curve

From Figure 6, you note that angle of D subtends 100' of chord. Therefore, the number of such angles in the whole central angle will give you the number of 100' chords in the curve:

Thus the length of curve

$$L = I/D \text{ (in stations)}$$

5. Deflection Angles

Curves are usually staked out by the use of deflection angles turned from the tangent to a point on the curve, together with chords measured from point to point along the curve. For example, in Figure 5, the deflection angle for the PT of the curve is the angle at the PC marked I/2. The deflection angle for any other point on the curve will be some angle less than I/2 measured at the PC from the tangent. Note the relationship between the central angle at the center of the circle (I) and the corresponding deflection angle for the same point (I/2). The deflection angle is always one-half of the angle subtended at the center of the circle.

Referring to Figure 6 and using the above theory, the deflection angle for 100' of chord on a curve is D/2, and for one foot of chord, the deflection angle is $D/2 \div 100$.

Ex.	D	=	$1^\circ 00'$
D/2		=	$0^\circ 30'$
Def. ∠ per ft.		=	$0^\circ 30'/100 = 0^\circ 0.3'$

Deflection angles can then be calculated for any length of chord. The maximum length of chord normally used in staking a curve is 100'.

C. Sample Problem

P.I.	=	22+58.30
I.	=	8° 43' Rt. (Delta Angle)
D.	=	1° 00' (Curve Selected)
T.	=	436.68' (Length of Tangent)
L.	=	871.67' (Length of Curve)

T. = $\frac{\text{Tangent for } 1^\circ \text{ Curve}}{D} = \frac{436.68}{1} = 436.68'$

L. = $\frac{I}{D} \times 100 = \frac{8.7167}{1} \times 100 = 871.67'$

P.I. = 22 + 58.30'
− 4 + 36.68' (Length of Tangent)

P.C. = 18 + 21.62'
+ 8 + 71.67' (Length of Curve)

P.T. = 26 + 93.29'
Def ∡(100') = 0°-30'
Def ∡(1') = 0°-00.3'

		STA.		
P.C.	=	18+21.62	=	0°00'00"
		19+00	=	0°23'31"
		20+00	=	0°53'31"
		21+00	=	1°23'31"
		22+00	=	1°53'31"
		23+00	=	2°23'31"
		24+00	=	2°53'31"
		25+00	=	3°23'31"
		26+00	=	3°53'31"
P.T.	=	26+93.29	=	4°21'30"

D. Field Procedure

There are several different methods of staking horizontal curves in the field. The following points are the more basic considerations and do not entail the unusual problems often encountered in the field.

1. Centerline staking is carried concurrently to the P.I.
2. I angle is turned by repetition to whatever degree of accuracy is desired, usually doubled.
3. Curve data is calculated, using desired degree of curve.
4. Distance is measured down forward tangent to the P.T. P.T. is set, using 2" x 2" hub.
5. Distance is measured down back tangent to P.C. Check to nearest back station to see if plus is correct. P.C. is set, using 2" x 2" hubs.
6. Curve is run in setting centerline hubs on 50' or 25' spaces, depending on degree of curvature. Transit is not moved from P.C. unless necessary. The instrument is sighted on the P.I. with the plates set at zero. The lower motion is clamped and not touched again. The first deflection angle is turned off, and the distances and line are accurately set. The next angle is turned and measurement made from the previous point set. This procedure is repeated until the P.T. is reached.
7. Check line and distance against pre-set P.T. and pre-calculated station number.

8. In the event the transit must be moved from the P.C. to an intermediate point on the curve, the following rule should be observed in orienting the instrument to continue running the curve.

<u>Rule:</u> A back sight is taken on the point at which the transit was last set up (telescope inverted), with the deflection angle of the point on which the transit is located, turned off. The lower motion is clamped, the telescope plunged, and the deflection angles for the succeeding points, as previously calculated, used.

III. Centerline and Topography

A. <u>General Procedures</u>

1. Organizing Field Party

The procedure normally used in running the centerline of a proposed road and mapping the topography along that centerline is called a transit-tape survey. This is the case for which the transit is employed in running straight lines and curves and the tape or chain is used to measure horizontal distances.

This type of field party will consist of:

a. Instrumentman

b. Head Chainman

c. Rear Chainman

d. Notekeeper and Party Chief

If the line is to be run through wooded country, several brush cutters must also be used.

The equipment required for a transit party usually consists of:

Transit
100' Steel Chain
50' Metallic Tape
Chain Cutters
Chaining Pins
String and String Level
Stake Bag
Stakes
Tacks
Axe or Hammer
Marking Crayon
Boot Spikes
Red Flagging
2 Plumb Bobs
2 Range Poles
Field Notebook
First Aid Kit
Cold Chisel

Other specialized items may be required, but those listed above are the normal requirements.

Prior to leaving the office for the field to begin work, the party chief should satisfy himself that he thoroughly understands the required work. In particular, he should know the beginning and ending points of the centerline as well as any other alignment requirements.

2. Staking the Centerline

The beginning point of any roadway centerline is station 0+00. The centerline is then marked off with stakes set every 100 feet. These 100-foot points are called Full Stations or even stations. Intermediate points between full or even stations are called plus stations. Thus, a full or even station, 1200 feet from the beginning point, would be numbered 12+00, or simply 12, and a plus station, 1357.6 feet from the initial point, would be numbered 13+57.6.

a. Hub Line

The first detail of the alignment survey is the establishment of a line of hubs following the approved location. Hubs, consisting of a tack point in a 2" x 2" stake driven flush with the ground, properly guarded and referenced, are set at:

(1) Each point of angular deflection.

(2) Each point where conditions require setting the instrument.

(3) At each intersection with city, county, or State boundary.

(4) At or near each end of major structures.

(5) At such other points as necessary to provide maximum separation of 2,000 feet.

Each hub to be used as a transit point should be carefully and accurately set by double center. Intermediate points may be set either by direct foresight or by double center.

b. Reference Stakes

Each hub should be referenced by setting reference hubs at a distance of 50 feet and 100 feet on a line at right angles to the centerline. Each angle point should be marked by reference stakes so selected and set that the point may be readily re-established, preferably without measurement.

c. Guard Stakes

Each transit point should be guarded by a stake, or stakes, so driven as to protect the hub from disturbance. Guard stakes should generally be at such angle that they will indicate the location of the hub should it be covered with dirt. The guard stake should not extend over the top of the hub, since this would interfere with the plumb bob of the transit.

d. Centerline Stakes

Stakes should be accurately set on the centerline at each 100-foot station, and at such intermediate points as appear necessary for cross sectioning and topography measurements. Stakes for this purpose should generally be 1" x 2" x 18" (nominal), driven approximately 8 inches deep. The stake should bear the station number on the face toward the beginning of the survey. (Some engineers consider the plus stakes superfluous. Check with the Resident Engineer for his preferred method of operation.)

e. Stakes in Cultivated Areas

Stakes in cultivated fields or hay meadows should be suitably marked by lath and driven to such heights that there may be no damage to cultivating and mowing equipment. Considerable damage to equipment and resultant ill will has been caused by unflagged stakes in fields. Before stakes are set in fields, methods should be discussed with owners or tenants.

f. Topographic Measurements

On tangents, it is preferred that measurements of distances to locate objects be at right angles to the centerline. However, angular measurements can be made if they are more desirable.

Location of intersecting property lines or fences should include both the angle and point of intersection with the centerline.

On curves of small degree of curvature, measurements of satisfactory accuracy can be made from the centerline. On curves of a large degree of curvature, measurements may be made from the tangents of the curve rather than the curve.

B. Correct Form for Field Notes.

1. Alignment Data

The alignment data is kept on the left-hand page of the notebook. The stations are numbered from bottom to top of the page. Five 100-foot increments are set off on each page, with a station being recorded on the bottom line and one every five lines up the page, resulting in a station being recorded on the top line of a page. This station number is then repeated as the first station number on the bottom of the next page. Station numbers are usually arranged so that the numbers on top of a page, which are repeated on the bottom of the next page, are even 500-foot increments. Figure 7 is an example of the normal alignment of notes carried on the left-hand page of the field book. The small circle with the dot in the center indicates a transit point or P.O.T.

2. Topographic Data

The right-hand side of the page is used to draw a scaled map of the topographic data. The red line running vertically up the center of the page is used to represent the centerline. The stations should be indicated on this red line with small dashes on the same line that the number appears. This, in effect, simulates a scale of 1"=80'. The line going vertically on the

Sta.	Point.	Def. ∡	Tot. Def. ∡	Remarks
10+00				
+17.92	P.T.	0°27'	10°00'	POT
9+00		1°15'	9°33'	
+80				Wire Fence County Rd. R.O.W. North
+50		1°15'	8°18'	
+40				Wire Fence County Rd. R.O.W. South
8+00		1°15'	7°03'	
+50		1°15'	5°48'	Curve Data
				Δ = 20°
+20	P.I.			D = 5°
7+00		1°15'	4°33'	L = 400'
				T = 202.08'
+50		1°15'	3°18'	
6+00		1°15'	2°03'	
+52				5' Net Wire Fence
+50		0°48'	0°48'	
+17.92	P.C.	0°00'	0°00'	POT
5+00				

FIG. 7

right-hand page should be assigned the same scale which will allow the notekeeper to use the line as guidelines in the event he does not have a scale. All details, objects, and fences should be clearly indicated on this sketch. Figure 8 is an example of typical topographic notes.

IV. Profile Levels and Cross Sections

Profile levels and cross sections develop essential data for the determination of three major features of design:

(1) Gradient.

(2) Quantities of earthwork and distribution.

(3) The layout of drainage facilities.

A. Profile Levels

Profile levels should, by reference to bench marks established during the progress of bench level surveys, indicate the true elevation above mean sea level of each break in the ground surface along the centerline of the road. Readings should be to the nearest 0.1 of a foot and should be checked at each of the bench marks previously set. The error closure at any bench mark should not exceed 0.05 foot.

B. Cross Sections

Cross sections are usually obtained concurrently with profile levels, and consist of a profile extending perpendicular to the centerline for at least the full width of the right of way. In instances where necessary to truly

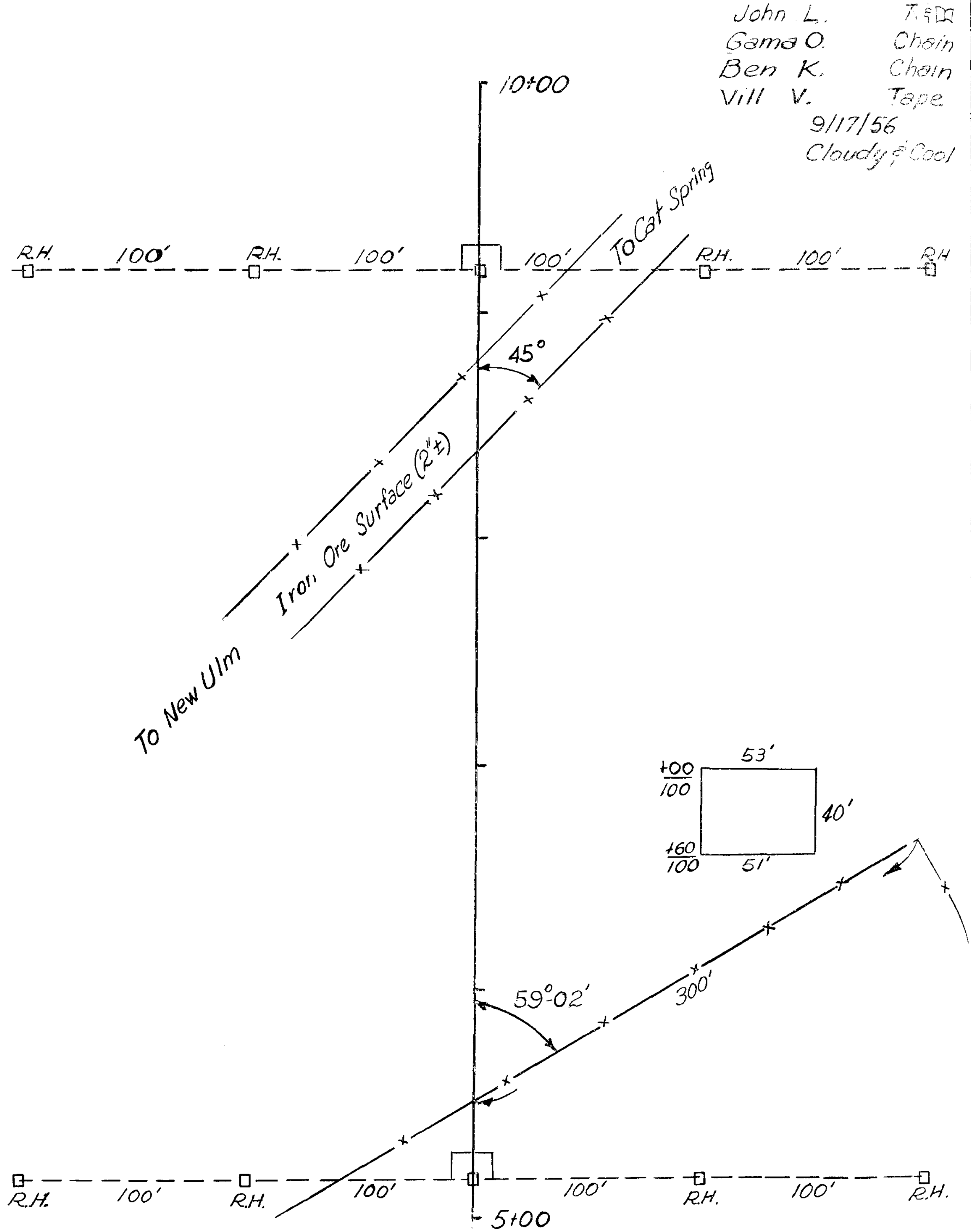

John L. T.&R
Gama O. Chain
Ben K. Chain
Vill V. Tape
9/17/56
Cloudy & Cool
10+00
To Cat Spring
R.H.
100'
R.H.
100'
100'
R.H.
100'
R.H
45°
Iron Ore Surface (2"±)
To New Ulm
53'
+00
100
40'
+60
100
51'
59°02'
300'
R.H.
100'
R.H.
100'
100'
R.H.
100'
R.H.
5+00

FIG. 8

indicate drainage conditions, general slope, or contours necessary to determine proper design, cross sections should be extended as required.

C. <u>General Procedures</u>

In obtaining cross sections, it should be recognized that the primary purpose of cross sections is the determination of quantities of earthwork. Therefore, a sufficient number of sections should be obtained so that the true ground surface will be represented. Cross sections should be so defined at right angles to the centerlines that subsequent sections, as required during construction, will correspond with the original section. The preferred method of defining cross sections is by setting a stake at, or adjacent to, each right of way line. The section can then be taken by lining between the stakes. This stake should be driven down flush and the elevation of its top recorded. This can be done during the taking of the cross section. In addition to serving to define the section, this stake also serves as an elevation hub and alignment stake during construction operations.

In order that a true determination of quantities may be made, it is necessary that all cross sections be accurately perpendicular to the centerline. A right angle may be readily measured by a right angle mirror or prism.

HIGHWAY DESIGN II

I. Plan-Profile

A. General Remarks

1. Function

The plan-profile sheets of a set of plans can be compared to the piston of an engine. While they alone are not sufficient for the construction of a project, the information shown makes a project move along during construction. These sheets picture on paper, both horizontally and vertically, the natural and man-made features that are necessary to establish a clear outline of the work to be done. Too much or too little detail can produce unsatisfactory results.

2. Contents

It is assumed that the students are familiar with what a plan-profile sheet looks like and remember the short discussion and illustrations given in a previous lecture. Therefore, we shall go directly into the minimum requirements for preparation of these sheets. It is the purpose here to establish a mutual concept of what constitutes the elements of a good set of plan-profile sheets, but there is no intention to convey the thought that these requirements are inflexible. Plates 1 and 2 are introduced at this time for the purpose of illustrating the lecture on plan-profile sheets.

B. Scale

The plan view is commonly to a scale of 1" = 100'. However, in the case of a congested area where many factors will influence the construction, the use of a 1" = 50' scale is justified. On some occasions, a scale of 1" = 200' is used. Suggested vertical scales for use with these horizontal scales would be 1" = 10', 1" = 5', or 1" = 20', respectively. When selecting the scale to be used, consideration should be given to the amount of the project to be shown per sheet. There is a maximum number of stations that can be shown on a sheet. Full utilization of the space provided should be provided for, since a saving both in preparation and reproduction costs can be realized.

C. General Arrangement of Sheets

Sufficient space should be provided to show the profile beyond each end of a project in order to indicate a properly designed beginning and ending grade. In addition, the entire length of the project must be studied to determine the proper division of the project into each plan-profile sheet. By studying this arrangement in advance, it may be possible to avoid dividing any of the major features such as large bridges, highway intersections, etc., between two sheets.

D. <u>Required Drafting and Drafting Instruments and Methods of Plotting</u>

1. Drafting

A draftsman must understand the principles used to represent objects on drawings. That is, to be able to draw plans, a person must be able to read plans. A person must know how to use and care for the instruments and materials that are used. A draftsman must also know what factors contribute to making drawings effective and easily read.

The method of presenting the work on plan-profile sheets could be interpreted as the orthographic projection method. These sheets depict the vertical and horizontal planes along a centerline on which the project is to be constructed. The plan view is placed directly above the profile view and any point on either view can be analyzed by a perpendicular projection between the two views.

The profile view gives dimensions graphically by showing elevations, while the plan view uses the conventional dimensioning procedure. All dimensions and other information should be placed so that they may be read from the bottom or the right of the drawing. Inclined information should be placed so that it may be read by turning the drawing through the smallest possible angle.

A draftsman needs good instruments and materials, and he must know how to use and care for them. Teaching an inexperienced person to become a draftsman requires careful explanation and demonstration on the part of the instructor, followed by diligent practice by the student. The use of a good standard text on the subject is strongly recommended. Following is a brief description of drafting instruments and their use.

2. Drafting Instruments

The drafting instruments commonly used are straightedges, triangles, scales, protractors, compasses, railroad curves, French curves, and flexible curves. All drawings are usually made in pencil on paper or cloth. In order to provide clear and legible prints from the drawings, it is recommended that a rounded or ball-type pencil point be used instead of a very sharp pencil point. Different draftsmen will find that certain grades of pencils are more suited to their touch and method of drafting.

The plan-profile sheet contains many straight lines, both long and short. The short lines may be drawn by using the straightedge of a triangle. The long lines can be drawn by using a steel straightedge. The plan view is usually laid out by starting from some straight line drawn on the paper. This straight line is usually the centerline of the highway. Drawing this line with a steel straightedge will provide the accurate and straight line that is necessary for plotting the other data by offsets.

The scale is an engineer's scale, triangular in shape, 12 inches long, and provides six different scales. The scales have the inch divided into 10, 20, 30, 40, 50, and 60 parts.

The protractor is a graduated arc and is used in plotting angles in the plan view. In plotting an angle with the protractor, the bottom line of the instrument, which is the zero degree point, is made to coincide with the line from which the angle is to be laid off, and the center of the protractor, which is marked, is made to coincide with the point on the line. On the outside of the arc, a mark is made on the drawing at the desired reading. The protractor is then removed from the drawing and the line drawn on the plan. There are other methods of plotting angles in case a protractor is not available. A right angle can be obtained by using two triangles, a $30^\circ - 60^\circ$ and a 45° triangle, or other angles can be plotted by tangents, using trigonometry.

Railroad curves are used to plot the horizontal curves discussed in the lecture on surveying. The curves are commonly made of transparent material and come in sets of 15 minutes, 30 minutes, or 1 degree intervals of degree of curvature. They are made for a scale of one inch = 100 feet, and have a short straightedge tangent to the curve at one end with the beginning of the curve marked by a line. If the scale is other than 1 inch = 100 feet, the curve used is proportional to the scale used. If the degree of curve to be plotted is 5 degrees and the scale is 1 inch = 50 feet, the 2 degree 30 minute curve is used. If the scale is 1 inch = 200 feet, a 10 degree curve is used. The French curve is an irregular curve that comes in a variety of shapes. This instrument is commonly used to plot the vertical curves discussed in the lecture on surveying.

The flexible curve usually has a flexible metal back and can be used under the same conditions as the French curve.

The compass is an instrument used for drawing the arcs of circles such as the circles placed at the beginning and ends of horizontal and vertical curves and right of way markers. However, these symbols can also be provided through the use of a template. These figures are used to guide the pencil in tracing out the object on the paper.

Last, but not least, is an important subject, lettering. Lettering must be legible and easily executed. The style of lettering in use is illustrated on present highway drawings. Good lettering consists of just a few simple fundamentals. Knowing these fundamentals, the draftsman acquires the ability to letter well only through diligent and conscientious practice. A common type of lettering device available which aids the draftsman in making uniformly spaced guide lines is the lettering triangle. Horizontal guidelines, correctly spaced, are formed by inserting a pencil point in the holes and sliding the triangle along a straightedge. Inclined guidelines are rapidly made, using the slot in the triangle. The guidelines may be drawn on a small sheet of drawing paper, and then these lines may be inserted underneath the proposed drawing in the proper position for the lettering. This guideline sheet can be used again and again until the paper wears out. The large size plan drawings are reproduced at a reduced size to be included in the contract and for permanent records. Lettering smaller than No. 5 on the lettering triangle becomes illegible on the small reproductions. Therefore, the No. 5 letters are best suited for the drawings.

