ROAD DESIGN

CHAPTER 9

Road selection and design depend on the nature of the subgrade; the traffic and drainage conditions; the construction time available; the supply of local and imported materials; and the engineer equipment, personnel, and expertise available. The completed design must then meet the requirements for the given load class and allow safe and efficient traffic movement.

The load-carrying capacity of a road surface depends on continuous, stable support furnished by the subgrade. Subgrade stability requires adequate drainage and proper load distribution by the surface and base courses. Surface and base courses of sufficient thickness and quality to spread the wheel loads over the subgrade are necessary so that the applied stress is less than the unit load capacity of the subgrade. in areas where seasonal freezing and thawing occur. the load-carrying capacity of inadequately designed or improperly constructed roads can be dramatically decreased to the extent that failure may occur.

For safe and speedy traffic movement, the geometric design requirement for given road classes must be met. In a combat zone, military urgency dictates rough, hasty work designed to meet pressing needs. An improved network of well-surfaced, high-quality roads may be required in rear areas and near major airfields, ports, and supply installations. Road design uses stage construction for the progressive improvement of the road to meet increased traffic demands. Road design also uses many technical terms. Figures 9-1 and 9-2, page 9-2, show terms used to designate road features and components. In addition to this chapter TM 5-337 provides additional detailed information on the design of bituminous and concrete-surfaced roads.

GEOMETRIC DESIGN

The geometric design process begins with good-quality topographic surveys. In most cases, a minimum 5-foot contour interval is required to clearly describe the terrain.
The design process can be described in the following steps:

1. Draw the proposed centerline on the topographic survey.

2. Plot the centerline on plan-and-profile paper.

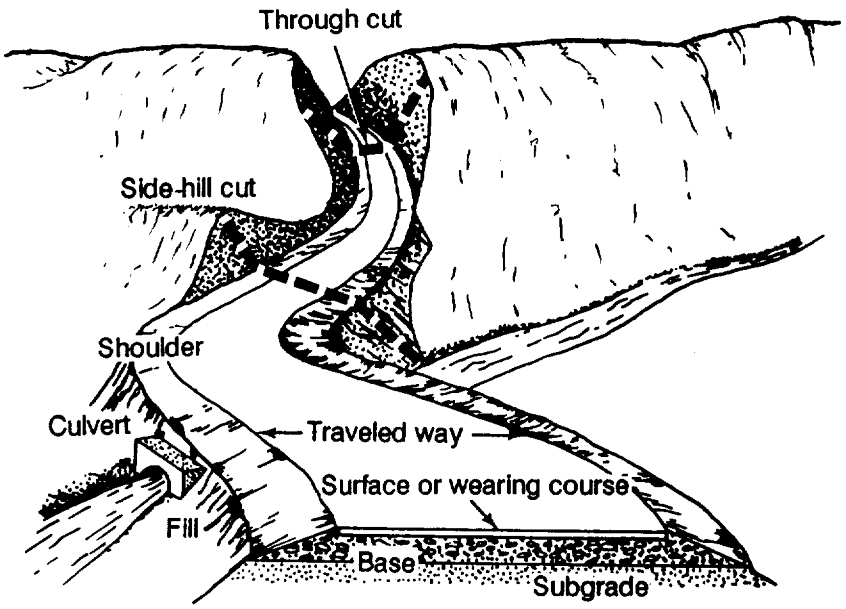


Figure 9-1. Road nomenclature

3. Calculate grades, the degree of curvature of horizontal curves, and curve lengths of vertical curves.

4. Compare the values of step 3 with the military road specifications stated in Table 9-1.

5. Adjust the centerline, if possible, to reduce any calculated grades and limit horizontal and vertical curves that exceed the specifications.

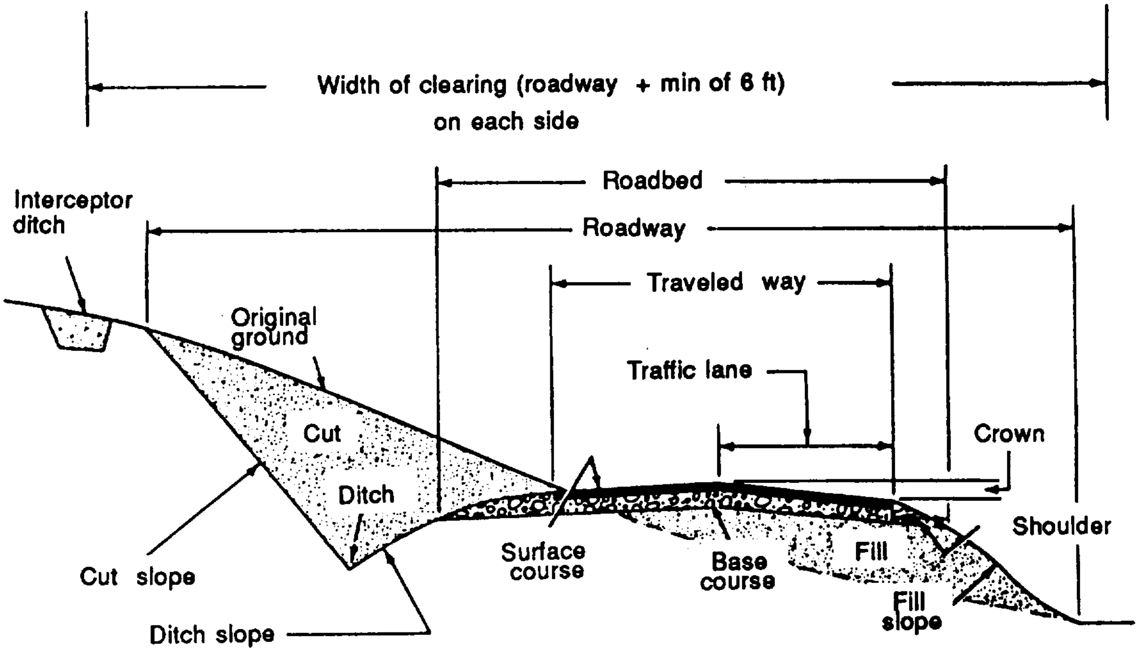


Figure 9-2. Road cross section and nomenclature

Table 9-1. Geometric design data for military roads

Design Controls and Elements		**Class A (4 Lane)**	**Class B (2 Lane)**	**Class C (2 Lane)**	**Class D (1 Lane)**
Design Controls					
1. Traffic composition	(1)				
Average daily traffic (ADT) (45% trucks)		3,400-6,700	935-3,400	200-935	Under 200
Design hourly volume (DHV)		510-1,000	140-510	30-140	Under 30
Sight distance restriction, %	(2)	40-0	80-0	80-40	100
2. Design speed (V), mph (kph)		60 (97)	60 (97)	40 (64)	30 (48)
Average running speed, mph (kph)		45 (72)	45 (72)	35 (56)	25 (40)
Cross-Section Elements					
3. Pavements	(3)				
Minimum width of traffic lane, ft (m)					
with barrier curb		12 (3.658)	12 (3.658)	10 (3.048)	10 (3.048)
without barrier curb		12 (3.658)	12 (3.658)	10 (3.048)	10 (3.048)
Minimum distance between curb faces, ft (m)		53 (16.154)	29 (8.839)	25 (7.620)	15 (4.572)
Lateral clearance from edge of traffic lane to obstructions, ft (m)		6 (1.829)	6 (1.829)	6 (1.829)	4 (1.219)
Normal cross slope (crown slope) rate		0.0104-0.0108	0.0104-0.0208	0.0208-0.0417	0.0208-0.0417
4. Shoulders	(4)				
Minimum width w/o barrier curbs, ft (m)		10 (3.048)	10 (3.048)	6 (1.829)	4 (1.219)
Normal cross slope, rate		0.0417-0.0625	0.0417-0.0625	0.0417-0.0625	0.0417-0.0625
Type, (perm road)		Dustless	Stable	Compacted soil	Compacted soil
5. Bridge clearance (perm)*					
6. Curb offset for barrier curb, ft (m)		2.5 (0.762)	2.5 (0.762)	2.0 (0.610)	2.0 (0.610)
Alignment Elements					
7. Sight distance					
Minimum stop sight distance, ft (m)		475 (144.780)	475 (144.780)	275 (83.820)	200 (60.960)
Minimum pass sight distance, ft (m)		N/A	2,100 (640.081)	1,500 (457.201)	N/A
8. Horizontal alignment					
Maximum horizontal curvature	(5)	5.5°	5.5°	14.5°	26.7°
Pavement widening, ft (m)	(6)	None	None	2-4 (0.610-1.1219)	2-5.5 (0.610-1.676)
9. Vertical alignment					
Grade					
Maximum grade, %		6	6	10	15
Critical length, ft (m)	(7)	700 (213.360)	700 (213.360)	450 (137.160)	250 (76.200)
Minimum grade, %		0.3	0.3	0.3	0.3
Vertical curves	(8)				
Overt (crest) vertical curve k, ft (m)		160 (48.768)	160 (48.768)	55 (16.764)	35 (10.668)
Invert (sag) vertical curve k, ft (m)		105 (32.004)	105 (32.004)	55 (16.764)	28 (8.534)
Absolute minimum length, ft (m)		180 (54.864)	180 (54.864)	120 (36.576)	80 (24.384)

Remarks:

(1) The DHV shown for all roads is in total vehicles per hour for all lanes in both directions. The DHV is approximately 15 percent of the ADT.

(2) The values shown for this term indicate the combined effects of horizontal (curves) and vertical (grade) alignment on capacity. A value of zero percent indicates an absolutely straight, flat alignment with no restriction on sight distance. A value of 100 percent indicates a road with numerous sharp curves and grade changes on which the sight distance is less than 1,500 ft(457.201 m) at any point on the road.

(3) If the anticipated traffic includes a significant number of vehicles having widths in excess of 8.5 ft (2.591 m), the traffic lanes should be widened in the amount by which the vehicle width exceeds 8.5 ft (2.591 m).

(4) There should be a color or texture contrast between traffic lane and shoulder surfaces.

(5) Values shown are calculated on basis of maximum rate of superelevation of 0.100.

(6) Pavement widening for a class C or class D road varies 2 to 5.5 ft (0.610 to 1.676 m) as the curvature varies from 2 to 26.7°. Values obtained may be rounded off to the nearest 0.5 ft (0.152 m).

(7) The term *critical length* is used to indicate the maximum length of a designated upgrade upon which a loaded truck can operate without an unreasonable reduction in speed. Critical lengths may be increased at an approximate rate of 50 ft (15.240 m) per percent decrease in grade from the values shown.

(8) The minimum lengths of vertical curves are determined by multiplying k by the algebraic differences in grades (in percent).

Notes:

1. As can be seen, capacities are shown as a range of values. If maximum (or minimum) design values shown are rigidly adhered to, then the resultant capacity of the road will be on the lower side of the capacity range. Therefore, discretion should be used in selecting design values by avoiding maximums or minimums whenever possible.

2. Turnouts should be provided at 1/4-mile (402.250 m) intervals on class-D roads.

3. Curbs will generally not be provided in open areas.

*Bridge clearance (permanent) width of the traveled way should be equal to the width of the lanes plus 5 ft (1.524 m) [2.5 ft (0.762 m)] on each side; 14.75 ft (4.498 m) vertical clearance.

6. Plot new tangents (straight sections of road) on the plan and profile in those locations where horizontal and vertical curves exceed the military road specifications.

7. Design horizontal and vertical curves for all tangent intersections.

8. Plot newly designed curves on the plan and profile.

9. Develop a mass diagram for the project. Balance the cuts and fills and optimize ruling grade and earthwork volumes.

10. Design superelevations (curve *banking)* and widening for all horizontal curves.

11. Draw typical cross sections.

12. Design the required drainage structures and bridges.

SELECTION OF ROAD TYPE

Structural characteristics should accommodate traffic volumes throughout the road's design life. Table 9-1, page 9-3, shows four possible road types. They are based on expected traffic volumes and show the values for the design control elements for each road class. The capacities arc shown as a range of values. Only road classes B, C, and D apply to TO construction. If the maximum (or minimum) design value for the various criteria is always adhered to, the resulting vehicle capacity of the road will be on the lower side of the range. Use discretion by designing the road to the best possible standard in a given road class.

DESIGN CALCULATION

The values in Table 9-1 for each geometric feature must be attained to ensure that the desired road will have a capacity equal to or greater than either the average daily traffic (ADT) or design hourly volume (DHV) shown. The first step in the design of a road is to estimate the daily or hourly number of vehicles in a military organization. Where this cannot be done, the number of vehicles organic to the units that will use the road, multiplied by a factor of two, is suggested as a reasonable estimate. This conservatively assumes that each vehicle uses the road twice (one round-trip) per day.

Figure 9-3 shows the relationship between DHV and sight distance restriction. If either anticipated DHV or ADT is known and the sight distance restriction can be estimated from preliminary plans, the necessary road type can be determined from Figure 9-3. If ADT or DHV and the road type desired are known, sight-distance-restriction requirements can be determined from Figure 9-3.

A range of possible DHV values is given for each road classification in Table 9-1. The actual DHV for a road is a function of the sight-distance-restriction factor, which also has an allowable range for each type of road. The DHV varies directly with a change in the sight-distance-restriction factor. Figure 9-3 shows this straight-line relationship.

After the sight-distance-restriction factor is determined from the design plans of an assumed road class, the actual DHV is determined to ensure that the capacity is adequate.

Example:

A road is to be designed for a military organization having approximately 250 vehicles.

ADT = 250 x 2 = 500 and DHV = 0.15 x 500 = 75. The 0.15 factor clusters the traffic into rush hours. Otherwise, the hourly volume = 500 vehicles (per day)/24 hours (per day) - 21 vehicles per hour.

Solution:

The calculated DHV of 75 could be met by a class C road. Therefore, assuming a class C road is used, plan-and-profile designs could be drawn and a sight-restriction factor can be determined from the design.

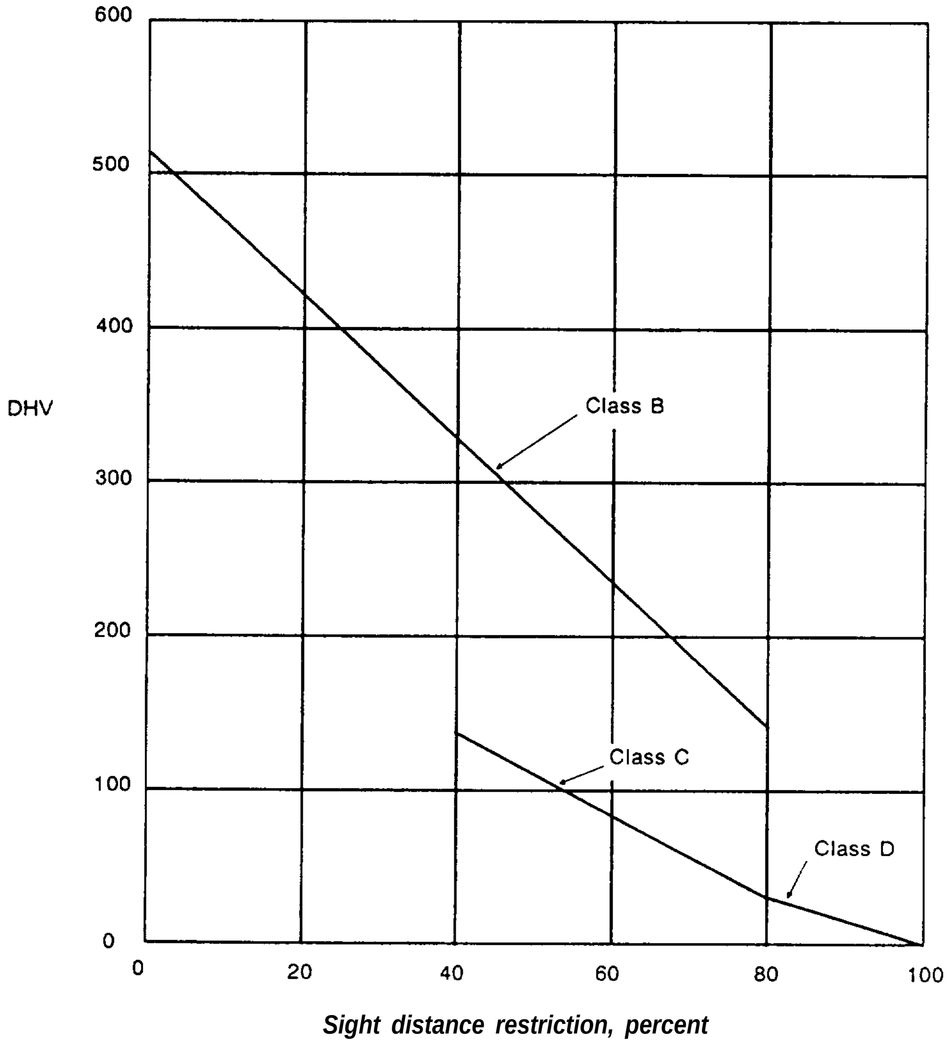


Figure 9-3. Interpolation of DHV for selection of road class (not to scale)

From Figure 9-3, a sight-distance-restriction factor of 62 percent is determined (based on a class C road and a DHV of 75). Using Figure 9-3, the maximum sight-distance-restriction factor for a class C road is 80 percent. This provides a DHV for a class C road of only 30. Since the sight-distance-restriction factor for the example (62 percent) is less than the maximum of 80, this meets the initial requirement of the DHV being greater than or equal to 75. Therefore, the class C road assumption is adequate. If a DHV of 75 could not be handled by the class C road, it would be necessary to construct a class B road.

ESTIMATING CAPACITY

The information in Figure 9-3 and Table 9-1, page 9-3, is adequate for the geometric design of military roads. However, additional information is available in TM 5-822-2. The information can be used to evaluate the capacity of existing roads by obtaining pertinent characteristics and comparing them to the values in Table 9-1. If the data does not conform to that shown for a given road type, use discretion in estimating the road type and ADT or DHV to which the data best conforms. The volume and capacity values in Table 9-1 are for roads of a given class when they are new or in good condition. As the road surface deteriorates, the road is less able to accommodate the traffic for which it was designed. Plan and carry out a maintenance program to keep the road in good condition.

GRADE AND ALIGNMENT

Before building a road or an airfield, the engineer must determine the best vertical and horizontal alignment of the facility concerned. Design both horizontal and vertical alignment to keep sight distance restrictions to a minimum. Define the route by a series of straight lines and curves to meet the stated mission and capacity. This provides the shortest, most efficient route that requires the least construction effort. Define the route vertically in a series of grades and curves that fall within acceptable specifications and requirements. Horizontal and vertical alignment are interrelated and must be considered concurrently. However, the principles on each are best studied separately. Horizontal and vertical curves of all types are discussed in FM 5-233.

HORIZONTAL ALIGNMENT AND HORIZONTAL CURVES

The principles of horizontal alignment are summarized as follows:

Tangents (straight sections of road) should be as long as possible, because the shortest distance between two points is the connecting straight line. Terrain conditions, however, seldom permit the construction of a route between two points in one tangent line. Therefore, the engineer should make each tangent as long as possible, limit the number of curves, and provide long straight stretches, thereby improving the route capacity.

Make curves as gentle as possible. Long, gentle curves increase the capacity of the roadway by permitting higher speeds. They also provide a safer path of travel for the vehicle. Making gentle, horizontal curves will increase the curve length, thereby decreasing the tangent length. However, this reduction in tangent length is minor compared to the benefits gained by reducing the total number of curves.

Tangents should intersect other roads and railroads at right angles. Military roads normally supplement existing roadnets and have intersections at one or both ends of the military road. Operating efficiency usually is improved when these intersections approach right angles.

Frequently used horizontal curves are shown in Figure 9-4. The most common are the simple curve, the reverse curve, the compound curve, and the spiral curve.

- A simple curve uses the arc of a circle to provide a smooth transition between two tangents. This curve is used frequently in the TO because it fills the needs of the low-speed design roads normally used and is easy to construct. A reverse or compound curve can be designed using the same basic equations.

- A reverse curve uses two simple curves tangent to a common line at a common point. Their centers are on opposite sides of the common line. The radii of the curves may or may not be equal in length.

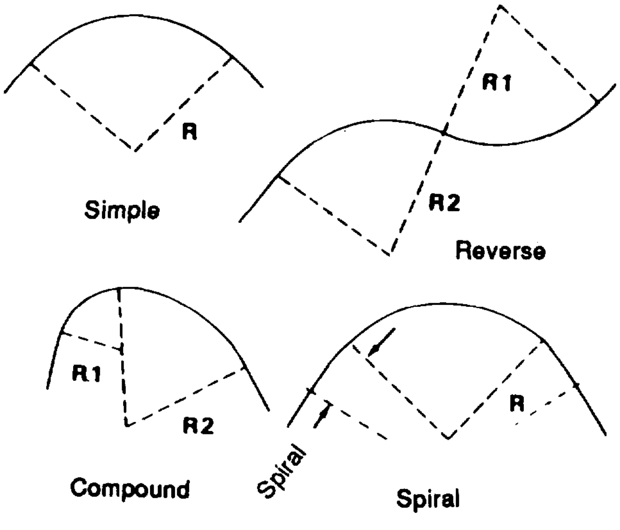


Figure 9-4. Types of horizontal curves

- A compound curve has two simple curves tangent to a common line at a common point. The centers of these curves are on the same side of the common line, and the curves have radii of different lengths.

- A spiral curve is a simple curve in the center with parts of a spiral on each end to smooth transition to the tangent. The spiral is used only on high-speed roads (classes A and B). Detailed steps for the design and layout of spiral transition curves are in FM 5-233. Low design speeds of class-C and -D roads do not require spiral transition sections.

ELEMENTS OF A HORIZONTAL CURVE

The following are elements of a simple, horizontal curve as shown in Figure 9-5:

- The PC is the point where the curve begins or leaves tangent A—the tangent nearest the origin of stationing (station 0 + 00) or start of the project.

- The PT is the point where the curve ends or joins tangent B.

- The PI is the intersecting point of two tangents that must be connected by a horizontal curve.

- The tangent distance (T) is the distance from the PI to the PC or from the PI to the PT.

- The radius (R) of curvature is the radius of the circle whose arc forms the curve from the PC to the PT.

- The length of curve (L) is the distance from the PC to the PT along the curve, measured as an arc or as a series of 100-foot arcs. Railroad engineers measure L as a series of 100-foot chords.

- The angle of intersection (I) is the exterior angle at the PI formed by tangents A and B. The central angle, between the radius points at O, is equal to the exterior angle.

- The external distance (E) is the distance from the PI to the midpoint of the curve.

- The long chord (C) is the straight-line distance from the PC to the PT.

- The middle ordinate (M) is the distance from the midpoint of the curve to the midpoint of the long chord.

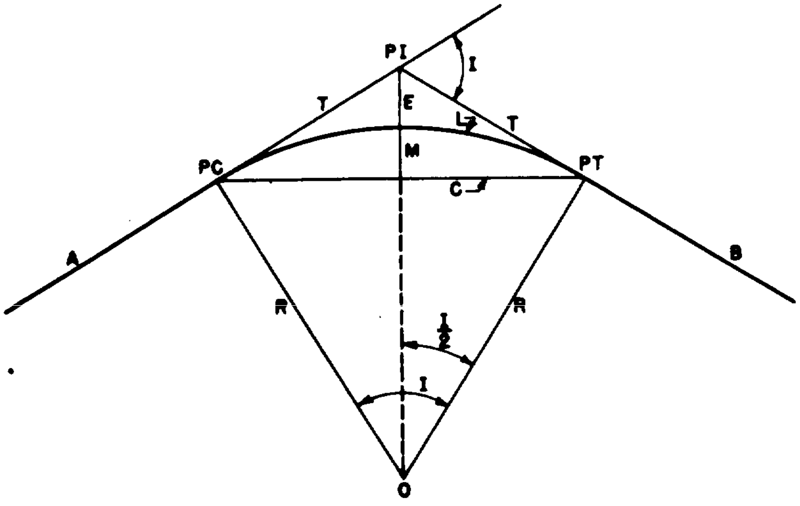


Figure 9-5. Elements of 8 simple, horizontal curve

DEGREE OF CURVATURE

The connecting curve between two tangents may be short and sharp or long and gentle, depending on the properties of the circle chosen. Sharpness is defined by the radius of the circle. For example, a curve may be called a 150-foot curve. However, a curve is seldom referred to by its radius because the center of the curve is often inaccessible on the long, gentle curves used on modern highways. The more practical and common reference term for defining curve sharpness is the degree of curvature (D). The degree of curvature is established as a whole or half degree. The degree of curvature may be stated in terms of either the arc or the chord.

Arc Definition

The degree of curvature, D, is that angle which subtends a 100-foot arc along the curve. (See Figure 9-6.) This definition is used by state highway departments and the Corps of Engineers in road design.

Chord Definition

The degree of curvature, D, is the angle which subtends a 100-foot chord on the curve. (See Figure 9-7.) This definition results in a slightly larger angle than the arc method, and it is used by the railroad industry and the Corps of Engineers in railroad design.

The difference between the arc and chord definitions is very slight and nearly insignificant (frequently well below 1 percent) for TO construction. However, because the arc definition is the most widely used procedure in road design, only its definition will be used throughout the rest of the chapter.

EQUATIONS FOR SIMPLE, HORIZONTAL-CURVE DESIGN

The two methods commonly used to solve horizontal curve problems are the 1-degree-curve method and the trigonometric method. Both methods may be used with the same degree of accuracy. The 1-degree-curve method requires the Functions of a 1-Degree Curve table shown in Appendix F of this manual.

Appendix F is based on the trigonometric relationships for a curve of D = 1°. Curves of different degrees of curvature can be readily designed because of the proportionality between all curves and the 1-degree curve. For example, a curve of D = 15° has one-fifteenth the L, E, T, and M values as for a 1-degree curve (D = 10). The only information needed to obtain the L, E, T, and M values for a 1-degree curve is the angle of intersection (I), and I is always known at the onset of the design process. The trigonometric method requires a calculator with trigonometric functions or trigonometric tables found in TM 5-236 or any surveying manual.

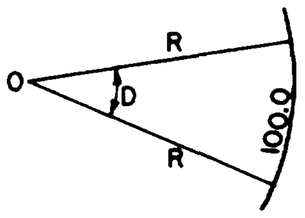


Figure 9-6. Arc definition for degree of curvature

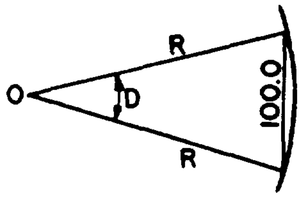


Figure 9-7. Chord definition for degree of curvature

Radius of Curvature

As previously described in the arc definition, D is that angle subtended by a 100-foot arc on a circle. By comparing the 100-foot arc and the total circumference of the circle, an equation for R is developed in terms of D.

$$\frac{D_{arc}}{100'} = \frac{360^\circ}{2\pi R}$$

Solving for R—

$$R = \frac{(100)(360)}{2\pi D} = \frac{5{,}729.58}{D}$$

Tangent Distance

In the right triangle shown in Figure 9-5, page 9-7, the vertices are at PC (or PT), PI, and O. The tangent distance (T) is found using the 1-degree-curve method, as follows:

$$T = \frac{T_{1^\circ}}{D} \text{ (arc definition)}$$

T_{1° is found in Appendix F, Table F-1, for a given I. Use Table F-2 to determine the chord correction.

External Distance

Using the 1-degree-curve method (refer to Figure 9-8), the external distance (E) is found as follows:

$$E = \frac{E_{1^\circ}}{D} \text{ (arc definition)}$$

Middle Ordinate

Using the 1-degree-curve method (refer to Figure 9-8), the middle ordinate (M) is found as follows:

$$M = \frac{M_{1^\circ}}{D} \text{ (arc definition)}$$

Length of Curve (L)

Measure the length of the curve in 100-foot arcs. Because D subtends a 100-foot arc, the total number of such arcs in a horizontal curve must be the number of times that D can be included in the central angle I.

$$L = \frac{I}{D} \times 100$$

The central angle subtended by the entire horizontal curve has sides that are radii to the PC and PT. Both of these radii are perpendicular to the tangents that form the

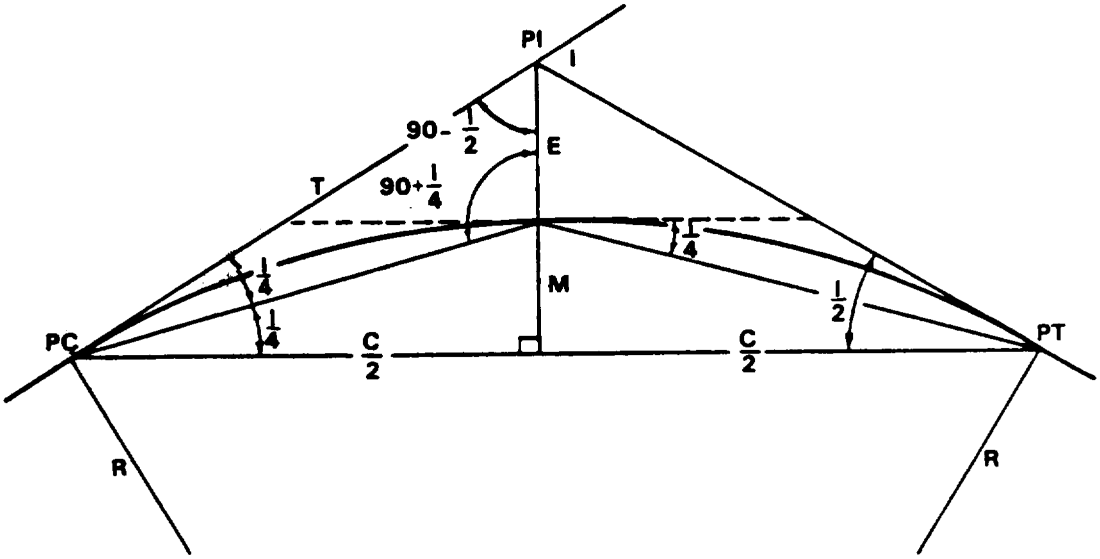


Figure 9-8. Derivation of external distance

intersection angle I. The quadrilateral formed by the four points of PI (180°-I), PC (900), O (I), and PT (90°) must total 360°. 1(180-I) + 90 + I + 90 = 360.] Hence, the central angle is equal to the angle of intersection I.

DESIGNING HORIZONTAL CURVES

The engineer designing horizontal curves must know two facts about the curve from the preliminary survey: the location and station of the PI and the angle between intersecting tangent lines (I). The curves can be designed after this information is obtained.

The first step is to determine the desired sharpness of the curve. This is defined by the radius or the degree of curvature. Topographic conditions govern the final location of the centerline and sharpness of the curve. A maximum or minimum tangent distance may fit the terrain conditions, or there may be a limit on the external distance or the middle ordinate. If a restriction exists, solve for the degree of curvature by transposing the equations previously given. Where no terrain condition dictates the sharpness of the curve, choose a degree of curvature within allowable specifications.

When choosing a degree of curvature, remember that gentle curves are more desirable. However, these long curves may increase surveying and construction time, materials, and effort required. There is no restriction on the length of the curve with respect to a minimum degree of curvature. However, the maximum allowable degree of curvature is specified by the road classification. Table 9-1, page 9-3, specifies the maximum degree of curvature for each class of road as stated in the row titled "Maximum horizontal curvature."

After the degree of curvature is selected, determine the stations of the PC and the PT. Next, design the curve except for the calculations needed to locate stationing points of the curve between the PC and PT. The following steps show the design of horizontal curves using the 1-degree-curve method:

1. Find the degree of curvature, D, by one of three methods:

- If the curve is unrestricted,

$$D = \frac{5,729.58}{R}$$

where R = the radius of the curve

Ž If the curve is restricted by the tangent distance,

$$D = \frac{T_{1^\circ}}{T_{(restricted)}}$$

where—

T_{1° = tangent distance for a 1-degree curve (found in Appendix F, based on the angle of intersection)

$T_{(restricted)}$ = restricted tangent distance for a horizontal curve

Ž If the curve is restricted by the external distance,

$$= \frac{E_{1^\circ}}{E_{(restricted)}}$$

where—

E_{1° = external distance for one-degree curve (found in Appendix F, based on the angle of intersection)

$E_{(restricted)}$ = restricted external distance for a horizontal curve

2. Round up the degree of curvature to the next half degree when possible.

3. Determine the length of the tangent.

$$T = \frac{T_{1^\circ}}{D}$$

4. Find the stationing of PC.

PC = P I - T

5. Calculate the length of the curve.

$$L = \left(\frac{I}{D}\right) 100$$

6. Find the stationing of PT.

$$PT = PC + L$$

Horizontal-Curve Design Examples

This section describes the horizontal-curve design procedures for three common situations:

- No terrain restriction which limits T or E.
- Terrain restriction of the tangent distance.
- Terrain restriction of the external distance.

Example:

Degree of Curvature with No Terrain Restriction. Figure 9-9 illustrates the following computations:

Given: I = 50°, PI at 14 + 28

Find the station and location of PC and PT for a class C road.

Solution:

A degree of curvature, D, of 6° is selected as a flat, gentle curve. D = 6° is far below the maximum allowable of D = 14.5° for class-C roads and is slightly sharper than the maximum allowable of D = 5.5° for class-B roads.

Use $D = 6°$

$$R = \frac{5{,}729.58}{D} = \frac{5{,}729.58}{6} = 954.93'$$

$$T = \frac{T_1°}{D} = \frac{2{,}671.58}{6} = 445.30' \text{ (arc}$$

definition)

$$L = \frac{I}{D} \times 100 = \frac{50}{6} \times 100 = 833.33'$$

PC = PI - T = (14 + 28) - (445.29')
= (9 + 82.71)

PT = PC + L = (9 + 82.71) + (833.33')
= (18 + 16.04)

The station of the PT is determined by adding the curve length to the station of the PC, not by adding T to the station of the PI. However, the actual point of the PT is found by measuring a distance T (at angle I) from the PI. The station is the distance from the point of origin at station (0+ 00), as measured along the centerline.

Example:

Terrain Restriction of the Tangent Distance. Figure 9-10 illustrates the following computations:

Given: I = 32°, PI at 25 + 87, T_{Res} is 282' (due to bridge)

Find the station and location of PC and PT.

Solution:

Knowing that T must not exceed 282 feet and that the D that will give this value is

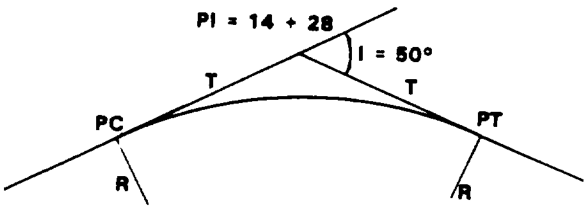


Figure 9-9. Horizontal curve with no sharpness restriction

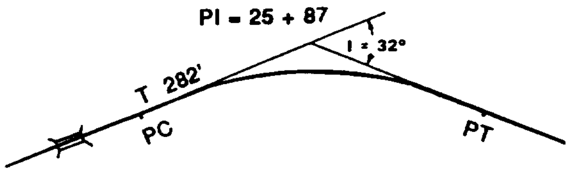


Figure 9-10. Horizontal curve with restriction on tangent

probably not equal to a whole or half degree, it is necessary to first find which D gives 282 feet for T_{Res} and then round it off, as shown.

$$D = \frac{T_1°}{T_{Res}}$$

$$D = \frac{1{,}643}{282} = 5.83° = 5°50'$$

If the value of T was specified as exactly 282 feet (as opposed to a maximum or restricted value), the value for D of 5°50' must be used. Rounding D up to the next half degree (D = 6°) will slightly sharpen the curve and will reduce T slightly below the 282-feet maximum.

Use D = 6°

$$R = \frac{5{,}729.58}{D} = \frac{5{,}729.58}{6} = 954.93'$$

$$T = \frac{T_1°}{D} \text{ (arc definition)}$$

$$T = \frac{1{,}642.9300}{6} = 273.82'$$

$$L = \frac{I}{D} \times 100 = \frac{32}{6} \times 100 = 533.33'$$

$$PC = PI - T = (25 + 87) - (273.82') = (23 + 13.18)$$

$$PT = PC + L = (23 + 13.18) + (533.33') = (28 + 46.51)$$

Increasing the degree of curvature decreases the values of the radius and tangent distance and vice versa. When the degree of curvature was changed from 5°50' to 6°00', it caused the radius and the tangent distance to decrease from 983.5 feet to 954.9 feet and 282 feet to 273.8 feet, respectively. Therefore, if the maximum value of the tangent distance is used to determine a trial value of D, the rounding must be to the next higher half degree. If minimum value of the tangent is given, the rounding is to the next lower half degree.

Example:

Terrain Restriction on the External Distance. Figure 9-11 illustrates the following computations:

Given: $E \leq 85$ feet, $I = 80°$, Sta PI at 43 + 32.75

If E exceeds 85 feet, the road centerline will be closer than 25 feet to the building.

Find the station and location of PC and PT.

Solution:

$$D = \frac{E_1°}{E_{Res}}$$

$$D = \frac{1{,}749.9}{85} = 20.59° = 20°35'$$

Because the limiting value for the external distance and the value used to get this trial value of D are maximums, it is necessary to round to the next higher half degree, thereby decreasing T and E.

Use D = 21°

$$R = \frac{5{,}729.58}{21} = 272.83'$$

$$T = \frac{T_1°}{D} = \frac{4{,}807.6867}{21} = 228.94'$$

$$E = \frac{E_1°}{D} = \frac{1{,}749.8548}{21} = 83.33 \leq 85' \text{ (check)}$$

$$L = \frac{I}{D} \times 100 = \frac{80}{21} \times 100 = 380.95'$$

$$PC = PI - T = (43 + 32.75) - (228.94') = (41 + 03.81)$$

$$PT = PC + L = (41 + 03.81) + (380.95') = (44 + 84.76)$$

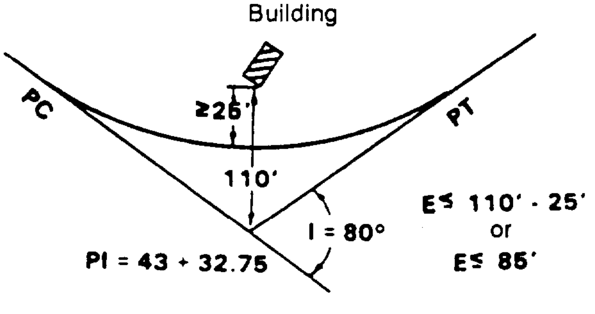


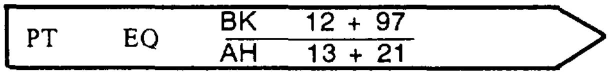
Figure 9-11. Horizontal curve with restriction on the external distance

Station Adjustments Due to Curve Installation

Horizontal curves occasionally are designed at the site by the surveying team. When this is done, the route is staked out and stationed progressively along the centerline from the point of origin of the project. It is not necessary to calculate station adjustments required by the shortening of the overall centerline length by a distance of 2T-L. However, when horizontal curves are designed in the office with data supplied by the preliminary survey, the adjustments must be calculated.

When the preliminary tangent alignment of a route is first determined and stationing along the tangent lines is accomplished, the station of any point represents its distance from the point of origin as measured along straight lines only. When a horizontal curve is installed and becomes the centerline of the route, the stationing distance from the PC to the PT is shortened by 2T-L for each horizontal curve.

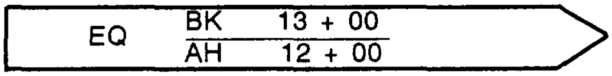
In Figure 9-5, page 9-7, the initial centerline distance from the PC to the PT is measured along the two tangents and is equal to 2T. When the curve is installed and the new centerline is created, the final centerline distance from the PC to the PT becomes L. At this point, the centerline stationed ahead would need to be restationed or adjusted in some manner. To prevent restaking the rest of the project centerline, an adjustment is made to the construction stake at the PT. The method of adjustment will produce a stationing equation at the point of adjustment that will satisfy both the stationing back and the stationing ahead. The equation will have a station which corresponds with the correct station to the rear (or back) and the correct station forward (or ahead). The equation will be written on the construction stake as follows:



where—

PT = point of tangent
EQ = equation
BK = correct station back
AH = correct station ahead

Equations most often will occur at the PT but may be used anywhere an adjustment to the centerline stationing is required. The equation indicates that an adjustment to the centerline stationing has occurred for some reason. For example, if the survey crew accidently placed two centerline stakes with the same station number, say 13 + 00, the equation stake would look like this:



The adjustments shown in the preceding equation indicate that the total length of the road has been shortened by the difference of 24 feet in the first example and lengthened by 100 feet (or one station) in the second example.

Equations normally are shown in the profile section of the plans as a gap in the grade with the back and ahead stations written out.

Field Methods of Curve Layout

The location and station of the PC and PT of a horizontal curve constitute only two points on the curve. They do not adequately define the necessary construction. The following methods are applicable to military construction for locating points on the curve:

Arc Method. When the radius of a curve is less than 100 feet and topographic conditions permit, locate the center of the circle and swing an arc to locate a curve or fillet, Curves with a small radius are seldom used except at street intersections and for fillets between hardstands, taxiways, or other operational features of an airfield.

External-Distance Method. For short curves where three points are adequate for the construction standard desired, calculate the external distance and use it to locate the center of the curve. This method is not recommended for precise construction or for long curves. It is impractical when the terrain on the curve side of the PI is difficult to negotiate and measure.

Deflection-Angle Method. This method of curve layout usually is the fastest and most exact method, particularly for curves with a long radius. In the arc definition, a deflection angle is the angle formed between a tangent line and a chord from the same point. (See Figure 9-12.)

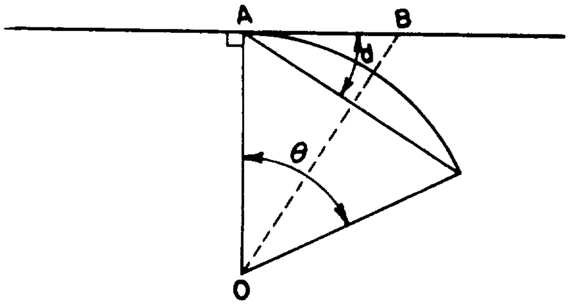


Figure 9-12. Deflection angle

In triangle OAB—

$$\text{Angle ABO (at B)} = 90 - \frac{\theta}{2}$$

$$d = 180 - (90 + B)$$

$$d = 180 - 90 - 90 + \frac{\theta}{2}$$

$$d = \frac{\theta}{2}$$

NOTE: In other words, the deflection angle is always one-half the intercepted central angle.

If the initial arc is 100 feet long, the central angle will be the degree of curvature D, and the deflection angle will be one-half the degree of curvature D, or D/2, as shown in Figure 9-13. With the addition of each 100-foot arc, the total central angle increases by D and the total deflection angle increases by D/2.

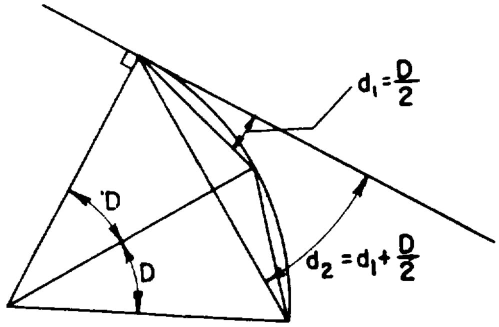


Figure 9-13. Deflection angles for 100-foot arcs

When laying out a curve, it is common practice to locate stakes at every full station. In view of this and because the PC of any curve rarely falls on an even station, the first arc will be something less than 100 feet in length (called a subarc). The deflection angle for the subarc to the first full station is the same proportion of D/2 that the subarc is to 100 feet (Figure 9-14).

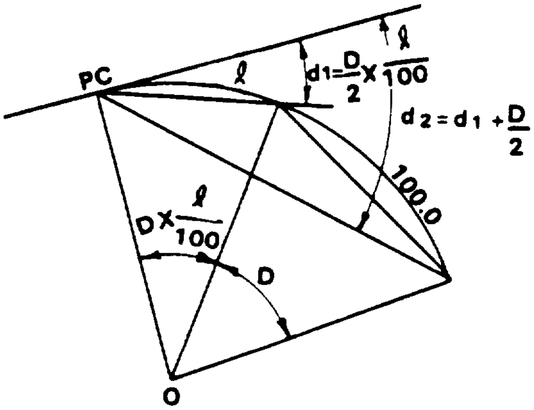


Figure 9-14. Subarc deflection angles

Once located at a full station, the curve continues by 100-foot arcs. Therefore, the central angle increases by D and the deflection angle increases by D/2 (Figure 9-15).

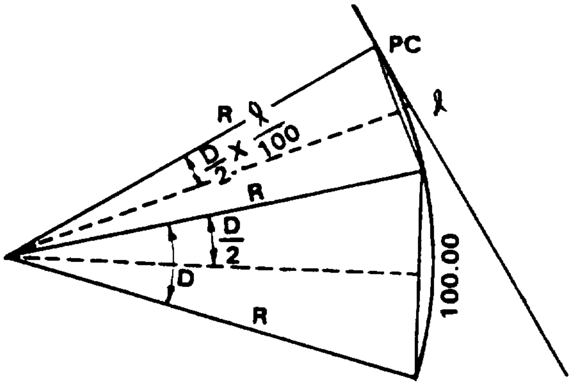


Figure 9-15. Calculation of chord lengths

The length of the chord for a 100-foot arc on the curve is equal to 2R Sin (D/2). For the first and last arcs, which are almost always less than 100 feet, the measured chord Is equal to *2R Sin [(D/2)(L/100)]* where L is the distance from the PC or PT to the closest full station.

A summary of the deflection-angle and chord-length calculations is shown in Figure 9-16.

LOCATION ON ARC	DEFLECTION ANGLE	CHORD LENGTH
PC to first full station	$d_1 = \frac{D}{2} \times \frac{\ell}{100}$	$C_1 = 2R Sin\left(\frac{D}{2} \times \frac{\ell}{100}\right)$
Full station to full station	$d_n = \frac{D}{2} + d_{n-1}$	$C_n = 2R Sin\left(\frac{D}{2}\right)$
Last full station to PT	$d_f =$ $\left(\frac{D}{2} \times \frac{\ell}{100}\right) + d_{f-1}$	$C_f = 2R Sin\left(\frac{D}{2} \times \frac{\ell}{100}\right)$

Figure 9-16. Deflection-angle and chord-length determinations

Example:

In the example of a horizontal curve with no terrain restrictions, the station of PC is 9 + 82.71, the station of PT is 18 + 16.04, and the deflection angles and chord distances are shown in Table 9-2. A useful check on the long series of computations is that the final deflection angle from the PC to the PT must always equal I/2. This is based on the previously stated principle that the deflection angle (from PC to PT) is one-half the total angle subtended (I). This check is illustrated in Table 9-2 for d = 25° = 1/2 = 500/2 for station, (18 + 16.04), which is the PT.

Layout Techniques

When using the deflection-angle method, set the transit up at the PC. Set zero on the vernier, sight the PI (or take a backsight down the centerline), and turn the first deflection angle. Measure the subarc distance along the instrument's line of sight. To locate the second point on the

Table 9-2. Deflection angles and chord distances

Station	Deflection computation	d	Chord computation	chord length
PC 9+82.71				
10 + 00	$d_1 = \left(\frac{D}{2} \times \frac{\ell}{100}\right) = \frac{6}{2} \times \frac{17.29}{100} = 0.519°$. $0.519 \times 60 = 31.1$	$0° 31' 6"$	$C = 2R\ Sin\left(\frac{D}{2}\frac{\ell}{100}\right) = 2(954.93)(0.52336)\left(\frac{17.20}{100}\right)$	17.28'
11 + 00	$d_2 = d_1 + \frac{D}{2} = .519 + \frac{6}{2} = 3.519°$	$3° 31' 6"$	$C = 2R\ Sin\frac{D}{2} = 2(954.93)(0.52336)$	99.954'
12 + 00	$d_3 = d_2 + \frac{D}{2} = 3.519 + \frac{6}{2} = 6.519°$	$6° 31' 6"$	$C = 2R\ Sin\frac{D}{2} = 2(954.93)(0.52336)$	99.954'
13 + 00	$d_4 = d_3 + \frac{D}{2} = 6.519 + \frac{6}{2} = 9.519°$	$9° 31' 6"$	$C = 2R\ Sin\frac{D}{2} = 2(954.93)(0.52336)$	99.954'
14 + 00	$d_5 = d_4 + \frac{D}{2} = 9.519 + \frac{6}{2} = 12.519°$	$12° 31' 6"$	$C = 2R\ Sin\frac{D}{2} = 2(954.93)(0.52336)$	99.954'
15 + 00	$d_6 = d_5 + \frac{D}{2} = 12.519 + \frac{6}{2} = 15.519°$	$15° 31' 6"$	$C = 2R\ Sin\frac{D}{2} = 2(954.93)(0.52336)$	99.954'
16 + 00	$d_7 = d_6 + \frac{D}{2} = 15.519 + \frac{6}{2} = 18.519°$	$18° 31' 6"$	$C = 2R\ Sin\frac{D}{2} = 2(954.93)(0.52336)$	99.954'
17 + 00	$d_8 = d_7 + \frac{D}{2} = 18.519 + \frac{6}{2} = 21.519°$	$21° 31' 6"$	$C = 2R\ Sin\frac{D}{2} + 2(954.93)(0.52336)$	99.954'
18 + 00	$d_9 = d_8 + \frac{D}{2} = 21.519 + \frac{6}{2} = 24.519°$	$24° 31' 6"$	$C = 2R\ Sin\frac{D}{2} = 2(954.93)(0.52336)$	99.954'
PT 18+16.04	$d_{10} = d_9 + \left(\frac{D}{2} \times \frac{\ell}{100}\right) = 24.519 + \frac{6}{2} \times \frac{16.04}{100}$ $= 24.519 + .481 = 25.00$	$25° 00' 00"$ check $\frac{I}{2} = 25° 00'$	$C = 2R\ Sin\left(\frac{D}{2}\frac{\ell}{100}\right) = 99.954\left(\frac{16.04}{100}\right)$	16.032'

curve (station 11 + 00), turn the second deflection angle (the angle is measured turning from the PI to station 11 + 00) with the transit still at the PC. Measure the intersection of this line of sight and the 100-foot arc from the preceding station to locate station 11 + 00. Lay out the rest of the curve in this manner.

If the curve is long so that the transit must be moved or if an obstruction prevents a clear line of sight, move the transit to an intermediate station. The same deflection angles previously calculated may be used to locate the rest of the curve. (See Figure 9-17.)

If station 17 + 00 cannot be sighted, move the transit to station 16 + 00. Set zero on the vernier, backsight the PC, and turn the angle 21°31'6" to sight station 17 + 00. Figure 9-17 shows that angle D must be turned for the transit at station 16 + 00 to become tangent to the curve at that point. Once the transit is tangent to the curve, angle D/2 must be turned to locate the next station because the arc is 100 feet long. The total angle turned is d_7 + D/2, which is d_8 as originally calculated.

Frequency of Placing Survey Stakes (In Feet)

Horizontal curves should be staked at a minimum interval of 100 feet. The staking interval on horizontal curves should be based on the degree of curvature and can be determined from the following table:

Degree of Curvature (100’)	Radius (meters)	Staking interval
0 to 3°	> 1,910’	100’
> 3° to 8°	1,910’ to 721’	50’
> 8° to 16°	720’ to 360’	25’
> 16”	< 360°	10’

Horizontal Curve Design Using Metric Units

The design of horizontal curves using metric units is essentially the same as in English units. The only difference lies in the relationships of arc length to the degree of curvature as shown in Figures 9-18a, 9-18b, and 9-18c.

NOTE: The functions of a 1° curve table are also applicable to metric design based on the relationship shown in Figure 9-18b. However, if designing using metric units, the lengths of T, E, M, and R are in meters.

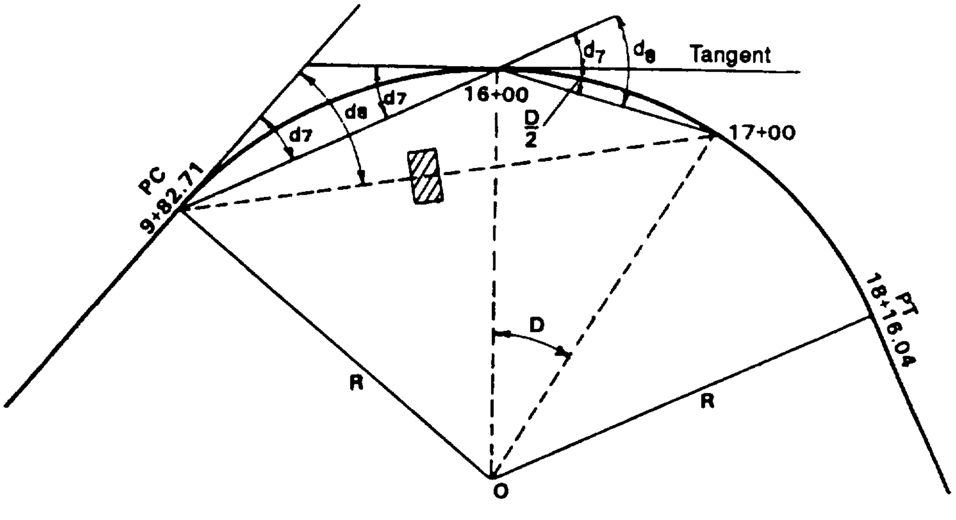
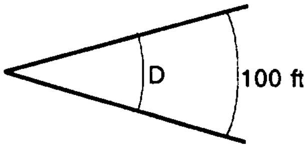


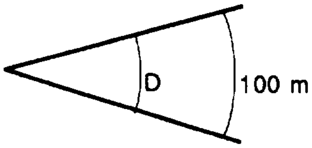
Figure 9-17. Obstruction on a curve



$$\frac{D_{100\,ft}}{100\,ft} = \frac{360}{2\pi R}$$

$$D_{100\,ft} = \frac{5729.58}{R(ft)}$$

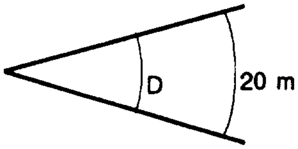
Figure 9-18a. D based on a 100-ft arc



$$\frac{D_{100\,m}}{100\,m} = \frac{360}{2\pi R}$$

$$D_{100\,m} = \frac{5729.58}{R(m)}$$

Figure 9-18b. D based on a 100-m arc



$$\frac{D_{20\,m}}{20\,m} = \frac{360}{2\pi R}$$

$$D_{20\,m} = \frac{5729.58}{R(m)}$$

Figure 9-18c. D based on a 20-m arc

If you design the curve based on D_{100} m, but intend on staking at an interval of 20 m, you must determine the degree of curvature based on 20 m ($D_{20\,m}$) to determine the correct deflection angles. A summary of the deflection-angle and chord-length calculations based on $D_{20\,m}$ is shown in Figure 9-18d.

Frequency of Placing Survey Stakes (In Meters)

Horizontal curves should be staked at a maximum interval of 20 meters (m). The staking internal on horizontal curves should be based on the degree of curvature and can be determined from the following information:

Degree of Curvature (100')	Radius (meters)	Cord Lengths (meters)
0 to 3°	>585	20
>3° to 8°	585 to 221	10
>8° to 16°	220 to 110	5
>16°	<110	5

LOCATION ON ARC	DEFLECTION ANGLE	CHORD LENGTH
PC to first full station	$D_1 = \frac{D_{20\,m}}{2} \times \frac{\ell}{20\,m}$	$C_1 = 2RSin\left(\frac{D_{20\,m}}{2} \times \frac{\ell}{100}\right)$
Full station to full station	$d_n = d_{n-1} + \frac{D_{20\,m}}{2}$	$C_n = 2RSin\left(\frac{D_{20\,m}}{2}\right)$
Last full station to PT	$d_f = d_{f-1} + \left(\frac{D_{20\,m}}{2} \times \frac{\ell}{20\,m}\right)$	$C_f = 2RSin\left(\frac{D_{20\,m}}{2} \times \frac{\ell}{100}\right)$

NOTE: ℓ is the distance from the PC or PT to the closest full station.

Figure 9-18d. Deflection-angle and chord length selection based on $D_{20\,m}$

VERTICAL ALIGNMENT

The capabilities of vehicles or aircraft using any particular road or airfield determine the maximum allowable grades that should be established. However, other factors may be considered. Excessive grades can be installed where speed and capacity are not essential. Whenever possible, grades should be less than the prescribed maximum values stated in Table 9-1, page 9-3.

Within limitations imposed by various other criteria, place tangent grade lines so that earthwork is minimized. The earthwork required in most road-construction projects is usually the largest, single work item. Anything that reduces earthwork will improve job efficiency and economy. Attempt to balance the earthwork operations between cut and fill in any area, within the capabilities of available equipment. When drawing the grade lines, the engineer can usually do this balancing by inspection, keeping the profile area of cut equal to the profile area of fill. These areas are not necessarily proportional to the actual volumes involved, but they serve as a basis for comparison. It is impractical to balance a volume of cut with an equivalent volume of fill at a distance beyond the hauling capabilities of the available equipment.

Along any proposed route will be points at which the elevation is already fixed. Intersections with existing roads and railroad crossings present predetermined elevations that the engineer must meet when locating the tangent grade lines.

In addition to the controlling specifications for grades, other criteria may control the placement of grade lines. These criteria include the minimum allowable gradients, the maximum allowable change in grade at any Intersection point, the permissible depth of cut or fill, and the maximum gradients in approaching bridges or points of intersection.

PLOTTING A PROFILE VIEW

The profile of a road or airfield is a side view of the project. It represents the horizontal distance, or stations, as abscissa (x axis) against the elevations at these stations, which are plotted as ordinates (y axis). When a horizontal alignment is set and the project stationed, determine the elevation of critical points along the centerline. Engineers usually calculate the elevation at all half and full stations, PVC, PVT, and HP and LP elevations.

A break point where the prevailing grade makes an appreciable change should be stationed and the elevation ascertained. The most common procedure for determining existing terrain elevations is by a ground survey. However, it is possible to obtain elevations for specific points from a contour map on which the proposed horizontal alignment has been plotted. Unless the scale of the contour map is large, this method is inaccurate and should be used only for preliminary planning and initial location. The centerline profile may not represent the typical or prevailing condition across the entire section at any particular point. This error may be noticeable when the section is wide, as for an airfield. In such cases, additional profiles may be needed along the shoulder line. It is also possible to make a typical profile that represents the average elevation across the entire section.

PLOTTING TRIAL GRADE LINES

After studying the profile, determine the tangent grade lines. These grade lines serve as the proposed final profile of the project. It is possible for rough, pioneer construction to follow existing contours with a little smoothing of rough spots. Such a route provides a rough and relatively unsafe roadbed that is not capable of carrying a large volume of traffic. A well-designed route has a series of tangent grades with a smooth transition between them. These tangent grade lines can be determined with a good profile.

GRADE DETERMINATION

The degree of steepness measured longitudinally is normally defined as the percentage of grade. It is established as a relationship between vertical rise or fall for each 100-foot horizontal distance and is expressed as a percentage (per 100).

The equation for determining grades is—

$$G = \frac{V}{H}(100)$$

where—

G = percentage of grade
V = rise or fall between the two points
H = horizontal distance between the two points

NOTE: V and H must be in the same units.

To differentiate between rising and falling grades along the centerline, a plus sign is used to denote rising grades in the direction of increasing stations and a minus sign is used 10 denote falling grades.

VERTICAL CURVES

After grade lines are placed, define the route vertically in a series of grade lines (straight segments of constant grade) between points of vertical intersection. Design a transition that provides smooth, easy movement from one grade line to another at these intersections. The vertical curves used for this transition and its pertinent dimensions are easily calculated.