E. Plan

1. Centerline

On the plan portion of the plan-profile sheet, the project centerline is plotted as a medium-weight solid line about the center of the plan space. When the alignment changes, small circles are shown at each P.I., P.C. and P.T. The centerline should be placed to avoid breaking the plan view or running the line out of the plan space. (The centerline angles at points of curvature are best plotted by the method of tangents mentioned under the discussion of the protractor as a drafting instrument.)

All stationing should run from left to right, marking each 100-foot station by a short vertical line and numbering each station that is divisible by five. The centerline should not be plotted beyond the limits of the length for which quantities are computed on the sheet. The bearing of each tangent should be shown, and on each sheet show a distinct north point accurately positioned. A fancy north point is not advisable. A template or stamp could be used for this purpose. All curve data should be shown at each curve. This data should include the station number of the P.C. and P.T., written along a dashed line perpendicular to the centerline, indicating the location of these points.

A list giving the P.I. station, the angle of deflection and its direction, the degree of curve, the tangent length, and the curve length should be shown within the limits of the curve. Where spiraled curves are used, the data shall be amplified to include all essential information. In the case of frontage roads on freeway projects, the station numbers of the P.C. and P.T. are usually not shown in order to promote clarity of the plans.

All equations and exceptions should be indicated in a manner similar to the P.C. and P.T. of curves. Exceptions may or may not be plotted, depending upon the length and value to the job. The exception can be eliminated from the drawing by showing a gap in the drawing and picking up the full station in the plan view at the point desired and at a station point directly above the same point in the profile view.

Equations can become difficult to show. An equation may be a plus equation or may be a minus equation and may be more or less than a station in length. Since the even station is shown on the heavy lines in the profile view, it is necessary to provide a gap in the profile if the equation has much length.

2. Right of Way Lines

The proposed right of way lines are plotted as light-weight solid lines. If the right of way is widened, then the existing right of way line should not be shown. The distance of right of way lines from the centerline should be shown on each sheet, preferably at each end, and at every point of change in the right of way width. It may be necessary to eliminate some of the dimensions on freeway projects in order to avoid confusion.

The proper symbol should be used to indicate the position of all right of way markers to be placed under the contract. Where right of way markers are in place and to be retained, a symbol such as the circumference of a circle in a lightweight solid line could be used. If the marker is to be removed, then the outline of a circle could be a dotted line, since the customary symbol to show structures removed is by the use of dotted lines. Previous suggestions in the form of memorandums have been furnished as an aid to locating markers. No attempt will be made at this time to discuss the subject.

3. Old Road

The position of the old road should be properly indicated if the road occurs in the limits of the area shown on the plan view and influences the proposed construction. When shown, the old road is usually indicated by dotted lines using appropriate symbols to indicate the portion to be removed and the portion to remain in place. If the old road is a certain fixed distance from the proposed centerline, then it may be possible to show the position of the old road sufficiently clear on the typical cross section sheet and eliminate showing on the plan-profile sheet.

4. Existing Improvements

On the plan, existing improvements are to be shown by proper symbol and in their exact location. Only those features that actually affect the proposed construction, under the conditions that will govern at the time of award of contract, should be shown on the plan. This will eliminate cluttering up the plan with obstructions, structures, buildings, fences, etc., within the right of way that have already been removed and do not have any bearing on the project. Items adjacent to and outside the right of way, if affecting the proposed construction, should be shown. The symbols for showing most of the existing improvements are covered by the legend shown on the title sheet. Generally, all utilities within or adjacent to the right of way lines should be shown, as it is quite often necessary to remove or adjust these utilities. Railroads should be shown in all cases. All improvements which may contribute to traffic congestion or add traffic hazards, such as schools, play grounds, churches, cemeteries and side roads should be shown.

Existing culverts and bridges should be shown, using a single line outline symbol similar to that shown in the legend on the title sheet, except the flared line at each end of the symbol should be used only when the structure has wings. If the structure has parallel wings, then the flare should be normal to the structure, and the showing of other types of wings should follow this reasoning. The method of indicating items to be removed by the use of dotted lines should be followed. It is not necessary to describe and give the disposition of existing culverts and bridges if some system of identifying and differentiating is used. A recommended system is that of using a number and a letter for each structure; the number identifies the structure and the letter gives the disposition. This system is carried into the summary sheets of the estimate and quantity section of the plans.

5. Topography

The essential topographic features should be shown on the plan. Stream and channel meanders adjacent to each end of a structure with the direction of flow and name of stream shall be shown. On some occasions, the limits of wooded areas are shown in order to define the work to be performed in clearing and grubbing. In the case of steep hills controlling grade and other design features, it may be necessary to indicate contours. However, this is a feature that is rarely used. Land use and type of soil are items that have been shown on these sheets in the past, but since these items are of informational nature and considered elsewhere on the job, it is recommended that this information be eliminated from these sheets.

6. Construction in Project

The plan should show the construction to be performed under the contract for the project. Proposed culverts and bridges are shown by a single line outline, and descriptions are not shown. This is the same procedure as recommended for the showing of existing structures. The stationing for the beginning and end of structures of bridge classification should be shown in either plan or profile views. It need not be shown both places.

Channel easements that adjoin the right of way should be shown, even though the channel may be shown on a separate sheet of the plans. A reference to this other sheet of the plans is advisable. The easement lines are shown by the same symbol used for right of way lines. A typical channel section should be provided either on the plan-profile sheet or the separate channel sheet.

On complex projects such as freeways, curb and gutter jobs, and non-controlled access highways of more than two lanes, it is advisable to outline the limits of the road surfaces throughout the length of the project in order to provide a more clear outline of the work to be performed. However, some consideration should be given to the fact that there may be long lengths of roadway where this may not be necessary. Time and work can be saved by merely drawing the centerlines of the roadways with occasional dimensioning.

Other features in the plan view may be dykes, borrow pits and erosion control measures. The methods of showing these features are many.

7. Special Features

In addition to the general requirements for plan information on all of the plan-profile sheets, special data and other features are required. On the first and last plan-profile sheets, the proper indication of the connecting highway, where one occurs, should be shown. This should consist of the alignment shown by plotting, type of construction and name of nearest town. The beginning and end of project should be shown in a manner similar to that shown on the title sheet. The control of access line should be shown on Interstate projects and other Federal Aid projects for which access rights have been acquired. The control of access shown on the plans must coincide with that secured in the acquisition of the right of way. The symbol used in the attachment to Road Design Information Circular No. 3-57, dated January 17, 1957, is satisfactory.

The line work used in showing features on the plan could be summarized as follows: it is desirable to show the existing improvements which are to be removed in the construction of the project as dotted lines, existing improvements which are to remain, as light lines, and all new construction, by heavier lines of the proper convention. All existing construction and new construction should be made clear by good presentation.

F. Profile

1. Location on Sheet

On the profile portion of the plan-profile sheet, some consideration must first be given to determining the location of the profile. If the project is a freeway providing for main lanes and frontage roads, then the profile portion will contain profiles only. On other projects, the profile may be plotted as close to the bottom of the sheet as practical, leaving clearance for the low points of the profile and the necessary culvert data. This is done in order to leave as much space as possible for the haul diagrams that may be plotted above the profile. In plotting a profile in a hilly area, the first step is to decide from an examination of the range of elevations where to start so that the profile will come within the limits of the paper. When the difference of elevation is such that the profile line, if continued, would run off the top or the bottom of the paper, the profile line should be stopped at a heavy vertical line, which would be an even station, and resumed at the same vertical line, lower or higher, as the case may require. The numbering of the horizontal elevation lines should then be changed to correspond.

2. Ground Line

The first profile plotted is the ground line along the centerline of the location. This should be plotted as a medium weight solid line. Where the centerline lies on an old road or in a ditch, some consideration should be given to the type of construction that is proposed before determining what profile or what additional profiles should be provided. On a curb and gutter project, the primary interest may lie in a profile of the natural ground. The profile is plotted by using the rulings of the profile paper as a scale. The heavy vertical lines are used as even stations for scales of 1" = 50', 100' and 200'. The heavy horizontal lines should represent some even elevation such as 100, 110, 115, etc. It will be found, if the profile section is measured with a scale, that the divisions scale longer than they should. In plotting a profile on these sheets, no attempt is made to use a scale, except for the plotting of intermediate points, such as pluses. A straightedge is used in drawing the profile, and points of ground-slope change should not be rounded off. The plotting should include all cross roads, ditches and stream beds.

3. Datum Reference

The stations on the sheet are indicated at the bottom of the profile by lettering in the station numbers only. It is advisable to show the complete station number at the beginning and end of sheet and for the even five or ten stations, as this will enable a person to determine the sheet limits and intermediate points readily. The other stations may be shown by giving only the last, or last two, figures of the station number. At the margin of the sheet, preferably on both the right- and left-hand side of the sheet, the elevations at each one-inch interval should be shown. This means that a minimum of two elevations should be shown in the margin for each profile.

4. Elevations

Previous practice has been the showing of the elevation of each station, given to the tenth of a foot, written vertically to the right of the station line. Federal Aid projects require this data if plain sheets are used but do not require this data if the standard plan and profile sheets are used. Showing these elevations can become quite a chore, particularly on a freeway project where profiles are provided for main lanes and both frontage roads. Previously, the proposed profile elevation of each station has been shown to the nearest hundredth foot, writing the figures vertically to the left of, or above the station line.

Federal Aid project requirements are the same in regard to proposed and existing elevations. Assuming that a freeway project provides main lanes, which are usually at the same elevation, two frontage roads which are usually at different elevations, this means that six elevations would be shown at each station based upon previous methods of plan preparation. It appears that this amount of work should be given some consideration or possibly eliminated where feasible.

5. Grade Line

On the completed plan-profile sheet, the grade line is shown as a medium-heavy, dashed line accurately placed on the profile elevation. This elevation should be the same as that shown on the typical section sheet, and reference is made to the immediate previous discussion in regard to showing elevations. All points of grade change, such as the P.I., P.C., and P.T. of vertical curves, are shown by small circles centered on the proper point, and the grade line is not drawn through the circles. In addition, the data for all vertical curves is shown, as well as the per cent of grade on each grade tangent. Vertical curve data consists of P.I. station, elevation, length of curve, and the value of the external.

Ditch grades should be shown in a manner similar to the centerline grade line except for the possibility of altering the symbol somewhat. The same data should be shown on ditch grades that is shown on the centerline grade line, except vertical curves are not used. Equations and exceptions should be shown in the profiles in a manner similar to that recommended for the plan view. A notation should be included with all profiles to indicate what the profile represents. This notation need not be shown on every sheet but should be shown often enough to avoid thumbing through too many sheets to find what the grade line represents. Elevations and curve data are usually shown crosswise of the sheet with other information shown lengthwise of the sheet.

G. <u>Structures</u>

The structures plotted in the profile view are the highway cross structures. Usually, side structures, private entrances and crossroads, are not shown in the profile view but are handled by the letter notation method recommended in the plan view discussion. If a side structure is proposed at a flow line elevation other than the side ditch grade, then the structure could be plotted in order to show the proposed flow line elevations. Box culverts and pipe structures are plotted as a centerline section and not as an end elevation. Due to the warped scale of the profile view, a box culvert section should be drawn the same as a barrel section on the culvert detail sheets, except the walls should be shown as a single line. A pipe culvert section should be shown as a single line outline in the form of an ellipse. Culvert data should be shown and should include the station number of the center of the structure, size and length, type of construction by reference to the design detail sheet, and the flow line elevation. Culverts of bridge classification should provide the stationing of the beginning and end of the structure instead of the station at the center of the structure. The profile view of bridges of the trestle type may be limited to a line showing the finished grade together with vertical lines at each end to show the limits of the bridge. A description of the bridge may be omitted and a note substituted, referring to the bridge layout sheet number, since a complete description is shown on the bridge layout.

H. <u>Mass Diagrams</u>

The mass diagrams that may be placed on the plan-profile sheets in the space just above the profiles, will be discussed later in this lecture.

I. <u>General Quantities</u>

The items of work, referred to as general quantities to distinguish them from the grading quantities which are computed for each station, are usually shown in the top lines of the quantity space above the profile. These are the quantities which are computed over some considerable length, but are computed for definite dimensions. One of these general quantities to be shown on this sheet is clearing and grubbing. The quantity line should show graphically the limits of the length of each area and the quantity. The items of work which are not estimated in small increments at various definite locations will be shown elsewhere in the plans.

J. Grading Quantities

The grading quantities are indicated in the ruled spaces provided above the profile and, where possible, the estimated quantities should be placed in the left-hand division of each station. The final quantities can then be placed in the right-hand division. The usual order in this listing is: excavation items, embankment items, and then other items, plus overhaul.

K. Sheet Totals

The sheet totals of general and grading quantities are shown in the space indicated on the standard sheet or in an improvised space on those sheets that do not make such provisions; item names are commonly shown at the left of the sheet opposite the applicable quantities. The standard plan-profile sheets provide space for item names on the left side of the sheet and another space to the right of the sheet totals. The placement of item names to the right of the sheet totals is much more convenient. The provision of sheet totals on each sheet will allow the elimination of a summary of grading on the estimate and quantity sheets.

L. <u>Sheet Notes</u>

Sheet notes are shown in the lower right-hand corner of the sheet. The standard plan-profile sheet provides a blank space for these notes. The most common notes appearing in this space are the level bench marks, giving the bench mark number, its elevation, description and location with reference to the centerline. On the first plan-profile sheet, a reference to the datum on which the levels for the project are based should be shown.

II. Grades

A. General Remarks

The vertical alignment of the roadway and its effect on the safe and economical operation of the motor vehicle constitutes one of the most important features of road design. The vertical alignment, which consists of a series of straight lines connected by vertical curves, is known as the grade line. When the grade line is increasing in elevation in the direction of the stationing, it is known as a plus grade, and when it is decreasing in elevation in the direction of the stationing, it is known as a minus grade. Ideal grades are those that have long distances between points of intersection, with long vertical curves between tangent points to provide good visibility and smooth riding qualities.

B. Principles of Design

1. Facility for Traffic Flow

The grades of a highway must be designed in accordance with several principles. The first principle is to provide an adequate facility for the flow of traffic. One of the main restrictions to uniform traffic flow is the maximum grade on the highway. The design standard sets out the grade considered to be the maximum for the road under consideration, and these maximums should not be exceeded except in very special conditions.

The restriction to the uniform flow of traffic offered by the maximum per cent of grade depends on the length of that maximum grade and on the frequency at which it occurs. In designing the grade line, the length of each maximum per cent of grade and the total length of all the steeper grades must be considered. In other words, on those sections of highway with high traffic volume and heavy truck traffic, emphasis should be given to the use of a broken grade profile with the steeper rates at the bottom of the grade rather than a long, sustained grade near the maximum allowable. The mechanics of checking this feature and determining the necessity of a remedy, such as the provision of climbing lanes, have been made simple by the use of a speed distance curve provided in several of the design manuals. This relationship of grades seldom offers any problems in this area of the country.

2. Construction Economy

Another principle in the design of grades is to establish that design which will provide for economy of construction. The first method of obtaining economy is to design a grade which will require the minimum amount of cut and the minimum amount of fill. This may be accomplished by fitting the grade line to the natural ground surface as closely as possible. Good drainage is also usually accomplished in this manner. There are very distinct restrictions which will prevent the achieving of maximum economy by this method, a few of which are:

a. Maximum permissible grade.

b. Required grade to meet drainage structures.

c. Necessity to provide adequate passing and non-passing sight distance and the elimination of blind spots.

d. Necessity of keeping grade above high water elevations, both where the location crosses an overflow area and where it parallels a stream.

e. The requirement that the entire design must produce a pleasing appearance and a facility which will not be expensive to maintain.

3. Safety

The primary safety features of a grade line are met by obtaining adequate passing and non-passing sight distance. Sight distance is the length of highway ahead, visible to the driver. When this distance is not enough to permit safe passing of overtaken vehicles, it may be termed non-passing sight distance. The minimum non-passing sight distance is the distance required to permit a vehicle travelling at the assumed design speed of the highway to stop before reaching a stationary object in the same lane and is actually safe stopping distance. A convenient chart is included in the design manuals for use in checking for non-passing sight distance. For high point, or crest, vertical curves, this chart can be used as follows: Obtain the algebraic difference in grades (per cent). (This means if a plus grade meets a minus grade, then add the two grades together. If a plus grade meets a plus grade or a minus grade meets a minus grade, then take the difference in the two grades.) Find this algebraic difference on the ordinate provided and the point where this value intersects the speed design curve desired, then the other ordinate of the chart will give the minimum length of vertical curve to provide safe stopping distance. A similar chart is provided to give the length of vertical curve in the sag of a highway, a sag being a low point in the highway. When the sag vertical curve is beneath a structure, as in the case of an underpass, checks should be made to assure that the structure has not obstructed the line of sight of the design safe-stopping sight distance.

On two-lane, two-way highways, fast-moving vehicles frequently overtake slow-moving vehicles. Passing must be accomplished on a lane that may be occupied by opposing traffic. If passing is to be accomplished with safety, the driver of the passing vehicle must see enough of the highway clear of opposing traffic, so that if vehicles appear after starting to pass, then there will be sufficient time to pass and return to the right lane without cutting off the passed vehicle and before meeting opposing traffic. The mechanics of checking a gradient for passing sight distance sections is a bit more complicated than that for checking for non-passing sight distance. This method is coordinated with the method employed by the maintenance division for marking barrier stripes on the highways at points of restricted sight distance. Due to the limited need for checking this feature in this area of the country and the complexity of the method of checking, no attempt will be made to explain the method.

The blind spot referred to earlier in this discussion is a dip in grade in which a car might be concealed and the driver of an approaching car can see over the car in the dip to the pavement beyond and obtain a false impression that safe passing is provided.

4. Drainage

When designing the grade line, consideration must be given to the grade of the side ditches, as the side-ditch grades usually have a definite relation to the centerline grade when good drainage is provided. The depth and width of the ditch and the type of back slope affect the width of the highway cross section and right of way requirements. The design of a roadway to provide for the drainage parallel to the highway is a problem in hydraulics applied to the design of highway grades and sections. The hydraulics applied to this problem will be given later in another lecture.

II. Section Templates, Earthwork Computations and Mass Curves

A. General Remarks

1. Method

This section of the lecture will be restricted to the manual method of determining the amount of earthwork necessary on a project. No attempt will be made to discuss the computation of these quantities by the use of the electronic computer. It is recognized that the machine method of computation is a time and money saver, but as stated, only the manual method will be considered.

2. Purpose

The purpose of earthwork computations is to obtain the pay quantities required under several of the most widely used specification items. The item under consideration in the example that follows will be the item of roadway excavation. This item requires roadway excavation to be measured in its original position and the volume computed in cubic yards by the method of average end areas. The embankment referred to in this item and formed from the excavated material will be determined in the same manner.

3. Detailed Cross Sections

The detailed cross sections, which are not part of the plans and which were mentioned in the discussion of the typical cross sections of a set of plans, are used to determine the quantity of earthwork.

In order to determine earth excavation and embankment quantities, a section outline of the <u>proposed</u> highway, commonly referred to as a template section, is placed on the <u>original</u> ground cross section. The areas in cut and the areas in fill are determined, and the volumes between the sections are computed.

The limits of the cross section template are established from the typical design section. The design section should provide such information as the location of the centerline profile, the roadbed, which is generally fixed throughout the length of the project, and the governing slopes to be used. The source of the profiles that fix the vertical location of the section is the working profile or the profile section of the plan-profile sheets. An example, Plate 3, is introduced at this time for the purpose of illustrating the discussion.

B. <u>Plotting Existing Cross Sections</u>

1. Material and Scales

The original ground cross sections on which the section template is plotted, are usually plotted on standard cross section paper to scale. The information for plotting is obtained from the field books described under the lecture on surveying. A scale of one inch equals five feet vertically and horizontally is commonly used. However, on some highways such as freeways, the horizontal scale is: One inch equals ten feet because of the wide right of way.

2. Horizontal Spacing

Very often, even with the change in horizontal scale, it is not possible to place the sections on the sheet as shown in the example. Several solutions are possible. Instead of plotting the sections as shown in the example, sections can be plotted in the other direction, utilizing the wide portion of the sheet. Another method is the cutting of sheets from continuous roll cross section paper that will be sufficiently wide to contain the cross sections.

Still another method, but one that is seldom used except for individual sections that are exceptionally wide, is the plotting of sections by the use of match points and placing the continuation of the section just beneath the section that is being continued. This last method could be adopted more satisfactorily by plotting half sections and thus avoiding the confusion common to the combination of part sections.

3. Vertical Spacing

The spacing of the sections up the sheet should be given some consideration. Sufficient space should be provided between two successive cross sections, so computation information shown on the example can be provided. Ordinarily, the cuts and fills are moderate and the spacing between sections is uniform. Sometimes a high fill or a deep cut is proposed and additional space between sections is necessary to avoid overlapping the sections. The matter of proper spacing must be considered when plotting the original ground line, since this line fixes the position of the proposed template.

4. Plus Points

Cross sections are commonly taken at full stations, but sometimes a section is taken at a "plus" which is a point between full stations. Sometimes, it is necessary to provide by interpolation, a plus section because of the proposed work. Usually, if the survey forces take a plus section, then the section should be plotted and used in the earthwork computations. However, this is not always true and may not be realized until after the existing section has been plotted. It may be necessary to improvise a plus section because of an opening in the embankment due to a proposed bridge. The survey forces will not know the location of a proposed bridge at the time of taking the cross sections and the location may not be known at the time of plotting the existing cross sections. At least one section is needed at each end of a proposed bridge, and it may be necessary to revise the existing sections near the end of a bridge in order to provide the necessary plus sections.