Types of Vertical Curves

Two types of vertical curves must be considered: overt and invert. (See Figure 9-19.) Overt curves are commonly called crest curves, and invert curves are referred to as sag curves. Both types are designed the same way but different specifications govern their dimensions.

Elements of Vertical Curves

Figure 9-20 shows a typical vertical curve installed between two grade lines. The parts of a vertical curve include the following:

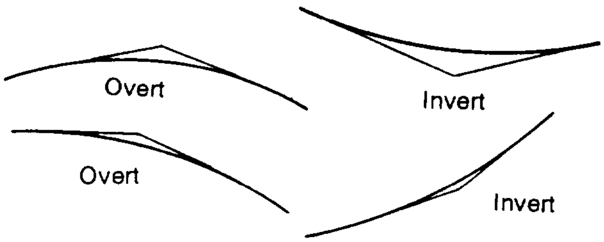


Figure 9-19. Types of vertical curves

- The PVI is the intersection of two grade lines. This station is always read from the profile view.
- The PVC is the point along the first grade line at which the vertical curve begins. The grade line is tangent to the parabolic curve at this point. By convention. the PVC is always one-half the length of the vertical curve from the PVI, measured horizontally.
- The PVT is the point along the second grade line at which the vertical curve ends. It has the same properties as the PVC.
- The percentage of grade (G) on the grade line nearest the point of origin is called G1, and the other grade line percentage is called G2. These two grade lines, which are tangent to the parabolic curve at the PVC and PVT, intersect at the PVI.

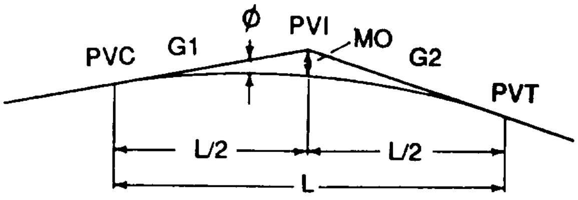


Figure 9-20. Elements of a vertical curve

- The length of vertical curve (L) is the horizontal distance from the PVC to the PVT. The walking distance along the actual curve has no significance. The PVI is horizontally midway between the PVC and PVT. Therefore, the distance from the PVC to the PVI is L/2, and the distance from the PVI to the PVT is also L/2.

- Offsets (Ø) are the vertical distances from the grade lines to the vertical curve. The heights of offsets are computed for selected points along the length of the vertical curve. The selected points are usually at every station and half station.

- The maximum offset (MO) is the offset at the PVI. It is always the greatest offset along the vertical curve.

Design of Vertical Curves

The design of vertical curves includes two tasks-determining the curve length and calculating the heights of a sufficient number of offsets to adequately define or locate the final grade line.

Length Determination. It is possible to design vertical curves to be long and gentle (flat) or short and abrupt. This is done by varying the curve length. Depending on the facility to be constructed and the standards of construction desired, there are certain limitations on curve length. Minimum lengths usually are specified.

Change of Grade (ΔG). The difference in grade between the two grade lines is called the change of grade. This difference, which Is symbolized as ΔG, is computed as $|G_1 - G_2|$ which represents the absolute value of $G_1 - G_2$. The curve installed between two grade lines with a large ΔG which might occur at the top of a steep hill, is longer than the curve required between two grades with a smaller ΔG.

Allowable Rate of Change of Grade [r). Criteria have been established to ensure that the rate at which the change in gradient is made throughout a vertical curve is consistent with the operating characteristics of the vehicles or aircraft using the facility. One criterion (called “r”) is expressed as an allowable rate of change of grade for a specific horizontal distance. For example, with a criterion of 0.5 percent change in grade over 500 feet, a ΔG of 1.0 percent requires a curve length of 1,000 feet. However, r is usually expressed as the allowable gradient change in 100 feet of length. The term “r” is frequently used for airfield vertical curve design.

Sight Distance (S). When an overt curve is traversed, the ability of the driver to see down the road or airfield is curtailed. If a vertical curve is quite short, the distance that can be seen ahead becomes critically short. Reduced speed is required to reduce the safety hazard. Sight distance depends upon the design speed permitted.

Vertical-Curve-Length Factor (k). This factor is used when determining road vertical curve lengths. It is equal to the horizontal distance, in feet, required to effect a 1-percent change in gradient while providing the minimum stopping distance.

Determination of the Vertical Curve Length. Determine the vertical curve length by using the vertical-curve-length factor (see Table 9-1, page 9-3) for the given class of road (A, B, C, or D) and for the type of curve. The factor “k” is used in the following equation:

$$L = \frac{k\Delta G}{100}$$

where—

L = length of vertical curve in 100-foot stations
k = vertical-curve-length factor (Table 9-1)
ΔG = change of grade

If length L, as computed, is not in whole stations, round up to the next full 100-foot station. The length derived by this procedure is compared to the absolute minimum length found in Table 9-1.

Knowing the curve length and the station of the PVI, compute the station of the PVC and the PVT.

PVC = PVI - L/2
PVT = PVI + L/2

Offset Determinations. For the curve to be defined, the engineer must determine elevations at various locations along the curve. In order to do so, the engineer must determine the offset ($\varnothing$) which is the vertical distance from the original grade line to the designed curve.

Maximum Offset. As previously stated, the MO will always be located at the PVI. The following formula is used to calculate MO:

$$MO = \frac{L\Delta G}{8}$$

where—

MO = vertical height of the maximum offset in feet
L = length of vertical curve in sections
ΔG = change of grade in percent

Intermediate Offsets. Offsets at locations along the curve other than the PVI are referred to as intermediate offsets. Since it is common practice to stake vertical curves at whole and half stations, intermediate offsets are determined at every whole and half station along the curve. Use the following formula to calculate the intermediate offsets:

$$\varnothing = \frac{\Delta G}{2L} d^2$$

where—

$\varnothing$ = offset at a distance, d, from the PVC or PVT in feet
d = selected distance (in stations) from the PVC or PVT at which an offset distance is to be calculated
L = curve length in stations
ΔG = change of grade in percent

Since ΔG and L have been determined prior to using this equation, the term $\Delta G/2L$ is a constant. Finding the offsets is a simple matter of varying the value of d.

NOTE: The offsets at equal distances from the PVC or PVT are equal. In other words, the offsets are symmetric about the PVI. (This does not mean that the resulting curve is symmetric (unless $G_1 = G_2$).) Thus, the offset for only one side of a vertical curve needs to be calculated. Therefore, the above equation can be used to calculate the offset at any point within the vertical curve.

Elevations Along Vertical Curves. Vertical curves have the shape of a parabola. Use the following equation to calculate elevations along the vertical curve:

Invert curve:

y = elev PVC - change in elevation + offset

$$y = elev\ PVC - G_1 d + \frac{\Delta G}{2L} d^2$$

y = elev PVT ± change in elevation + offset

$$y = elev\ PVT \pm G_2 d + \frac{\Delta G}{2L} d^2$$

Overt curve:

Y = elev PVC + change in elevation - offset

$$y = elev\ PVC + G_1 - \frac{\Delta G}{2L} d^2$$

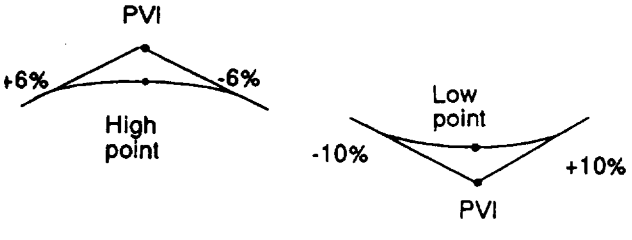
y = elev PVT ± change in elevation - offset

$$y = elev\ PVT \pm G_2 d - \frac{\Delta G}{2L} d^2$$

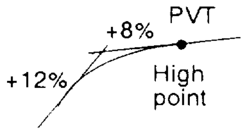
where—

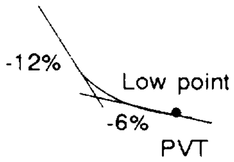
y = elevation of point on curve in feet
d = horizontal distance of point on curve from PVC or PVT in stations
ΔG = change of grade in percent
G_1 = percent slope of first grade line
G_2 = percent slope of second grade line
Elev PVC = elevation at point of vertical curve in feet

High or Low Point of a Vertical Curve. When the tangent grades (G_1 and G_2) are equal, the high or low point of the curve occurs at the PVI. (See the following example:)

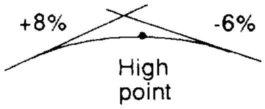


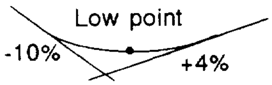
When the tangent grades are the same sign (both positive or both negative), the high and low points correspond with either the PVC or PVT. (See the following example:)





When the tangent grades are unequal, the high or low point of the curve always falls on the flatter of the two grades. (See the following example:)





To determine the location along the curve of the maximum (or minimum) elevation, use the following equation:

$$d = \frac{GL}{\Delta G}$$

where—

d = horizontal distance along curve from PVC (or PVT) in stations
L = length of vertical curve in stations
G = percent slope of flattest grade
ΔG = change of grade in percent

Cut or Fill Values. By using the calculated curve elevations and the existing ground elevations, we can determine the cut or fill values to place on the grade stakes for construction operations. The ground elevations can be determined from the profile view established from the initial survey. The difference in elevation between the curve and the ground elevation constitutes the cut or fill value. For example, if the ground elevation at a point on a curve was 86 feet and the curve elevation at that point was 82 feet, the construction stake would indicate a cut of 4 feet (86 feet - 82 feet).

Design Steps.

The following steps show the design procedure for vertical curve:

1. Compute the change of grade.

$$\Delta G = |G_1 - G_2|$$

2. Compute the vertical curve length (L).

$$L = \frac{k\Delta G}{100}$$

Round up to the next higher full station (if possible).

3. Determine the PVC.

$$PVC = PVI - (L/2)$$

4. Determine the PVT.

$$PVT = PVI + (L/2)$$

5. Determine the elevation of PVC.

$$EL_{PVC} = EL_{PVI} \pm |G_1| \times (L/2)$$

6. Determine the elevation of PVT.

$$EL_{PVT} = EL_{PVI} \pm |G_2| \times (L/2)$$

7. Determine the maximum offset (MO).

$$MO = \frac{L\Delta G}{8}$$

8. Determine final curve elevations. Compute at every half station and full station along the curve.

a. Determine grade-line elevations (GLEs).

$$GLE = EL_{PVC} \pm |G_1| \times d \text{ from } PVC$$
$$GLE = EL_{PVT} \pm |G_2| \times d \text{ from } PVT$$

b. Determine intermediate offsets ($\varnothing$).

$$\varnothing = MO \times \left(\frac{d}{L/2}\right)^2 \text{ or } \left(\frac{\Delta G}{2L}\right) d^2$$

c. Determine curve elevations.

$$\text{Elev curve} = \text{GLE} \pm \varnothing$$

9. Determine the location of maximum (or minimum) elevation, if required.

$$d = \frac{GL}{\Delta G}$$

10. Determine the highest (lowest) elevation, if required.

$$Y = \frac{-\Delta G x^2}{2L} + G_1 x + elev\ PVC$$

Example:

Complete the design of a vertical curve to include PVC, PVT, and offsets, with cuts and fills determined every 50 feet (one-half station).

Given:

The unit survey section has completed a centerline survey for a proposed vertical curve. The road is class D.

Solution:

PVI = 5 + 00, elevation = 73.00’

$G_1 = +3.1\%$, $G_2 = -5.75\%$

(1) Determine ΔG.

$$\Delta G = |G_1 - G_2| = |(+3.1) - (-5.75)| = 8.85\%$$

(2) Determine L.

From Table 9-1, page 9-3, k for crest vertical curve on a class-D road is 35.

$$L = \frac{k\Delta G}{100} = \frac{35(8.85)}{100} = 3.10 \text{ stations}$$

Use L = 4, stations = 400’

(3) Determine the PVC.

$$PVC = PVI - L/2 = (5 + 00) - (2 + 00) = (3 + 00)$$

(4) Determine the PVT.

$$PVT = PVI + L/2 = (5 + 00) + (2 + 00) = (7 + 00)$$

(5) Determine the elevation of PVC.

$$\begin{aligned} EL_{PVC} &= EL_{PVI} \pm |G_1|\ (L/2) \\ &= 73.00 - |0.031|\ (400/2) \\ &\quad \text{or } 73 - (3.1)\ (4/2) \\ &= 66.80' \end{aligned}$$

(6) Determine the elevation of PVT.

$$\begin{aligned} EL_{PVT} &= EL_{PVI} \pm |G_2|\ (L/2) \\ &= 73.00 - |-0.0575|\ (400/2) \\ &\quad \text{or } 73 - 5.75\ (4/2) \\ &= 61.50' \end{aligned}$$

(7) Determine the maximum offset (MO).

$$MO = \frac{L\Delta G}{8} = \frac{4(8.85)}{8} = 4.43'$$

(8) Determine final curve elevations.

(a) Determine GLEs (Figure 9-21).

$$GLE = EL_{PVC} \pm |G_1|\ x\ d \text{ from } PVC$$

$$GLE = EL_{PVT} \pm |G_2|\ x\ d \text{ from } PVT$$

(b) Determine intermediate offsets (Ø)

$$\varnothing = \left(\frac{\Delta G}{2L}\right) d^2 = \left(\frac{8.85}{2(4)}\right) d^2 = 1.106\, d^2$$

NOTE: The term $\Delta G/2L$ becomes a constant (1.106).

Station	GLE	d	Ø	Curve elevation
3 + 00	66.80	0	0	66.80
3 + 50	68.35	0.5	0.28	68.07
4 + 00	69.90	1.0	1.11	68.79
4 + 50	71.45	1.5	2.49	68.96
5 + 00	73.00	2.0	4.43	68.57
5 + 50	70.13	1.5	2.49	67.64
6 + 00	67.25	1.0	1.11	66.14
6 + 50	64.38	0.5	0.28	64.18
7 + 00	61.50	0	0	61.50

Figure 9-21. Compiling vertical curve design data

Where—

$\varnothing$ = offset from the GLE to the curve
d = distance, from the PVC or PVT in stations
$\varnothing_{(zero\ stations)} = 1.106(0)^2 = 0$ (There is no offset at the PVC and PVT.)
$\varnothing_{(0.5\ station)} = 1.106(0.5)^2 = 0.28'$ (at stations 3 + 50 and 6 + 50)
$\varnothing_{(1.0\ station)} = 1.106(1.0)^2 = 1.11'$ (at stations 4 + 00 and 6 + 00)
$\varnothing_{(1.5\ station)} = 1.106(1.5)^2 = 2.49'$ (at station 4 + 50 and 5 + 50)
$\varnothing_{(2.0\ station)} = 1.106(2.0)^2 = 4.43'$ (at station 5 + 00)

(9) Determine the location of the maximum or minimum elevation, if required.

$$D = \frac{GL}{\Delta G} = \frac{(3.1)(4)}{8.85} = 1.40 \text{ stations or } 140'$$

(The maximum or minimum elevation is always on the flattest grade when grades have opposite signs.)

Station maximum elevation point = PVC + d (or PVT - d)

Station maximum elevation point = (3 + 00) + (1 + 40) = 4 + 40

(10) Determine the highest elevation, if required.

$$y = \text{elev PVC (or PVT)} + Gd \pm \varnothing$$

NOTE: + or - is determined by inspection.

$$y = PVC_{elev} + Gd - \left(\frac{\Delta G}{2L}\right)d^2$$

$$y = 66.80 + 3.1(1.4) - \frac{8.85}{8}(1.4)^2$$

$$y = 66.80 + 4.34 - 2.17 = 68.97$$

Vertical Curve Through a Known Point. When the vertical curve must go through a known point and the known point is at the PVI, the length of the curve can be determined using the following formula:

$$L = \frac{MO(8)}{\Delta G}$$

When the known point is at a location other than the PVI, the length of the curve can be determined using the following formula:

$$L = 2\left[A + \frac{2(\varnothing)}{\Delta G}\right] + 4\sqrt{\left(\frac{A(\varnothing)}{\Delta G}\right) + \left(\frac{\varnothing}{\Delta G}\right)^2}$$

Where—

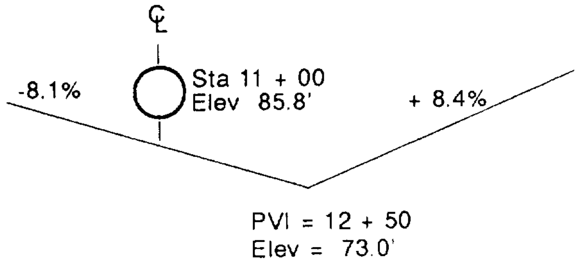
A = horizontal distance from PVI to known point
$\varnothing$ = offset between elevation of known point and GLE of known point

NOTE: ΔG must be entered as a decimal.

Once the length of the curve has been determined, the remainder of the design must be completed according to the vertical curve design procedures previously outlined.

Example:

A new road with a PVI at station 12 + 50 and an elevation at 73.00 feet is to pass over a 24-inch culvert at station 11 + 00. The invert of the culvert is at elevation 85.8 feet.



Solution:

Determine the length of the vertical curve required to clear this culvert with 1 foot of cover.

1. Determine the horizontal distance (A) from the PVI to the known point.

A = 1,250' - 1,100' = 150'

2. Determine ΔG (as a decimal).

$$\Delta G = |G_1 - G_2| = |-0.081 - 0.084|$$
$$\Delta G = 0.165$$

3. Determine the elevation of the vertical curve required to clear the culvert with 1 foot of cover (at the known point).

EL_{CURVE} = 85.8' + 2.0' (pipe diameter) + 1.0' (cover required)

EL_{CURVE} = 88.8'

4. Determine the GLE at the known point (directly below the culvert).

GLE = EL_{PVI} + $|G_1|$ x d (from PVI to known point)

GLE = 73.0' + |0.081| x 150'

GLE = 85.15'

5. Determine the offset (Ø) between the elevation of known point and the GLE of known point.

Ø = 88.8'- 85.15' = 3,65'

6. Determine the length of the vertical curve.

$$L = 2\left[A + \frac{2(\varnothing)}{\Delta G}\right] + 4\sqrt{\left(\frac{A(\varnothing)}{\Delta G}\right) + \left(\frac{\varnothing}{\Delta G}\right)^2}$$

$$L = 2\left[150' + \frac{2(3.65')}{0.165}\right] + 4\sqrt{\left(\frac{150(3.65)}{0.165}\right) + \left(\frac{3.65}{0.165}\right)^2}$$

= 388.48' + 246,82'
= 635.30'

Vertical-Curve Design Using Metric Units. The design of vertical curves using metric units is the same as in English units. The only difference lies in the use of meters as units of measurement for elevations and distances.

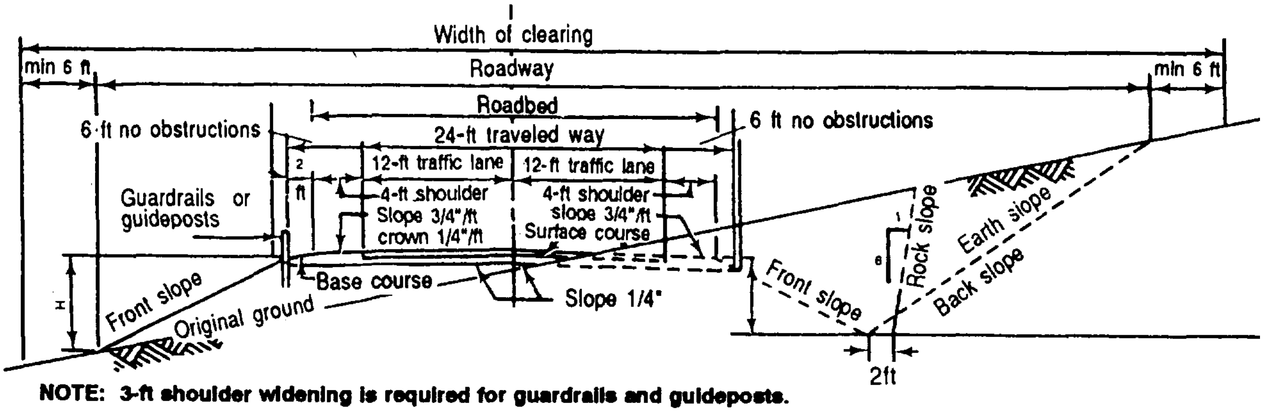
Frequency of Placing Survey Stakes. Vertical curves should normally be staked at 50-foot (every half station) or 10-meter intervals. On extremely rugged terrain, the interval should be reduced.

THE CROWNED SECTION

The typical cross section of a road is the crowned cross section. The amount of crown provided depends on the type of surface used. Normal crown slopes are provided in Table 9-1, page 9-3. Figure 9-22 shows a typical cross section for a class-A road. If the road is to be surfaced, the subgrade and the finished surface till have the same crown.

SUPERELEVATION

The outer edge of a road is elevated to balance the overturning forces experienced by a vehicle rounding a horizontal curve. The amount of superelevation is governed by the degree of curvature (or the curve radius) and the design speed. Detailed information for designing superelevation on



NOTE: 3-ft shoulder widening is required for guardrails and guideposts.

Figure 9-22. Normal crown cross section for a class-A road curves is in FM 5-233. Table 9-3 lists superelevation rates and appropriate transition lengths to develop the superelevated section as a function of the design speed and degree of curvature. Figure 9-23 shows a class-A road section with a superelevated curve.

As a safely factor, the pavement width on the inside lane of a curve is increased. The amount of increase is governed by the degree of curvature and the design speed. Table 9-4 lists pavement widening requirements. As shown in Figure 9-24, the transition from a normal cross section on a tangent (A-A) to a fully superelevated, widened cross section on a curve (D-D) is a uniform, gradual change. The length of highway needed to accomplish this transition is given in Table 9-3. Two-thirds of the specified transition length is affected on the tangent and one-third is affected on the curve.

Table 9-3. Superelevation lengths and transition lengths

D	R		V = 30 mph (48 kph)	L		V = 40 mph (64 kph)	L		V = 60 mph (97 kph)	L	
	ft	m	E	ft	m	E	ft	m	E	ft	m
0° 15'	22918	6985.420	NC	0	0	NC	0	0	NC	0	0
0° 30'	11459	3492.710	NC	0	0	NC	0	0	RC	175	53.340
0° 45'	7639	2328.372	NC	0	0	NC	0	0	.024	175	53.340
1° 00'	5730	1746.507	NC	0	0	RC	125	38.100	.032	175	53.340
1° 30'	3820	1164.338	RC	100	30.480	.021	125	38.100	.048	175	53.340
2° 00'	2865	873.254	RC	100	30.480	.028	125	38.100	.058	175	53.340
2° 30'	2292	698.603	.021	100	30.480	.034	125	38.100	.069	190	57.912
3° 00'	1910	582.169	.025	100	30.480	.040	125	38.100	.079	210	64.008
3° 30'	1637	498.959	.029	100	30.480	.046	125	38.100	.087	230	70.104
4° 00'	1432	436.474	.033	100	30.480	.051	125	38.100	.093	250	76.200
5° 00'	1146	349.301	.040	100	30.480	.061	130	39.524	.099	270	82.296
6° 00'	955	291.085	.046	100	30.480	.070	150	45.720	.100	270	82.296
7° 00'	819	249.832	.053	100	30.480	.077	160	48.768	D MAX = 5.5°		
8° 00'	716	218.237	.059	110	33.528	.084	180	54.864			
9° 00'	637	194.158	.064	120	36.576	.089	190	57.912			
10° 00'	573	174.651	.068	120	36.576	.093	200	60.960			
11° 00'	521	158.801	.073	130	39.624	.097	200	60.960			
12° 00'	477	145.390	.077	140	42.672	.099	210	64.008			
13° 00'	441	134.417	.080	140	42.672	.100	210	64.008			
14° 00'	409	124.663	.083	150	45.720	.100	210	64.008			
16° 00'	358	109.119	.089	160	48.768	.100	210	64.008			
18° 00'	318	96.927	.093	170	51.816	D MAX = 14.5°					
20° 00'	286	87.173	.097	170	51.816						
22° 00'	260	79.248	.099	180	54.864						
24° 00'	239	72.847	.100	180	54.864						
28° 00'	205	62.484	.100	180	54.864						
			D MAX = 26.7°								

D - Degree of curvature
R - Radius of curvature
V - Design speed
E - Rate of superelevation
L - Minimum length of transition
NC - Normal crown section
RC - Remove adverse crown, superelevate at normal crown slope
Transitions desirable but not as essential above heavy line

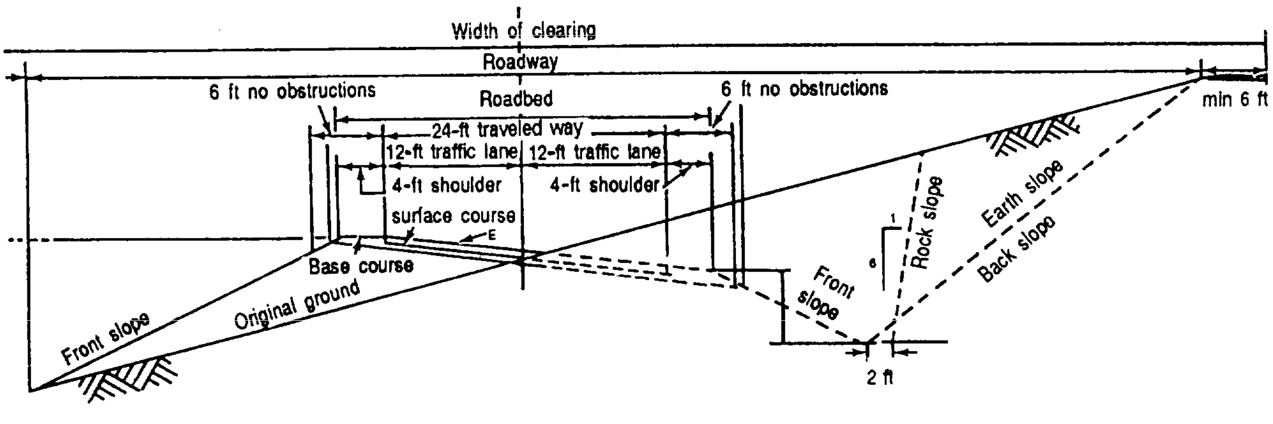


Figure 9-23. Superelevated cross section

Table 9-4. Pavement widening

	Widening for 2-lane pavements on curves for width of pavement on tangent of 20 ft		
Degree of Curve	**Design Speed**		
	30 mph	**40** mph	**50** mph
1	0.0'	0.0'	2.0'
2	2.0'	2.0'	2.5'
3	2.0'	2.0'	2.5'
4	2.0'	2.5'	3.0'
5	2.5'	2.5'	3.0'
6	2.5'	3.0'	3.5'
7	2.5'	3.0'	
8	3.0'	3.0'	
9	3.0'	3.5'	
10-11	3.0'	3.5'	
12-14.5	3.5'	4.0'	
15-18	4.0'		
19-21	4.5'		
22-25	5.0'		
26-26.7	5.5'		

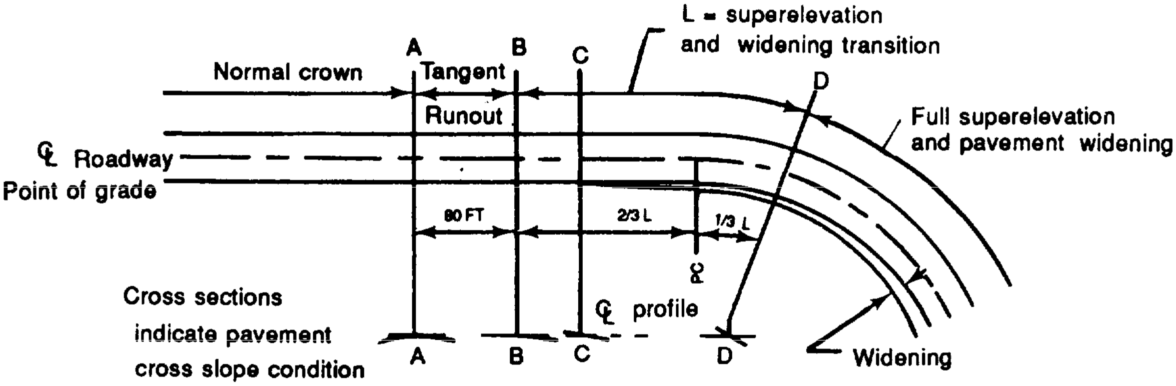


Figure 9-24. Method for transition (not to scale)

STRUCTURAL DESIGN

In the TO, few roads receive a bituminous or portland-cement concrete surface. Most two-lane roads are surfaced with sand, gravel, crushed rock, or the best locally available material. Expedient surfacing methods are used when required.

This section describes the procedures to improve natural earth surfaces and to resurface them with sand, gravel, or other materials. Included are some common methods of expedient surfacing, guidance, and criteria to determine thickness requirements for bituminous pavements in the TO. The design of mixes and aggregates and the procedures for placing bituminous and concrete surfaces are in TM 5-337. For subgrade and base-course requirements, refer to Chapter 5 of this manual. Additional information in Chapter 12 of FM 5-430-00-2/AFPAM 32-8013, Vol 2, supplements the frost-design procedures in this chapter.

Road surfaces in the TO consist of earth in the most expedient circumstances. When in-place soil is not strong enough, it may be chemically or mechanically stabilized or covered with a bituminous surface treatment. As time becomes available, earthen roads can be improved for increased traffic loads by covering them with material from a borrow pit or with processed material.

EARTH

Earthen roads consist of native soils graded and drained to form a surface for carrying traffic. They are designed to satisfy immediate traffic needs and provide a subgrade for surfaces of better quality. Their use is generally limited to dry weather and light traffic. For continued use, periodic maintenance by graders and drags is necessary to maintain a high crown and smooth surface for draining surface water. Dust control must also be provided in dry climates or during dry weather.