5. Methods

There are several methods that can be employed in plotting existing ground cross sections. The scales should be marked on the sheets as shown in the example in a manner that will aid and speed up the work. The horizontal scale should be marked at the bottom or top of the sheet. Marking each one-inch heavy line in multiples of five feet or ten feet will aid the work. The vertical scale should be marked in a similar manner. The first step in plotting is to show the station and centerline elevation of the existing section. Each elevation point in a section can be plotted by mentally noting the difference between the centerline rod reading and the reading of the point in question. By utilizing the vertical scale and by noting the horizontal distance from the centerline, the point is plotted. This method will prove most satisfactory with experience. Another method of plotting is determining the actual elevation of all points and plotting accordingly. Still another method is placing a straightedge at the height of instrument elevation and then by sliding a triangle that is marked at the edge to the same scale as the vertical scale, to the horizontal position of the point in question, the rod reading of the point can be read on the scale and the point plotted. This last method involves some inaccuracies, as one might reason.

C. Cross Section Templates

1. Fixed Portion

The plotting of the proposed highway cross section can be accomplished by several methods. In the lecture discussing the typical cross section sheet of a set of plans, it was pointed out that, generally, the roadbed portion of the section, that is, the width from crown line to crown line, will be constant throughout the project. This will be true, except where the section is super-elevated for horizontal curves and for other special conditions. Knowing the elevation of the proposed road from the profiles and the relation to the dirt subgrade from the design cross sections, the profile elevation can be plotted. The remainder of the fixed portion of the proposed section can be plotted by determining the amount of fall to the crown line and plotting the point.

Another method for plotting the fixed portion of a section is the cutting of a template out of some transparent material and using this template to draw the section.

2. Variable Portion

The remainder of a proposed highway cross section is variable to the extent that the design section and the ditch profiles and shapes fix the sections. This portion of the proposed section can be plotted by the same methods recommended for the plotting of the fixed portion of the section. It should be realized that the design section can usually be provided without difficulty at the points where normal conditions are encountered, while extreme conditions, such as at the outlet points of ditches, give the least desirable section. The plotting of the normal and extreme conditions first, will provide a guide for the transition between the two conditions.

The job of determining the slopes on the typical cross section sheet may be facilitated if the method shown on the sample sheet is followed. The party plotting the proposed sections knows, at the time the section is drawn, the value of the slopes. If these slopes are shown whenever a change occurs, then this information can be used for determining the typical cross sections. It must be remembered that the design section and the typical cross sections may not exactly conform.

D. <u>Earthwork Computation</u>

1. End Area

After plotting the cross sections of the original ground line and the "templates" on original ground sections, the process of computing earth excavation quantities can begin. Turning to the example provided, it will be noted that the figures shown in the areas are preceded by a "C" or an "F" which are abbreviations for the terms, "cut" and "fill." The identification of those areas by this method is recommended, particularly in cases where the areas are numerous. The areas of cut and fill may be measured by the use of a planimeter or some other suitable method and are recorded in square feet. The planimeter is a small instrument consisting of an arm, carrying a tracing point, which is fastened to the frame of the instrument. The frame touches the paper at only three points: The anchor point, the tracing point, and the circumference of a small wheel which is free to revolve. On the rim of this wheel is a scale and beside it is a vernier which is used in reading the scale. The length of the arm is factory set, and it is recommended that the length not be tampered with. In using the instrument, the anchor point is set at some convenient position on the drawing <u>outside</u> of the area to be measured, and then the tracing point is run around the perimeter of the area to be determined. The reading on the wheel is recorded when the tracer is at the starting point. The tracer in passing around the perimeter, should be kept as closely as possible on the boundary line and should return exactly to the starting point. Then the scale is again read, and the difference between the two readings is the area that has been traced out expressed in some unit, depending on the length of the arm. The result can be transposed easily into the unit of the scale of the drawings by first testing the setting by running the instrument around a known area, such as four square inches. This interval, divided by four, will be the value of one square inch of plan area, which is equivalent to a certain number of square feet of surface, depending upon the scale of the drawing. Another method of determining the area that is rapid and accurate, results in dividing the area into triangles and computing the triangles in groups of two. This method is made more rapid by the use of an engineer's scale and an electric calculator. This is illustrated by reference to the section at Station 151+00 on the sample sheet. The fill section with area of 33 square feet is chosen, and for illustrative purposes, each break in continuity of the existing and proposed section is shown with a circle and marked with a letter. Beginning at Point A, the point where the existing and proposed sections intersect, the horizontal distance, AC, is multiplied by the vertical distance between the sections at Point B, then horizontal distance, BD, times vertical distance at C, etc., until the final multiplication of horizontal distance, FH, times vertical distance at G. These computations are accumulated in the calculator and the total divided by two in order to determine the area. Under most conditions, the values to be placed in the calculator can be determined by eye. The operation of the calculator is so easy to learn that many who do not know how to make other types of computations can learn quickly how to perform this operation.

2. Method of Computation

The areas of cut and fill are used to compute the volumes of excavation and embankment between the sections by the average end area method. Tabulation of quantities as shown at the top of the sample sheet will facilitate the work. The average end area method is based on the formula for the volume of a right prism whose volume is equal to the average end area multiplied by the length, or: $V = \frac{1}{2}L(A_1 + A_2) \div 27$ where V is the Volume in cubic yards, A_1 and A_2 is the area of end sections in square feet, and L is the distance between end sections in feet.

3. Tabulating

The total single end areas for each section are tabulated opposite each section. The computations of double end areas, distances, and volumes are placed between the cross sections. The double end areas are obtained by adding the single end areas at each station. The volumes are obtained from a table that gives volumes for double end areas per station. If the table is not available, a factor can be computed from the formula given above and used to determine the volumes.

4. Plus Sections

When a section changes from a cut section to one of fill, a point is reached when a zero cut and zero fill occurs. This may occur along an irregular line across the roadway or may be nearly at right angles. Plus sections would be desirable at these location (grade points), in order to properly compute the volumes. This situation is not recognized at the time sections are taken, and it may be necessary to interpolate a plus section or handle the situation as shown on the example. Between station 152 and 153 on the example, the section passes from a fill to a cut. The computation of fill in this case was made by using the fill single end area at station 152 and averaging this area with a zero fill section that occurs 50 feet from station 152. The 50-foot dimension was determined by examining the existing and proposed centerline profiles and determining the point where the two intersect.

5. Shrinkage and Swell

When earth is excavated and placed in an embankment, the freshly excavated material generally increases in volume due to its loose and porous condition. However, during the process of building the embankment, it is compacted, so that the final volume is less than when in its original condition. This difference in volume is usually defined as "shrinkage." The amount of shrinkage may vary according to various types of soil and the depth of the fill. When rock is excavated and placed in the embankment, the material will occupy a larger volume and this increase is called "swell." This condition will not be discussed, because it is uncommon to this area. Shrinkage is usually expressed as a percentage and added directly to the computed fill volume. (See Plate 3.)

E. Mass Curves

1. General Remarks

The payment section of the excavation items refer to the item of overhaul for measurement and payment of the hauling of materials. In a previous lecture, the item of overhaul was briefly mentioned under the subject of haul diagrams. In this discussion, an attempt will be made to present the method for computation of overhaul. At this time, Plates 4 and 5 are introduced for the purpose of illustrating the discussion.

PLATE 4

Station	Cut	Fill	Fill + Sh(20%)	Ordinate
	122	120	144	
150+00				-22
	130	124	149	
151+00				-41
	135	102	122	
152+00				-28
	317	21	25	
153+00				-264
	433	0	0	
154+00				+697
	417	0	0	
155+00				+1114

2. Basic Theory

Haul is work done in moving excavated material to place it in an embankment. "Overhaul" is the work done in moving excavated material to the embankment through a horizontal distance greater than that specified as "Free Haul."

Overhaul is calculated by obtaining the product of the volume of material times the haul length expressed as quarter miles. The haul length is the total distance the material is moved less the specified free haul length. In order to express the haul length as quarter mile, it is necessary to divide by 1,320, which is the number of feet in a quarter-mile.

It is very difficult to determine haul length and overhaul quantities directly from the cross sections. To do so would be very tedious and complicated. Therefore, we shorten the work by resorting to a graphic method known as the mass curve. The mass curve may be defined as a graph whose absiscissae are distances along the centerline and whose ordinates are accumulated total difference between excavation and embankment at the various stations. These abscissae and ordinates are plotted from a line known as the base line. The mass curve itself is a series of straight lines connecting these points that have been plotted. The mass curve shows, by the points at which the curve crosses the base line, the location of balance points, the direction of haul, and the amount of earth taken from, or hauled to, any location. It is a valuable aid in the supervision of grading operations and can be analyzed to obtain the most economical distribution of the material.

3. Specifications

For all plans for projects to be constructed by the Texas Highway Department, the Standard Specifications of this Department must govern. Therefore, the computation of overhaul must be in accordance with the specifications.

The specifications define "overhaul" as the performing of all operations necessary for moving previously excavated embankment material over 600 feet from designated or approved sources to the required points of disposal. The specifications further state that the measurement of all materials for computing overhaul will be made in the original position by the method of average end areas and the unit of measurement for overhaul will be "yard quarter."

4. Method of Construction of Mass Curve

The first step in constructing the mass curve is to prepare a table of mass ordinates. (See Plate 4) In the first column are the station numbers from the cross section notes. The second column contains the amount of cut between successive stations. The third column gives the fills, and the fourth gives the fills corrected for shrinkage. The fifth column gives the mass curve ordinates. The ordinate column is merely an accumulated total difference between cut and fill at each station.

Example:

Sta.	149+00	to	150+00				
	122 cut	-	144 fill				-22
Sta.	150+00	to	151+00				
	-22 fill	+	130 cut	-	149 fill	=	-41
Sta.	151+00	to	152+00				
	-41 fill	+	135 cut	-	122 fill	=	-28
Sta.	152+00	to	153+00				
	-28 fill	+	317 cut	-	25 fill	=	+264

You will note from the above example that in computing the ordinates, the cuts are assigned plus signs and the fills are assigned the minus signs. The ordinate sheet is then filled out as shown on Plate 4.

A suitable horizontal base line is chosen and stationed off as shown in Plate 5. From this base line, the mass ordinates are plotted at their respective stations. Pluses are plotted above the base line and minus are plotted below. The points are plotted to a suitable vertical scale expressed as one inch equals X cu. yds. Those points are connected by lines which is the mass curve.

5. Methods of Computation

To illustrate the theory of overhaul, the use of the mass curve and the application of the specifications to the computation of overhaul, Plate 5 is referred to. Several methods of calculation are illustrated for the sample given.

Referring to the figure in the upper left-hand corner of the sheet, two methods are illustrated under the same figure, thus the notation - Figures 1 and 2. One method is to draw the average haul length parallel to the base line and through the midpoint of the maximum ordinate. The 800-foot average haul length is shown at this point and the overhaul is calculated as 152 yard-quarters.

A second method, represented by Figure 2, provides for subbases introduced at each break in the slope of the mass curve, in this case, at the concave break in the diagram at an ordinate of 200 cubic yards, and another subbase at the convex break in the diagram at an ordinate of 800 cubic yards. The curve is thus broken into segments. The average hauls of 1,600 feet and 800 feet for each segment are obtained, with a small free haul loop in the segment. The overhaul is calculated as 243 yard-quarters.

Since the break in the mass curve at the 800 ordinate is minor and is convex, this may be omitted as shown under Figure 3 and a subbase placed at the 200 ordinate only. With this division, the haul is calculated as 192 yard-quarters.

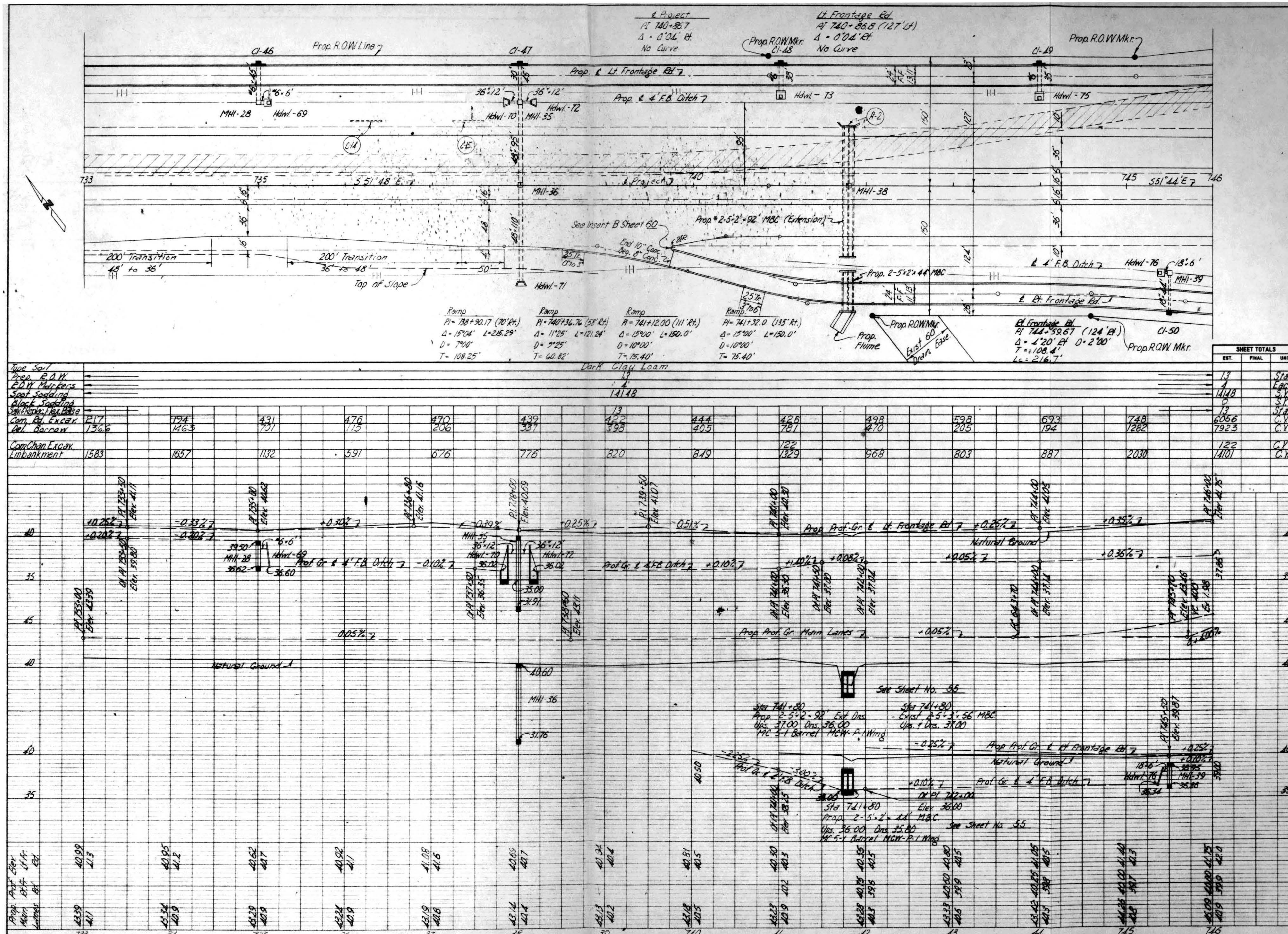
Another method is the plotting of a 600-foot average haul length for the free haul as shown by Figure 4. A subbase is then drawn at a position, such that the 600-foot haul length is at the mid-point of the maximum ordinate between this subbase and the peak of the curve. Then, by placing another subbase at the concave break in the diagram at 200 cubic yards, the pay overhaul will be determined, as in Figure 2, where two subbase lines were introduced in the curve. The pay overhaul will be the yardage represented by the difference between the subbase lines times the average haul for that quantity, and the haul is calculated as 192 yard-quarters.

In examining these methods, to determine which is more reliable, it is evident that either the method given under Figure 3 or 4 is more nearly accurate than any method which fails to place a subbase at breaks in the mass diagram.

6. Precautionary Measures

There are several matters to keep in mind when preparing haul diagrams that may be helpful. When there is an accumulation of excess of excavation, the line of the diagram should ascend in the direction of the increase in stationing, and when there is an accumulation of excess of embankment, the line should descend. Keeping this in mind will prevent diagrams being plotted upside down and avoid resulting errors. When it becomes necessary to obtain excavation from a borrow pit in order to complete the embankment, the haul distance is determined as stated in the specifications and would be the distance from the center of mass of the borrow pit to the center of mass of the embankment as measured along the haul route, less the amount of free haul. The portion of the haul from the center of mass of the pit to the centerline of the highway is commonly referred to as dead haul. Therefore, the haul length would be the dead haul plus the average haul from the mass curve minus the free haul. The mass curve under this condition would end with a vertical line at the point on the highway where the borrow is hauled in.

In all the applications of these principles of the haul diagram, the major requirement is to calculate haul with reasonable accuracy, recognizing all of the limitations and errors inherent in the mass diagram.



Type Soil				
	SHEET TOTALS			
EST.	FINAL	UNIT		
			Type Soil	
13		Sta.	Preparing R.O.W.	
4		Each	R.O.W. Markers	
1448		S.Y.	Spot Sodding	
0		S.Y.	Block Sodding	
13		Sta.	Salvaging & Replacing Flexible Base	
6056		C.Y.	Common Road Excavation	
7923		C.Y.	Delivered Borrow	
122		C.Y.	Common Chanel Excavation	
14101		C.Y.	Embankment	

CROSS SECTION DATA

STATION NUMBER	SLOPE (RATIO TO 1)	DITCH DEPTH FT.	DITCH WIDTH FT.	SLOPE (RATIO TO 1)	CROWN WIDTH (FEET)	SLOPE (RATIO TO 1)	DITCH WIDTH FT.	DITCH DEPTH FT.	SLOPE (RATIO TO 1)	AVERAGE GROUND SLOPE PER 100'	TYPICAL X-SECT. NO.

SHEET NOTES

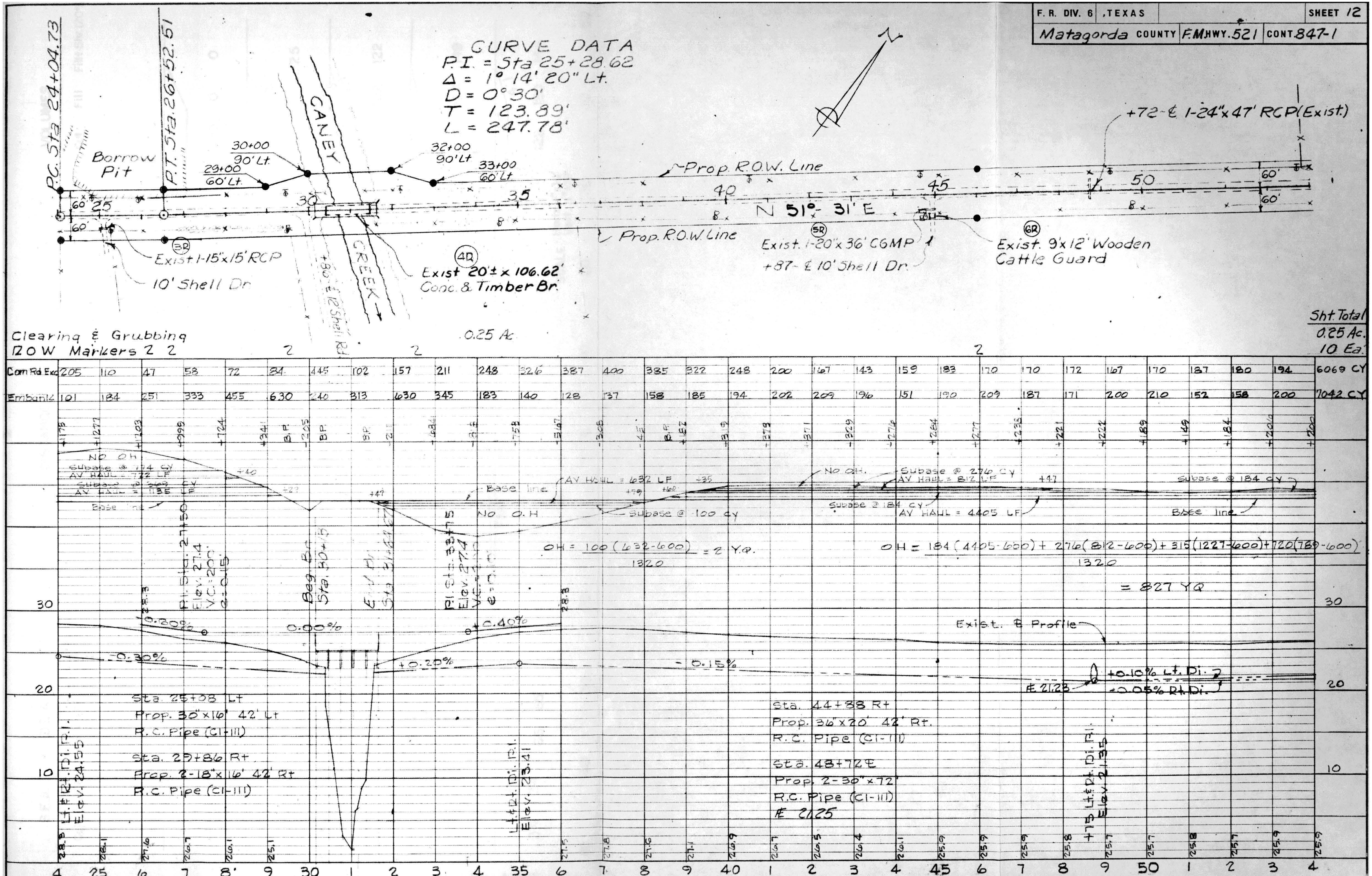
B.M. #10 Sta 741+80 "X" in top S.E. corner culvert 8' Lt Ⓒ Elev. 41.00

FED. ROAD DIV. NO.	STATE	FEDERAL AID PROJECT NO.			SHEET NO.
6	TEXAS	I-610-7-(26)-801			41
STATE DIST. NO.	COUNTY	CONTROL NO.	SECTION NO.	JOB NO.	HIGHWAY NO.
12	HARRIS	271	14	22	IH-610

PLATE 10

PLAN - PROFILE - NEW STYLE

PLATE I



F. R. DIV. 6 , TEXAS
SHEET 12
Matagorda COUNTY F.M. HWY. 521 CONT. 847-1
CURVE DATA
P.I. = Sta 25+28.62
Δ = 1° 14' 20" Lt.
D = 0° 30'
T = 123.89'
L = 247.78'
P.C. Sta 24+04.73
P.T. Sta 26+52.51
Borrow Pit
29+00 60' Lt.
30+00 90' Lt.
32+00 90' Lt.
33+00 60' Lt.
CANEY CREEK
Prop. R.O.W. Line
N 51° 31' E
+72 - ℄ 1-24" x 47' RCP (Exist.)
Exist. 1-15" x 15' RCP
10' Shell Dr.
+80 ℄ 12' Shell Rd
Exist 20'± x 106.62' Conc. & Timber Br.
Exist. 1-20" x 36' CGMP
+87 - ℄ 10' Shell Dr.
Exist. 9' x 12' Wooden Cattle Guard
Clearing & Grubbing 0.25 Ac
ROW Markers 2 2 2 2 2
Sht. Total 0.25 Ac. 10 Ea.
Com Rd Exc 205 110 47 58 72 84 445 102 157 211 248 326 387 400 385 322 248 200 167 143 159 183 170 170 172 167 170 187 180 194 6069 CY
Embank 101 184 251 333 455 630 240 313 630 345 183 140 128 137 158 185 194 202 209 196 151 190 209 187 171 200 210 152 158 200 7042 CY
Base line
No O.H.
AV HAUL = 632 LF
Subase @ 100 cy
Subase @ 276 CY
AV HAUL = 812 LF
Subase @ 184 CY
AV HAUL = 4405 LF
OH = 100 (632-600) / 1320 = 2 Y.Q.
OH = [184 (4405-600) + 276 (812-600) + 315 (1227-600) + 720 (789-600)] / 1320 = 827 YQ
P.I. Sta. 27+50 Elev. 27.4 V.C. 200' e = 0.15
Beg Br. Sta. 30+19
End Br. Sta. 31+26.81
P.I. Sta. 33+75 Elev. 27.4 V.C. 200'
-0.30%
0.00%
+0.40%
-0.30%
+0.20%
-0.15%
Exist. ℄ Profile
+0.10% Lt. Di.
+0.05% Rt. Di.
℄ 21.23
Sta. 25+08 Lt Prop. 30" x 16' 42' Lt R.C. Pipe (Cl-III)
Sta. 29+86 Rt Prop. 2-18" x 16' 42' Rt R.C. Pipe (Cl-III)
Sta. 44+88 Rt. Prop. 36" x 20' 42' Rt. R.C. Pipe (Cl-III)
Sta. 48+72 ℄ Prop. 2-30" x 72' R.C. Pipe (Cl-III) ℄ 21.25
Lt. & Rt. Di. P.I. Elev. 24.55
Lt. & Rt. Di. P.I. Elev. 23.41
+75 Lt. & Rt. Di. P.I. Elev. 21.35
30
20
10
4 25 6 7 8 9 30 1 2 3 4 35 6 7 8 9 40 1 2 3 4 45 6 7 8 9 50 1 2 3 4

PLATE 2

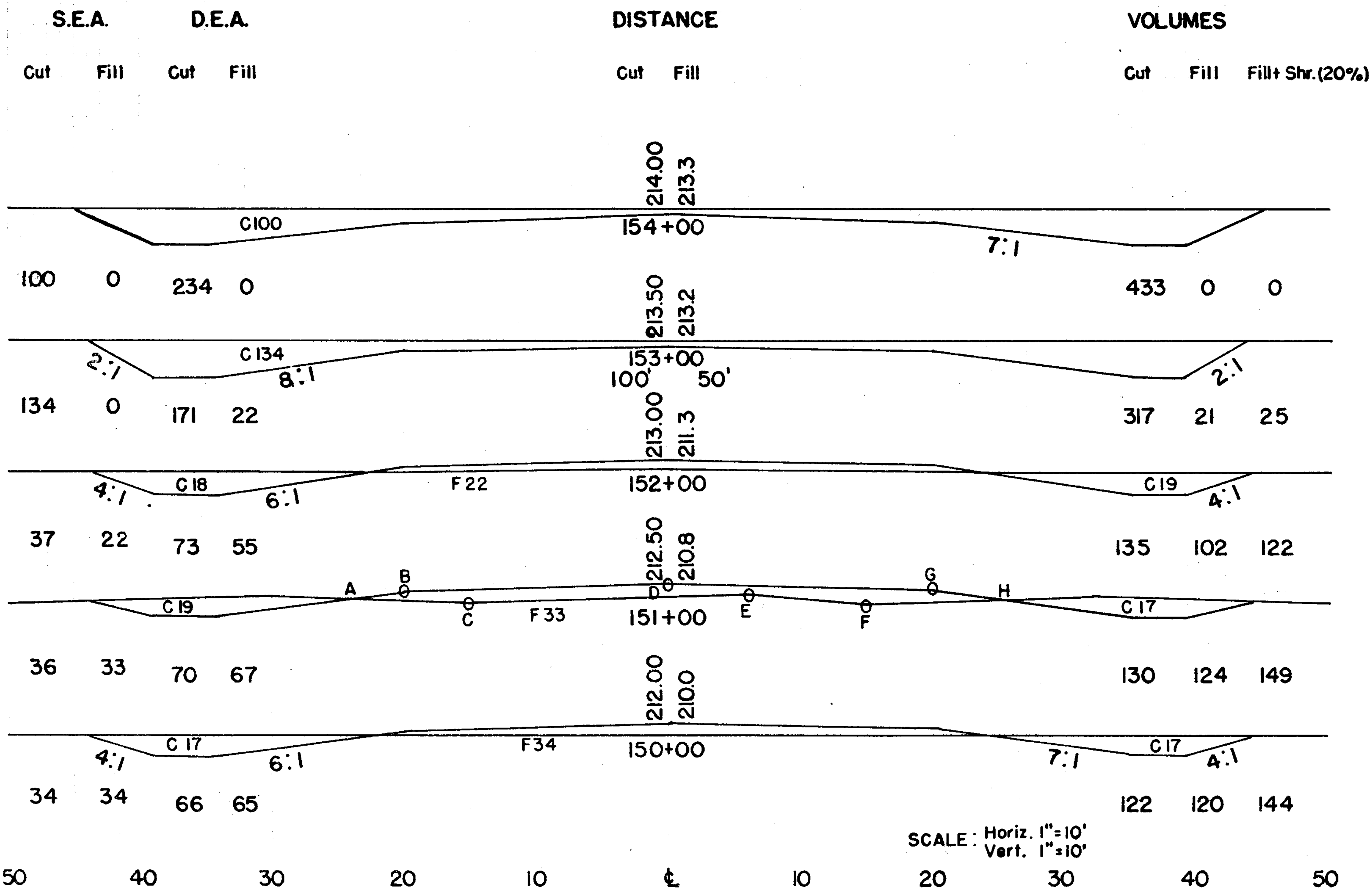
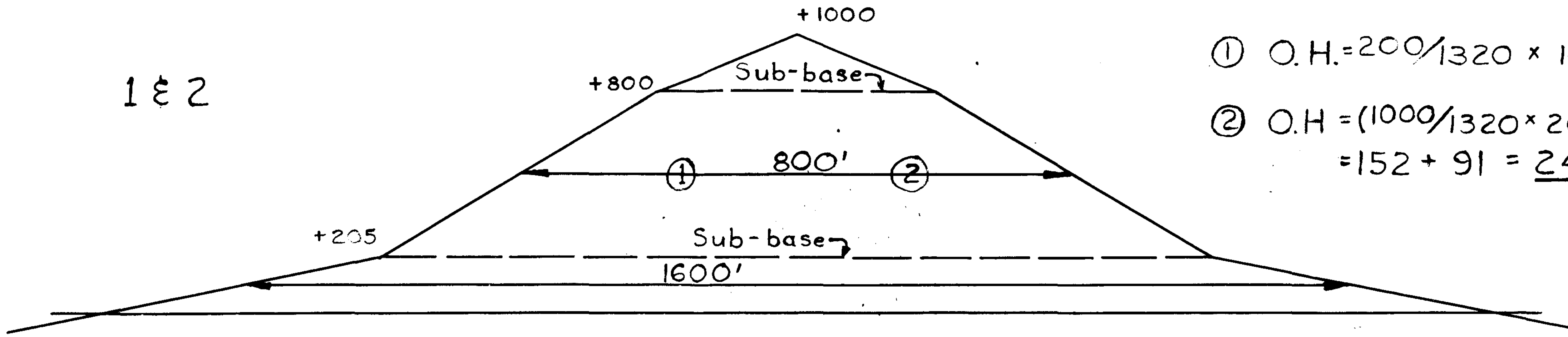

S.E.A.
D.E.A.
DISTANCE
VOLUMES
Cut Fill Cut Fill
Cut Fill
Cut Fill Fill+ Shr.(20%)
214.00 213.3
C100
154+00
7:1
100 0 234 0
433 0 0
213.50 213.2
C 134
2:1
8:1
153+00
100' 50'
2:1
134 0 171 22
317 21 25
213.00 211.3
C 18
4:1
6:1
F 22
152+00
C 19
4:1
37 22 73 55
135 102 122
212.50 210.8
A B C D E F G H
C 19
F 33
151+00
C 17
36 33 70 67
130 124 149
212.00 210.0
C 17
4:1
6:1
F34
150+00
7:1
C 17
4:1
34 34 66 65
122 120 144
SCALE: Horiz. 1"=10'
Vert. 1"=10'
50 40 30 20 10 ℄ 10 20 30 40 50

PLATE 3

Excav.	50	50	50	50	150	150	150	150	100	100	0	0	0	0	0	0	0	0	0	0
Emb'k	0	0	0	0	0	0	0	0	0	0	100	100	150	150	150	150	50	50	50	50

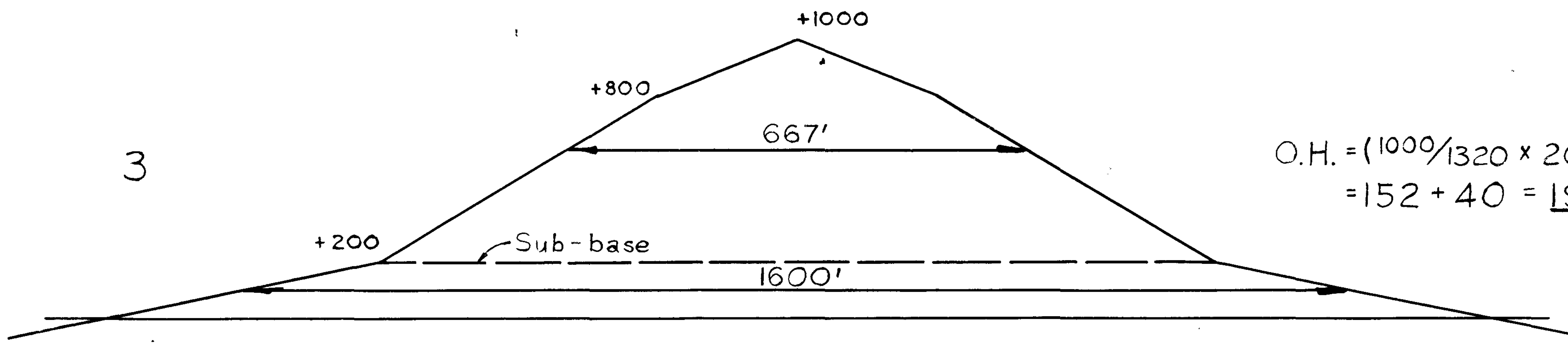
1 & 2



① O.H. = $200/1320 \times 1000 = \underline{152}$ Yd. Qtrs.

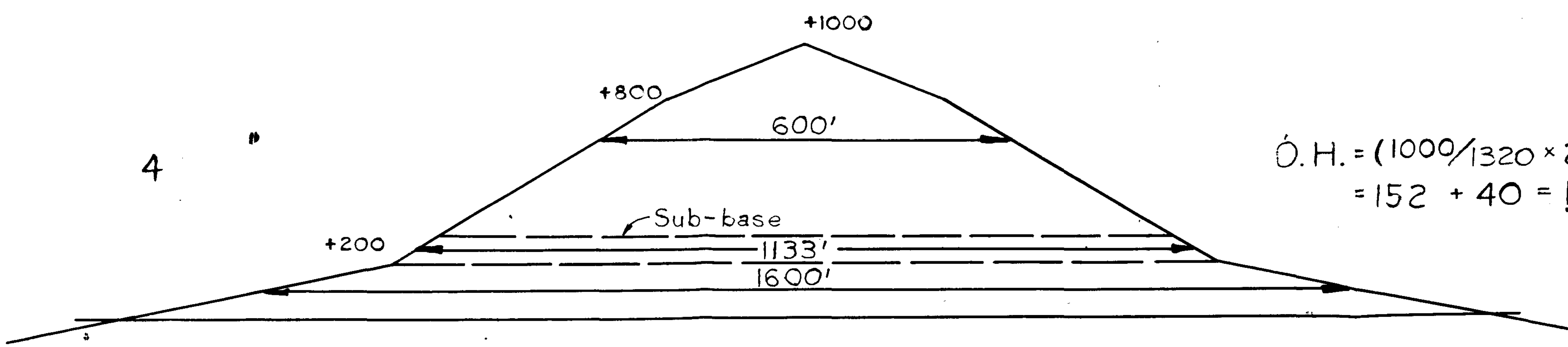
② O.H = $(1000/1320 \times 200) + (200/1320 + 600)$
$= 152 + 91 = \underline{243}$ Yd. Qtrs.

3



O.H. = $(1000/1320 \times 200) + (67/1320 \times 800)$
$= 152 + 40 = \underline{192}$ Yd. Qtrs.

4



O.H. = $(1000/1320 \times 200) + (533/1320 \times 100) + 0$
$= 152 + 40 = \underline{192}$ Yd. Qtrs.

0 2 4 6 8 10 12 14 16 18 20

PLATE 5

CONSTRUCTION INSPECTION II

I. Stabilized Subgrade

A. General

A stabilized subgrade is an earthen subgrade which has had a stabilizing additive mixed with it in order to improve its load-bearing capacity. Under normal wet and dry conditions, many of our natural soils available in this area have radically different characteristics, depending upon the moisture content. For example, black clay is extremely hard when dry but is very soft and pliable when wet. On the other hand, in the case of sand, the reverse is true. The native soils available for use for subgrades of our roads are subject to varying wetting and drying cycles. By adding a stabilizing agent, we try to reduce the effect of the wet-dry cycle and make the soil characteristics remain constant. This is a brief and simple explanation of the theory of stabilization, and the more technical aspects will be covered in the laboratory courses. There are many different stabilizing agents, but this course will deal with two of the more prominent agents used to stabilize the natural subgrades. They are hydrated lime and Portland cement.

Hydrated lime has a peculiar effect on heavy gumbo clays. The net result of the chemical reaction of lime with clay is to reduce the clay-like characteristics of the soil and induce characteristics of a sandy loam type of soil. The effect of lime on a sandier type of soil is not so apparent, since it already has many of the characteristics induced by the addition of lime.

On the other hand, cement has a very definite effect on a sandy type soil. The main effect, of course, is a cementing action produced by the addition of cement and moisture to the soil. In the case of heavy clays, the addition of cement does not produce nearly so good a result.

B. <u>Lime-stabilized Subgrade</u>

1. Specification Requirements

Item 260, Lime Treatment for Materials in Place, page 160, is the governing specification for lime stabilization of existing subgrade. Item 264, Hydrated Lime and Lime Slurry, page 171, establishes the requirements for the hydrated lime and/or commercial lime slurry to be used. Item 260 also refers to: Item 204, Sprinkling, Item 214, Item 213, and Item 216, Rolling, Item 500, Weighing and Measuring Equipment. It is these specifications together with pertinent special provisions or notes on the plans that form the basic requirements of this operation.

2. Construction Methods

a. Prior to beginning any lime treatment, the proposed roadbed shall be constructed and shaped to conform with the typical sections and lines and grades as shown on the plans. The material to be treated shall then be excavated or loosened to the secondary grade, (Proposed bottom of lime treatment). The specifications allow two different methods of procedure in loosening or excavating material to be treated. One method proposes that the material shall be actually removed and windrowed to expose the secondary grade or the bottom of the lime treatment. Then, any wet or unstable materials below this grade can be corrected by scarifying, rolling and compacting. The excavated material proposed for lime treatment can then be spread back across the desired cross section. The main objection to this type of operation is the fact that during the period of time that the excavated material is windrowed, a trench exists which, in the case of rain, would fill with water and cause softening of the lower or secondary subgrade.

The other alternate offered by the specifications is the use of a cutting and pulverizing machine that will remove the subgrade material accurately to the secondary grade and pulverize the material at the same time. By using this type of equipment, the contractor is not required to expose the secondary grade nor windrow the material. If this method is used, the equipment shall have a tell-tale which will indicate that the material is being cut uniformly to the proper depths. It shall also have cutters that will plane the secondary grade to a smooth surface over the entire width of the cut.

b. After the material has been excavated or loosened, it will normally be necessary to disc or harrow the material in order to prepare for the application of the lime. The application of the lime may be performed under two alternates: one alternate is the use of dry lime placed directly on the subgrade and mixed; the other is the placing of lime in the form of a slurry which is applied with water trucks directly on the material.

In the case of the use of dry lime, the lime shall be spread by an approved screw-type spreader box, or by bag distribution in accordance with the rate shown on the plans. One of the main problems in the use of dry lime is the fact that if a high wind is blowing, a great deal of loss occurs due to the dusting of the dry lime. There is also a very definite traffic hazard involved and very possibly, a hazard to the adjacent property owners. Inspectors are cautioned to observe wind conditions prior to beginning the spreading of dry lime. This is particularly critical in an urban area where many people and houses may be present. Proper distribution of the lime in accordance with the rate shown on the plans is usually accomplished by successive passes on a measured course or land.

In the case of the use of lime slurry, the thin water suspension is usually applied by the use of water trucks, making successive passes over a measured course or land. The water trucks, or distributor trucks, shall be equipped with an agitator which will keep the water and lime suspension in a uniform mixture. This type of lime placement is usually superior in an urban area, in that it avoids the danger of nuisance or damage due to the blowing of dry lime.

c. The next step in the lime-stabilization procedure is the mixing of the soil and lime into a uniform homogeneous mass. The mixing procedure is the same regardless of whether the dry placing or the slurry placing method was used. The material and the lime are thoroughly mixed by approved road mixers or other equipment and this mixing operation shall be continued until a friable mixture of material and lime is obtained free from large clods or lumps. The equipment used in this process is a disc or harrow or, in some cases, a patented pulvi-mixer type of equipment.

After the material has been mixed as thoroughly as possible and brought to the proper moisture content, it is left to cure from one to four days as required or directed by the Engineer. The material must be kept moist during the curing period. With the use of dry lime, it is advisable to apply the moisture immediately after the placing of the dry lime. This avoids as much loss as possible through the action of the wind and reduces the nuisance problem of blowing lime. In other words, it is not essential that the lime be mixed prior to the application of the water. After the lime and soil mixture has cured the proper length of time, the mixing process is again repeated in order to reduce the clods that are remaining in the stabilized material. This mixing is done again with the disc or harrow or the patented pulvi-mixer type of equipment. The material shall be cured and mixed until it meets the sieve requirements of Item 260.

d. Compaction of the mixture shall begin immediately after final mixing, and, in no case, later than three days after the final mixing. Prior to the beginning of compaction operations, the material must either be dried or wetted until it is brought to the proper optimum moisture content. The material is normally then windrowed on either side and rolling operations begun at the bottom and continued until the entire depth of mixture is uniformly compacted.

The Inspector is cautioned that it is usually advisable to blade out and windrow on either side sufficient material to allow the rollers to begin compaction at the bottom of the stabilized section. If this is not done, inadequate compaction will result.

e. After the final layer or course of the lime-treated subgrade has been compacted, it shall be brought to the proper line and grade in conformance with the typical section. The completed section shall be moist-cured for a minimum of seven days before further courses are added or any traffic is permitted unless otherwise directed by the Engineer. In cases where subgrade or subbase sets up sufficiently to prevent damage from traffic, such layers may be opened to traffic two days after compaction.

3. Inspector's Checklist

a. Check the weights of the lime as it is brought in on the job and see that each truck has a public scale certification or that the Contractor has a set of standard platform scales.

b. Check the rate of application of lime as shown on the plans and stake off proper lengths of roadway for the lands or courses.

c. Check the method of excavating or loosening the material to see that the proper depths, widths, and section is being excavated.

d. Check the weather conditions, particularly the wind conditions, prior to the placing of dry lime.

e. In the case of placing by means of a lime slurry, check the distribution trucks to see that they are equipped with proper agitation equipment.

f. During the mixing operation, check to see that the mixing equipment is thoroughly and properly blending the entire depth of the loosened material.

g. During the curing period, keep a constant check on the progress of the chemical reaction and require proper moisture and/or further mixing if they are needed.

h. Check to see that the compaction equipment is thoroughly compacting the lower levels of the stabilized layer.