Earthen roads become impassable in wet weather because of the rutting action of heavy traffic. Generally, they are used in combat areas where speed of construction is required with limited equipment and personnel. They are also used as haul roads in construction areas and as service roads for military installations.

TREATED SURFACE

Earthen roads may be treated with bituminous materials to control dust and to waterproof the surface. This helps prevent softening of the surface in wet weather. Treated surfaces are most successful with silt or clay soils. The bituminous material should be of low viscosity and should contain a wide range of volatile materials of light fractions. Slow-curing liquid asphalts are frequently used, particularly grades SC-70 and -250. Medium-curing cutback asphalts, grades MC-30, -70, and -250, have also been used successfully. Road tars have been used to some extent, especially RT-1.

Many residual oils from oil refineries have been used in this work. In only expedient situations, waste military oils (such as crankcase oils) can be used. The amount of oil ranges from about 1/2 to 1 gallon per square yard and is applied in two or three increments, depending on the type and condition of the oil. The serious environmental, ecological implications of these methods must be considered. Also, using these methods will greatly impair the ability of bituminous admixtures and surface applications to properly cure, if applied later.

STABILIZED SOIL

Bituminous, stabilized soil mixtures and soil-cement are used as road surfaces to carry light traffic in expedient situations for relatively brief periods. Mechanically stabilized soil mixtures are widely used as surfaces for military roads under favorable conditions. Requirements for mechanically stabilized surfaces are discussed below:

Gradation requirements for mechanically stabilized soils used directly as surfaces are shown in Table 9-5. Mixtures that have a maximum size of aggregate of 1 to 1 1/2 inches are preferred because the large partitles tend to work to the surface under traffic. Somewhat finer soil is desirable in a mixture that will serve as a surface compared with one used for a base. The finer soil makes the surface resistant to the abrasive effects of traffic and to the penetration of precipitation. Such a surface will

Table 9-5. Suggested grading requirements for gravel and composite-type surface course of processed materials

Sieve Designation	Percent Passing by Weight
1 in	100
3/4 in	85-100
3/8 in	65-100
No. 4	55-85
No. 10	40-70
No. 40	25-45
No. 200	10-25

also more easily replace (by capillary action) moisture that is lost by evaporation.

Road surfaces require an LL of 35 or less and a PI ranging between 4 and 9. For best results, the PI of a stabilized soil that will function first as a wearing surface and then as a base, with a bituminous surface to be provided later, should be 5 or less. The LL should be less than 25. Compaction, bearing value, and frost action are important considerations for surfaces of this type.

SAND CLAY

One type of mechanically stabilized soil surface is called a sand-clay road. It consists of a natural or artificial mixture of sand and clay that is graded and drained to form a road surface. Although difficult to obtain, the PI should be less than 5 and LL less than 25, in case this layer becomes a subbase after placing additional layers above the sand clay. The gradation requirements for a typical sand-clay surface are in Table 5-4, page 5-12, under the column for 1 -inch sand-clay. The addition of fine gravel (slightly larger than the No. 4 sieve) usually adds stability.

Sand-clay roads will carry light traffic reasonably well and heavy traffic except under bad weather conditions. The amount of moisture these roads absorb determines their stability under traffic loads. Dust control, blading, and dragging are needed. Sand-clay roads withstand traffic better than ordinary earthen roads, but their use is limited to areas where a suitable mixture of sand and clay occurs naturally or where a deficiency of either is readily corrected. As a base course for future surfacing, sand-clay roads produce poor results, unless the plasticity can be reduced by adding a chemical stabilization agent such as lime.

GRAVEL

Gravel roads consist of a compacted layer of gravelly soil that meets the plasticity requirements for mechanically stabilized soil mixtures. The gravel is graded from coarse to fine, with a maximum allowable size of 1 inch. Recommended gradation requirements for a gravel surface are given in Table 9-6. A natural pit- or bank-run gravel may meet these requirements without further processing other than screening. Some pit- or bank-run gravels may require both screening and washing to meet the requirements. River-run gravels normally require the addition of binder to the soil, as do mechanically stabilized soil mixtures. River-run gravels may also require crushing to provide a rough, angular surface rather than the natural, smooth surface characteristic of river-run materials. The ability to carry heavy, sustained traffic depends on the strength and hardness of the gravel, the cohesiveness of the clay binder, the thickness of the layer, and the stability of the subgrade. These roads can be built rapidly, even in cold weather. Organizational equipment of combat engineer units is readily adapted to hauling and placing a gravel surface.

Like other untreated surfaces, gravel roads require considerable maintenance such as blading and dust control in dry weather. During wet weather, proper maintenance is difficult, especially under heavy traffic. Gravel road surfaces with low plasticity make excellent base courses for later-stage pavements.

Table 9-6. Suggested grading requirements for coarse-graded type surface course of processed materials

Sieve Designation	Percent Passing by Weight
3/4 in	100
No. 4	70-100
No. 10	35-80
No. 40	25-50
No. 200	8-25

PROCESSED MATERIALS

Processed materials are prepared by crushing and screening rock, gravel, or slag. A composite-type surface material should meet the gradation requirements of Table 9-5, page 9-28. A coarse-graded type of surface material should meet the gradation requirements in Table 9-6, page 9-29. The information presented here about gravel roads generally applies to roads of processed materials. When gravel or sand-clay is available, processed materials should not be used except when their use will save time and effort.

EXPEDIENT-SURFACED ROADS

Several types of roads are considered expedient surfaced. These are unsurfaced roads and roads where some material has been placed on the natural soil to improve the roadway. Types of expedient-surfaced roads include corduroy, chespaling, landing mats, Army track, plank tread, wire mesh, snow and ice, and sand grid.

CORDUROY-SURFACED ROADS

A corduroy road is an expedient road which uses logs or small trees as the road surface (decking). This method of construction is used in extremely muddy terrain when there is a sufficient supply of natural material. There are three types of corduroy construction: standard corduroy, corduroy with stringers, and heavy corduroy.

Standard Corduroy

The most frequently used corduroy road, shown in Figures 9-25 and 9-26, is built of 6- to 8-inch diameter logs about 13 feet long. The logs are placed across the road surface adjacent to each other from butt to tip. Along the edges of the roadway, place 6- to 8-inch-diameter logs as curbs and attach them in place with driftpins. Drive pickets about 4 feet long into the ground at regular intervals along the outside edge of the road to hold the road in place. To give this surface greater smoothness, fill the gaps between logs with brush, rubble, or twigs. Cover the whole surface with a layer of gravel or dirt. Construct side ditches and culverts as for normal roads.

Corduroy with Stringers

A more substantial corduroy road is made by placing log stringers, as shown in Figure 9-27, parallel to the centerline on about 3-foot centers. Lay a standard corduroy over them, Securely pin the corduroy decking to the stringers, and prepare the surface as described in the preceding paragraph.

Heavy Corduroy

Sleepers (heavy logs 8 to 10 inches in diameter) are used for heavy corduroy roads. The sleepers must be long enough to span the entire road. Place the sleepers at right angles to the centerline on 4-foot centers. Build a corduroy with stringers, as shown in Figure 9-28, on top of the sleepers.

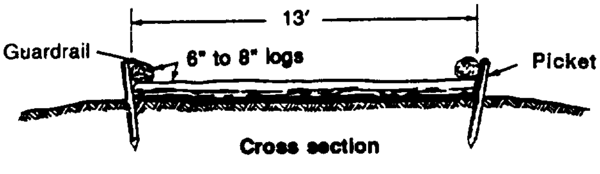


Figure 9-25. Standard corduroy

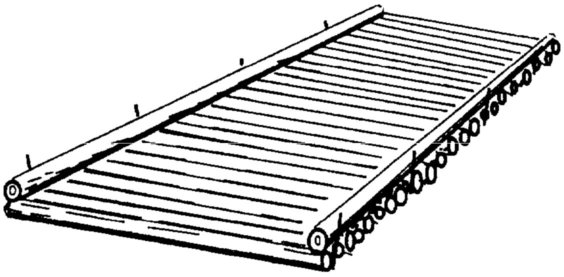


Figure 9-26. Standard corduroy - oblique view

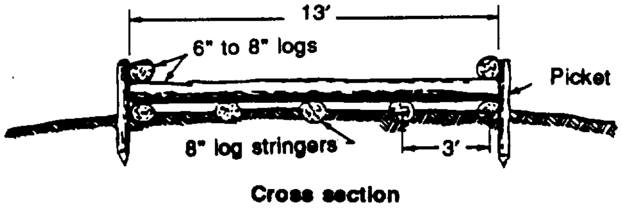


Figure 9-27. Corduroy with stringers

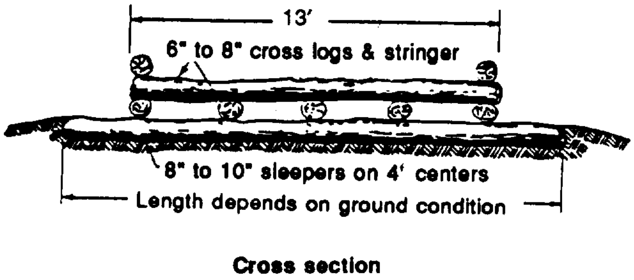


Figure 9-28. Heavy corduroy

Choice of Corduroy Type

Generally, softer ground requires a heavier type of corduroy. The stringers and sleepers do not increase the bearing capacity of the decking. They serve as a crib, keeping the road surface above the level of the surrounding mud. They sink into the ground until a stratum capable of supporting the load is reached. On fairly firm ground, the standard corduroy may be adequate; on softer ground, stringers are needed, Portable corduroy mats can be prefabricated and put down quickly when needed, They are made by wiring 4-inch-diameter logs together.

Diagonal corduroy is preferred for heavy traffic. It is made by placing the decking at an angle of 45 degrees to the centerline. This modified construction is applicable to all three corduroy types. The angled decking decreases the impact load because each log supports only one wheel at a time and there is longitudinal and lateral weight distribution.

CHESPALING

Chespaling is a hasty expedient used in either mud or sand. It is made from small, green saplings, preferably about 1 1/2 inches in diameter and 6 1/2 feet long. They are wired together to form a 12-foot-long mat as shown in Figure 9-29. Chespaling is often rolled into bundles and carried on each wheeled vehicle. The mats are used to

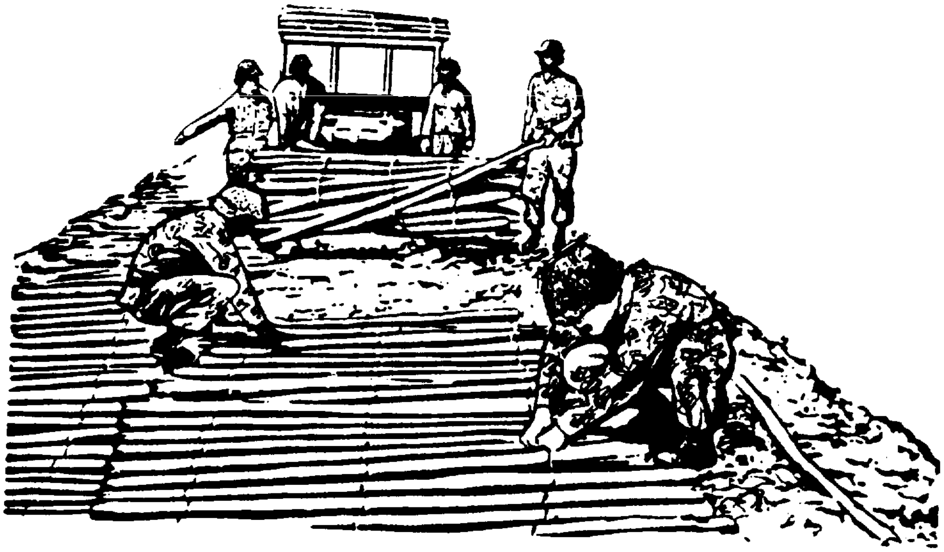


Figure 9-29. Chespaling

cross sandy terrain or to get out of mud. Some mats are constructed from dimensioned timbers wired together to resemble a picket fence. A variation slightly more effective for crossing sand is made by attaching chicken-wire netting to the bottom of the mats.

To build a chespaling road, lay a double row of mats, each mat having its long axis parallel to the centerline with a 1-foot overlay at the centerline. Wire the mats together. Keep the road wet to prevent the saplings from becoming brittle and breaking.

Bamboo mats are an excellent chespaling-type expedient for beach roadways. These mats are light and comparatively strong. They are made by splitting 2-inch bamboo rods and weaving them into a mat in a manner similar to rug weaving. Soak the rods before weaving, and keep the mats moist while they are in use. An 11- by 4-foot mat takes about 15 man-hours to construct. The mats are placed with the long dimension parallel to the centerline. The mats remain serviceable for three or four months on firm ground or sand. Bamboo mats can also be used over mud.

LANDING MATS

The demand for rapidly constructed airfields led to the development of several poriable, metal landing mats. When metal airfield landing mats became a standard supply item in the TO, they were quickly put to use on beaches as well as on airfields. They are still the foremost expedient for crossing sandy terrain. Landing-mat designs fabricated from aluminum alloys can support heavier loads. They also provide smoother surfaces and have a lower weight per square foot.

When used on sand, place the metal landing mats directly on the sand to the length and width desired. If pierced steel mats are used, place an impervious membrane under the mat to smooth and firm the subgrade, thus improving the road.

Place the mat so that its long axis is perpendicular to the flow of traffic. If a width greater than the effective length of one plank is required, use half sections to stagger the joints. A second layer of the steel mat, laid as a treadway over the initial layer, increases its effectiveness.

Landing mats tend to curl at the edges. This problem can be overcome by anchoring the edges properly. Screw-type earth anchors furnished with the mat sets provide the best means of anchoring. Another method of securing the edges is to use a curb of timber on the outside edge of the road and either wire it tightly to buried logs laid parallel to the road or stake it. One type of landing-mat surface is shown in Figure 9-30. If MO-MAT (a reinforced plastic material) is available, it may be used as a roadway surface for vehicular traffic.

ARMY TRACK

A portable timber expedient called Army track, shown in Figure 9-31, can be used to pass vehicles across sandy terrain. The track consists of 4- by 4-inch or larger timbers threaded at each end onto a 1/2-inch wire rope or a 3/4-inch hemp rope. The timbers resemble railroad ties, and a cable runs through them on each side. Space the timbers so that the smallest-wheeled vehicle using the road can obtain traction. Drill cable holes at a 45-degree angle to the centerline so the cable will bend. This practice will prevent individual timbers from moving together. Anchor the cables securely at both ends. Fill spaces between the timbers with select material to smooth out the surface.

PLANK-TREAD ROAD

The plank-tread road is shown in Figure 9-32, page 9-34. To construct a plank-tread road, first place sleepers 12 to 16 feet long, perpendicular to the centerline on 3- to 4-foot centers, depending on the loads to be carried and subgrade conditions. (If finished timber is not available, logs may be used as sleepers.) Then place 4- by 10-inch planks parallel to the line of traffic to

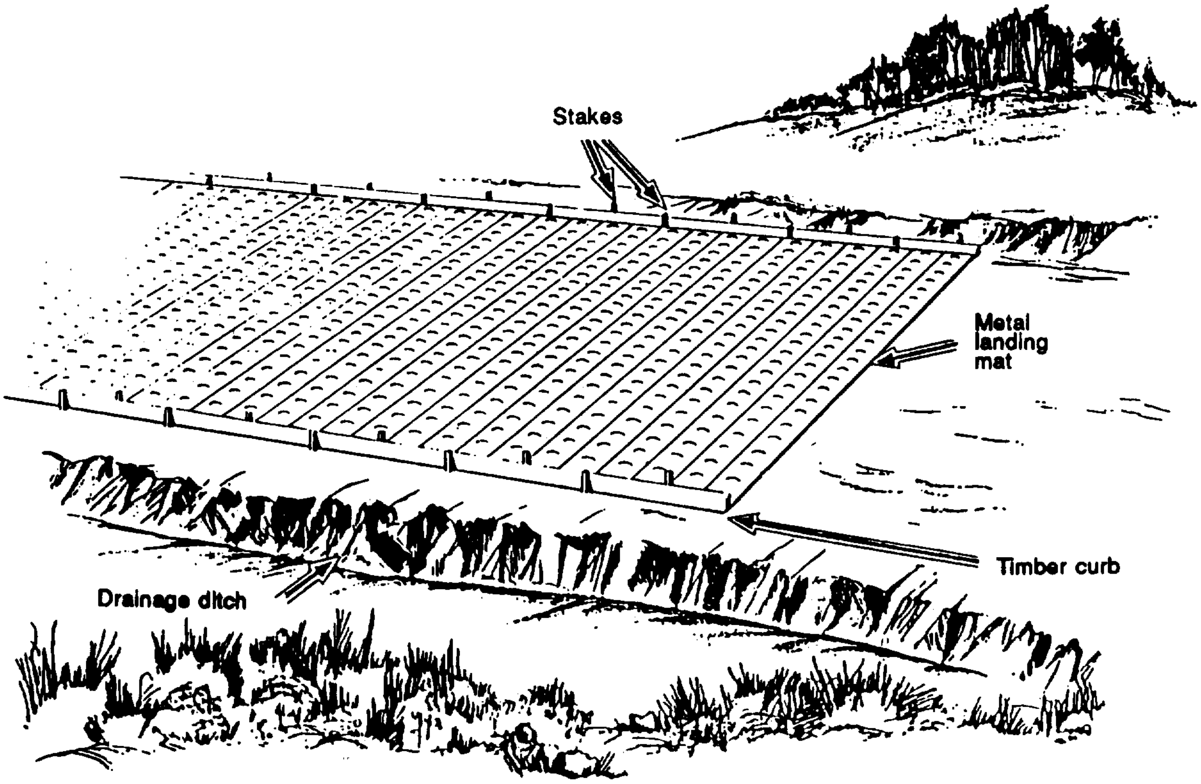


Figure 9-30. Landing-mat road

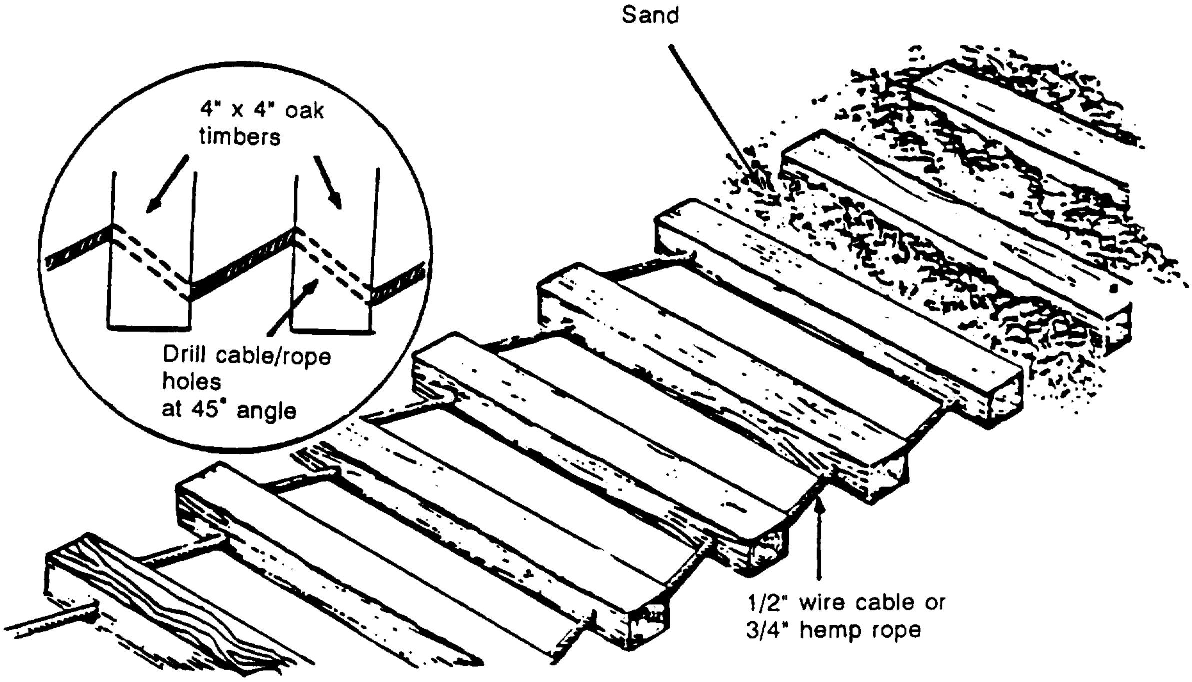


Figure 9-31. Army track

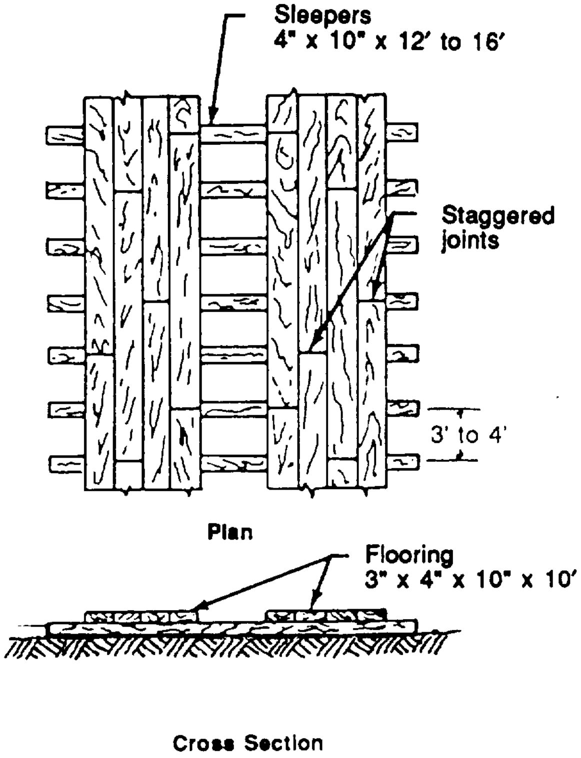


Figure 9-32. Plank-tread road

form two treads about 36 inches apart. Stagger the joints to prevent forming weak spots. If desired, 6-inch curbs may be installed on the inside of the treads.

Use plank roads for crossing short sections of loose sand or wet, soft ground. When built with an adequate base, plank roads last for several months. Planks 3 to 4 inches thick, 8 to 12 inches wide, and at least 13 feet long arc desirable for flooring, stringers, and sleepers. When desired, 3- by 10-inch planks (rough, not finished) can replace the 4- by 10-inch timbers shown in Figure 9-33. Rough 3- by 8-inch and 3- by 10-inch planks can be cut to order.

Position stringers in regular rows parallel to the centerline, on 3-foot centers, with staggered joints. Lay floor planks across the stringers with about 1-inch gaps when seasoned lumber is used. The gaps allow for swell when the lumber absorbs moisture. Spike the planks to every stringer.

Place 6-inch-deep guardrails on each side, with a 12-inch gap left between successive lengths of the guardrail for surface-water drainage. Place pickets along each side at 15-foot intervals to hold the roadway in line. Where necessary, use corduroy or other expedient cross sleepers spaced on

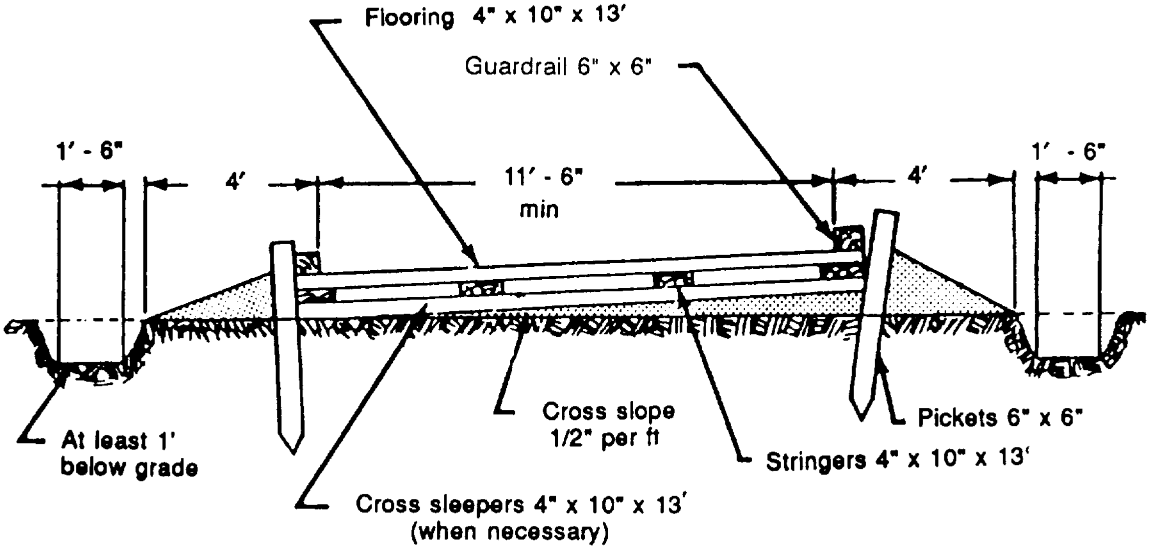


Figure 9-33. Construction details for a plank road

3- to 5-foot centers to hold the stringers in place and to gain depth for the structure.

For drainage, construct the base for a plank road with a transverse slope instead of a center crown. To provide a smoother-riding surface, place treads parallel to the line of traffic over the floor planks.

WIRE-MESH ROAD

Most wire-mesh surfaces are expedient measures. Applied directly to the subgrade, they provide passage for a limited number of vehicles for a short time. Longer life can be obtained by proper subgrade preparation, multilayer or sandwich construction, and frequent staking. Wire-mesh roads should never be crossed by other roads unless planking or some such material is placed over the mesh to protect it.

Chicken wire, expanded metal lath (used for plastering walls), and chain-link wire mesh may be used as road expedients in sand. Mesh surfaces should not be used on muddy roads because they prevent grading and reshaping of the surface when ruts appear.

Any wire-mesh surface is much more effective if a layer of burlap or similar membrane material is placed underneath it to help confine the sand. (See Figure 9-34.) Lighter forms of wire mesh, such as chicken wire or cyclone fencing, require an extra layer. Often a sandwich type of construction is used-one layer of wire mesh followed by one layer of burlap, then a second layer of wire mesh.

Wire mesh must be kept taut. Anchor the edges of a wire-mesh road at 3- to 4-foot intervals. Diagonal wires crossing the centerline at a 45-degree angle and attached securely to buried pickets reinforce the light mesh.

SNOW AND ICE ROADS

In regions with heavy snowfall and where temperatures are below freezing for extended periods, expedient roads can be constructed over the snow. When the road is

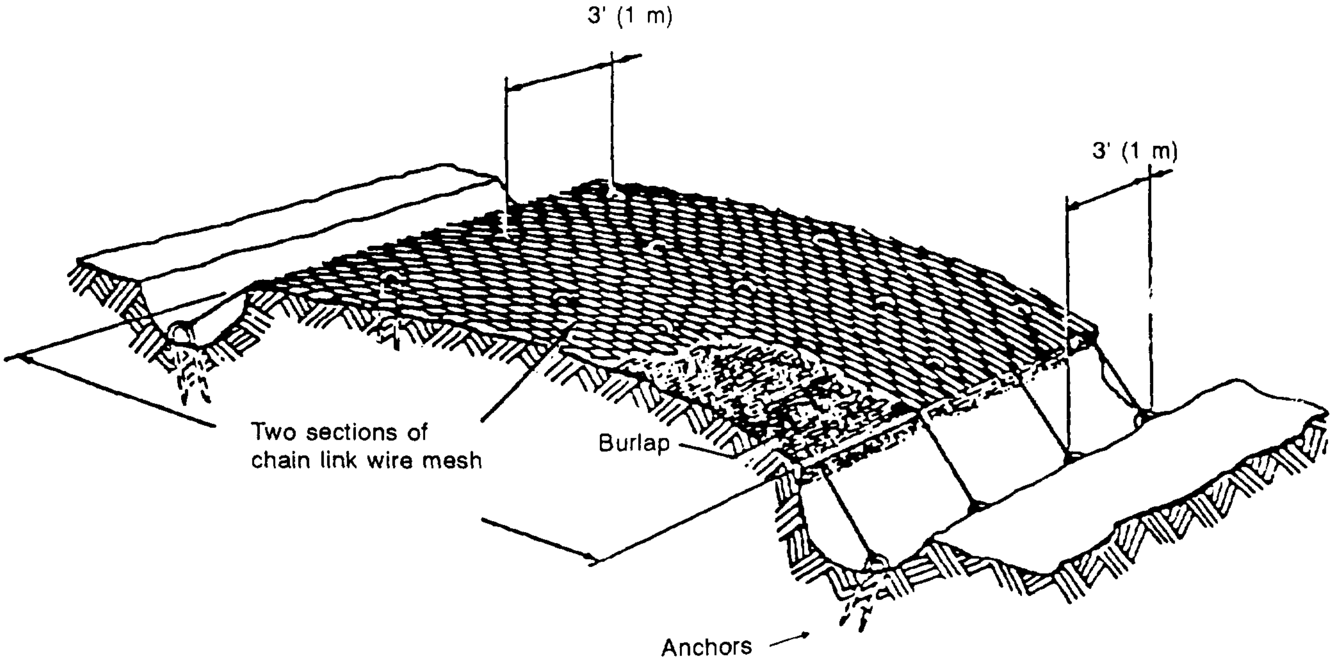


Figure 9-34. Construction details for a wire-mesh road

laid out, make grades and curves as gentle as possible. Compact the snow until it is capable of supporting the weight of vehicles. Add water on the compacted snow and allow it to freeze to produce a hard surface. Frozen lakes or streams can be used to move traffic, but first carefully reconnoiter the route for quality of ice, thickness, cracks, and shore conditions. Determine the load-bearing capacity either by an actual test or by consulting Table 9-7.