4. Measurement and Records to be kept.

Since the lime is measured and paid for by the ton, it is necessary that an accurate record be kept of the weights of lime placed on the job. The Inspector should issue tickets daily for the amount of lime used and the ticket number and weight should be recorded in a hardback field book for future reference. This record is the support for the payment of lime on the final estimate. A daily record should also be kept of the station numbers of the various lands that are stabilized each day.

C. Cement Stabilized Subgrades

1. Specification Requirements

Item 270, Portland Cement treatment for materials in place, page 173, is the governing specification for cement stabilization of existing subgrade. This item refers to Item 500, Weighing and Measuring Equipment. It is these specifications together with pertinent special provisions or notes on the plans that form the basic requirements of this operation.

2. Construction Methods

a. Prior to beginning any cement stabilization operation, the proposed roadbed shall be constructed and shaped to conform with the typical sections in lines and grades as shown on the plans. Unsuitable soil or material shall be removed and replaced with acceptable soil.

b. The soil to be stabilized shall be loosened and pulverized in such a manner that the sieve requirements of Article 270 are met. This process usually involves the use of scarifier discs, harrows, or a patented pulvi-mix type of equipment. The pulverization process should continue until such time as the entire mass of material has been broken down into a friable well-graded mass.

c. The Portland cement shall be spread uniformly on the pulverized soil at the rate specified on the plans or approved by the Engineer. If a cement spreader is used, it shall be positioned by string lines or other methods during spreading to insure uniform distribution of cement. Inspectors are cautioned that cement shall be applied only to such an area that all mixing and laying operations can be completed in daylight and within six hours of the beginning of the application of cement. The percentage of moisture in the soil at the time of the cement application shall not exceed the quantity that will permit uniform mixing of the soil and cement and shall not exceed the specified optimum moisture content for the soil-cement mixture. In general, this will necessitate the Inspector checking the moisture content of the pulverized soil immediately prior to the placing of the cement in order to determine if the moisture content is low enough to permit operations to continue. In the event it is not low enough, it will be necessary to continue mixing or pulverizing process if the Contractor elects, in order to dry the material out. In no case, should the cement be placed until the moisture content has been properly reached. Inspectors are cautioned to see that the spreading of the cement is done in such a manner as to have a uniform application of cement over the top of the pulverized soil. The cement should not be disturbed after it has been spread, and in no case, should a blade be allowed to spread the cement.

d. The specifications allow two alternate methods of mixing and processing the soil-cement subgrade. One method is the use of the multiple pass traveling mixing plant, and the other is the use of a single pass traveling mixing plant. In either case, after the cement has been applied, it must be dry-mixed with the soil prior to the application of water. This dry-mixing shall continue until, in the opinion of the Inspector, the cement has been sufficiently blended with the soil to prevent the formation of cement balls when water is applied. Inspectors are cautioned that any mixture of soil and cement that has not been compacted and finished should not remain undisturbed for more than thirty minutes. If it were allowed to remain undisturbed for any great length of time, the cement with the natural moisture in the soil would begin the hydration process.

e. After the dry-mixing has been accomplished, either with the multiple pass traveling mixer or the single pass traveling mixer, the proper amount of water shall be applied to the mixture in order to bring it to the optimum moisture content. The specifications require that this water shall be applied uniformly through a pressure spray-bar. This, of course, will eliminate the use of the normal water truck type of application. Most of the traveling mixing plants are equipped with a water tank, gauge, and pressure spray-bar.

f. As the water is being applied to the soil, the traveling mixer shall in one continuous operation, mix the air-dry soil and cement full depth and the required moisture uniformly through the soil-cement mixture. It is normally spread then evenly over the machine-processed width of the subgrade and left in a loose condition ready for compaction. In some cases, this mixture of water, soil, and cement may be left in a uniform windrow behind the pug mill, depending upon the type of equipment used.

g. Compaction must begin immediately after the water has been incorporated into the soil-cement mixture. Due to the fact that the cement will begin the hydration process, it is necessary that rolling begin immediately after the mixing of the water with the soil-cement. The rolling shall continue until the mixture is uniformly compacted to the required density within approximately two hours. To meet this requirement, it is necessary that the Contractor be efficiently organized and prepared to go to work immediately with the compaction process. Inspectors are cautioned to check this facet of the operation prior to the addition of cement to the soil. After the process begins, it is too late to stop without losing the entire soil-cement mixture.

h. After the compaction process, it is necessary to properly finish the top part of the soil-cement subgrade. The specifications set out very definitely the process that is to be used. In general, it is intended that the surface of the soil-cement subgrade be tight-bladed by a power grader to a depth of approximately one-quarter inch, removing all loosened soil and cement from the section. This skinned surface shall then be thoroughly compacted by pneumatic rollers and so forth. Inspectors are cautioned to refer to the specifications for detailed requirements in this connection. Should the Contractor fail to finish the subgrade surface properly, it will be almost impossible to do later on, due to the fact that the cement will have set up.

i. After the cement-treated course has been finished, the surface should be protected against rapid drying by several alternate methods. This protection should be in place for the length of time as shown on the plans, but, in no case, less than three days, or until the surface or subsequent courses are placed on top.

The alternate methods for curing are:

(1) Maintaining in a thorough moist condition by continuous maintenance sprinkling.

(2) Application of two-inch layer of earth on the completed course and maintaining in a moist condition.

(3) Application of an asphalt membrane immediately after the completion of compaction of the soil-cement subgrade. If asphalt is used, the quantity and type of asphalt shall be sufficient

to completely cover and seal the total surface of the base and fill all the void. It will be necessary that the Contractor protect the asphalt membrane from being picked up or destroyed or damaged by traffic. This may be done by sanding or dusting the surface or by other methods that may be elected by the Contractor.

3. Inspector's Checklist

a. Check the weights of the cement as it is brought in on the job and see that each truck has a public scale certification or that the Contractor has a set of standard platform scales.

b. Check rate of application of cement as shown on the plans and stake off the proper length of roadway for the lands or courses.

c. Check the method of pulverization of the material to see that the proper depths, widths, and sections are being pulverized and that the soil is being reduced to a homogeneous, friable mass.

d. Check Contractor's equipment to see that it is on the job and in running condition and available when needed for this process. Inspectors are discouraged from allowing the procedure to begin if all of the equipment is not located in the immediate area and not available for immediate use.

e. During all of the mixing operations, check to see that the mixing equipment is thoroughly and properly blending the entire depth and width of the loosened material.

f. Check to see that the compaction is being done properly and in accordance with the requirements of the specifications, and see that the proper density and optimum moisture content have been achieved. It is particularly important to check to see that the compaction is thoroughly compacting the lower levels of the stabilized layer. In the event that this is not occurring, the Inspector should require that the Contractor immediately take such corrective action as is necessary to compact the lower levels of the stabilized subgrade.

g. During the curing period, keep a constant check on the progress of the chemical reaction and require any corrective steps that are necessary to insure that the proper moisture content is being maintained.

4. Measurement and Records to be kept.

Since the cement is measured and paid for by the ton, it is necessary that an accurate record be kept of the weights of cement placed on the job. The Inspectors should issue tickets daily for the amount of cement used and a ticket number and weight should be recorded in a hardback field book for future reference. This record is the support for the payment of cement on the final estimate. A daily record should also be kept of the station numbers of the various lands that are stabilized each day.

I. Flexible Bases

A. Shell with Sand Admixture

1. Specification Requirements

Item 234, Flexible Base (Shell with Sand Admixture), page 104 of the standard specifications is the governing specification for this operation. Item 234 refers to: Item 110, Roadway Excavation, Item 130, Borrow, Item 150, Blading, Item 152, Road Grader Work, Item 154, Scraper Work, Item 204, Sprinkling, Item 210, 211, 212, 213, and 214, 215 and 216, Rolling, and Item 500, Weighing and Measuring Equipment. It is these specifications together with any pertinent special provision or notes on the plans that form the basic requirements of this operation.

Sand Shell Flexible Base consists essentially of a mixture of oyster shell with a fine sand or sandy loam admixture. The shell shall be, or consist of, durable particles with or without natural binder material and may either be washed, partially washed, or unwashed. The sand shall consist of a fine sand or sandy loam and shall be practically free from roots, grass, and other foreign materials

2. Construction Methods

a. The roadbed should be checked before beginning hauling operations. All holes, ruts, and depressions shall be filled with approved material, and, if required, the subgrade should be thoroughly wetted with water, re-shaped, and rolled to the extent directed in order to place the subgrade in an acceptable condition to receive the base material.

b. The specifications require that all materials shall be delivered in approved vehicles of a uniform capacity. This will necessitate that the Inspectors measure the capacity of all the trucks prior to beginning of hauling operations. Every effort should be made to have trucks of a uniform capacity in order to avoid confusion by the checker when he is issuing the haul tickets. It is very definitely required that the trucks be measured prior to the hauling of any material. Many times contractors will suggest that the measuring can be done later during the day or in the evening in order to avoid interruptions of work during the day. This should not be agreed to by the Inspector, and no tickets should be issued to a truck that has not been previously measured. A windshield sticker should be placed on each truck, indicating the size of the truck and the dimensions of the bed. This will serve as notice to the checker on the road that the truck has been measured and is approved for hauling.

c. After the shell has been delivered on the road, it should be spread uniformly across the section and allowed to dry. This drying period is required to assure proper slaking and mixing of the binding material since the shell is normally wet when delivered on the job. The length of time required for proper drying will be greatly dependent upon the weather conditions and the amount of moisture in the shell. Upon completion of the drying period, the shell should be bladed and spread uniformly over the roadbed in order that uniform mixing and proportioning between the shell and sand will be accomplished. Obviously, if the shell is not spread uniformly, then the sand which will be dumped on top of it will not be proportioned properly. Careful attention should be given to this point. The sand admixture shall then be spread uniformly across the top of the shell, and then the material shall be sprinkled as required and thoroughly mixed by blading, harrowing, or other approved mixing methods. The inspectors are cautioned to be very critical and careful of the mixing process as it is being performed. It is very important that the entire amount of shell and sand be thoroughly mixed throughout the entire mass of material. Many times, through improper mixing, small segregated nests of shell or sand are left unmixed, thus causing a soft spot or loose spot in the finished base material. Inspectors should always insist that the mixing process continue until the entire mass of material is thoroughly and completely mixed.

d. Failure to proceed with the hauling of sand admixture and mixing and placing operations will be grounds for the suspension of placing shell. In no case, should the Inspector allow the Contractor to proceed with hauling shell unless he is following up in a uniform sequence the hauling of sand and the mixing and compaction operation. It is the intent of this requirement to avoid having a great deal of loose shell spread over a road without any prospect of having the material mixed and properly compacted.

e. After mixing, the homogeneous mass of material shall be windrowed on one side or both sides and then spread over the section in layers not to exceed approximately two inches in loose depth. After each lift is spread, it should be sprinkled to secure the proper moisture and rolling operation begun. As the rolling operation continues, additional material should be spread over the roadway, sprinkled, and rolled, until the entire mass of material has been properly placed and compacted. During this process, any areas or nests of segregated material should be corrected immediately or removed and replaced with well-mixed material.

f. After the entire mass has been compacted thoroughly and uniformly and presents a smooth surface, it is necessary that the Contractor "pull" each shoulder of the base section. Normally, when laying a flexible base, the Contractor will not attempt to build the proper slope on the shoulders of the section. Instead, the section is usually built a little bit wide. The Contractor should set stakes delineating the shoulder line of the base material as well as the toe of slope of the base material. This slope is cut after the material has been compacted. This will enable the blade to operate more efficiently and cut a smooth and uniform section. The material thus "pulled" from the shoulder slope is then spread out over the entire roadway, wetted and rolled, and finished off, and becomes part of the flexible base section.

g. Several days subsequent to the compaction operation are required for a proper curing period. During this time, it is essential that the surface of the base be kept in a moist condition and rolled and bladed as necessary. After several days a hardened crust will form on the surface of the flexible base, signifying that the curing period has been completed.

From this time, until the time that the surface course is placed, it is necessary that the Contractor maintain the base section in such a manner as to preclude the loss of fines from the surface of the base. This is done by regular maintenance such as watering or sprinkling, rolling and blading. Inspectors are cautioned to insist that this maintenance operation be performed under whatever pay requirements are set up in the plans and specifications for such operation.

3. Inspector's Checklist

a. Be sure to check the capacity of all vehicles used to haul material on the road. The dimensions and volume of each vehicle should be posted prominently on the vehicle and further recorded in a book.

b. Check the rate of application of the sand and shell or flexible base and see that the spacing used by the Contractor in dumping a load is proper to produce a desired amount of material per lineal foot of roadway.

c. Check to see that the Contractor spreads the sand and shell uniformly on the roadway in order to achieve the proper proportions.

d. Check to see that the entire mass of material has been completely mixed.

e. Check depth and density of compacted material.

f. After compaction and finishing operations, check to see that the Contractor performs maintenance operations as required in order to avoid the loss of fines from the upper portion of the flexible base. This maintenance operation should continue until the surface course is placed.

4. Measurement and Records to be kept

Regardless of whether the flexible base is to be paid for by the cubic yard or by the ton, payment is normally made by the issuance of haul tickets for each truckload of material that is dumped on the subgrade. The tickets themselves form a record of payment for flexible base. However, in addition, each ticket number, together with the data shown on the ticket, such as the quantity, quarter-haul, etc., should be noted in a hardback field book. This record will then form the basis of payment for flexible base and sand admixture and additional quarter-mile haul, whichever is indicated on the plan.

A record should be kept either in the job diary or in a separate hardback field book, which will indicate the date of hauling, mixing and laying of the flexible base. In this way, the length of time the base has been laid can be easily checked, and in the event there is some question about a part of the material delivered on a certain day, this material can be easily located on the road.

When ordinary compaction is indicated on the plan, all sprinkling performed will be measured and paid for in accordance with the items of sprinkling and rolling respectively. In this case, it will be necessary to issue haul tickets for both sprinkling and rolling. Separate records of these tickets should also be kept. Unless otherwise provided by the plan, all excavation required by this item in the preparation of subgrade or for the completion of the shoulders and slopes after the flexible base has been laid, will be measured and paid for in accordance with the provisions governing the items of roadway excavation and borrow respectively, with the provision that yardage will be measured and paid for once only regardless of manipulation involved. When shown on plans, the excavation required in the preparation and shaping of the subgrade for the completion of shoulders and slopes and for finishing shall be measured and paid for in accordance with the following items: blading, road-grader work, or scraper work. In no event however, will payment for roadway excavation be allowed within the limits designated for the items: blading, road-grader work, or scraper work.

B. <u>Iron Ore Gravel</u>

1. Specification Requirements

Item 240, Flexible Base (Iron Ore), page 121 of the Standard Specifications, is the governing specification for this operation. Item 240 refers to Items 110, Roadway Excavation, Item 130, Borrow, Item 150, Blading, Item 152, Road Grader Work, Item 154, Scraper Work, Item 204, Sprinkling, Items 210, 211, 212, 213, 214, 215, and 216, Rolling, and Item 500, Weighing and Measuring Equipment. It is these specifications together with any pertinent special provisions or notes on the plan that form the basic requirements of this operation. Iron ore flexible base consists of a base composed of iron ore material found in its natural state, with or without sand, but shall not contain an excess of free clay.

2. Construction Methods

a. The excavation of the iron ore is one of the most critical points in this entire operation. In its natural state, iron ore is normally overlaid by a thin layer of sand or top soil. The iron ore is usually in a layer laying immediately under this top soil which will vary from a few inches to as much as two feet thick. Underneath this layer of iron ore, there is normally found a layer of red or yellow clay which has a very high PI. It is necessary that this iron ore material be removed without undue contamination from either the overlying sandy top soil or the underlying excess clay. An inspector should be stationed at the pit during the excavation process in order to be sure that the Contractor uses every effort to avoid the contamination of the material. A normal excavation process consists of blading off or removing the overlying top soil and placing it in a windrow at one side of the pit in such a way that it will not become mixed with the iron ore that will subsequently be removed. The iron ore is then bladed or removed to a large windrow with care being taken that the material below the limits of the free clay layer shall not be disturbed.

In the event that the free clay layer is disturbed in the excavation process, the portion of iron ore that has been contaminated should be condemned by the Inspector and not allowed to be placed in the windrow of iron ore. The moisture conditions existing in the pit will have a great deal to do with how close the iron ore material can be removed without disturbing the layer of free clay. In the event of a rather dry pit with very little natural moisture, the material might be removed quite close to the free clay layer. On the other hand, when unusual amounts of moisture are present in the soil, usually after a prolonged rainy period, the clay will hold the moisture at the lower levels of the iron ore, and it will be practically impossible for the Contractor to remove the iron ore material very near the free clay layer. The type of equipment used will also have a bearing on how much or how close the iron ore material can be removed from the free clay layer. The use of rubber-tired equipment will allow the Contractor to work very close to the bottom of the iron ore. On the other hand, the use of track equipment such as caterpillar tractor, scrapers, or bulldozers will necessarily require a greater tolerance between the bottom of the iron ore and the top of the free clay layer. It is necessary that the Inspector in the pit exercise a great deal of judgment and control over the excavation process for iron ore.

b. Prior to hauling iron ore base, the roadbed should be checked to see that it has been shaped in conformity with the typical sections shown on the plans and to the lines and grades established by the Engineer. All unstable or otherwise objectionable material shall be removed from the subgrade and replaced with approved material and all holes, ruts, and depressions shall be filled with material and, if required, the subgrade shall be thoroughly wetted and re-shaped and rolled in order to place it in acceptable condition to receive the base material.

c. The iron ore material shall be delivered from the pit to the road in approved vehicles of uniform capacity, and it is necessary that the Contractor deliver the required amount of material in each 100-foot station. This will necessitate inspectors measuring the capacity of all trucks prior to beginning of hauling operations. Every effort should be made to have trucks of a uniform capacity in order to avoid confusion by the checker when he is issuing the haul tickets. Again, it is very definitely required that the trucks be measured prior to the hauling of any material. Many times, contractors will suggest that the measuring can be done later in order to avoid interruptions of work. This should not be agreed to by the Inspector, and no ticket should be issued to a truck that has not been previously measured. A windshield sticker should be placed on each truck, indicating the size of the truck and the dimensions of the bed. This will serve as notice to the Checker on the road that the truck has been measured and is approved for hauling.

d. After dumping on the road, the material is normally bladed into a uniform windrow prior to the beginning of compaction operations. This windrow may be located in the center of the road, or the Contractor may elect to use two windrows, one on either side of the road. The material is then spread over the roadway section in layers, not to exceed approximately two inches in loose depth. After each lift is spread, it should be sprinkled to secure the proper moisture, and rolling operations begun. As the rolling operation continues, additional material should be spread over the roadway, sprinkled, and rolled until the entire mass of material has been properly placed and compacted.

e. After the completion of the compaction operations, it is necessary that the Contractor "pull" each shoulder of the base section. Normally when laying a flexible base, the Contractor will not attempt to build a proper slope on the shoulders of the section. Instead, the section is usually built a little bit wide. Stakes are usually set, delineating the shoulder line of the base material as well as the toe of slope of the base material. This slope is then cut after the material has been compacted. This will enable the blade to operate more efficiently and cut a smooth and uniform section. The material "pulled" up from the shoulder is then spread out over the entire roadway, wetted and rolled, and finished off and becomes part of the flexible base section.

f. Several days subsequent to the compaction operation are required for a proper curing period. During this time, it is essential that the surface of the base be kept in a moist condition as well as rolled and bladed as necessary. After several days, a hardened crust will form on the surface of the flexible base, signifying that the curing period has been completed.

From this time until the time that the surface course is placed, it is necessary that the Contractor maintain the base section in such a manner as to preclude the loss of fines from the surface of the base. This is done by regular maintenance such as watering or sprinkling, rolling and blading. Inspectors are cautioned to insist that this maintenance operation be performed under whatever pay requirements are set up in the plans and specifications.

3. Inspector's Checklist

a. Be sure to check the method used by the Contractor to excavate and stockpile the iron ore at the pit site. In particular, attention should be given to the removal of the overlying top soil, sand, and also to the problem of eliminating any contamination of the iron ore material by the underlying free clay layer.

b. Be sure to check the capacity of all vehicles used to haul material on the road. The dimensions and volumes of each vehicle should be posted prominently on the vehicle and further recorded in a book.

c. Check the rate of application of the iron ore and see that the spacing used by the Contractor in dumping a load is proper to produce the desired amount of material per lineal foot of roadway.

d. Check depth and density of compacted base.

e. After compaction and finishing operations, check to see that the Contractor performs maintenance operations as required in order to avoid the loss of fines from the upper portion of the flexible base. This maintenance operation should continue until the surface course is placed.

4. Measurement and Records to be kept

Payment for iron ore flexible base is normally based on the cubic yard measurement. Haul tickets should be issued to truck drivers for each truckload of material that is dumped on the subgrade. The tickets, themselves, form a record of payment for flexible base. However in addition, each ticket number together with the data shown on the ticket, such as the quantity, quarter-haul, etc., should be noted in a hardback field book. This record will then form the basis of payment for flexible base iron ore, and additional quarter-mile haul, whichever is indicated on the plan. A record should be kept, either in the job diary, or in a separate hardback field book which will indicate the date of hauling and laying of the flexible base. In this way, the length of time the base has been laid can be easily checked, and in the event there is some question about a part of the material delivered on a certain day, this material can be easily located on the road.