Table 9-7. Load capacity of ice

Ice Thickness (inches)	Capacity	Maximum Spacing
1 1/2	Individual soldiers	20 paces
2	Individual soldiers	5 paces
4	Single infantry columns	65 feet
8	Administrative vehicle, artillery, up to 2 1/2 tons, or 4-ton vehicles with maximum axle load of 2.7 tons	65 feet
10 to 13	8-ton (gross) vehicles, including loaded 2 1/2-ton trucks	65 feet
12 to 15	10-ton vehicle (gross)	65 feet
14 to 18	20-ton vehicle (gross)	65 feet
20 to 36	40-ton vehicle (gross)	100 feet

USE OF POLYMER CELLS (SAND GRID) TO BUILD ROADS IN SANDY SOILS

Trafficability over sandy soils is difficult to maintain. The soil strength is adequate, but the soil will displace under a load, due to its cohesionless nature. Wheeled vehicles arc particularly affected. In order to improve trafficability, sand-grid base layers can be used.

Sand grid involves the confinement and compaction of sand or sandy soils in interconnected cellular elements called grids to produce a load-distributing base layer. Uses of the grid include road and airfield pavements, airfield crater repair, erosion control, field fortifications, and expedient dike repair.

Plastic grids (national stock number (NSN) 5680-01-198-7955) are manufactured and shipped in collapsed 4-inch thick, 110-pound sections. (See Figure 9-35.) Each expanded grid section is 8 by 20 feet and contains a honeycomb arrangement of cells. Each cell has a surface area of 39 square inches and a depth of 8 inches. Grids are delivered in 3,000-pound pallets, each containing 25 collapsed 8- by 20-foot sections.

A sand-asphalt surfacing is incorporated within the top portion of the sand-grid cells. Its function is to seal the sand into cells and provide a wearing surface for moderate amounts of rubber-tired traffic. The sand-asphalt surfacing is formed by spraying a suitable liquid-asphalt cement, emulsion, or cutback (rapid-curing (RC) 250 at 165+°F is preferred) on the surface of

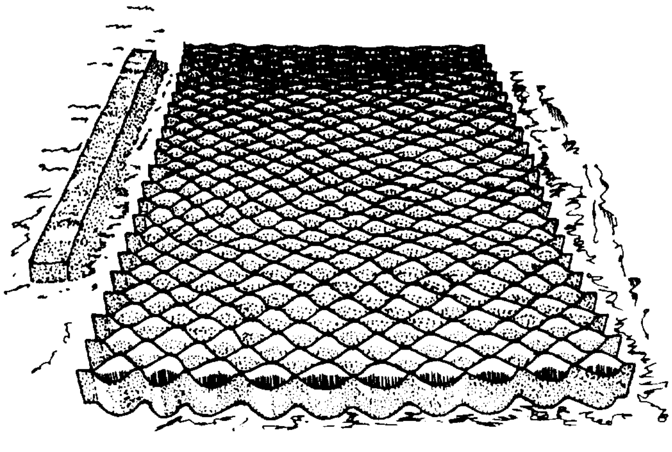


Figure 9-35. Plastic grids

the sand-grid layer. The asphalt used should penetrate into the top 1/2 to 1 inch of sand in the cells. Over a sand subgrade, such a sand-grid road is capable of handling over 10,000 passes of heavy truck traffic, including tandem-axle loads of up to 53,000 pounds. **Avoid tracked vehicles** traveling over this road, as their tracks will easily damage the grid cells.

The following are the procedures for emplacing sand grid.

EQUIPMENT RECOMMENDED

Equipment recommended for the emplacement of sand grid includes bulldozers; smooth-bucket (no teeth) scoop loaders; rough-terrain forklifts; vibratory rollers; water distributors; bituminous distributors; long-handled, round-pointed shovels; and 3/8-inch by 8-foot by 4-foot plywood sheets.

SITE PREPARATION

Site preparation includes the following steps:

1. Perform normal cut or fill operations to reach desircd road grade.

2. Back blade the surface for smoothness.

3. Compact the sand subgrade at a moisture content approaching saturation using the vibratory roller.

GRID INSTALLATION

Grid installation includes the following Steps:

1. Set up stakes and string lines in 8-foot by 20-foot boxes. See Figure 9-36 for layout patterns.

2. Deliver grid pallets with the forklift.

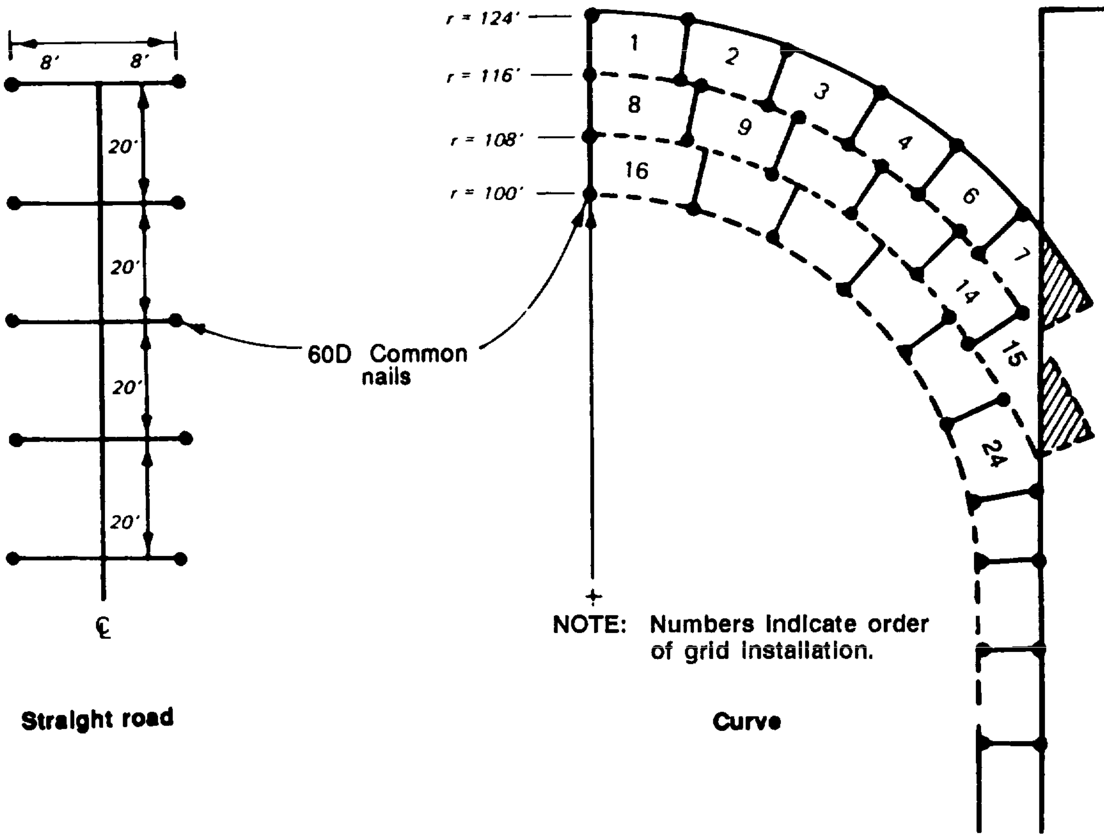


Figure 9-36. Sand-grid layout patterns

3. Expand each grid section using three people on each end, pulling outward to slightly over 20 feet, then shaking the section in midair to obtain uniform cell openings. (See Figure 9-37.) Place the section where string lines dictate, (8-foot by 20-foot steel frames can be ordered.)

4. Shove sand from road shoulders into each end cell and approximately every fifth sirtc-edge cell to anchor the grid in place.

5. To construct joints between grids, use small, 3/8-inch plywood sheets to allow soldiers to stand on top of the unfilled grid, allowing access to the joint cells. For end joints, the rounded end cells from different sections should touch each other. For longitudinal (side-by-side) joints, interlock the “welded” cell portions of each section, as if fitting a puzzle. Fill the jointed cells with sand.

6. Level the joints by placing plywood over the joints and having soldiers walk on top of the plywood.

7. Completely fill each grid using scoop loaders. (See Figure 9-38.) Drop the sand vertically into the cells from a height of at least 2 feet. Do not push the sand forward or the cells will be displaced. Overfill grids by 2 to 4 inches so scoop loaders can operate on the sand-filled grid layer without damaging any cells. Have scoop loaders vary wheel paths to achieve uniform initial compaction of the road.

8. If water is readily available, wet the sand using a water distributor. This will significantly aid in the compaction process.

9. Compact the road surface with one or two passes of the vibratory roller.

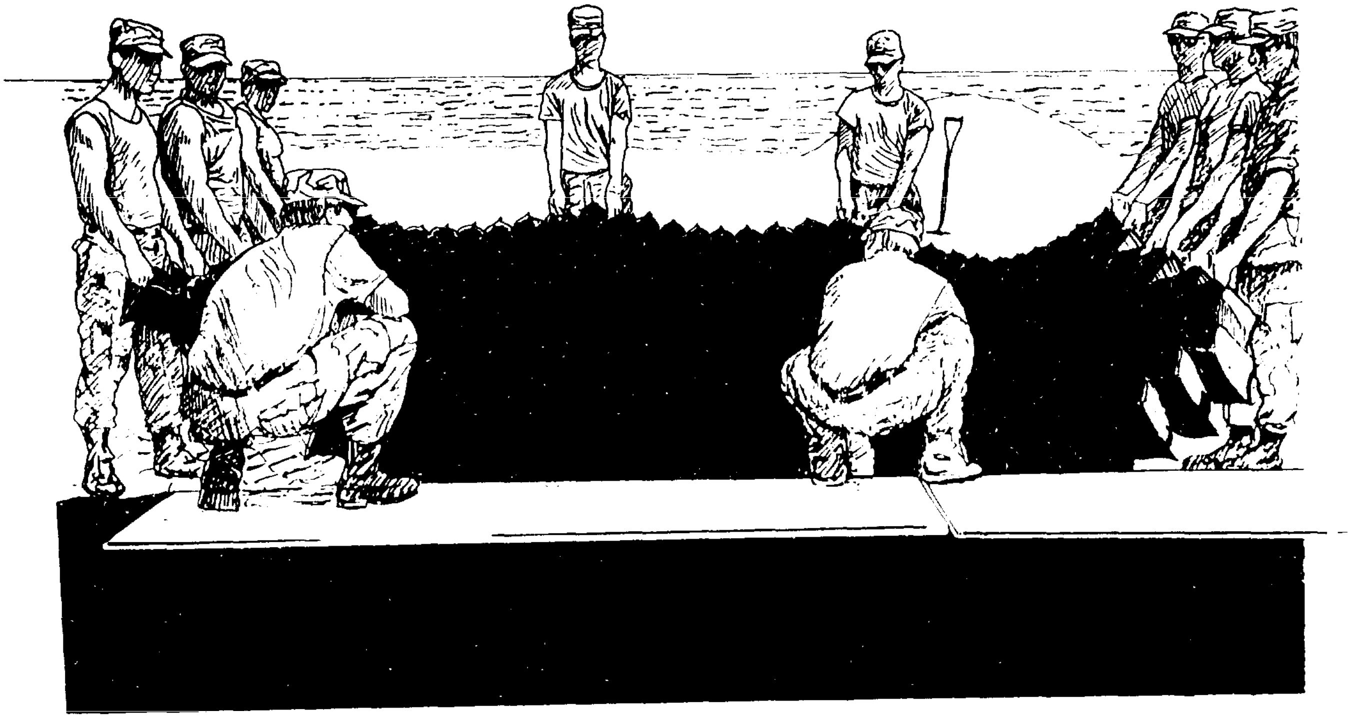


Figure 9-37. Plastic sand-grid section emplacement

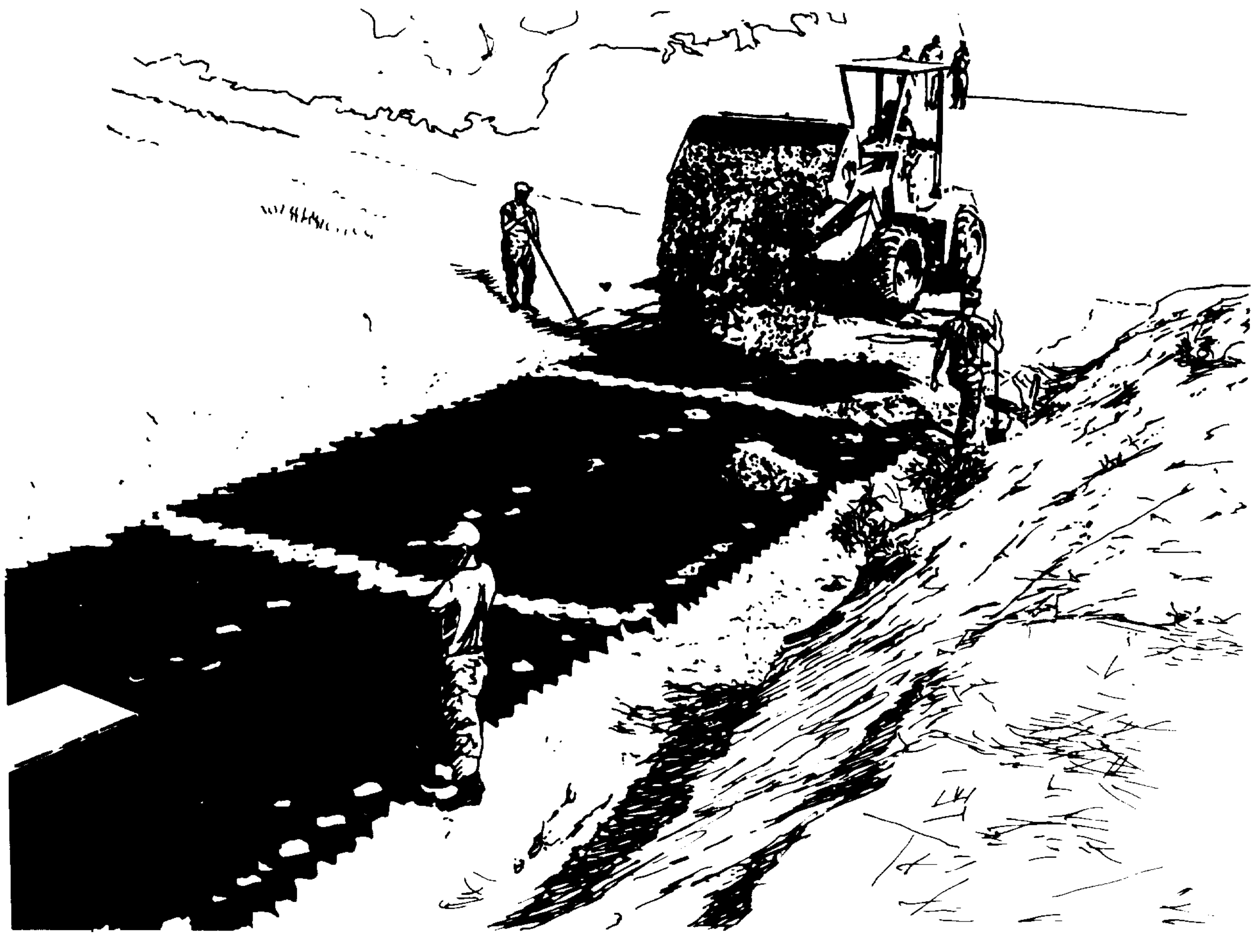


Figure 9-38. Sand-grid road - filling cells with sand

10. Remove excess sand from the grid surface with a grader or by back blading with a smooth-bucket scoop loader. Do not use a bucket with teeth, as cell damage can result.

11. Recompact the road with one pass of the vibratory roller. (See Figure 9-39, page 9-40.)

12. Spray the asphalt product on the road surface and allow enough time for the asphalt product to completely soak into the grid structure (usually about 10 hours). (See Figure 9-40, page 9-40.)

13. Apply a very light coat (1/4 inch) of blotter sand using shovels.

14. Compact the road using one pass of a **nonvibrating roller.** Vibrating the road at this point will break the asphaltic bonds,

15. Apply and compact a 3-inch surface coat of 1-inch (maximum) gravel, if available. This layer will add a protective cover material over the sand-grid road, significantly increasing the road life.

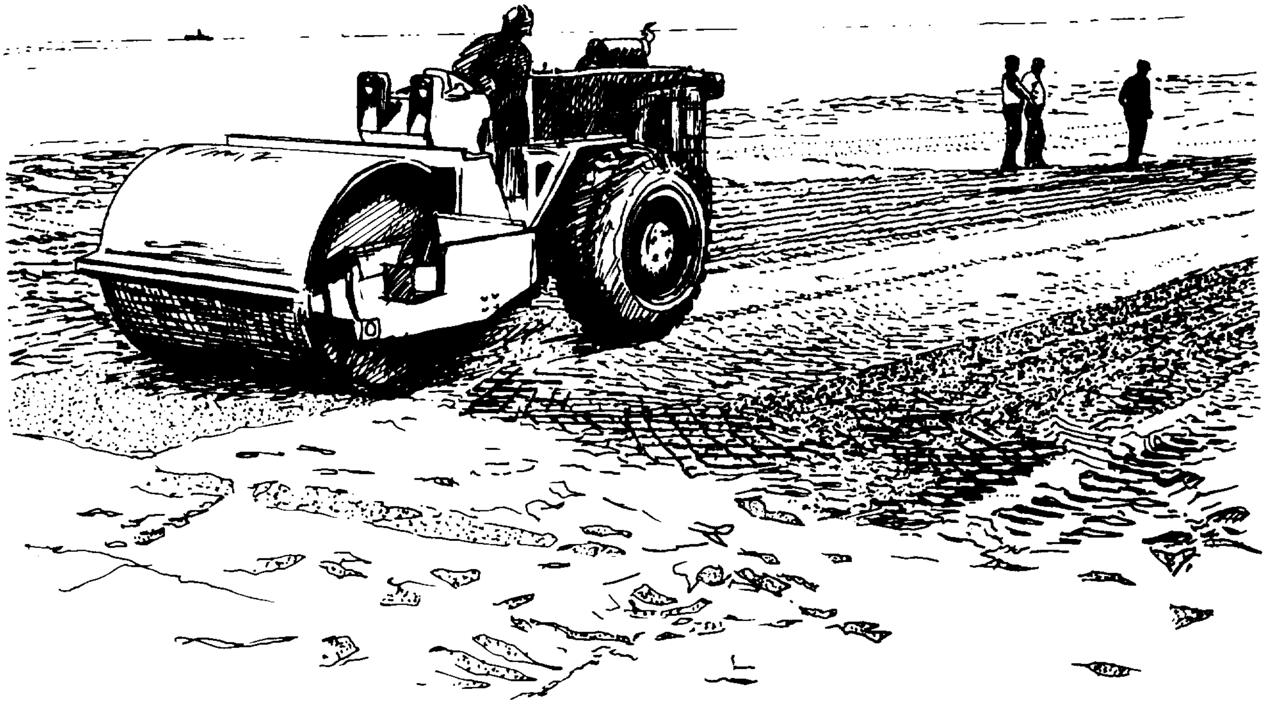


Figure 9-39. Sand-grid road - compacting sand with roller

Figure 9-40. Sand-grid road - spraying asphalt coating

SPRAY APPLICATIONS AND SURFACE TREATMENTS

Surface treatments are the most economical troop-constructed surfaces. They require the fewest resources and minimal quality control effort, and they are placed in the shortest period of time. Surface treatments range from single, light applications of bituminous material to multiple surface courses made up of bitumen and aggregates. Surface treatments can be divided into two categories: sprayed treatments and sprayed bitumen with an aggregate surface.

Spray applications provide soil or aggregate surfaces with the following:

- Prime coat (waterproofing).
- Tack coat (binding bituminous pavement to surface).
- Dustproofing.

Sprayed bitumen with an aggregate surface provides a waterproof, abrasive, wear -resistant surface with no structural strength. Bitumen with aggregate surface pavements will be either of the following:

- Single surface treatment.
- Multiple surface treatment.

Bituminous materials are either tars, road-tar cutbacks, asphalt cement, asphalt cutbacks, or asphalt emulsions. Uses of bituminous materials are shown in Figure 9-41, page 9-42. Asphalt cement is the heavy material left at the end of the petroleum distillation process. Crude oil is refined into gasoline, kerosene, diesel, motor oil, asphalt, and many other products as shown in Figure 9-42, page 9-43. Asphalt cement may then be further modified by cutting back the asphalt with some petroleum product, specifically naphtha, gasoline, kerosene, or diesel, to form an asphalt cutback. Asphalt may also become an emulsion by mixing asphalt cement, water, and an emulsifying agent together with variable-speed pumps to form an asphalt water suspension. Emulsions are either anionic (carrying a negative charge) or cationic (carrying a positive charge).

Tars are the residue from the high-temperature conversion of coal to coke. (See Figure 9-43, page 9-44.) They may be modified by cutting them with a light to medium coal oil to form a road-tar cutback. Tars do not dissolve in petroleum products. They become soft and bleed at high temperatures and are brittle at cold temperatures. Because of their susceptibility to temperature change, tars normally arc used only in areas where fuel spills are commonplace, such as tank farms, fuel depots, and aircraft refuel points.

FIELD IDENTIFICATION

Field identification consists of a series of simple tests designed to identify an unknown bitumen product in the field. The purpose of these tests is to determine the uses of a bituminous material and how to use it safely, rather than the exact specifications to which it conforms. Field-identification procedures are applicable to both tars and asphalts.

Bituminous materials are often found stockpiled in unmarked or incorrectly marked containers. This leads to confusion and delay in construction since the various types and grades of bituminous material are manufactured for a specific purpose.

Field identification is important to the military engineer because—

- Once the type and grade of material are known, the type of surface that can be constructed may be determined. The safety procedures to be followed also depend on the material identification.
- Once the surface type is known, the construction procedure may be outlined and scheduled for a specific target date.
- Once established, the procedure will determine the proper equipment for the job.

TYPE OF CONSTRUCTION	ASPHALT CEMENTS														
	VISCOSITY GRADED -ORIGINAL					VISCOSITY GRADED -RESIDUE					PENETRATION GRADED				
	AC-40	AC-20	AC-10	AC-5	AC-2.5	AR-16000	AR-8000	AR-4000	AR-2000	AR-1000	40-50	60-70	85-100	120-150	200-300
ASPHALT - AGGREGATE MIXTURES CONCRETE AND HOT LAID PLANT MIX															
PAVEMENT BASE AND SURFACES															
HIGHWAYS		X	X	X	1	X	X	X	A	1		X	X	X	1
AIRPORTS		X	X	X			X	X				X	X		
PARKING AREAS		X	X			X	X	X				X	X		
DRIVEWAYS		X	X				X	X				X	X		
CURBS	X	X	X			X	X				X	X	X		
INDUSTRIAL FLOORS	X	X				X	X				X	X			
BLOCKS	X										X				
GROINS	X	X									X				
DAM FACINGS	X	X									X	X			
CANAL AND RESERVOIR LININGS	X	X									X	X			
COLD - LAID PLANT MIX															
PAVEMENT BASE AND SURFACES															
OPEN-GRADED AGGREGATE*															
WELL-GRADED AGGREGATE*															
PATCHING, IMMEDIATE USE															
PATCHING, STOCKPILE															
MIXED - IN - PLACE (ROAD MIX)															
PAVEMENT BASE AND SURFACES															
OPEN - GRADED AGGREGATE*															
WELL - GRADED AGGREGATE*															
SAND				X	X									X	X
SANDY SOIL				X	X									X	X
PATCHING, IMMEDIATE USE															
PATCHING, STOCKPILE															
ASPHALT - AGGREGATE APPLICATIONS (SURFACE TREATMENT)															
SINGLE SURFACE TREATMENT				X	X									X	X
MULTIPLE SURFACE TREATMENT				X	X									X	X
AGGREGATE SEAL				X	X									X	X
SAND SEAL									X						
SLURRY SEAL															
(PENETRATION MACADAM)															
PAVEMENT BASES															
LARGE VOIDS			X										X		
SMALL VOIDS				X										X	
ASPHALT APPLICATIONS (SURFACE TREATMENT)															
FOG SEAL															
PRIME COAT, OPEN SURFACES															
PRIME COAT, TIGHT SURFACES															
TACK COAT															
DUST LAYING															
MULCH															
(MEMBRANE)															
CANAL AND RESERVOIR LININGS	X										X				
EMBANKMENT ENVELOPES	X	X									X	X			
(CRACK FILLING)															
ASPHALT PAVEMENT															
PORTLAND CEMENT CONCRETE PAVEMENT	4										4				

TYPE OF CONSTRUCTION	CUTBACK ASPHALTS												
	RAPID CURING (RC)				MEDIUM CURING (mc)					SLOW CURING (SC)			
	70	250	800	3000	30	70	250	800	3000	70	250	800	3000
ASPHALT - AGGREGATE MIXTURES CONCRETE AND HOT LAID PLANT MIX													
PAVEMENT BASE AND SURFACES													
HIGHWAYS													
AIRPORTS													
PARKING AREAS													
DRIVEWAYS													
CURBS													
INDUSTRIAL FLOORS													
BLOCKS													
GROINS													
DAM FACINGS													
CANAL AND RESERVOIR LININGS													
COLD - LAID PLANT MIX													
PAVEMENT BASE AND SURFACES													
OPEN-GRADED AGGREGATE*								X					
WELL-GRADED AGGREGATE*		X					X	X	X		X	X	X
PATCHING, IMMEDIATE USE		X	X				X	X	X			X	X
PATCHING, STOCKPILE							X	X			X	X	
MIXED - IN - PLACE (ROAD MIX)													
PAVEMENT BASE AND SURFACES													
OPEN - GRADED AGGREGATE*		X	X	X				X	X		X	X	
WELL - GRADED AGGREGATE*		X					X	X			X	X	
SAND		X	X			X	X	X					
SANDY SOIL	X	X	X				X	X					
PATCHING, IMMEDIATE USE		X	X				X	X	X			X	X
PATCHING, STOCKPILE							X	X			X	X	
ASPHALT - AGGREGATE APPLICATIONS (SURFACE TREATMENT)													
SINGLE SURFACE TREATMENT		X	X	X				X	X				
MULTIPLE SURFACE TREATMENT		X	X	X					X				
AGGREGATE SEAL		X	X	X				X	X				
SAND SEAL		X					X	X					
SLURRY SEAL													
(PENETRATION MACADAM)													
PAVEMENT BASES													
LARGE VOIDS			X	X									
SMALL VOIDS		X											
ASPHALT APPLICATIONS (SURFACE TREATMENT)													
FOG SEAL													
PRIME COAT, OPEN SURFACES	X	X				X	X						
PRIME COAT, TIGHT SURFACES	X				X	X							
TACK COAT	X												
DUST LAYING						X							
MULCH													
(MEMBRANE)													
CANAL AND RESERVOIR LININGS													
EMBANKMENT ENVELOPES													
(CRACK FILLING)													
ASPHALT PAVEMENT													
PORTLAND CEMENT CONCRETE PAVEMENT													

TYPE OF CONSTRUCTION	EMULSIFIED ASPHALTS												
	ANIONIC							CATIONIC					
	RS-1	RS-2	MS-1	MS-2	MS-2h	SS-1	SS-1h	CRS-1	CRS-2	CMS-2	CMS-2h	CSS-1	CSS-1h
ASPHALT - AGGREGATE MIXTURES CONCRETE AND HOT LAID PLANT MIX													
PAVEMENT BASE AND SURFACES													
HIGHWAYS													
AIRPORTS													
PARKING AREAS													
DRIVEWAYS													
CURBS													
INDUSTRIAL FLOORS													
BLOCKS													
GROINS													
DAM FACINGS													
CANAL AND RESERVOIR LININGS													
COLD - LAID PLANT MIX													
PAVEMENT BASE AND SURFACES													
OPEN-GRADED AGGREGATE*			X	X	X					X	X		
WELL-GRADED AGGREGATE*						X	X			X		X	X
PATCHING, IMMEDIATE USE						X	X					X	X
PATCHING, STOCKPILE													
MIXED - IN - PLACE (ROAD MIX)													
PAVEMENT BASE AND SURFACES													
OPEN - GRADED AGGREGATE*			X	X						X	X		
WELL - GRADED AGGREGATE*				X		X	X			X		X	X
SAND						X	X					X	X
SANDY SOIL						X	X			X		X	X
PATCHING, IMMEDIATE USE						X	X					X	X
PATCHING, STOCKPILE													
ASPHALT - AGGREGATE APPLICATIONS (SURFACE TREATMENT)													
SINGLE SURFACE TREATMENT	X	X						X	X				
MULTIPLE SURFACE TREATMENT	X	X						X	X				
AGGREGATE SEAL	X	X						X	X				
SAND SEAL	X	X						X	X				
SLURRY SEAL						X	X					X	X
(PENETRATION MACADAM)													
PAVEMENT BASES													
LARGE VOIDS		X						X	X				
SMALL VOIDS	X	X						X	X				
ASPHALT APPLICATIONS (SURFACE TREATMENT)													
FOG SEAL						2	2					2	2
PRIME COAT, OPEN SURFACES													
PRIME COAT, TIGHT SURFACES						X							
TACK COAT	X					2	2	X				2	2
DUST LAYING						2	2					2	2
MULCH						2	2						
(MEMBRANE)													
CANAL AND RESERVOIR LININGS													
EMBANKMENT ENVELOPES													
(CRACK FILLING)													
ASPHALT PAVEMENT						3	3					3	3
PORTLAND CEMENT CONCRETE PAVEMENT													

TYPE OF CONSTRUCTION	TARS													
	1 RT	2 RT	3 RT	4 RT	5 RT	6 RT	7 RT	8 RT	9 RT	10 RT	11 RT	12 RT	RTCB	RTCB 6
ASPHALT - AGGREGATE MIXTURES CONCRETE AND HOT LAID PLANT MIX														
PAVEMENT BASE AND SURFACES														
HIGHWAYS														
AIRPORTS											X	X		
PARKING AREAS											X	X		
DRIVEWAYS											X	X		
CURBS											X	X		
INDUSTRIAL FLOORS														
BLOCKS														
GROINS														
DAM FACINGS														
CANAL AND RESERVOIR LININGS														
COLD - LAID PLANT MIX														
PAVEMENT BASE AND SURFACES														
OPEN-GRADED AGGREGATE*								X	X	X				
WELL-GRADED AGGREGATE*							X	X	X	X				
PATCHING, IMMEDIATE USE													X	X
PATCHING, STOCKPILE														
MIXED - IN - PLACE (ROAD MIX)														
PAVEMENT BASE AND SURFACES														
OPEN - GRADED AGGREGATE*						X	X	X	X	X				
WELL - GRADED AGGREGATE*					X	X	X	X	X					
SAND														
SANDY SOIL														
PATCHING, IMMEDIATE USE													X	X
PATCHING, STOCKPILE														
ASPHALT - AGGREGATE APPLICATIONS (SURFACE TREATMENT)														
SINGLE SURFACE TREATMENT				X	X	X	X	X	X	X	X	X		
MULTIPLE SURFACE TREATMENT				X	X	X	X	X	X	X	X	X		
AGGREGATE SEAL				X	X	X	X	X	X	X	X	X		
SAND SEAL				X	X	X	X	X	X					
SLURRY SEAL														
(PENETRATION MACADAM)														
PAVEMENT BASES														
LARGE VOIDS											X	X		
SMALL VOIDS											X	X		
ASPHALT APPLICATIONS (SURFACE TREATMENT)														
FOG SEAL			X	X	X	X								
PRIME COAT, OPEN SURFACES		X	X	X										
PRIME COAT, TIGHT SURFACES		X	X											
TACK COAT			X	X	X	X	X	X	X	X				
DUST LAYING	X	X												
MULCH				X	X	X	X							
(MEMBRANE)														
CANAL AND RESERVOIR LININGS														
EMBANKMENT ENVELOPES														
(CRACK FILLING)														
ASPHALT PAVEMENT	X	X	X	X										
PORTLAND CEMENT CONCRETE PAVEMENT	X	X	X	X										

* Evaluation of emulsified asphalt-aggregate system required to determine the proper grade of emulsified asphalt to use.

1 FOR USE IN COLD CLIMATES

A FOR USE IN BASES IN COLD CLIMATES

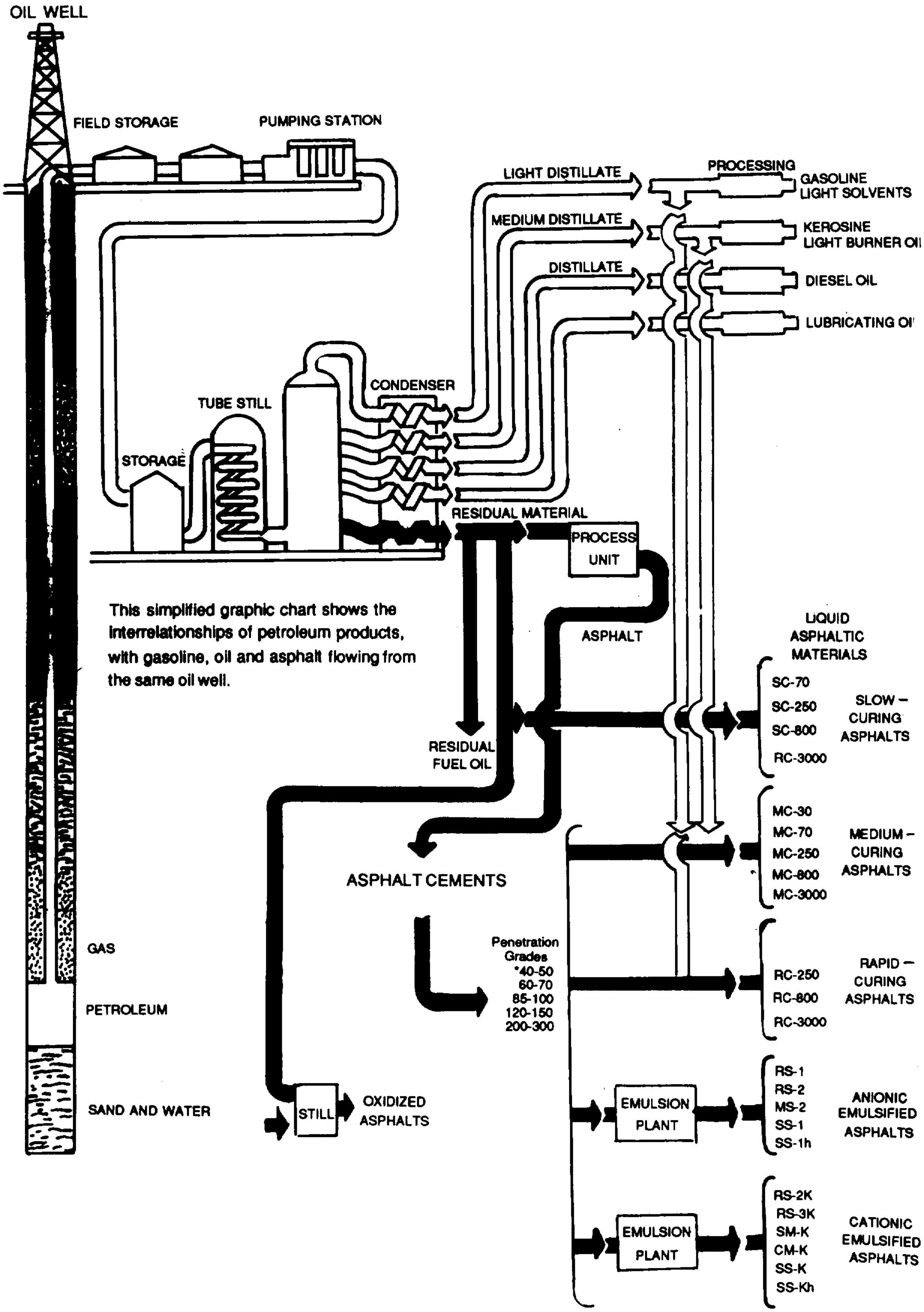
2 DILUTED WITH WATER

3 SLURRY MIX

4 RUBBER ASPHALT COMPOUNDS

Emulsified asphalts shown are AASHTO and ASTM grades and may not include all grades produced in all geographic areas.

Figure 9-41. Use of bituminous materials



This simplified graphic chart shows the interrelationships of petroleum products, with gasoline, oil and asphalt flowing from the same oil well.

Figure 9-42. Petroleum-asphalt flowchart

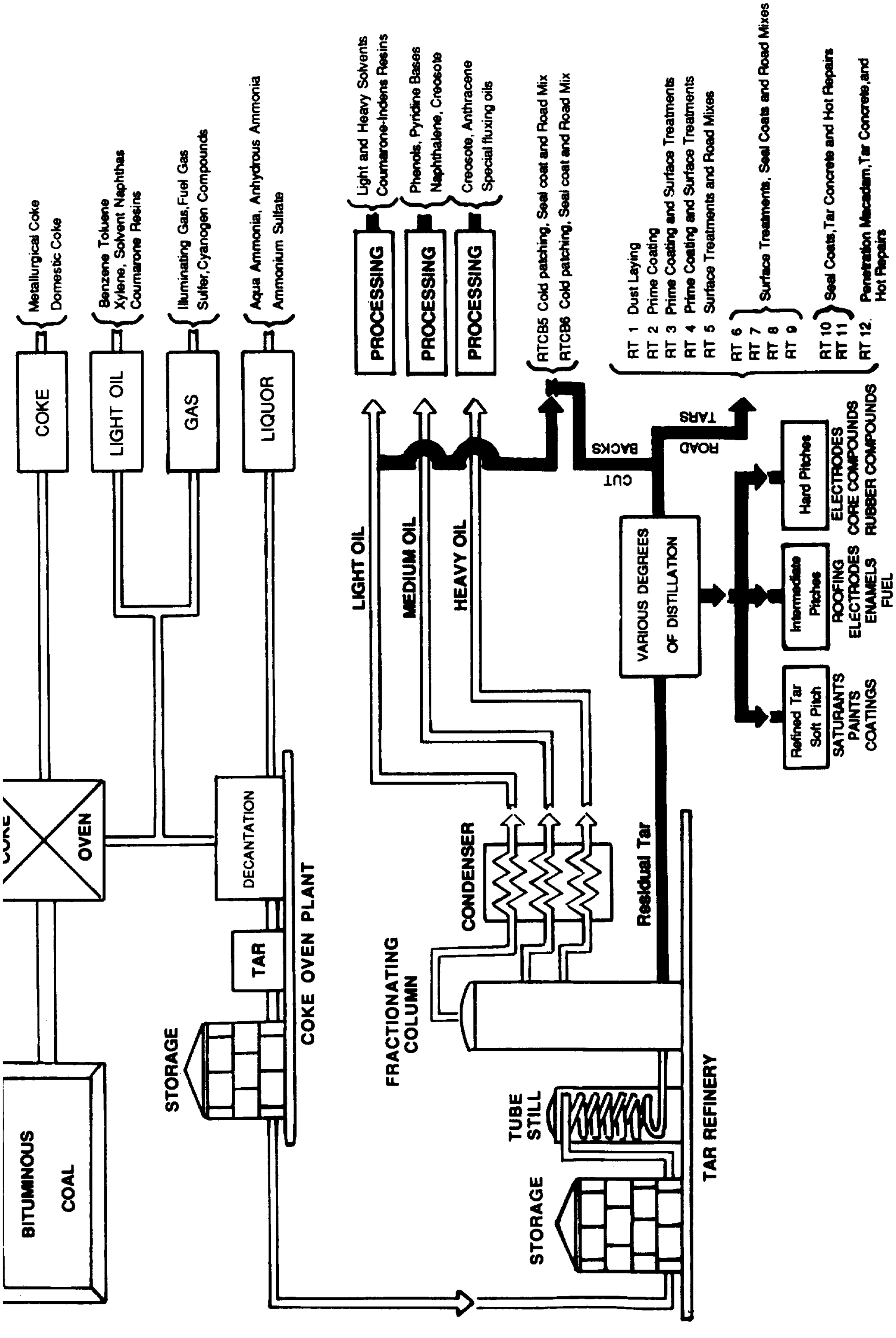


Figure 9-43. Tar simplified flowchart

Field tests may be performed to identify the bituminous paving material as asphalt cement, asphalt cutback, asphalt emulsion, road tar, or road-tar cutback. In addition, it is necessary to identify as closely as possible the viscosity grade of the bitumen. In order to distinguish among the several asphaltic and tar products, it is necessary to know something of their origin, their physical properties, and the manner in which they are normally used. The identification procedure outlined in Figure 9-44, page 9-46, is based upon the physical properties of these materials.

Asphalts and Tars

The first procedure in the identification of an unknown bituminous material is to determine whether it is an asphalt or a tar. Asphalts and tars may be differentiated by a simple volubility test. To perform the test, simply attempt to dissolve an unknown sample (a few drops, if liquid, or enough to cover the head of a nail, if solid) in any petroleum distillate. Kerosene, gasoline, diesel oil, or jet fuel is suitable for this test. Since asphalt is derived from petroleum, it will dissolve in the petroleum distillate. Road tar will not dissolve. If the sample is an asphalt, the sample distillate mix will consist of a dark, uniform liquid. If it is a road tar, the sample will be a dark, stringy, undissolved mass in the distillate. A check can be made by spotting a piece of paper or cloth with the mix. The volubility test provides a positive method of identification.

Grades of Asphalt Cement

The various grades of asphalt cement are distinguished principally by their hardness, as measured by a field penetration test explained in TM 5-337. This information may be sufficient for planning or, in some cases, actually starting emergency construction.

Asphaltic Cutbacks

The pouring or nonpouring quality is one way to distinguish between an asphalt cement and a cutback or emulsion. Asphalt cement is *cutback* with a petroleum distillate to make it more fluid. If the material does not *pour,* it is an asphalt cement. Note that at 77° F, even the softest asphalt cement will not pour or deform noticeably if the container is tilted. If it pours, it is a cutback or emulsion. If it is soluble or dilutable in water, it is an emulsion. In addition, the manner in which it pours will furnish a clue to its grade.

To determine whether a cutback is a RC asphaltic cutback or not, the *smear test* is performed. This is done by making a uniform smear of the substance on a piece of glazed paper or other convenient, nonabsorbent surface. This will give the volatile materials, if present, a chance to evaporate. Since RCs are cut back with a very volatile substance, most of the volatiles will evaporate within 10 minutes. The surface of the smear will then become tacky. This is not true of the lighter grades of medium- and slow-curing asphaltic cutbacks (MCs and SCs), which remain fluid and smooth for some time. An MC will not result in a tacky surface for a matter of hours; for SC materials, several days may be required.

To identify an 800- or 3,000-grade MC or SC cutback, a *prolonged* smear test is used. This process is necessary because these grades of MCs and SCs contain such small quantities of cutterstock that they, too, may become tacky in the 10-minute period specified above. A thin smear of the material is made on a nonabsorbent surface and left to cure for at least 2 hours. By the end of that time, if the material being tested is an RC, the smear will have cured and will be hard or just slightly sticky. However, if the material being tested is an MC or SC, the smear will not be cured and will still be quite sticky. If the material is an RC 3,000, it will cure completely in 3 hours, whereas an RC 800 will take about 6 hours. Even after 24 hours, an MC or SC will still be sticky.

Since MCs are cutback with kerosene and SCs with oil, this fact may be employed to differentiate between them. Heat is used to drive off the kerosene, if present, and make it show up in the form of an odor. It is best to heat the unknown sample in a

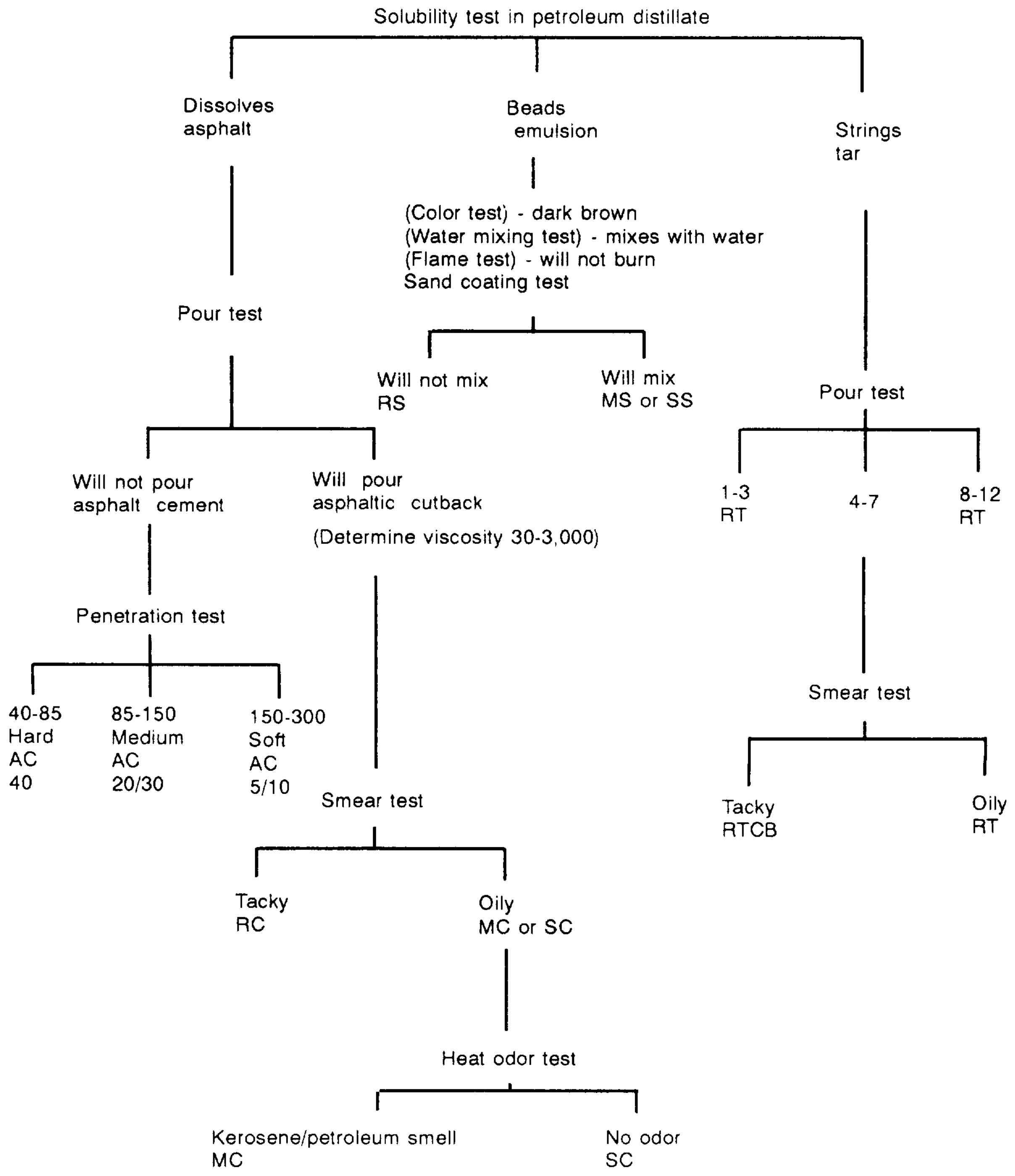


Figure 9-44. Identification of unknown bituminous materials

closed container in order to capture the escaping vapors, being careful not to apply too much heat. If the sample is an MC, it will have a strong petroleum or kerosene odor. On the other hand, if the sample is an SC, no kerosene or petroleum odor will be detected. It might smell somewhat like hot motor oil. The ability to distinguish an RC from an MC and an SC from either, is perhaps as important as any other part of field identification.

Asphalt Emulsions

Another asphaltic material used in paving work is an asphalt emulsion, which is a mixture of asphalt, water, and an emulsifying agent. It is easy to identify, since it is usually distinguished by its dark brown color, while the other bitumens are black, If mixed with kerosene or some other petroleum distillate, the emulsion can be detected by the appearance of small black globules or beads which fall to the bottom of the container. If mixed with water, an emulsion will accept the extra water and still remain a uniform liquid. The other bitumens will not mix with water. Since an emulsion contains water, a small piece of cloth saturated with it will not burn if a flame is applied. The other bitumens will burn or flame. After it has been established that the material is an emulsion, it is still important to know whether or not the emulsion is a mixing grade. The best way to tell if the emulsion is a mixing grade (slow-setting (SS) or medium-setting (MS)) is to try to mix a small amount (6 to 8 percent, by weight) with damp sand using a metal spoon. A rapid-setting (RS) emulsion cannot be mixed; it breaks immediately, gumming up the spoon with the relatively hard original asphalt cement. A SS or MS emulsion mixes nicely, coating the sand. Be careful not to add too much emulsion to the sand. This will saturate the sand and not give conclusive results. No further identification is necessary, since both MS and SS grades are largely used for the same jobs.

Road Tars

If the unknown bituminous material did not dissolve in the volubility test but formed a stringy mass, as shown in Figure 9-44, the material is a tar. The next step is to determine its viscosity grade by the pour test. By comparing the flow to that of common materials, such as water or honey, the viscosity of the tar may be closely estimated. The grades vary from road tar (RT)-1 to RT-12. If the identified tar has a viscosity in the range of RT-4 to RT-7 material, a smear test must be performed to determine whether it is a road tar or a road-tar cutback. The smear test is performed in the manner previously described for cutback asphalt. A great increase in stickiness in about 10 minutes identifies a road-tar cutback. No apparent change in consistency after 10 minutes indicates a road tar. It does not matter which grade of cutback is available, since both are used under approximately the same conditions.

AGGREGATE IDENTIFICATION

The aggregate must also be tested to determine its suitability for bituminous construction. The desirable characteristics of an aggregate used in bituminous construction include—

- Angular and rough.
- Tough, hard, and durable.
- Clean and dry.
- Hydrophobic.

Available aggregate may not always have all desirable characteristics. An aggregate meeting most of the requirements is usually selected, unless rejected for reasons such as availability, length of haul, or difficulty in conducting borrow-pit or quarry operations.

Angular and Rough

The aggregate in a pavement must transmit the traffic load to the base, usually by the interlocking and surface friction of the different particles. Angular particles with a rough texture arc best for this purpose since they do not tend to slide past each other. More binder may be required since the angular shape has a greater surface-area-per-unit volume than a round particle.

Tough, Hard, and Durable

The aggregate must withstand loads without cracking or being crushed. Resistance to weathering is also a function of the durability. The resistance-to-wear of an aggregate can be determined by the Los Angeles Abrasion Test, if the equipment is available. The equipment and procedures are detailed in the American Association of State Highway and Transportation Officials (AASHTO) method T96. The equipment for the above test is usually not available for field testing. The Mob's hardness scale may be used to determine the hardness of the aggregate. The Mob's scale ranges from 1 for talc or mica to 10 for diamond. By trying to scratch the aggregate or the common materials and vice versa, it is possible to establish which is harder; from this analysis the hardness of the aggregate can be determined. If both materials scratch each other, the hardness of each is the same. Be sure to rub the "scratch" mark to see that it is really a scratch and not a powdering of the softer material. Some common materials and their hardness are: fingernail, about 2: copper coin, between 3 and 4; and knife blade, nail, and window glass, about 5.5. If the material can be scratched with one of these common items, it is considered to be soft. If it cannot be scratched, it is considered to be hard.

Clean and Dry

The bituminous binder must penetrate into the pores of the aggregate and adhere to the surface of the particles. Coated (with clay or dust) or water-filled aggregate will prevent the penetration or the adherence of the binder and result in stripping of the binder. For hot mixes, the aggregate must be hot as well as dry. If the aggregate is not clean, it should be washed either as part of the crushing operation or by spreading it on a hard surface and hosing it with water. When washing is impractical, dry screening may remove a great deal of dust and clay. Hand picking may be necessary if no other method can be used. The aggregate should be made as clean as possible with the equipment and manpower available.

Hydrophobic

Affinity for water can make an aggregate undesirable. If the aggregate is porous and absorbs water easily (hydrophilic), the binder can be forced out of the pores. When this happens, the bond between the aggregate and binder weakens and breaks and *stripping* occurs. Stripping is the loss of the bituminous coating from the aggregate particles due to the action of water, leaving exposed aggregate surfaces. One of the following three tests can be used to determine the detrimental effect of water on a bituminous mix:

Stripping Test. A test sample is prepared by coating a specific amount of aggregate with bituminous material at the applicable temperature for the grade of bitumen to be used. The mixture is spread in a loose, thin layer and air-cured for 24 hours. A representative sample is placed in a jar (up to no more than one-half of its capacity) and covered with water. The jar is closed tightly and allowed to stand 24 hours. At the end of 24 hours, the jar with the sample is vigorously shaken for 15 minutes. A visual examination is made to determine the percentage of exposed aggregate surface which is reported as percent stripping.

Swell Test. Asphaltic mixtures containing fines of doubtful quality are sometimes measured for swell as a basis for judging the possible effects on a pavement. This test is more frequently used with dense-graded mixtures using liquid asphalts. A sample of the mix is compacted in a metal cylinder and cooled to room temperature. The specimen and mold are placed in a pan of water and a dial gage is mounted above the sample in contact with the surface. An initial reading is taken. The specimen is allowed to soak for a specified period (usually 24 hours) or until there is no further swelling. Another reading of the dial is taken. The difference in reading is the swell of the mixture. Experience has shown that bituminous pavement made with clear, sound stone; slag; or gravel aggregate and mineral filler produced from limestone will show test values of less than 1.5 percent. Aggregates of doubtful character should be tested for conformance to ASTM tests.

CONSTRUCTION METHODS

PRIME COAT

A prime coat is used when a surface treatment or pavement is placed on a soil or aggregate base. The prime coat should penetrate the base about 1/4 inch, filling the voids. The prime coat acts as a waterproof barrier to prevent moisture that may penetrate the wearing surface from reaching the base. Also, the bitumen acts as a bonding agent, binding the particles of the base to the wearing surface. Plan priming operations so that there will always be an adequate amount of cured, primed base ahead of the surfacing operations; but not so far ahead that the base will become dirty or completely cured *(dead)*. To preserve the base, a prime coat should be applied as soon as the base is ready; however, the prime coat will lose its effectiveness as a bonding agent if the wearing surface is not placed soon after curing.

Base Preparation

The base should be well-graded, shaped to the desired cross section, compacted to the specified density, well-drained, free from excessive moisture but not completely dry, and swept clean. The surface of the base should be broomed if it contains an appreciable amount of loose material, either fine or coarse, or if it is excessively dusty. When brooming is omitted, apply a prime coat to the base and lightly roll it with a pneumatic roller, or use a light sprinkling of water to settle the dust. Sprinkling is usually undesirable; but when it is necessary, lightly apply a spray of water at the rate of approximately 0.2 gallon to 0.3 gallon per square yard, depending on the condition of the base, the temperature, and the humidity. Completely cover the base with a minimum amount of water and allow it to become dry or almost dry before applying the prime coat so that it will absorb the prime material. If the base is too wet, it will not take the prime properly and the moisture will tend to come out, particularly in hot weather, and strip the prime from the base during construction. Rains also tend to strip the prime from a base that was too wet when primed. Heavy rains may also strip a properly primed base to some extent, but less than an improperly cured base. In general, the lowest acceptable moisture content for the upper portion of the base course prior to priming should not exceed one-half of the optimum moisture content. On the other hand, if the base dries out completely, cracks may develop and a heavy rain may then cause swelling and loss of density. See Chapter 5 of this manual for subgrade, subbase, and base-course preparation.

Materials

Bituminous materials used for prime coats will depend on the condition of the soil base and the climate. In moderate and warm climates, RT-2, RT-3, RT-4, MC-30, MC-70, SS-1, SS-1h, cationic slow-setting emulsified asphalt (CSS)-1, and CSS-1h are satisfactory. In cold climates, rapid-setting asphalt cutbacks, such as RC-70 and RC-250, have proved more satisfactory. If the climate is very cold, the prime coat may be eliminated because it is likely to be extremely slow in curing. RT-2 and MC-30 are satisfactory for a prime coat used on a densely graded base course. MC-70 is generally used on loosely bonded, fine-grained soils, such as well-graded sand. MC-250 is usually satisfactory for coarse-grained sandy soils.

The formula used to determine the quantity of prime coat material required is—

$$\frac{L \times (W + 2) \times AR \times LF}{9\ (\mathrm{ft}^2/\mathrm{yd}^2)} = Q_p \text{ Gallons}$$

where—

L = length of untreated surface in feet
W = width of untreated surface in feet
("+2" in the formula is to include for overspray of shoulders 1 foot on both side of the road.)
AR = application rate of prime coat in gallons per square yard

NOTE: AR for dense soils = 0.2, AR for soils with a lot of cracks = 0.5

LF = handing loss factor for prime coat (usually 1.05 - 1.10)
Q_p = quantity of prime-coat material in gallons

Example:

Compute the quantity (in gallons) of prime-coat material (Q_p) required to prime an untreated surface with dense soil. The surface is 1,000 feet long and 12 feet wide. Use a loss factor of 1.05.

Solution:

$$Q_p = \frac{L \times (W + 2) \times AR \times LF}{9\ (\text{ft}^2/\text{yd}^2)}$$

$$= \frac{1{,}000 \times (12+2) \times 0.2 \times 1.05}{9\ (\text{ft}^2/\text{yd}^2)}$$

$$= 326.67 \text{ or } 327 \text{ gallons}$$

TACK COAT

A tack coat is a sprayed application of a bituminous material that is applied to an existing wearing surface of concrete, brick, bituminous material, or binder course before a new bituminous pavement is placed over the existing surface. The purpose of the tack coat is to provide a bond between the existing pavement and the new surface. The tack coat should become tacky within a few hours. A tack coat is not required on a primed base unless the prime coat has completely cured and become coated with dust. Figure 9-45 shows the sequence of operations for the application of a tack coat. Operation of asphalt-surface-treatment equipment is explained in FM 5-434.

The procedure for estimating the bitumen required for a tack coat is similar to that described for a prime coat except that the tack coat is generally applied only over the proposed width of the pavement. The formula used to determine the quantity of tack coat required is--

$$\frac{L \times W \times AR \times LF}{9\ (\text{ft}^2/\text{yd}^2)} = Q \text{ gallons}$$

where—

L = length of treated section in feet
W = width of treated section in feet
AR = rate of application of bitumen in galions per square yard
LF = handling loss factor for bitumen (usually 1.05)
Q_t = quantity of tack coat material in gallons

The tack coat is generally applied only over the width of the existing area that is to be surfaced. A tachometer chart may be used to establish the rate of application, The usual rate of application vatries between 0.05 and 0.25 gallon per square yard. On a smooth, dense, existing surface, the minimum rate of 0.05 gallon per square yard should produce a satisfactory bond. If the surface is worn, rough, and cracked, the maximum rate of 0.25 will probably be required. An extremely heavy tack coat may be absorbed into the surface mixture resulting in a bleeding and flushing action and loss of stability. Roll the surface lightly with a rubber-tired roller or truck tires for uniform distribution of the bituminous material.

Example:

Compute the quantity (in gallons) of tack-coat material (Q_t) required to cover a worn, rough, and cracked surface. The surface is 1,000 feet long and 12 feet wide. Use a loss factor of 1.05.

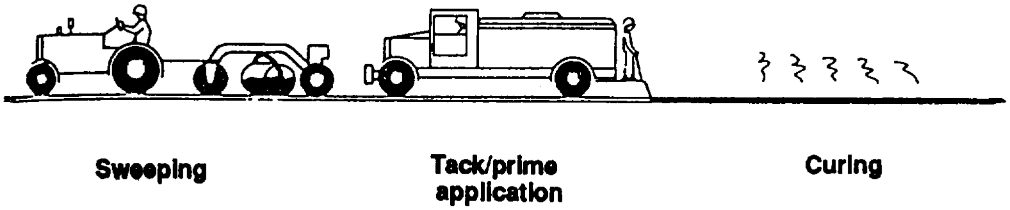


Figure 9-45. Tack-coat sequence of operations

Solution:

$$Q_t = \frac{L \times W \times AR \times LF}{9\ (ft^2/yd^2)}$$

$$Q_t = \frac{1{,}000 \times 12 \times 0.25 \times 1.05}{9\ (ft^2/yd^2)}$$

$$= 350.0 \text{ gallons (gal)}$$

DUSTPROOFING

Dustproofing consists of spraying an untreated surface with a diluted, slow-setting asphalt emulsion or a low-viscosity cutback The asphalt and dilutent penetrate the fine soil particles and adhere to the dust particles.