When ordinary compaction is indicated on the plan, all sprinkling performed will be measured and paid for in accordance with the items of sprinkling and rolling. In this case, it will be necessary to issue haul tickets for both sprinkling and rolling. Separate records of these tickets should also be kept. Unless otherwise provided by the plans, all excavation required by this item in the preparation of subgrade or for the completion of the shoulders and slopes after the flexible base has been laid, will be measured and paid for in accordance with the provisions governing the items of roadway excavation and borrow respectively, with the provision that the yardage will be measured and paid for once only regardless of the manipulation involved. When shown on plans, the excavation required in the preparation and shaping of the subgrade for the completion of shoulders and slopes and for finishing shall be measured and paid for in accordance with the following items: blading, road grader work, or scraper work. In no event however, will payment for roadway excavation be allowed within the limits designated for the items: blading, road grader work, or scraper work.

C. Miscellaneous Flexible Bases

1. Processed Gravel

This type of flexible base is a mixture of durable particles of gravel mixed with an approved soil binder material.

Item 238, page 115, is the specification that covers the requirements for processed gravel.

This type of material is usually "processed" or prepared at a central plant, usually located at the local source of gravel. The gravel is screened, crushed and re-screened, and then mixed with the proper amount of soil binder to meet the grading requirements as set out in Item 238.3, page 116, of the Standard Specifications.

All of the points discussed previously in Item II, A and B, above can be said to apply generally to this type of flexible base.

2. Bank-Run Gravel

This type of flexible base is also a mixture of durable particles of gravel mixed with an approved binding method. The main difference between this type of base and "Processed Gravel" base is the fact that this material may be hauled directly from the pit to the road without already being processed through a central plant. The binder may be added separately on the road, or it may be "bank run." This term means "as exists in the gravel bank or pit." While this material must still meet grading and other specification requirements, they are much more flexible in this case to allow the use of the natural material.

Item 236, page 110, is the specification that covers the requirements for bank or pit-run gravel.

The removal of the gravel from the pit is a point that must be closely checked. Like iron ore gravel, these pits are sometimes overlain by unsatisfactory material and are almost always underlain, and sometimes interlaced with, layers of a very heavy white or blue clay. Extreme care must be taken to avoid contaminating the gravel material with either of these unsatisfactory materials. An inspector should be stationed in the pit at all times during hauling operations to see that improper material is not removed.

Finishing of a "Bank-Run Gravel" base is extremely difficult due to the large stones that are usually present. It is usually impossible to get a completely "slick" finish; however, with care, an acceptable finish may be produced.

All of the points discussed previously in Item II, A and B, above, can be said to apply generally to this type of flexible base.

LABORATORY COURSE II

I. Resident Laboratory Work on Soils and Base Materials

As earthwork and base course placement begins on the construction project, the Resident Laboratory may be called upon by the Project Engineer to furnish the boundaries or limiting properties of the various soils in cut or fill sections, the gradation of base course mixtures prior to compaction, or criteria for the "Density Control" method of compaction. In order that the necessary data be obtained, the following items of laboratory work must be accomplished.

A. <u>Sampling</u>

The importance of obtaining representative samples of material for laboratory testing cannot be overemphasized. The proper reduction of large field samples to sizes usable for testing in the laboratory must be done carefully in order that the soil and base materials tested will be adequately representative of field conditions.

1. Soils

Sampling of the various roadway and borrow soils shall be in accordance with appropriate parts of Test Method Tex-100-E, Soils Section (Manual of Testing Procedures).

a. Sample locations in uniform subgrade layers to establish boundaries may be spaced at 500-1000 foot intervals.

b. Sample locations in borrow sources may be spaced at 100-500 foot intervals depending, of course, on the variations in soil types and volume of material to be removed.

2. Flexible and Stabilized Base Materials

Sampling of base materials from stockpile, plant, or roadway shall be in accordance, also, with appropriate parts of Test Method Tex-100-E.

a. A representative sample of base material for gradation should be taken from each 500 cubic yards of road-mixed material or 1000 tons of plant-mixed material used in construction.

b. Samples for compaction tests should be taken prior to base placement and on those occasions where the gradation of the mixture has varied appreciably. (This matter is discussed further in Section C-2.

B. <u>Sample Preparation and Testing</u>

Preliminary to the actual testing of soils and base materials is the preparation of field samples. Since certain inherent physical and chemical characteristics in the samples may be destroyed by overheating, use of chemicals, or rough handling techniques, it is extremely important to note the sample preparation controls cited in the following test procedures.

1. Determination of Moisture Content

The determinations of moisture content are required in numerous tests on all types of soils and aggregates, in conditions varying from saturation to that in which the moisture is of a hygroscopic nature and in so small a quantity that, to the eye, the sample appears to be dry. Test Method Tex-103-E outlines the mechanics of performing this test.

2. Determination of Liquid Limit

The liquid limit (L.L.), represents the moisture content at which a soil passes from a plastic to a liquid state.

Since the cohesion (a force by which particles of the same kind, or of the same body, are held together), of soil has been largely overcome at the liquid limit, this test is an index of cohesion.

Sandy soils have low liquid limits compared to silts, indicating less moisture required to lubricate the surface of the grains.

High liquid limits indicate soils of high clay content and poor engineering properties. Test Method Tex-104-E describes the procedure for determining the liquid limit of soils.

3. Determination of Plastic Limit

The plastic limit (P.L.), of soils is the moisture content at which a soil changes from a semi-solid to a plastic state.

The plastic limit is governed by clay content. Some silt and sand soils cannot be manipulated to the proper consistency required in this test procedure, therefore, have no plastic limit and are termed "non-plastic." Soils having plastic limits contain silt and clay, and the moisture content of such soils have a direct bearing on their load-carrying capacity. As the moisture content is decreased below the plastic limit, the load-carrying capacity increases very rapidly. On the other hand, load-carrying capacity decreases very rapidly as the moisture content is increased above the P.L. Test Method Tex-105-E describes the procedure for the plastic limit determination.

4. Determination of Shrinkage Factors

The calculation of the shrinkage limit moisture content (S.L.), and shrinkage ratic (S.R.), from the volumetric shrinkage test is described in Test Method Tex-107-E. These two values establish the "loose density" constant needed in Compaction Ratio Density calculations on clay and silt soils.

As these values are not required in the specifications, no further references are made to this test procedure.

5. Determination of Hydrometer and Mechanical Analysis of Soils

The "mechanical analysis" of a soil is the determination of the percent of individual grain sizes present in a sample. The mechanical analysis consists of two parts:

a. The determination of the amount of coarse material by the use of sieves, and

b. The analysis for the fine-grained fraction employing a hydrometer analysis.

As the relative sizes of the fine-grained soils are rarely needed, hydrometer procedures are not used in the Resident Labs.

The mechanical analysis of soils and base materials shall be run, therefore, in accordance with the section "Mechanical Analysis of Aggregate" in Test Method Tex-110-E.

6. Determination of Moisture-Density Relations of Soils and Base Materials

Throughout this discussion, the term "density" or "dry density" of any given soil mass, regardless of its moisture content, will refer to the calculated weight of any soil per cubic foot. The "wet density" will include the weight of soil plus water in pounds per cubic foot.

The term, "compaction," refers to the act of artificially densifying the soil. It means the pressing of soil particles together into a closer state of contact and, in so doing, expelling air or water from the soil mass.

The fact that different moisture contents give different densities to the same soil under the same load has been discovered independently by several sources, but Mr. R. R. Proctor of Los Angeles in 1933 worked out the first widely recognized test for determining the optimum moisture content of the soil and checking it in the field.

The optimum moisture content, at which maximum dry density is obtained, is the moisture content at which the soil has become sufficiently workable under the test compactive effort used to cause it to become packed so closely as to expel most of the air. At moisture contents less than optimum, the soil (except for cohesionless sands), becomes increasingly more difficult to work and thus to compress. As moisture contents are increased above optimum, most soils become increasingly more workable. However, a closer packing is prevented when the water fills the soil pores. Thus the moisture-density relationship established in the test is indicative of the relative workability of the soil at various moisture contents under the test compactive effort used. A plot of the relationship shows a curve having a positive slope up to a maximum and then negative slope as the moisture content continues to increase. (See Figure 8 in Test Method Tex-113-E.)

The zero air voids curve shown in the above figure represents the density in dry weight of soil per cubic foot, that could be obtained at the various moisture contents if there were no air voids present, i.e., if the compacted specimens contain only dry soil plus moisture. A point on this curve represents the maximum density that can be obtained in a given soil at that given moisture content.

The greater the distance between the moisture density curve and the zero air voids curve, the greater will be the amount of air voids in the compacted specimen. The actual % air voids, expressed as a percentage of the volume of the total soil mass, can be calculated from the following simple equation:

$$\%\ \text{Air Voids} = 100\left(1 - \frac{\text{Actual Density at a given moisture}}{\text{Zero Air Voids Density at same moisture}}\right)$$

If a line of equal air voids is calculated to intersect the peak of the moisture density curve obtained at a specific compactive effort, it would then intersect curves produced by other compactive efforts made on the same soil at or near to their point of highest density.

This phenomena is useful in determining the desirable moisture content in the Compaction Ratio calculations discussed in Section C-4.

The mechanics of the moisture density test are described in Test Method Tex-113-E.

7. Determination of In-place Density of Soils and Base Materials.

The density of soil in the field, either in its natural state or in compacted layers, is determined by obtaining the weight and moisture of a disturbed sample and measuring the volume occupied by the material prior to removal, by means of a Volumeter. The in-place density shall be performed in accordance with Test Method Tex-115-E. (See slides showing the "dos and don'ts" of making Volumeter measurements.)

C. Calculating and Evaluating the Engineering Properties of Soils and Base Materials from Test Results

1. Plasticity Index

The plasticity index is the range of plasticity of a soil or the range of moisture percentage in which the soil remains in a plastic state while passing from the semisolid up to the liquid state of the soil specimen. Therefore, the plasticity index is the numerical difference between the liquid limit and the plastic limit, or

PI = LL - PL = The plasticity index of the soil.

These plastic properties are furnished almost entirely by the clay particles present in the material. Neither this nor any other consistency test value will determine the actual amount of clay present in a given soil, because a given plasticity index value can be furnished by either a small amount of very active clay or a large amount of relatively inactive clay.

In general, though the more stable soils usually have plasticity index values of 15 or less, while the more unstable soils usually have plasticity index values greater than 15. These figures will hold true also for the soil binder in a base material, even though the percentage of binder present is relatively small. A soil or a base material which has a plasticity index value of nearly zero will have very little cohesion due to lack of clay-size particles and therefore, will be extremely difficult to "set up" in the road.

Some typical plasticity indices for several soils in the Gulf Coast Area are shown in Figure 1 (Form 476A). It may be noted that the PIs are reported to the nearest whole number.

2. Gradation

The grading of aggregates to be used for flexible pavements is important because in a large measure it controls the stability of the pavement. In fine-grained soils, the grading is usually unimportant, due to the more predominant effect of plasticity on the stability of the soil. As mentioned above, the plasticity is furnished almost entirely by clay particles, which generally all pass the No. 200 sieve.

The gradation control in our specifications refer only to sieve sizes larger than the 40 mesh; therefore, we will not divide any fine-grained material passing the 40 mesh according to grain size.

The grading is reported in a tabular form by giving the percentage larger than certain specified sizes (percentage retained), based on the dry weight of the total sample, including the weight of the soil binder. Representative gradation on several coarse-grain materials are shown in Figure 2. Grading may also be represented graphically by means of a particle size distribution curve as shown in Figure 3. The percentage retained is plotted against the sieve size which is on a logarithmic scale.

For control of compaction, use is frequently made of gradation values for verification of the uniformity of flexible base mixtures. Several studies made in this District have shown that the laboratory compacted densities of mixes having changes in percentage of aggregates retained in the No. 4 to 1-inch sieve sizes, may vary by as much as 5 pounds per cubic foot. See Figure 4 for ranges in densities due to gradation changes in the aggregates.

3. Compaction Ratio Density

Every soil and base material has a loose density (D_L). For clays, the loose density (D_L), is thought to be approximately that density of a soil shrinkage pat which has been molded at the liquid limit consistency (similar to clay formation freshly deposited by H_2O). For clean sands and granular materials, the loose density (D_l) is thought to be approximately that of the rodded unit weight.

Every soil and base material has a dense density (D_D), which is obtained from the peak of a moisture-density curve, using a high compactive effort of approximately 30 ft. lbs./cu. inch. This compactive effort corresponds to that exerted by the heaviest rolling equipment currently in use in the field.

Every soil and base material may be compacted to some percent maximum density in the field, using various rolling equipment, but oftentimes over-compaction of clays, resulting in excessive swelling, and under-compaction of mixtures of base materials occur when we arbitrarily select the minimum percent density desired.

In a search for a more realistic method of selecting densities which are comparable to ideal field conditions, the Materials and Tests Division in Austin reasoned that the degree of compaction should be determined on the basis of tests for both D_L and D_D rather than from arbitrary percent selections of the maximum D_D value. Hundreds of field tests have been made comparing the in-place densities of various materials that have been under traffic for many years and a ratio has been established for each soil type, using the following formula.

$$\text{Compaction Ratio} = \frac{\text{Actual Field Density} - \text{Loose Density}}{\text{Dense Density} - \text{Loose Density}}$$

$$CR(\%) = \frac{D_A - D_L}{D_D - D_L}$$

By subsititution in the above formula, the desirable field density, $D_A = \frac{CR}{100}(D_D - D_L) + D_L$ will produce a value somewhere between D_L and D_D, but this position of D_A depends upon the type of material being tested. A graphical method of obtaining the desirable D_A value is as shown in Figure 5. (See example problem on chart.)

A comparison of the ranges of D_A values for several types of material are shown in Figure 6.

4. Ranges of Moisture Content and Compaction Ratio Densities for Control of Compaction

The moisture content of the soil or base material at the time of compaction is the primary key to the densification accomplished with a given compactive effort. Optimum moisture content for rolling is estimated by drawing a line of equal air voids passing through D_D and parallel to the zero air voids line. (See Figure 7 for details of this procedure.) This line intersects D_A at a desirable moisture content for compaction.

Our Specifications on "Density Control" require that soils with P.I. of 20 or more shall be compacted to not less than 98 percent nor more than 102 percent of the D_A density. As such, this involves an allowable moisture range of several percentage points in lieu of an optimum percentage point. (See dashed lines in Figure 7.)

For other materials no particular moisture range is required except that the material should not be allowed to dry out to less than the optimum at D_A. See Figure 8, showing the compaction curve for lime stabilized clay subgrade which must be compacted to not less than 95 percent of D_A density.

Texas Highway Department
Form 476A

SECTION I

83136-462-20m

SOILS AND BASE MATERIALS TEST REPORT

Laboratory No. ______
Date Rec'd ______ Reported ______
Engineer W. E. Carmichael
Address Houston, Texas
Contractor ______
Sampler District 12 Lab
Sampler's Title ______
Sampled From ______
Producer ______
Quantity Represented by Sample ______
Has been Used on ______

Control Number ______ Section Number ______ Job Number ______
County ______ Federal Project No. ______ Highway No. ______
District No. 12 ______ I.P.E. No. ______ Req. No. ______ Date Sampled ______
Specification Item No. ______
Material from Property of ______
Proposed for Use as Subgrade soils

Lab. No.	LL	PL	PI	LS	SR	Class	Soil Binder	WBM % Loss	% Moist.	
262-1014A	20	14	6							
262-1078B	71	28	43							
262-1232	20	14	6							
258-662	43	17	26							
259-662C	35	15	20							
262-789N	88	27	61							
262-355	41	17	24							
258-454	53	18	35							
260-295	32	17	15							

PERCENT RETAINED ON

Lab No.	Square Mesh Sieve															Grain Diam.			Specific Gravity
	Opening in Inches								Sieve Numbers							in Millimeters			
	3	2½	2	1¾	1¼	⅞	⅝	⅜	4	10	20	40	60	100	200	.05	.005	.001	

SAMPLE IDENTIFICATION

Lab No.	Identification Marks	Location—Properties—Station Numbers	Type of Materials
62-1014A	Austin Co.	FM-1093 Brazos River to Wallis	Grey sandy silt
62-1078B	Brazoria Co.	FM-1462 Rosharon to Brazos R.	Red clay
62-1232	Ft. Bend Co.	US-59 Brazos River at Richmond	Reddish-brown silt
58-662	Galveston Co.	IH-45 at Vauthier Rd. Overpass	Black silty clay
59-662C	No.Harris Co.	IH-45 near Spring	Grey silty clay
62-789N	So.Harris Co.	IH-45 near FM-1959	Grey clay
62-355	Matagorda Co.	FM-2668 Celanese Plant Road	Silty clay
58-454	Montgomery Co	IH-45 near Willis	Tan & gray silty clay
60-295	Waller Co.	FM-2572 Pattison to Brazos River	Brown silty clay

SUMMARY OF LABORATORY TEST DATA

Res. Engineer ______________________ Control ______________________

Address ______________________ I.P.E. ______________________

Sampler District 12 Laboratory Highway ______________________

Date Sampled ______________________ County ______________________

Lab. No.	Material	Location and Depth of Course	LL	PI		% Material Retained On						Lab Dry Dens. pcf.	Triaxial Class Unconf.Comp.Str. Cohesiometer Val.
Specification Requirement						1 3/4	1 1/4	7/8	3/8	4	40	D_A	
1259-M 122	Sand-shell	Mayo Shell Co. Galena Park	18	4			5	15	37	54	78	128	
1262-841C	Sand-shell	Parker Bros. Co. Dickinson	26	6			0				69	128	
1262-994	Iron Ore	Champion Pit #7 Montgomery County	16	3			0			28	53	137	
1260-307	Iron Ore	Purkerson Pit Montgomery County					2	3	17	36	55	138	
1260-408	Processed Gravel	Horton & Horton Eagle Lake	23	8		3	12	25	47	61	68	136	
1262-1123	Crushed Limestone	Temple Crushed Stone	16	3		0	17	38	69	81	90		
1262-58	Pit sand	Mayo Shell Company	21	3						0	8		

FIG. 2

D12L-32

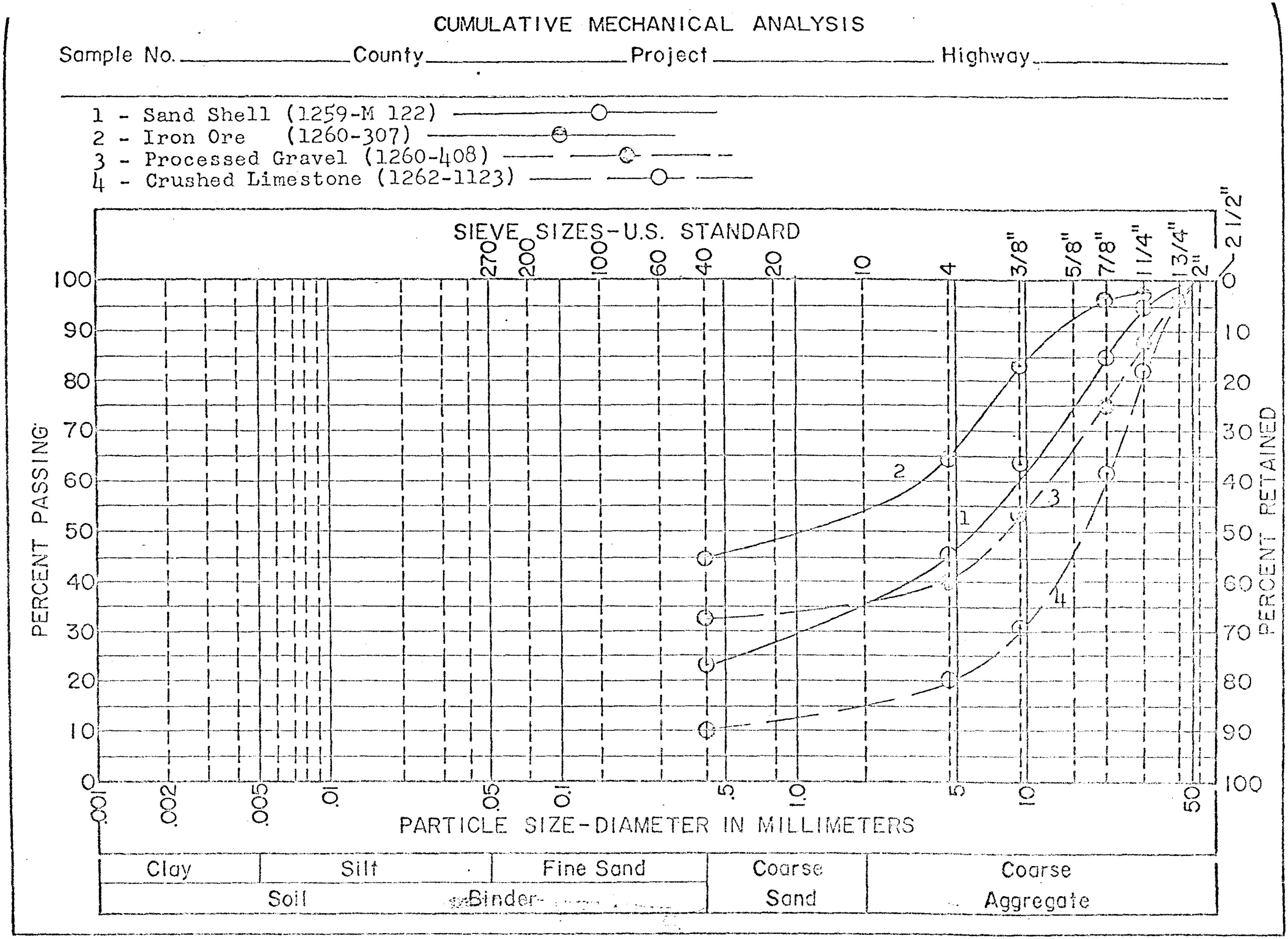

CUMULATIVE MECHANICAL ANALYSIS
Sample No. County Project Highway
1 - Sand Shell (1259-M 122)
2 - Iron Ore (1260-307)
3 - Processed Gravel (1260-408)
4 - Crushed Limestone (1262-1123)
SIEVE SIZES-U.S. STANDARD
270 200 100 60 40 20 10 4 3/8" 5/8" 7/8" 1 1/4" 1 3/4" 2" 2 1/2"
PERCENT PASSING
100 90 80 70 60 50 40 30 20 10 0
PERCENT RETAINED
0 10 20 30 40 50 60 70 80 90 100
.001 .002 .005 .01 .05 .1 .5 1.0 5 10 50
PARTICLE SIZE-DIAMETER IN MILLIMETERS
Clay
Silt
Fine Sand
Coarse Sand
Coarse Aggregate
Soil Binder