An asphalt cutback is usually sprayed at a rate of 0.1 to 0.5 gallon per square yard (gal/yd^2).. When using an emulsion, dilute it with up to five parts of water by volume. Diluted-emulsion rustproofing treatments usually require several treatments. The dust stirred by traffic between applications eventually conglomerates and no longer rises. This is an effective treatment in very dusty areas where one application of cutback asphalt is insufficient. In all cases, lay a test strip to determine what application rate will be the most effective. Apply with either an asphalt distributor or something as simple as a common watering can. Rustproofing is usually a short-lived solution and project plans should include regular inspections and maintenance, as required.

SPRAYING ASPHALT WITH COVERED-AGGREGATE AND SINGLE AND MULTIPLE SURFACE TREATMENTS

A sprayed asphalt with a cover-aggregate surface treatment consists of an application of asphalt followed by an application of aggregate. If the process is repeated, the resulting surfaces arc referred to as double, triple, quadruple, and so on, surface treatments, depending on the number of applications.

Apply these surface treatments on a primed, nonasphaltic base; an asphalt base course; or any type of existing pavement. This type of surface treatment, with a good prime coat (see preceding paragraph), provides the lowest-cost waterproof covering for a road surface. With good aggregate, this type of surface treatment will economically provide a wearing surface to meet the needs of medium and low volumes of traffic.

This type of surface treatment is very useful as a wearing surface on base courses in the staged construction of highways pending placement of asphalt-concrete surface courses.

Limitations in the use of sprayed asphalt with cover-aggregate surface treatments are—

- Weather conditions must be favorable.
- The surface on which the asphalt is sprayed must be hard, clean, and dry for the surface treatment to adhere properly.
- The amount and viscosity of the asphalt must be carefully balanced with the size and amount of cover-aggregate to assure proper retention of the aggregate.
- Heavy, high-speed traffic tends to dislodge the aggregate from the asphalt.

Because of these limitations, consider using plant-mix surface treatments when the above conditions are anticipated.

Single Surface Treatment

A single surface treatment usually consists of a sprayed application of a bitumen and an aggregate cover one stone thick. Surface treatment may be referred to as a seal coat, armor coat, or carpet coat. A single surface treatment, shown in Figure 9-46, is usually less than 1 inch thick. Surface treatments serve only as an abrasive and weather-resisting medium that waterproofs the base. They are not as durable as bituminous concrete and may require frequent maintenance. Although they are not recommended for airfields, they may be used as an expedient measure. They are particularly suitable for TO construction because they can be laid quickly with a minimum of materials and equipment, constructed in multiple layers with little interference to traffic, and used as the first step in stage construction. Surface treatment will not withstand the action of metal wheels on vehicles, tracked vehicles, or nonskid chains on vehicle wheels. Do not attempt surface treatments when the temperature is below 50° F.

The three requirements for a surface treatment arc as follows:

- The quality of the bitumen must be sufficient to bold the stone without submerging il.
- Sufficient aggregate must be used to cover the bitumen.
- The base course on which the surface treatment is laid must be sufficiently strong to support the anticipated traffic load.

Uniformly graded sand or crushed stone, gravel, or slag may be used for surface treatments. The purpose of the surface treatment dictates the size of aggregate to be selected. For example, coarse sand may be used for scaling a smooth, existing surface. For a badly broken surface, the maximum size of the aggregate should be about 3/4 inch; the minimum size should pass the No. 4 sieve. Surface treatments include the following: dust palliatives, prime coats, and sprayed asphalt with a cover aggregate (single and multiple surface treatments).

Material

RC and MC cutbacks, road tars, rapid-setting emulsions, and asphalt cements may be used for surface treatment. RC cutbacks are most widely used because they evaporate rapidly and the road can be opened to traffic almost immediately after applying the surface treatment. Viscosity grades of the bitumen depend on the size of aggregate used as cover stone. The larger particles of aggregate require a bitumen of higher viscosity so that the bitumen will hold the aggregate. For example, RC-70 or RC-250 may be used with coarse sand for a surface treatment to seal cracks in an otherwise satisfactory surface. For resurfacing a badly cracked or rough surface, RC-800 or RC-3,000 may be used with 3/4-inch aggregate.

To assure uniform distribution, the bitumen should be applied with a bituminous

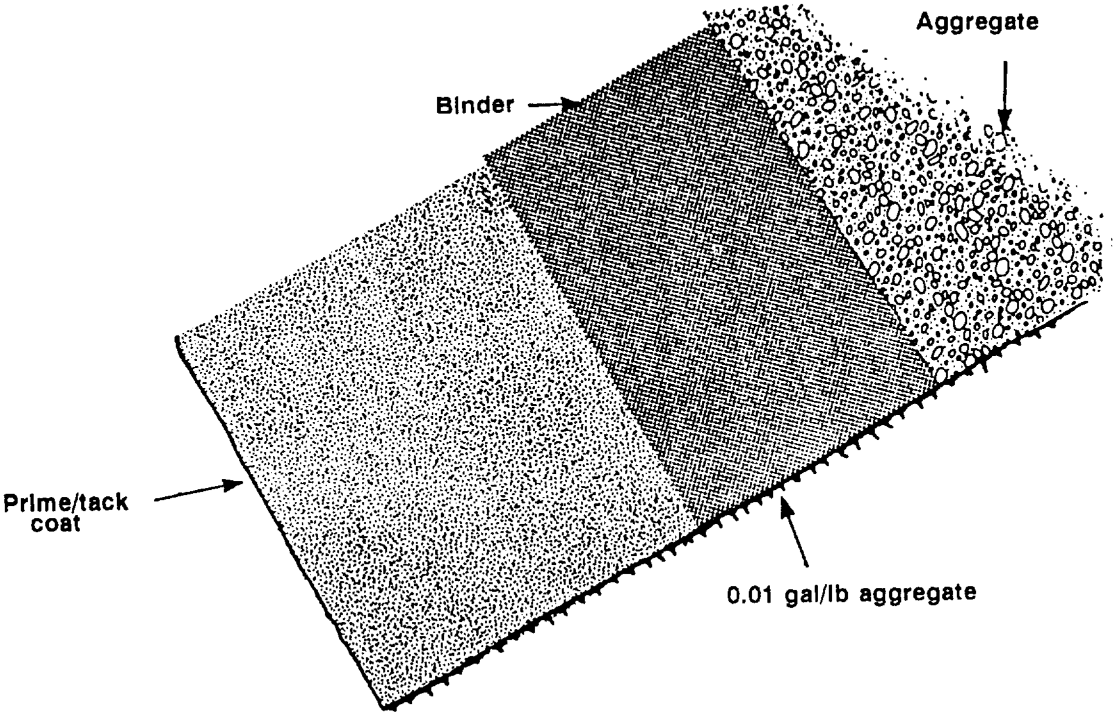


Figure 9-46. Single surface treatment

distributor. The quantity of the bitumen required is based on the average particle size of the cover stone. The bitumen must be sufficient to hold the aggregate in place without leaving a sticky surface. The aggregate must not be completely submerged in the bitumen. One-quarter-inch aggregate should be submerged approximately 30 percent: 3/8-inch aggregate, 32 percent; 1/2-inch aggregate, 35 percent; and 3/4-inch aggregate, 43 percent. Approximately 1 gallon of bitumen is usually used for 100 pounds of aggregate. The recommended rate of bitumen application is given by the following formula:

$$\frac{\text{wt of aggregate (lb)}}{\text{area (yd}^2\text{)}} \times \frac{\text{1 gal bitumen}}{\text{100 lb aggregate}}$$

$$= \text{quantity of bitumen in gal/yd}^2$$

Example:

Compute the recommended rate of bitumen application, in gallons per square yard, if 30 pounds of aggregate are required to cover an area of 1.0 square yard.

Solution:

$$\frac{\text{30 lb agg}}{\text{1 yd}^2} \times \frac{\text{1 gal bitumen}}{\text{100 lb agg}} = 0.30 \text{ gal/yd}^2$$

Requirements for a Surface Treatment

In bituminous surface treatments, the unit quantities of bitumen and aggregate can be determined by a test strip, by the specifications of the job, or by adding approximately 1 gallon of bitumen for every 100 pounds of aggregate or 0.1 gallon of bitumen for every 10 pounds of aggregate. The weight of the aggregate, one stone deep, required to cover 1 square yard is determined by spreading the aggregate to be used a depth of one stone over a measured surface, weighing it, and computing the amount in pounds per square yard.

The formula used to determine the quantity of binder material required for a surface treatment is—

$$\frac{L \times W \times AR_B \times AR_A \times LF}{9(ft^2/yd^2)} = Q_b \text{ Gallons}$$

where—

L = length of treated surface in feet
W = width of treated surface in feet
AR_B = application of bitumen in gallons per lb of aggregate (usually 1 gal per 100 lb aggregate or 0.01 gal per lb)
AR_A = application of aggregate in lb per square yard
LF = handling loss factor for bitumen
Q_b = quantity of binder material required in gallons
9 = square feet per square yard (ft^2/yd^2) conversion factor

Example:

Compute the required quantity of binder material needed for a single surface treatment. The surface is 1,000 feet long and 12 feet wide. Use a bitumen application rate of 0.01 gal per lb of aggregate and a loss factor of 1.05. The aggregate is 3/8-inch crushed stone with a unit weight of 100 lb/ft^3.

Solution:

Determine the application rate of the aggregate in pounds per square yard.

$$AR_A = 100\ lb/ft^3 \times (3/8\ in) \times (1\ ft/12\ in) \times (9\ ft^2/1\ yd^2)$$

$$= 28.125\ lb/yd^2$$

Now determine the binder quantity.

$$Q_b = \frac{L \times W \times AR_B \times AR_A \times LF}{9\ ft^2/yd^2}$$

$$= \frac{\substack{1{,}000 \\ ft} \times \substack{12 \\ ft} \times \substack{0.01 \\ gal/lb} \times \substack{28.125 \\ lb/yd^2} \times 1.05}{9\ ft^2/yd^2}$$

$$= 393.75 \text{ or } 394 \text{ gallons}$$

Multiple Surface Treatment

When a tougher, more resistant surface is desired than that obtained with a single surface treatment, a multiple surface treatment may be used. A multiple surface treatment is two or more successive layers of a single surface treatment (as shown in Figure 9-47). Smaller particles of aggregate and correspondingly less bitumen are used for each successive layer. Although multiple surface treatments are usually more than 1 inch thick, they are still considered surface treatments because each layer is usually less than 1 inch and the total surface treatment does not add to the load-carrying capacity of the base.

The first layer of a multiple surface treatment is laid according to instructions previously given for a single surface treatment. Loose aggregate remaining on the first layer must be swept from the surface so that the layers may be bonded together. As stated previously, the size of the aggregate and the amount of the bitumen will decrease for each successive layer. For the second layer, the bitumen will usually be reduced to one-third or one-half the amount of the first application. The aggregate used in the second application should be approximately one-half the diameter of that used in the first application. The final application of aggregate should be swept clean, if necessary, so that an even layer of aggregate will remain. It should also be rolled with a pneumatic roller so that the aggregate will become embedded in the bitumen. After the surface is rolled and cured, it is ready for traffic. If the multiple surface treatment has been laid on an airfield, loose aggregate must be swept from the surface so that it will not damage the aircraft. Final sweeping is also recommended for roads.

CONSTRUCTION OF SURFACE TREATMENTS USING SPRAYED ASPHALT WITH COVERED AGGREGATE

Weather

Weather conditions are an important factor for success in the construction of sprayed asphalt with covered-aggregate surface treat-

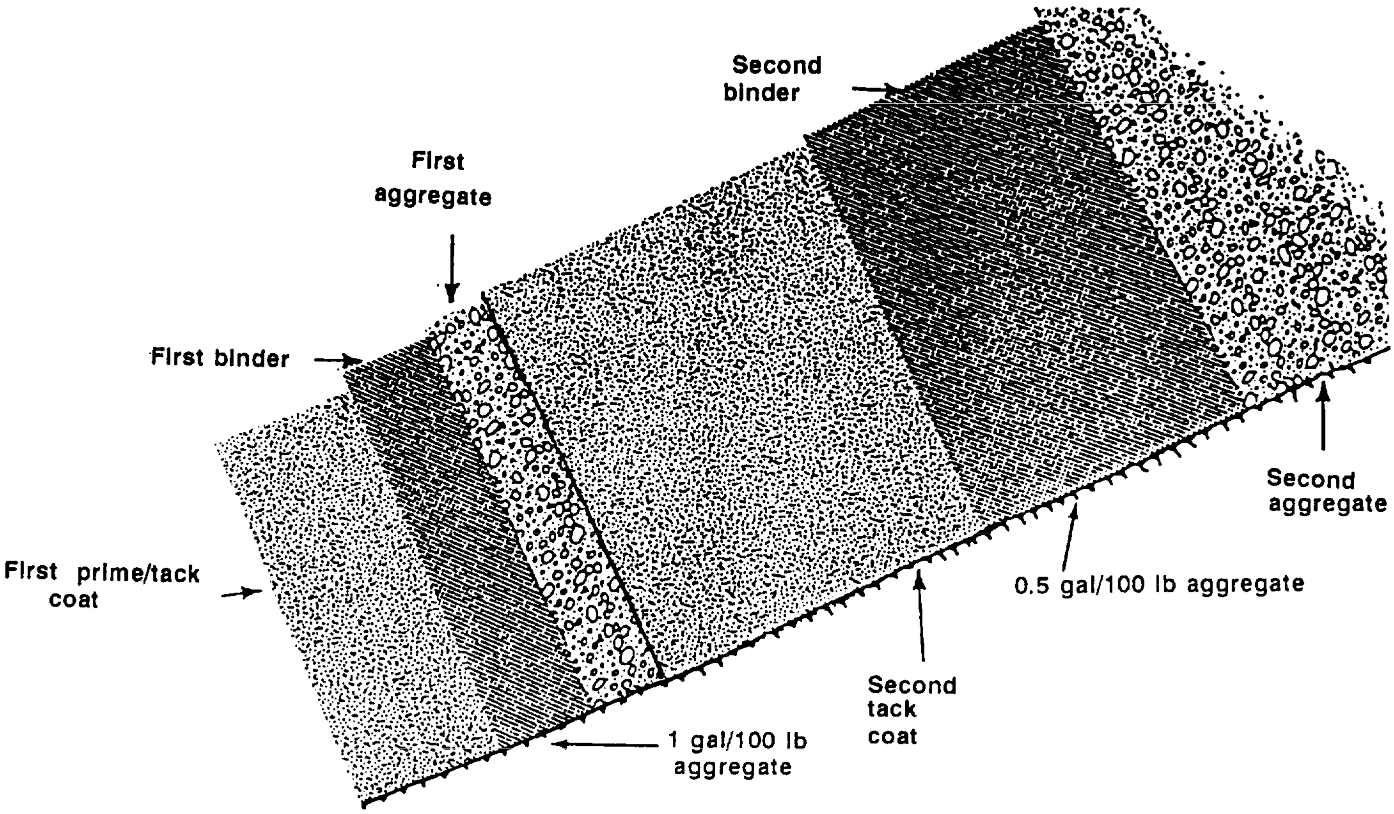


Figure 9-47. Multiple surface treatment

ments and seal coats. For best results in aggregate retention, the pavement temperature should be relatively high during the application of the seal coat and considerably lower before fast traffic is allowed to use the new seal coat. A certain amount of curing, or setting, is required even with the heaviest liquid-asphaltic materials. This curing takes place best when the air temperature is well above 50° F and the relative humidity is low, A survey of surface treatments rated excellent shows more than 85 percent were placed in the hot summer months. Every effort should be made to plan the work for placement in summer weather. After completion of the surface treatment, traffic should be controlled until the surface has cured.

Aggregate

Once an aggregate has been selected for use based upon the desirable characteristics, it is then necessary to determine what quantity of the aggregate will be required for a specific job. When placing a surface treatment with an aggregate cover, the quantity of aggregate required can be determined from the following formula:

$$\frac{L \times W \times AR_A \times LF}{9 \times 2{,}000} = Q_A \text{ Tons}$$

where—

L = length of treated surface in feet

W = width of treated surface in feet

LF = handling loss factor for aggregate (10 percent or 1.10).

AR_A = application rate for aggregate

Q_A = quantity of aggregate in tons

The materials for a multiple surface treatment are determined by the same method as above except that the results are multiplied by the number of treatment passes, The aggregate size (not quantity) must be cut in half for the second layer and each layer thereafter.

Spreading Aggregate. Before the application of asphalt begins, an adequate aggregate spreader should be available and properly adjusted for the aggregate actually to be used. The spray-bar width of the bituminous distributor should be equal to the width of the aggregate being spread in one pass. Normally, this is the width of one traffic lane. An adequate supply of aggregate should be on hand to cover the asphalt that has been spread, without interruption, in the shortest practical time after the asphalt hits the surface. In addition, the aggregate spreader should be filled, in place, and ready to spread aggregate before commencing the asphalt spray. A common fault is to operate the distributor too far ahead of the aggregate spreader.

Aggregate spreaders vary from a simple, controllable gate box attached to the dump truck, to very efficient, self-propelled units which apply the larger-size aggregate on the bottom and the finer on top. The more efficient, self-propelled units are most desirable.

Standard, Hopper-Type Aggregate Spreaders. The standard aggregate spreader shown in Figure 9-48 can handle aggregate which ranges from sand to 1 1/2-inch gravel. The rate and depth of application depend upon the gate opening. The width of spread may be varied from 4 to 8 feet in 1-foot increments. Depending upon the manufacturer, the spreader has either two or four wheels. It hooks on the rear of a 5-ton dump truck and the truck backs up. This allows the aggregate to be spread on the bitumen ahead of the truck tires, thus preventing pickup of the bitumen. As a safety precaution, men should not be allowed to stand on the aggregate, either in the truck or in the spreader, at any time.

Rolling. Pneumatic-tire rollers should be used for surface-treatment construction. Steel-wheeled rollers are not recommended for rolling, but if they are all that is avail-

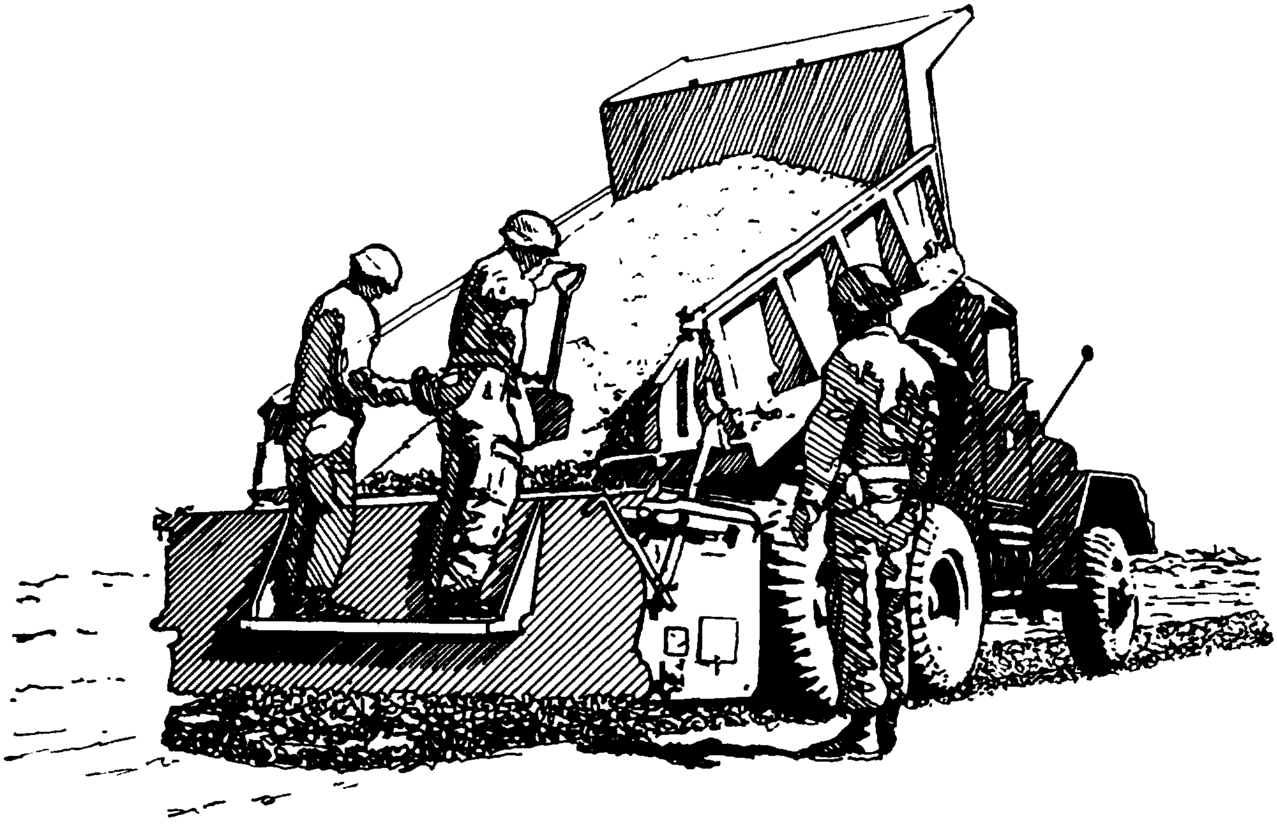


Figure 9-48. Typical hopper-type aggregate spreader

able, rollers should not be so heavy as to crush the aggregate particles. Pneumatic-tire rollers are essential to firmly embed the aggregate into low areas or graded deformities that would normally be bridged over by use of steel-wheel rollers and to produce conformity across the width of the roadway, particularly over the outer quarters of the surface where there is the least traffic. The rollers should be heavy enough to properly imbed the aggregate, but rolling should be stopped as soon as crushing becomes evident. When double or triple surface treatments are used, each course should be rolled before subsequent applications of asphalt. When an asphalt fog seal is used, it should be applied after the rolling is completed.

Traffic Control. It is extremely important that traffic be controlled to prevent loss of aggregate. One method of controlling traffic is to form a single line of traffic behind a pilot vehicle with a red flag between stops at each end of the work area.

The Asphalt Distributor

The asphalt distributor is the key piece of equipment in the construction of surface treatments. It consists of a truck (or a trailer) equipped with a mounted, insulated tank with a heating system, usually oil-burning, with direct heat from the flue passing through the tank. It is further supplied with a power-driven pump, suitable to handle products ranging from light, cold-application liquid asphalt to heavy asphalt cements heated to spraying viscosity. Attached to the back end of the tank is a system of spray bars and nozzles through which the asphalt is forced under pressure onto the construction surface. The construction of the spray bars should be such that there will be full circulation of the asphalt through the bar when not spraying. These spray bars should have a minimum application width of 8 feet. On larger equipment, the spray bars will cover as much as a 24-foot width in one pass when equipped with a suitable capacity pump. The height of the spray bar determines the type of coverage: single lap, double lap, or triple lap, as shown in Figure 9-49. A suitable thermometer should be installed in the tank to readily ascertain the temperature of the contents. A connection should be available to attach a hose for a single- or double-nozzle outlet to cover areas not reached by the spray bars or as a means of forcing a stream of asphalt to a desired point as in subsealing rigid, slab pavements. Distributors are made in sizes ranging from 800- to 4,000-gallon capacity. Some maintenance distributors as small as 400 gallons are available.

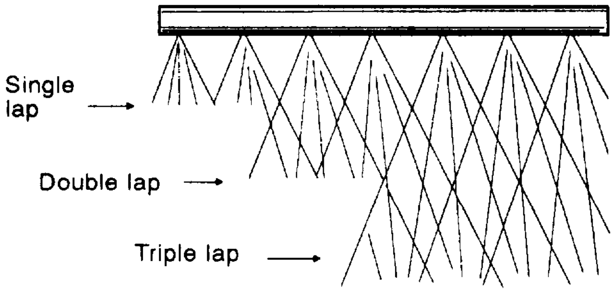


Figure 9-49. Spray bar coverage

It is essential that the distributor be capable of distributing the asphalt uniformly over the surface to be treated. For best results in surface treatments, observe the following points:

- Maintain uniform pressure and temperature on all spray nozzles. The fan of the spray from each nozzle must be uniform and set at the proper angle with the spray bar (according to the manufacturer's instructions) so that the spray fans do not interfere with each other.
- Maintain the spray bar at the proper height above the road surface (according to the manufacturer's instructions) 10 provide complete and uniform overlap of the spray fans.
- Ensure that the distributor road speed is uniform.
- Before beginning work, check the spread of the distributor spray bar.

Valve action should be instantaneous, both in opening and closing. The spraying operation should be inspected frequently to ensure that the nozzles are the proper height from the road surface and working fully. An otherwise good job may be spoiled if one or more spray nozzles are clogged.

MAINTENANCE AND REPAIR OF BITUMINOUS SURFACES

Inspection

Maintenance patrols frequently inspect bituminous pavements for early detection of failures. Small defects quickly develop into larger ones under the effects of weather and traffic and may result in pavement failure unless promptly corrected. Minor repairs are quickly made with small crews and hand-tools, with a minimum interruption of traffic. Larger bituminous repairs require more time, personnel, and equipment, and may result in interference with traffic or, in extreme cases, require construction of detours to avoid complete stoppage.

Patches

All patches should be trimmed square or oblong with straight, vertical sides running parallel and perpendicular to the centerline of the traffic area.

Temporary Repairs

Any stable material may be used for temporary repairs in combat areas or where suitable material is not available and the traffic area must be patched to keep traffic moving. Good-quality soil and masonry or concrete rubble are suitable for this purpose. All such patches must be thoroughly compacted and constantly maintained with replacement material. More permanent patching should be accomplished as soon as possible.

Maintenance of Shoulders

Shoulders are bladed to facilitate drainage of rainwater from the surface. Ruts and washouts are filled. Shoulder material is kept graded flush against pavement edges to restrict seepage of water to the subgrade and to prevent breaking of the pavement edge by traffic driving off the pavement onto the shoulder. Material displaced from shoulders is replaced with new material as required.

GENERAL ROAD STRUCTURAL DESIGN

TO roads will normally be designed as unsurfaced, aggregate, or flexible-pavement systems. The design procedure for each type first involves assigning a class (A - G) designation to the road based upon the number of vehicle passes per day. A *design category* (I - VII) is then assigned to the traffic based upon the composition of the traffic. A *design index* (1-10) is determined from the design category and road class. This design index is used to determine either the CBR strength requirements of the unsurfaced roads or the thickness of the aggregate surface or flexible-pavement system required above a soil with a given CBR strength.

NOTE: As mission requirements change (a forward-area road becomes a rear-area road), the road class and design index will change. The design procedures outlined in this section allow for the easy upgrading of roads as the mission changes. This ensures the ability to easily convert an unsurfaced road to an aggregate-surfaced road to a flexible-pavement road without major changes in the design procedure.

CLASSES OF ROADS

The classes of roads vary from A to G. Selection of the proper class depends upon the traffic intensity and is determined from Table 9-8.

Table 9-8. Road-class selection criteria

Road Class	Number of Vehicles Per Day
A	10,000
B	8,400-10,000
C	6,300-8,400
D	2,100-6,300
E	210-2,100
F	70-210
G	Under 70

Table 9-9. Pneumatic-tired traffic categories based on traffic composition

Traffic Category	Percentage of total traffic for vehicle groups		
	Group 1	Group 2	Group 3
Category I	≥ 99%	≤ 1%	■
Category II	≥ 90%	≤ 10%	
Category III	≥ 84%	≤ 15%	≤ 1%
Category IV	≥ 65%	≤ 25%	≤ 10%
Category IVA	Any amount	> 25%	> 10%

DESIGN INDEX

The design of roads will be based on a design index representing all traffic expected to use the road during its life. The design index is based on typical magnitudes and compositions of traffic reduced to equivalents in terms of repetitions of an 18,000-pound, single-axle, dual-wheel load. For designs involving pneumatic-tired vehicles, traffic is classified into three groups, as follows:

- Group 1. Passenger cars and panel and pickup trucks.
- Group 2. Two-axle trucks (excluding pickup trucks).
- Group 3. Three-, four-, and five-axle trucks.

Traffic composition will then be grouped into the following categories (summarized for easy reference in Table 9-9):

- Category I. Traffic composed primarily of passenger cars and panel and pickup trucks (Group 1 vehicles) but containing not more than 1 percent two-axle trucks (Group 2 vehicles).
- Category II. Traffic composed primarily of passenger cars and panel and pickup trucks (Group 1 vehicles), and containing as much as 10 percent two-axle trucks (Group 2 vehicles). No trucks having three or more axles (Group 3 vehicles) are permitted in this category.
- Category III. Traffic containing as much as 15 percent Group 2 but with not more than 1 percent of the total traffic composed of trucks having three or more axles (Group 3 vehicles).
- Category IV. Traffic containing as much as 25 percent Group 2 but with not more than 10 percent of the total traffic composed of trucks having three or more axles (Group 3 vehicles).
- Category IVA. Traffic containing more than 25 percent Group 2 or more than 10 percent trucks having three or more axles (Group 3 vehicles).

The design index to be used, if designing a road for the usual pneumatic-tired vehicles, will be selected from Table 9-10 based on

Table 9-10. Design index for pneumatic-tired vehicles

	Design Index				
Class	Category I	Category II	Category III	Category IV	Category IVA
A	2	3	4	5	6
B	2	2	4	5	6
C	2	2	4	5	6
D	1	2	3	4	5
E	1	2	3	4	5
F	1	1	2	3	4
G	1	1	1	2	2

the road class (A to G) and category (I to IVA) .