FIG. 3

SUMMARY OF LABORATORY TEST DATA

Res. Engineer ______________________ Control ______________________

Address ______________________ I.P.E. ______________________

Sampler District 12 Laboratory Highway ______________________

Date Sampled ______________________ County ______________________

Lab. No.	Material	Location and Depth of Course	LL	PI		% Material Retained On 1¼		4		40		Lab Dry Dens. pcf.	Triaxial Class Unconf.Comp.Str. Cohesiometer Val.
Specification Requirement												D_A	
1005	Sand-shell	Cement Stab. Base	24	9		1		36		49		124.0	
1009	"	" " "	20	5		4		48		65		129.5	
520	"	" " "	29	4		3		37		62		125.9	
1122	Limestone	Regular Pit Run	18	5		13		73		81		128.0	
1123	"	Washed	16	3		17		81		90		123.0	
841	Sand-shell	Flex. Base	23	7		0				59		131.1	
			22	6		0				66		129.6	
			26	6		0				69		127.8	

FIG. 4

D12L-32

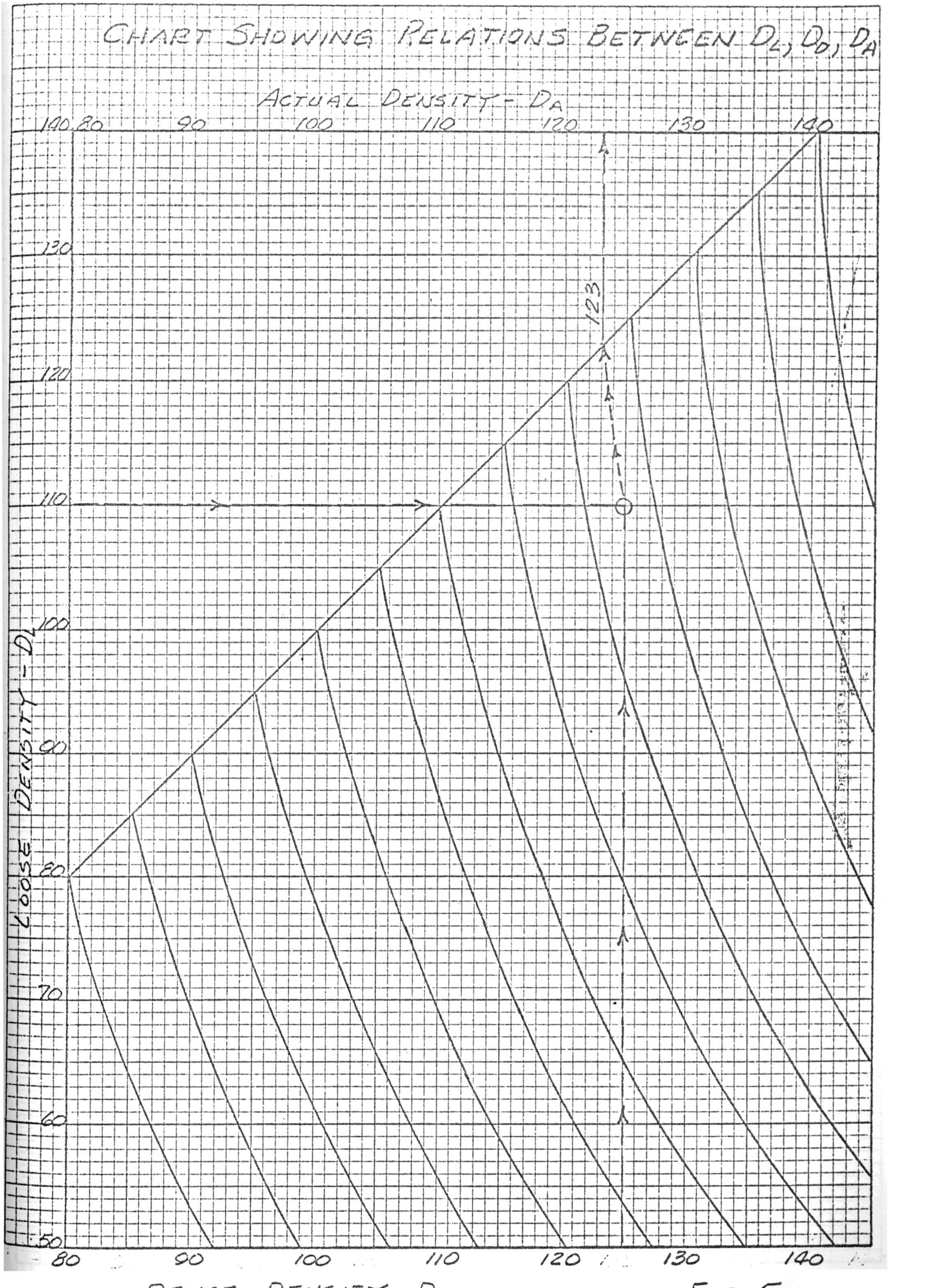


CHART SHOWING RELATIONS BETWEEN D_L, D_D, D_A
ACTUAL DENSITY - D_A
80
90
100
110
120
130
140
123
LOOSE DENSITY - D_L
DENSE DENSITY - D_D

FIG. 5

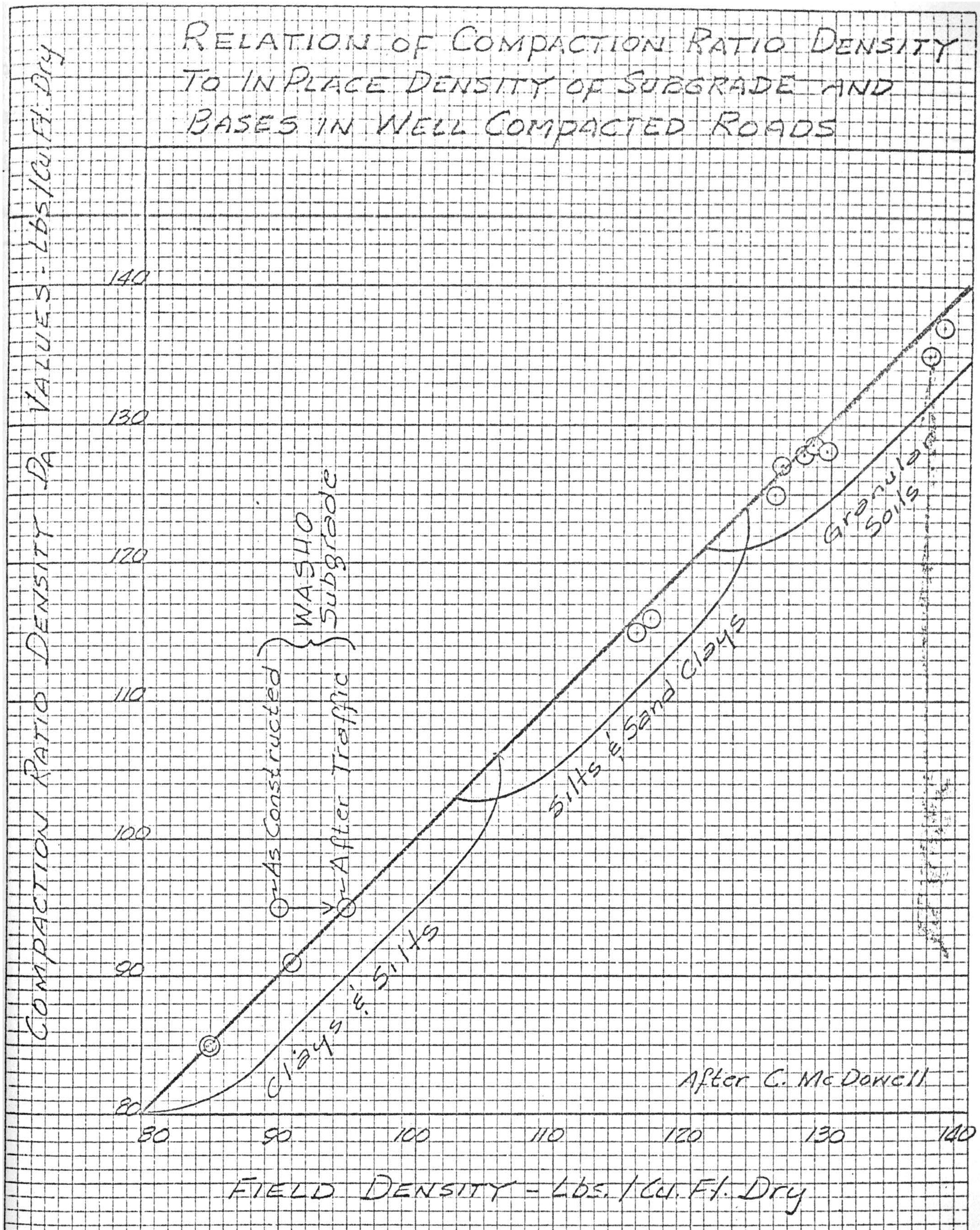

RELATION OF COMPACTION RATIO DENSITY
TO IN PLACE DENSITY OF SUBGRADE AND
BASES IN WELL COMPACTED ROADS
COMPACTION RATIO DENSITY DA VALUES - Lbs/Cu. Ft. Dry
FIELD DENSITY - Lbs./Cu. Ft. Dry
80
90
100
110
120
130
140
As Constructed
After Traffic
WASHO Subgrade
Clays & Silts
Silts & Sand Clays
Granular Soils
After C. McDowell

Fig. 6

SOIL COMPACTION CURVE

Control ______ Sec. ______ Job ______ Lab. No. ______

County ______ Highway ______ Date ______

IPE ______ Engineer ______ Comp. Effort 30.0 1-#/in.³

Station ______ Depth ______

Silty Clay Subgrade

PHYSICAL CHARACTERISTICS

LL = 40
PL = 17
PI = 23

SL = 12
VS =
SR = 1.85
LS =

D_p = 77
D_L = 78
CR = 77.6

MECHANICAL ANALYSIS

Coarse Aggregate
2½" =
2" =
1½" =
1" =
3/4" =
1/2" =
1/4" =
10M =

Coarse Sand
20 M =
40 M = 1.5

Fine Sand
60 M = 3
100 M = 4
200 M = 11

Silt
.05 MM = 24
.005 = 70

Clay
.001 = 100

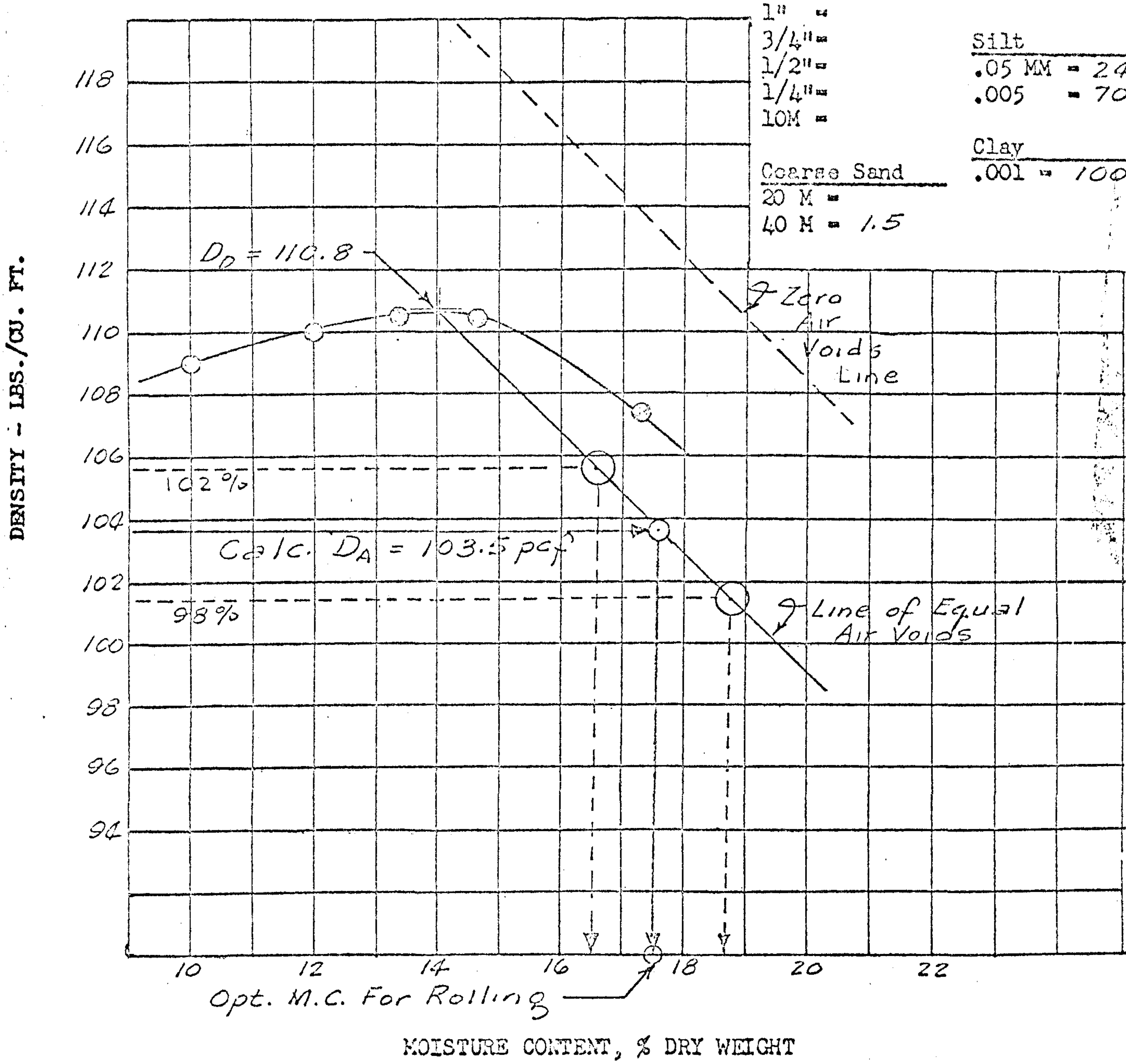


Fig. 7

D12L-29

SOIL COMPACTION CURVE

Control_______ Sec._______ Job_______ Lab. No. _______

County_______ Highway_______ Date _______

SPE_______ Engineer_______ Comp. Effort 30.0 ft-lb/in.³

Station_______ Depth_______

Lime Stabilized Clay Subbase

PHYSICAL CHARACTERISTICS

LL = 31
PL = 26
PI = 5

SL = 29
VS =
SR = 1.37
LS =

D_p = 83
D_L = 83
CR = 73.8

MECHANICAL ANALYSIS

Coarse Aggregate
2½" =
2" =
1½" =
1" =
3/4" =
1/2" =
1/4" =
10M =

Coarse Sand
20 M =
40 M = /

Fine Sand
60 M =
100 M =
200 M =

Silt
.05 MM =
.005 =

Clay
.001 =

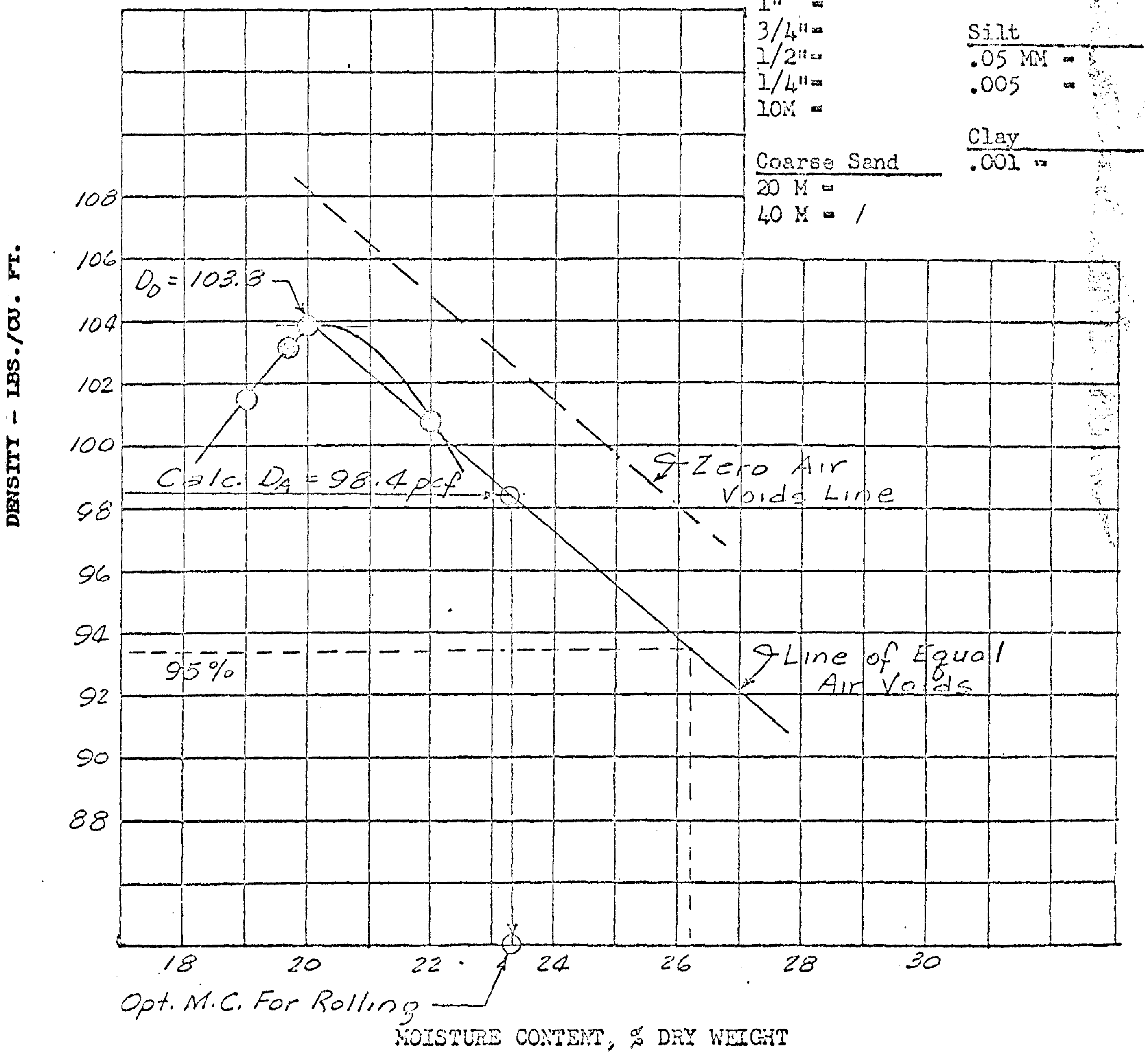


Fig. 8

II. Resident Laboratory Work on Aggregates

Aggregates used in asphaltic concrete, surface treatments, and portland cement concrete must be clean, sound, and specification-sized materials. Our Specifications on aggregates place limits on the permissible amounts of deleterious substances and cover requirements as to gradation, strength, and soundness. Some of the tests to provide this information, particularly for strength and soundness, must be run in the Austin Laboratory, due to lack of certain equipment in the Residency Laboratory. Specific laboratory work that may be accomplished in the Residency Lab to determine quality and gradation of the aggregate are discussed in the following sections.

A. Sampling

Unlike soils and base materials having considerable fine-grain sizes, aggregates are generally all larger than the No. 40 sieve size. As a means of separating aggregate groups for uniformity in design calculations, the coarse aggregate and fine aggregate fractions are handled separately. Aggregates for portland cement concrete generally larger than the No. 4 sieve are classified coarse aggregates, while those sizes passing the No. 4 sieve are termed fine aggregates. For hot mix asphaltic concrete, the coarse aggregates and fine aggregates are separated on the No. 10 sieve. Certain precautions must be taken in sampling each group, particularly to prevent segregation of the very fine particle sizes which have a large influence on the identification and workability properties of the final mixture. Specific sampling procedures found in the Manual of Procedures for aggregates are as follows.

1. Aggregate for Bituminous Mixtures

   Sampling of aggregate prior to plant processing or from the "hot bins" shall be in accordance with Test Method Tex-221-F.

2. Stone, Gravel, Sand, and Mineral Aggregates, including Shell, Slag, and Mineral Filler

   Sampling of the above aggregate from various sources shall be in accordance with Test Method Tex-400-A.

B. Sample Preparation and Testing of Aggregates for Acceptance

Since the Contractor must submit aggregates for testing to determine compliance with the governing specifications before delivering materials to the job, it is very important that each step of the standard procedures be followed meticulously. Failure to do so, even for one step, may give results not truly representative of the qualities of the aggregate. Test results run at a later date, which disprove these results, may mean costly delays in time and money to the State and to the Contractor.

1. Organic Impurities in Fine Aggregate

By this test, an approximate determination is made of the presence of injurious organic compounds in natural sands. Test Method Tex-408-A or Test Number C-11-8, in THD Bulletin C-11, describes the complete details for making this determination.

2. Loss by Decantation

The materials removed by decantation processing, as described in Test Method C-11-7 in the THD Bulletin C-11, are, in reality, clay, silt, and loam fine-grain soils that are finer than the No. 200 sieve size. Since this procedure is referred to in the Specifications, it will be the "official" Decantation Test. For comparison, only, Test Methods Tex-406-A and 407-A may be followed in testing of coarse and fine aggregates for portland cement concrete and Test Method Tex-217-F (Part II), on coarse aggregate for bituminous mixtures.

3. Sand Equivalent Test

This test indicates the relative proportion of detrimental fine dust or clay-like materials in mineral aggregates proposed for use in hot mix asphaltic concrete mixtures. Our Specifications require that the test be run on processed materials just prior to the addition of asphalt. Some idea, though, of how certain sands will affect the sand equivalent value may be had by running

TABLE I

SIEVE ANALYSIS

(Percent by Weight)

SIEVE SIZE	AGGREGATES FOR ASPHALTIC CONCRETE - ITEM 340			
	Limestone	Shell	Gem Sand	Fine Sand
1/2"-3/8"	10.6	2.5		
3/8"-No.4	75.3	29.7	67.6	
No.4-No.10	12.5	47.6	28.9	
No.10-No.40	0.6	18.1	2.7	4.6
No.40-No.80	0.2	1.2	0.6	48.9
No.80-No.200	0.4	0.6	0.1	39.3
Pass No. 200	0.4	0.3	0.1	7.2
	100.0	100.0	100.0	100.0

RETAINED SIEVE	AGGREGATES FOR CONCRETE - ITEM 421	
	Coarse Aggregate	Fine Aggregate
2"	0	
1-1/2"	0	
3/4"	45.1	
1/2"	67.7	
No. 4	97.9	2.2
No. 8		3.1
No. 16		23.8
No. 30		51.6
No. 50		89.1
No. 100		98.5
Fineness Modulus		268 ÷ 100 = 2.68

sand equivalent tests on combinations of mineral aggregates removed from the stockpile. Test Method Tex-203-F contains the procedures for this test.

4. Sieve Analysis of Fine and Coarse Aggregate

The grading of aggregates may be studied by making sieve analysis tests (same as mechanical analysis for base materials), in which the particles are divided into the various sizes by standard sieves. Due to the difference in the blending of aggregates for portland cement concrete and hot mix asphaltic concrete mixtures, the analysis should be made in accordance with Test Method Tex-401-A or Tex-200-F, or test methods included in THD Bulletins C-11 and C-14, depending, of course, on the intended use of the aggregate.

In addition to determining whether the materials meet the specifications, sieve analyses are of assistance in selecting the material to use if several aggregates are available. Those materials containing too large a proportion of any one size and with some of the sizes lacking or in too small quantities should be avoided. Typical sieve analyses for several aggregates used in hot mix asphaltic concrete and portland cement concrete are shown in Table 1 and Figure 1.

C. Tests Needed in the Design and Control of Asphaltic and Portland Cement Concrete Mixtures

The test methods listed below provide some of the basic information which is needed in the design and control of asphaltic concrete and portland cement concrete mixtures. Since the design of these mixtures will be covered in subsequent courses, the significance of the tests are not discussed herein.

1. Design of Bituminous Mixtures

		Bulletin C-14	200-F Series
a.	Bulk Specific Gravity of each size aggregate	Test No. 2	Tex-201 Tex-202
b.	Bulk Specific Gravity of compacted mixture	Test No. 5	Tex-207
c.	Hveem Stability Value of compacted mixture	Test No. 6	Tex-208

2. Design of Portland Cement Concrete

		Bulletin C-11	400-A Series
a.	Saturated Surface Dry Specific Gravity and Absorption of Aggregate	C-11-3 C-11-4 C-11-10 C-11-11	Tex-403
b.	Solids and Voids in Aggregates	C-11-12 C-11-13	Tex-404 Tex-405
c.	Slump of Concrete	C-11-16	Tex-415
d.	Flexural Strength	C-11-18	Tex-420

II. District Laboratory Specialized Work on Soils and Base Materials

Primarily, the District Laboratory's main task is to furnish the Resident Engineer organization the properties of soil and the character of its response to the forces to which it is subjected in engineering structures and processes. This task requires the use of specialized testing equipment which, for economical reasons, must be centrally located at the District Headquarters.

Secondary, with regard to total time spent but certainly not in importance, is the investigative work on conditions contributing to the behavior of certain pavement structures or research work on new or improved materials proposed for use in highways.

A review of some of this specialized work is included in the following sections.

A. Triaxial Compression Testing of Soils and Base Materials

The Texas triaxial classification determined for soils and base materials subjected to triaxial compression testing is a comparative measure of the shearing resistance of the material. It is used with empirical curves to determine flexible pavement thicknesses. Procedures are given in Test Method Tex-117-E for triaxial tests on laboratory-compacted specimens.

Since the product of laboratory compaction should closely represent the results of field compaction, the selection of a particular compactive effort for each group of soils and base materials must be made, using the recommendations of Test Method Tex-113-E.

B. Selection of Quantities of Chemical Additives for Treatment of Soils and Base Materials

Using the unconfined compressive test on compacted specimens of treated materials, a strength value is determined for various percentages of additive. By plotting these values, such as is shown in Figure 1, the optimum quantity which meets the minimum suggested strengths for stabilized subbases and bases is selected. Test Methods Tex-120-E and Tex-121-E describe procedures used in the testing of cement or lime-treated mixtures.

C. Sampling and Testing of Foundation Materials for Bridge Structures

The field drilling log shown in Figure 2 is the official record of an exploratory test boring at a bridge structure site. It is prepared during field drilling operations conducted by personnel of this office and is made available for inspection in the office of the Resident Engineer to all bidders on the proposed bridge construction project.

Briefly, the log reveals the location and identification of each sample taken for laboratory analysis, the nature of the ground with respect to soil layer thickness,

CUMULATIVE MECHANICAL ANALYSIS

Sample No.__________ County__________ Project__________ Highway__________

Concrete Aggregates ——⊙—— Hot Mix Aggregates — — —○— — —

1 - Gravel Coarse Aggregate
2 - Sand Fine Aggregate
3 - Limestone
4 - Shell
5 - Gem Sand
6 - Fine Sand

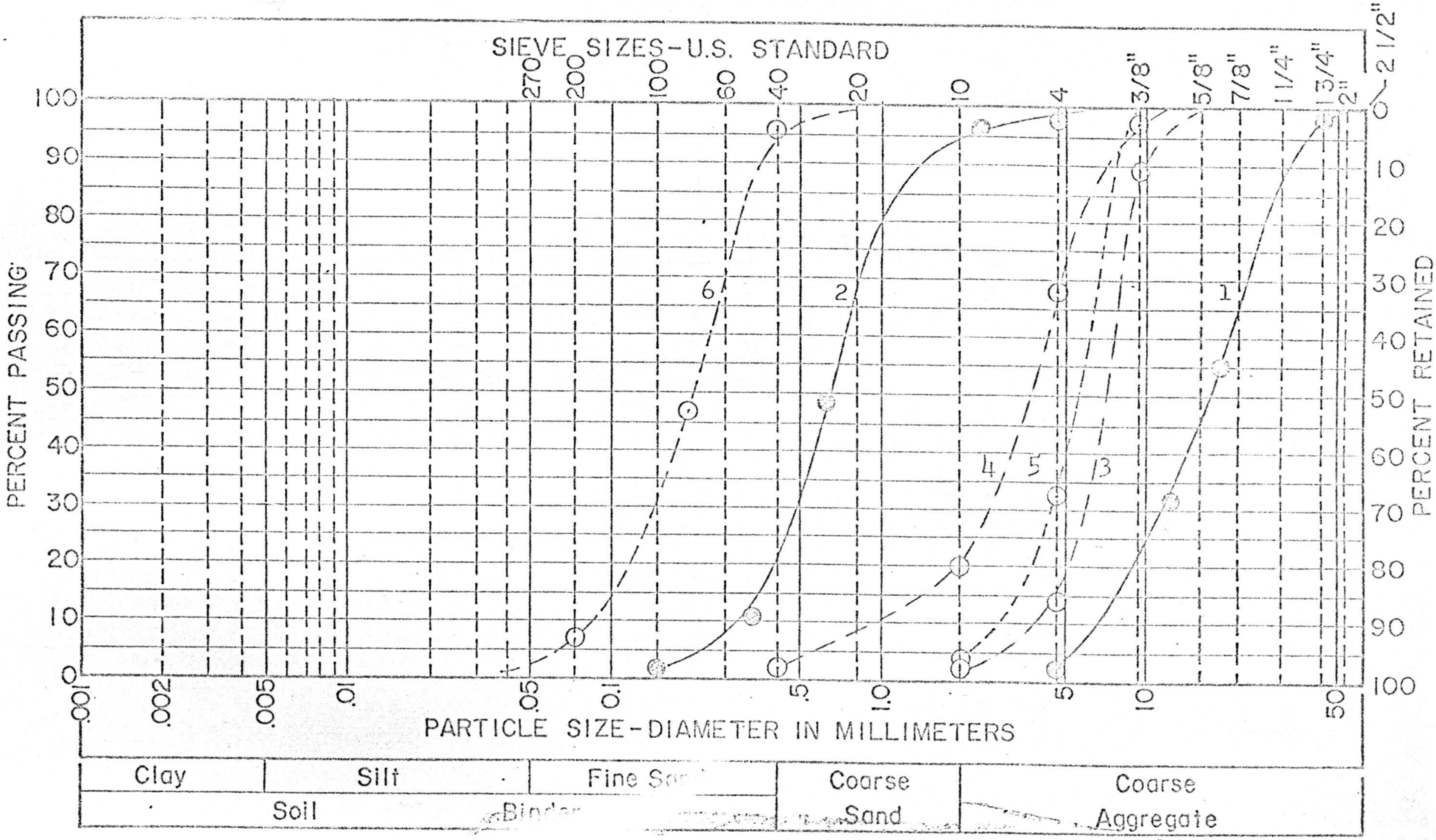


FIG. 1

color, consistency, organic content, relative moisture content, etc. The log shown in Figure 2 indicates also the location of seepage zones, the position of free water table if it can be determined, and the presence of cemented sandrock layers.

The soil formation profile on the bridge layout sheet is obtained by plotting data from the drilling logs made at the structure site, but shows only the boundaries and penetrometer consistency values of each soil layer. As such, the profile shown in Figure 3 is used for design purposes only.

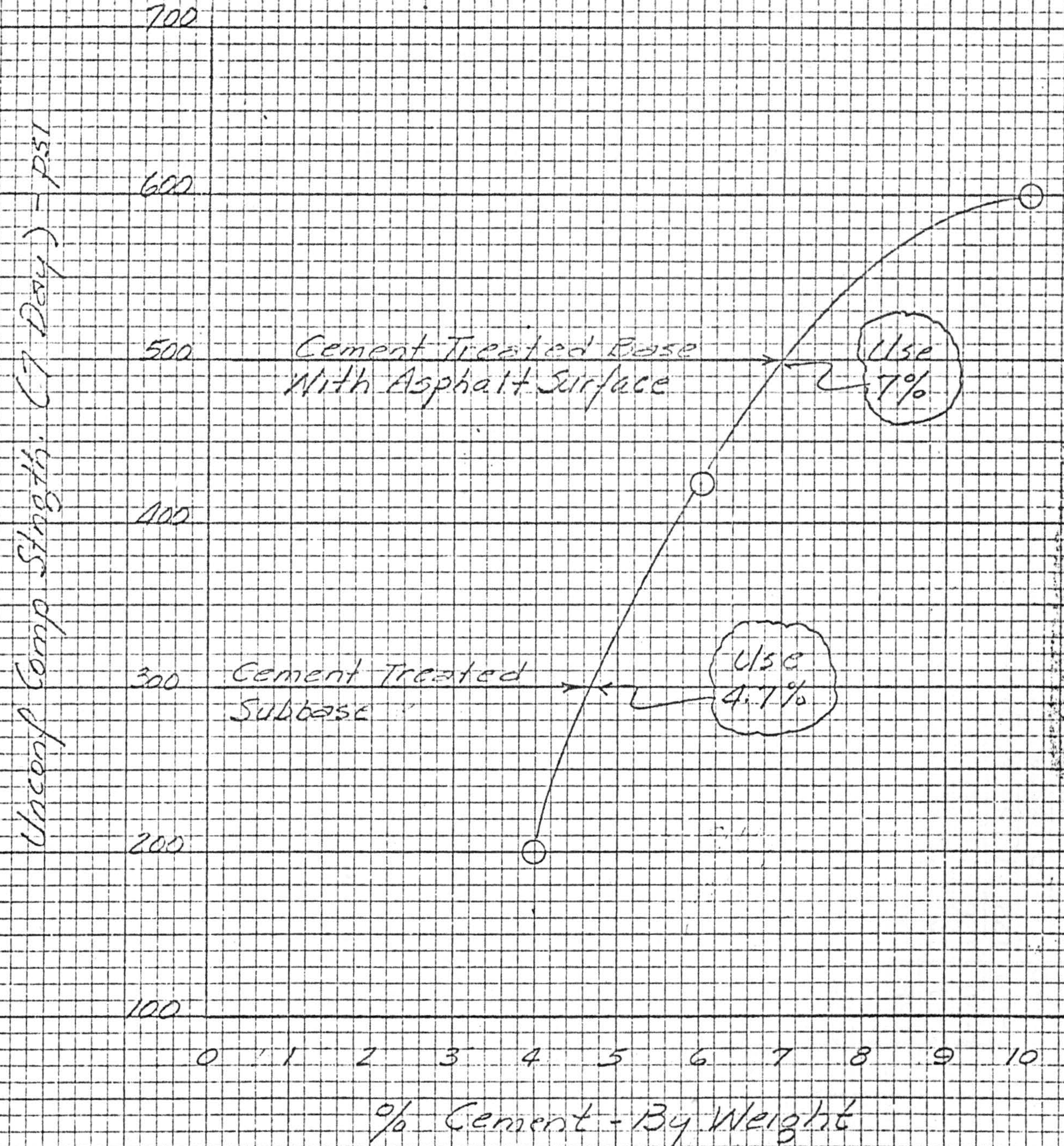
The recommended length of piling or drilled shafts on the plans are based on strength test results of soil cores removed at the site of the bridge foundation during the exploratory test boring operations.

FIGURE I

UNCONF. COMP. STRENGTH TEST

VS

CEMENT CONTENT



DRILLING REPORT
(For Use with Undisturbed Sampling & Testing)

County Harris ; Project No. IPE 138 ; Date 9/18/62 ; Gnd. Elev. 69.1 ; Sta. No. 538+22

Hwy. No. US-59 ; Control 27-13 ; ~~Stream Xing~~ Hillcroft Ave. ; Hole No. 1

Liquid Limit ...... Moisture Ct. ...... % Plastic Limit ......

0 10 20 30 40 50 60 70 80 90 100

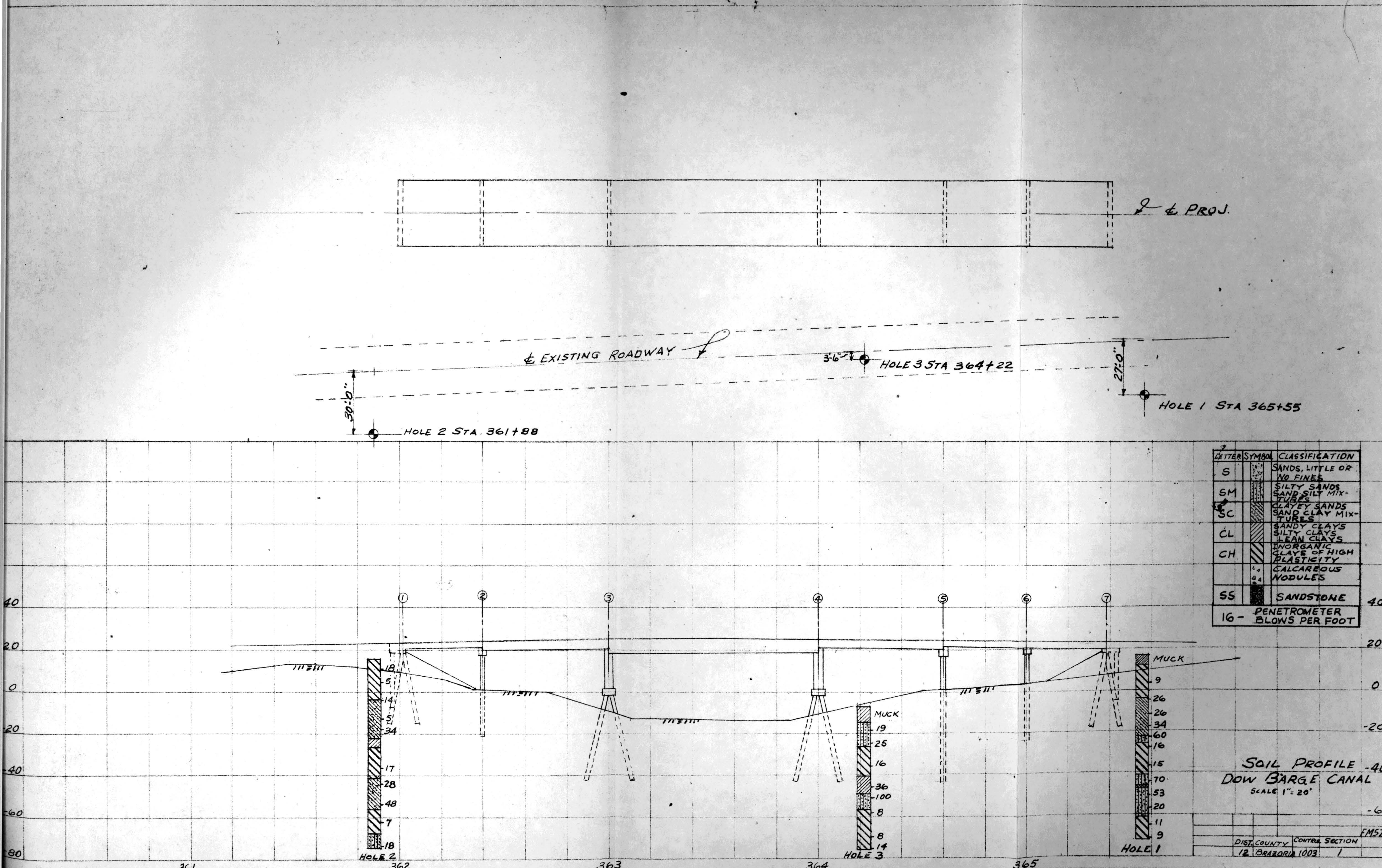
Depth & Bore Type	Symbol	Lt. Pressure	Sample	Sample Number	Wet. Den. #/c.f.	P.I.	On Centerline of Project — Remarks and Description of Stratum
							Firm gray sandy clay
5				1-1A	126	42	Firm moist tan & light gray clay with much
				1-1B	126		calcareous material
							45# 5/6 6/6
				1-2A	126	9	Firm moist light gray & tan very sandy clay
				1-2B	126	9	
10				1-3A	122	32	Firm red, brown, & light gray moist slightly
				1-3B	120	48	sandy clay
				1-4A	122		Firm red, brown & light gray moist slightly sandy clay w/calc. nods.
				1-4B	124	44	Same becoming stiff
							Firm red, brown, & light gray moist sandy
15				1-5	122	24	sandy clay with silt seams
							90# 7/6 7/6
				1-6	124		Firm moist red-brown slightly sandy clay with silt pockets.
							At 18' - 3" sandstone layer.
				1-7A	126		Firm moist tan sandy clay
				1-7B	131	25	
20				1-8A	126	12	Firm moist tan & light gray very sandy clay
				1-8B	129	9	
				1-9A	124	26	Firm moist tan sandy clay
				1-9B	126	16	Firm moist tan very sandy clay
25				1-10A	122	7	Soft moist light gray very clayey silt.
				1-10B		6	Same, becoming firm
							135# 8/6 15/6
28							Light gray water bearing sandy silt

Driller Williams

Inspector Milton Gardner

15532-1157-5m

FIG. 2



℄ PROJ.
℄ EXISTING ROADWAY
HOLE 3 STA 364+22
HOLE 1 STA 365+55
HOLE 2 STA 361+88
3'-6"
27'-0"
30'-0"
LETTER SYMBOL CLASSIFICATION
S SANDS, LITTLE OR NO FINES
SM SILTY SANDS SAND-SILT MIXTURES
SC CLAYEY SANDS SAND-CLAY MIXTURES
CL SANDY CLAYS SILTY CLAYS LEAN CLAYS
CH INORGANIC CLAYS OF HIGH PLASTICITY
CALCAREOUS NODULES
SS SANDSTONE
16 - PENETROMETER BLOWS PER FOOT
MUCK
HOLE 2
HOLE 3
HOLE 1
361
362
363
364
365
SOIL PROFILE
DOW BARGE CANAL
SCALE 1" = 20'
DIST. COUNTY CONTROL SECTION
12 BRAZORIA 1003 1
FM523

Fig. 3 - Sec. III