Where tracked vehicles or forklift trucks are involved in the traffic composition, the following three considerations apply:

- Tracked vehicles not exceeding 15,000 lb and forklift trucks not exceeding 6,000 lb are treated as two-axle trucks (Group 2 vehicles) in determining the design index.

- Tracked vehicles exceeding 15,000 pounds but not 40,000 pounds and forklift trucks exceeding 6,000 pounds but not 10,000 pounds are treated as three-axle trucks (Group 3 vehicles) in determining the design index.

- Traffic composed of tracked vehicles exceeding 40,000 pounds and forklift trucks exceeding 10,000 pounds has been divided into the three categories shown in Table 9-11.

Table 9-11. Tracked-vehicle and forklift traffic categories

	Vehicle Weight, Pounds	
Category	Tracked Vehicles	Forklift Trucks
V	40,001-60,000	10,001-15,000
VI	60,001-90,000	15,001-25,000
VII	Over 90,000	Over 25,000

Roads sustaining traffic of tracked vehicles weighing less than 40,000 pounds and forklift trucks weighing less than 10,000 pounds will be designed according to the pertinent class and category from Table 9-10, page 9-59. Roads sustaining traffic of tracked vehicles heavier than 40,000 pounds and forklifts heavier than 10,000 pounds will be designed according to the traffic intensity and category from Table 9-12.

NOTE: DO NOT include any wheeled vehicles in the total number of tracked vehicles and forklifts when using Table 9-12.

Design Life

The life assumed for design is less than or equal to 5 years. For a design life of more than 5 years, the design indexes in Tables 9-10 and 9-12 must be increased by one. Design indexes below 3 need not be increased.

Entrances, Exits, and Segments

Regardless of the design class selected for hardstands, special consideration should be given to the design of approach roads, exit roads, and other heavy-traffic areas. Failure or poor performance in these channelized traffic areas often has greater impact than localized failure on the hardstand itself.

Since these areas will almost certainly be subjected to more frequent and heavier loads than the hardstand, the design index used for the primary road should be used for entrances and exits to the hard stand.

Table 9-12. Design index for tracked vehicles and forklifts

Traffic Category	Number of Vehicles per Day (or Week as Indicated)							
	500	200	100	40	10	4	1	1 Per Week
V	6	6	6	6	5	5	5	--
VI	9	8	7	6	6	6	5	5
VII	10	10	9	9	8	7	6	5

NOTE: If number of vehicles is between values, round up to the next higher number.

In the case of large hardstands having multiple uses and multiple entrances and exits, consideration should be given to partitioning and using different classes of design. The immediate benefits that would accrue include economy through elimination of excessive design in some areas and better organization of vehicles and equipment.

UNSURFACED ROADS

An unsurfaced road is one in which the in-place natural soil or borrow soil is used as the road surface. Typically, the construction effort required includes only clearing and grubbing followed by scarifying grading, and compacting.

Designing unsurfaced roads consists of the following steps:

1. Estimate the number of passes of each type of vehicle expected to use a road on a daily basis.

2. Select the proper road class based upon the traffic intensity from Table 9-8, page 9-59.

3. Determine the traffic category based upon the traffic composition criteria shown in Table 9-9, page 9-59.

4. Determine the design index from Table 9-10, page 9-59, or Table 9-12.

5. Read the soil-surface strength required to support the design index from Figure 9-50.

6, Check whether the design (compacted) CBR value of in-place soil exceeds the CBR value required. If the in-place design CBR value is less than the CBR required, the engineer must decide whether 10 decrease the design life or improve the in-place soil to meet the CBR required by one of the following methods: soil stabilization, soil treatment, or placing aggregate.

7. Determine the required unsurfaced-soil thickness. Given the required CBR from step 6 and the design index from step 4, the required unsurfaced-soil thickness or depth of compaction can be obtained from Figure 9-51, page 9-62.

Example (Unsurfaced-Road Design):

To illustrate the procedure for determining soil-surface strength requirements, assume that an unsurfaced road is to be used one year. The road will be subjected to the following average daily traffic:

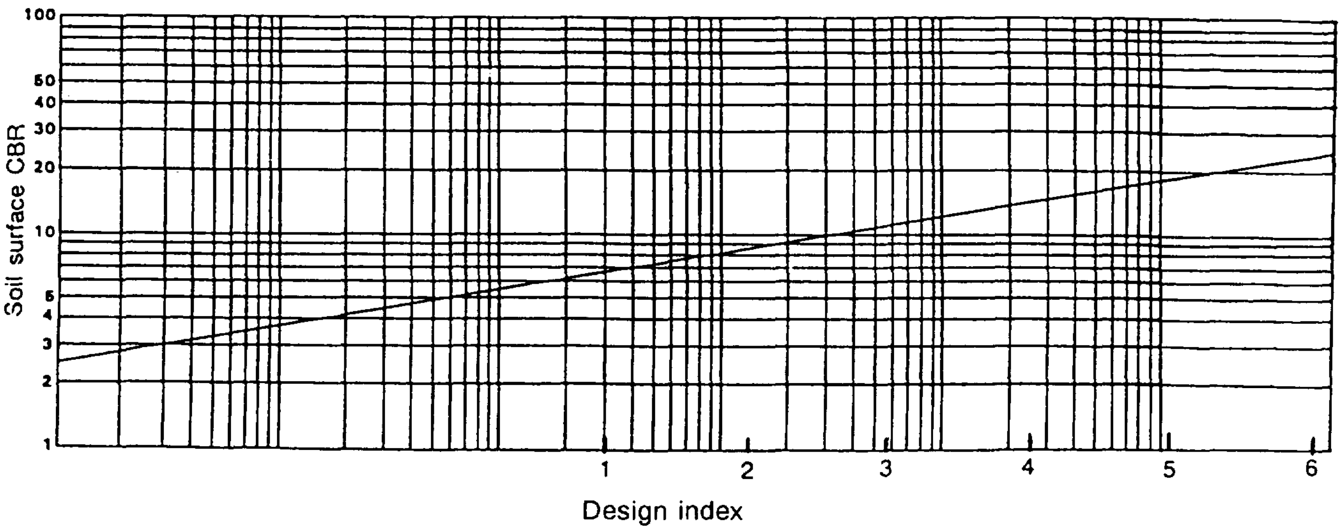


Figure 9-50. Unsurfaced-soil strength requirements

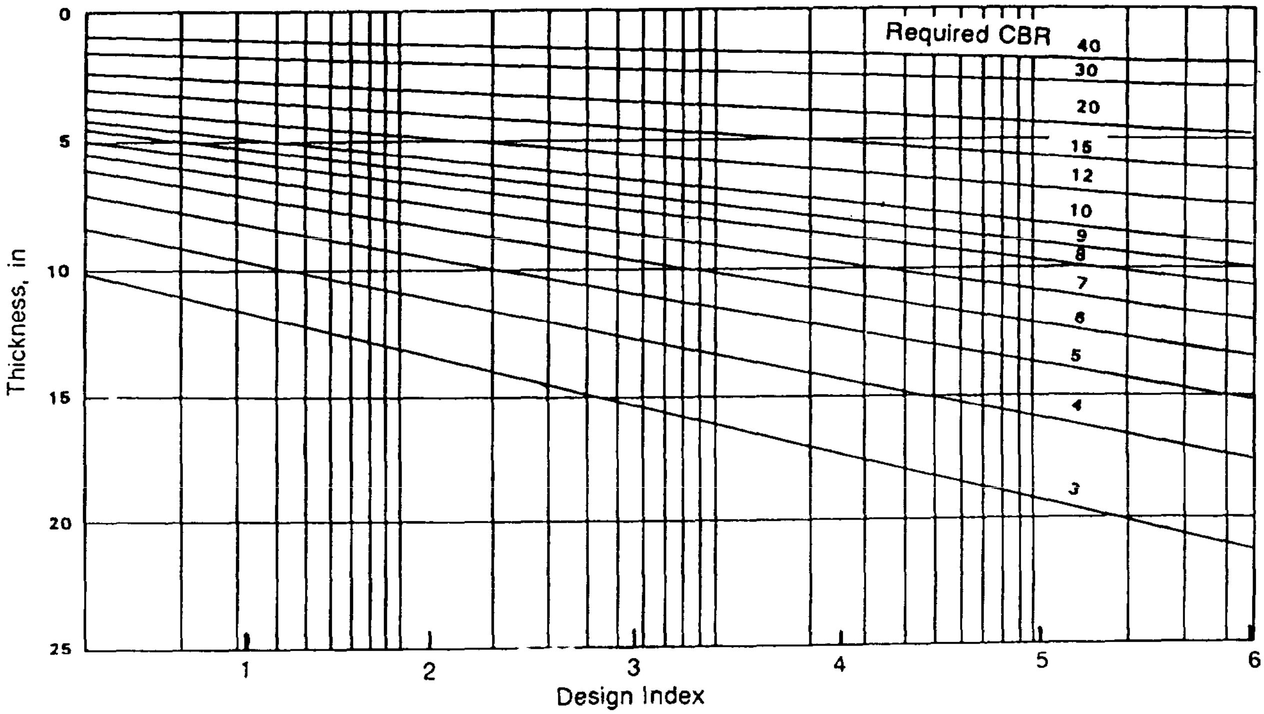


Figure 9-51. Unsurfaced-soil thickness requirements

Vehicle	Average Daily Traffic
M998 HMMWV (two axle)	180
M929 5-ton dump truck (three axle)	50

Solution:

1. Determine the average daily traffic (given).

2. Select road class E from Table 9-8, page 9-59, based upon 230 vehicles per day.

3. Select traffic category IVA, based upon the percentage of Group 3 vehicles.

4. The design index is 3 from Table 9-10, page 9-59.

5. The soil-surface strength reequirement for a design index of 3 is 10.8 CBR.

6. Check to ensure the design CBR value of the in-place soil exceeds the 10.8 CBR required. If not, consider using either soil stabilization or an aggregate road.

7. Determine the required unsurfaced-soil thickness from Figure 9-51. Given a design index of 3 and a required CBR of 10.8, the required thickness from Figure 9-51 is 6 inches.

AGGREGATE-SURFACED ROADS

The design of aggregate-surfaced roads is similar to the design of unsurfaced roads. However, in aggregate-surfaced roads. Layers of high-quality material are placed on the natural subgrade to improve its strength.

Materials

Materials used in aggregate roads must meet the requirements as stated in Chapter 5 of this manual and in the following paragraphs. The materials should have greater strength than the subgrade and should be placed so that the higher-quality material is placed on top of the lower-quality material.

Table 9-13. Compaction criteria and CBR requirements for an aggregate road structure

CBR requirements	Layer	Compaction requirements
50, 80, 100	Base course	100 - 105%
20 - 50	Subbase course	100 - 105%
0 - 20	Select material	Cohesive: 90 - 95% Cohesionless: 95 - 100%
	Design subgrade (SCIP)	Cohesive: 90 - 95% Cohesionless: 95 - 100%
	Uncompacted subgrade	

NOTES:

1. All lifts in a road design must be at least 4 inches.
2. A cohesive soil is one with a PI above 5.
3. A cohesionless soil is one with a PI of 5 or less.
4. Percent compaction Is compared to the CE 55 curve according to ASTM D1557.

Select and Subbase Materials

Select and subbase materials used in aggregate and flexible-pavement roads must meet the requirements of Table 9-13.

Base Course

Only good-quality materials should be used in base courses of heavy-duty aggregate roads. Specifications for graded, crushed aggregate; lime rock; and stabilized aggregate may be used without qualification for design of roads, streets, and parking areas.

Specifications for dry and water-bound macadam base courses may be used for design of heavy-duty roads only when the following two conditions are satisfied:

- The cost of the dry or water-bound macadam base does not exceed the cost of a stabilized, aggregate base course.
- The construction unit has the equipment and expertise to place a macadam surface (wet or dry) to acceptable standards of smoothness and grade.

Design CBR of Base Course. Where subbase material is used for base-course construction, the base course CBR must be at least 50 and the material must conform to the gradation and Atterberg limit requirement for a 50-CBR subbase as shown in Table 9-14. Otherwise, the design CBR of the base course must meet the requirements of Table 9-15, page 9-64.

Gradation Requirements. Gradation requirements for aggregate-surfaced roads and for macadam base courses are given in Chapter 5.

Table 9-14. Maximum permissible values for subbases and select materials

		Maximum Permissable Values for Gradation and Atterberg Limits				
		Gradation Requirements Percent Passing				
Material	**Maximum Design CBR**	**Size In**	**No 10 Sieve**	**No 200 Sieve**	**Liquid Limit**	**Plasticity Index**
Subbase	50	2	50	15	25	5
Subbase	40	2	80	15	25	5
Subbase	30	2	100	15	25	5
Select material	20	3	--	--	35	12

Table 9-15. Assigned CBR ratings for base-course materials - aggregate-surfaced road

Number	Type	Design CBR
1	Graded crushed aggregate	100
2	Water-bound macadam	100
3	Dry-bound macadam	100
4	Lime rock	80
5	Stabilized aggregate	80
6	Soil cement	80
7	Sand shell or shell	80

NOTE: It is recommended that stabilized-aggregate base-course material not be used for tire pressures in excess of 100 psi.

Thickness Requirements. Thickness requirements for aggregate-surfaced roads are determined from Figure 9-52, page 9-65, for a given soil strength and design index. The minimum thickness requirement will be 4 inches.

Figure 9-52 provides the thickness of aggregate based on CBR and design index. The thickness determined from the figure may be constructed of compacted granular fill for the total depth over the compacted subgrade or in a layered system of granular fill with subbases for the same total depth. The layered section must be checked to ensure that an adequate thickness of material is used to protect the underlying layer based on the CBR of the underlying layer. The granular fill may consist of base, subbase, and select material, provided the top 4 inches meet the gradation requirement ts

Compaction Requirements

Compaction requirements for the subgrade and granular layers are expressed as a percent of maximum CE 55 density as determined by using MIL-STD-621 Test Method 100.

Normal Subgrades. Compact the subgrade to 90-percent CE 55 density for cohesive soils (PI>5; LL>25) and 95-percent for cohesionless soils (PI≤5; LL≤25).

NOTE: It may be possible to compact the subgrade material to the required density in its natural state. However, in cases where the moisture content is out of the specification range, it may be necessary to scarify the soil (thereby aerating the soil to adjust the moisture content) and then compact. This process is called scarify and compact in place (SCIP).

Special Subgrades. The procedures for compacting subgrades of clays that lose strength when remolded, silts that become quick when remolded, and soils with expansive characteristics are described in Chapter 5 of this manual.

Subgrade in cuts and fills must have densities equal to or greater than the values shown in Table 9-13, page 9-63, except that fills will be placed at no less than 95 percent density for cohesionless soils or 90 percent for cohesive soils.

Where this is not the case for cuts, the subgrade must (1) be compacted from the surface to meet the densities shown; (2) be removed and replaced, in which case the requirements given above for fills apply; or (3) be covered with sufficient select material, subbase, and base so that the uncompacted subgrade is at a depth where the in-place densities are satisfactory.

Depth of Compaction. Compact the subgrade to the depth specified in Table 9-16, page 9-66, for cohesive soils (PI > 5) and Table 9-17, page 9-66, for cohesionless soils (PI ≤ 5).

NOTE: When depth of compaction from Table 9-16 or 9-17 is not feasible or attainable in cut sections, perform a 6-inch SCIP and continue design based on the uncompacted subgrade CBR.

Select Materials. The procedure is the same as for the subgrade.

Subbase. Compact the subbase to not less than 100-percent CE 55 density.

Base Course. Compact the base course to the maximum degree practicable but not less than 100-percent CE 55 density.

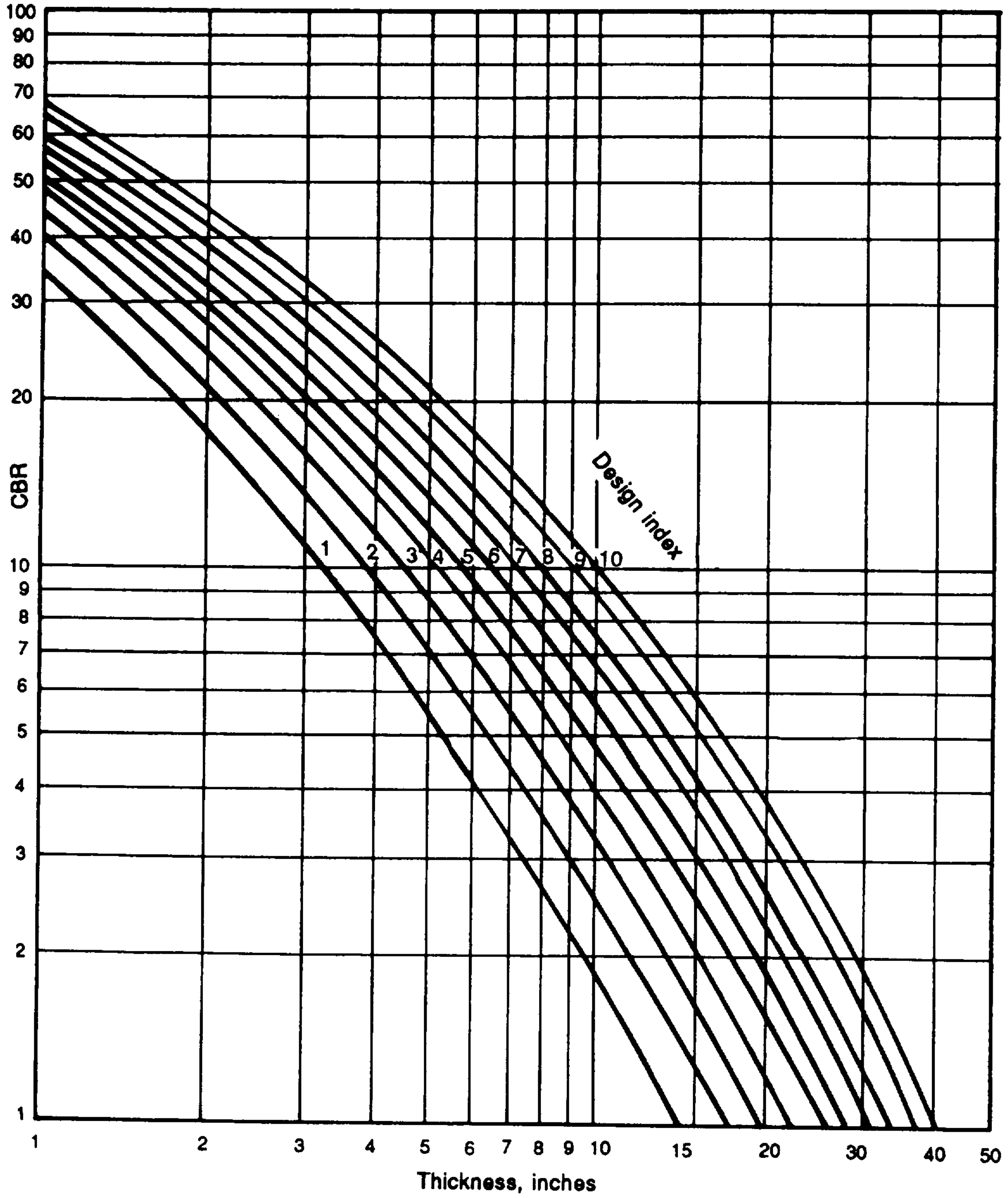


Figure 9-52. Design curves for aggregate-surfaced roads.

Table 9-16. Required depth of subgrade compaction for roads, cohesionless soils

Percent Compaction	Depth of Compaction (in inches) for Indicated Design Index									
	1	2	3	4	5	6	7	8	9	10
95-100[1]	7	8	10	11	12	14	15	17	19	21
90-95[2]	10	12	14	16	18	20	22	24	28	30

[1] Normally used.
[2] Use if on-site test strip results show the 95-100 range is not attainable.

Table 9-17. Required depth of subgrade compaction for roads, cohesive soils (PI>5)

Percent Compaction	Depth of Compaction (in inches) for Indicated Design Index									
	1	2	3	4	5	6	7	8	9	10
90-95[1]	6	7	8	9	10	11	12	13	15	17
95-100[2]	6	6	6	6	7	7	8	9	10	11

[1] Normally used.
[2] Use if on-site test strip results show these ranges are attainable, and shear failure is unlikely..

Design Steps for Aggregate-Surfaced Roads

1. Estimate the number of passes of each type of vehicle expected to use the road on a daily basis.
2. Select the proper road class based upon the traffic intensity from Table 9-8, page 9-59.

3. Determine the traffic category based upon the traffic-composition criteria given in Table 9-9, page 9-59.

4. Determine the design index from Table 9-10, page 9-59, or Table 9-12, page 9-60.

5. Check soils and construction aggregates using standard criteria in Tables 5-4, page 5-12; 9-14, page 9-63; and 9-15, page 9-64.

6. Determine the depth of compaction for the subgrade soil from Table 9-16 or 9-17,

7. Determine the total road-structure thickness and cover requirements.

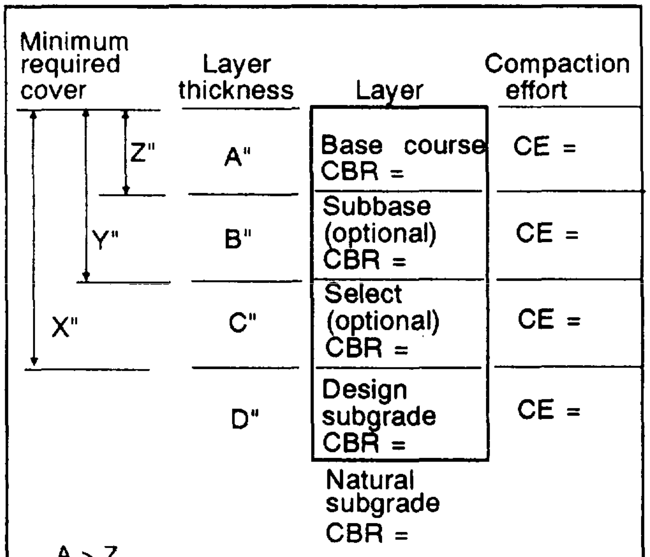
a. Enter Figure 9-52, page 9-65, for each layer of soil or aggregate with the following information:

—Design index.
—Design CBR values for subgrade, select, and subbase materials.

b. Determine the minimum cover thickness, in inches, for each layer of the aggregate road structure.

8. Determine the required percent compaction in terms of CE 55 for each layer from Table 9-13, page 9-63.

9. Draw the section of the aggregate road structure, as shown following.



A ≥ Z
B = Y - A or 4", whichever is greater
C = X - Y or 4", whichever is greater
D = Depth of compacted SCIP
X = minimum cover over compacted subgrade (Figure 9-52, page 9-65)
Y = minimum cover over select (Figure 9-52)
Z = minimum cover over subbase (Figure 9-52)

Total thickness above compacted subgrade = A + B + C

NOTES:

1. All layer thicknesses should be rounded up to the next full inch for construction purposes.

2. After all possible design sections are determined, the final section used should be determined on the basis of an economic analysis.

Example (Aggregate-Road Design):

An aggregate-surfaced road is to be used for two years. The road will be subjected to—

Vehicle	Average Daily Traffic
M998 HMMWV	10
M929 5-ton dump truck (dual axle)	25
M729 combat engineer vehicle (CEV) (60-ton tracked vehicle)	35

Available material CBR:
Natural subgrade = 5 (clay, PI = 15)
Design (compacted) subgrade = 8
Clean sand subbase = 30
Lime rock = 80; meets gradation requirement for maximum size aggregate of 1".

Solution:

1. Number of daily passes = 70 (given).

2. Select road class F from Table 9-8, page 9-59, based upon average daily traffic of 70.

3. Select traffic category VII from information previously given, based upon the presence of the 60-ton tracked vehicle.

4. Select design index of 9 from Table 9-12, page 9-60. **NOTE: You must round the average daily tracked-traffic value of 35 to the next higher value (40) in Table 9-12.**

5. Clean sand CBR 30. (Suitable for subbase CBR 30.) Crushed rock CBR 80. (Suitable for base course.)

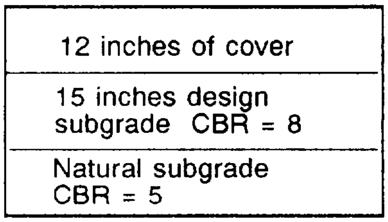
6. Depth of compaction based on CBR 5 for compacted subgrade is 15 inches. (See Table 9-17.

7. Determine the road-structure thickness required to support a design index of 9.

a. First, look at the required road thickness if the subgrade was not compacted to the design CBR. In this case, the natural subgrade CBR 5 is used in Figure 9-52. This results in a required total thickness of 16 inches, as shown.

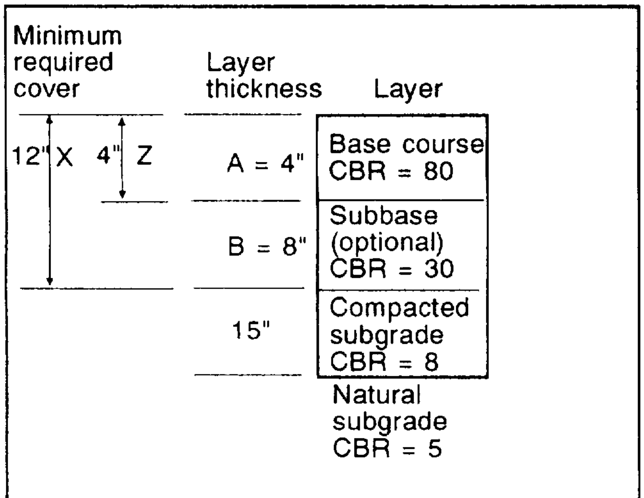
16 inches of cover
Natural subgrade CBR=5

b. Now, look at the required thickness when the subgrade is compacted, In this case, the design subgrade CBR = 8 is used in Figure 9-52, resulting in a required total thickness of 12 inches, as shown.



Notice how compacting the subgrade greatly reduces the required thickness of the cover material. This is why the subgrade is **always** compacted.

c. Finally, look at the total thickness and required cover for each layer when the subgrade is compacted and a clean sand subbase with CBR 30 is used. First, the design subgrade CBR 8 is used in Figure 9-52, page 9-65, to determine the 12-inch total thickness required above the compacted subgrade. Next, the clean sand CBR 30 is used in Figure 9-52 to determine the required cover of 4 inches above the subbase. This results in the section, as shown.



A = Z = 4"   Z = 4" = minimum cover over subbase (Figure 9-52)
B = X - A   X = 12" = Minimum cover over compacted subgrade
= 12" - 4"
= 8"

Total thickness above compacted subgrade = A + B
= 8 + 4
= 12"

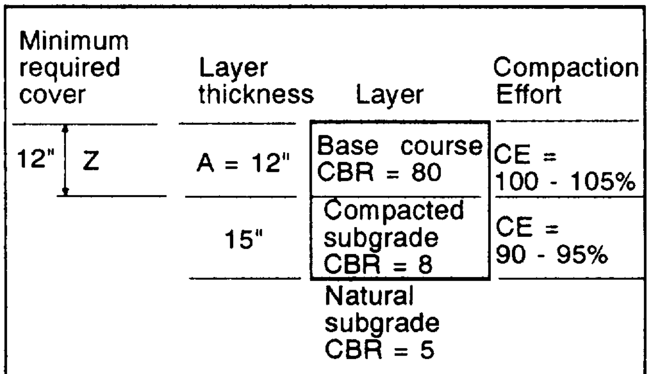
Notice how the addition of the clean sand subbase reduces the required thickness of the mom expensive lime rock.

8. The required percent compaction of each layer is determined from Table 9-13, page 9-63, as follows:

Crushed rock base course: 100-105 percent
Clean sand subbase course: 100-105 percent
Compacted subgrade-since the PI = 15, it is a cohesive soil: 90-95 percent

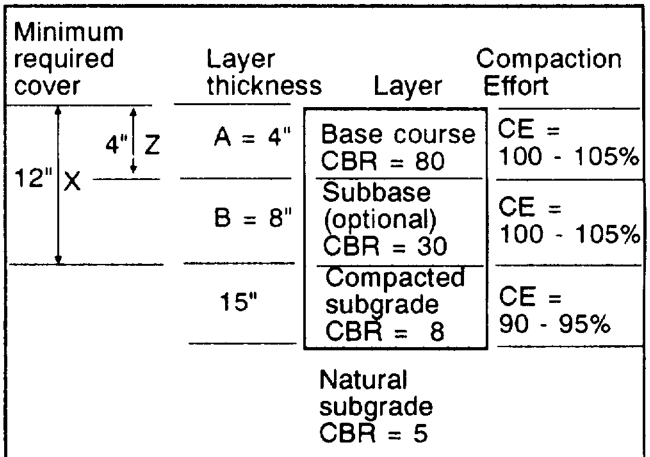
9. Draw the section of the aggregate road structure. Since two sections were designed, one with a subbase and one without, both should be drawn.

a. First, design the section without the subbase layer.



A = 12"   Z = 12" = Minimum cover over compacted subgrade (Figure 9-52)
Total thickness above compacted subgrade = A = 12"

b. Now, the design the section with the subbase layer.



A = Z = 4"   Z = minimum cover over subbase (Figure 9-52)
B = X - A   X = minimum cover over compacted subgrade (Figure 9-52)
= 12" - 4"
= 8"
Total thickness above compacted subgrade = A + B
= 8 + 4
= 12"

Given that the base-course material is more expensive than the clean sand subbase, section b would be the most economical design. Note, however, that all possible design sections for the available materials must be evaluated economically. There may be rare instances where the subbase material may be more expensive than the base course. In that case, only the base course would be used.

BITUMINOUS PAVEMENTS

Bituminous-, or flexible-, pavement designs permit the maximum use of readily available local construction materials. They are easier to construct and upgrade than rigid pavement designs. Thus, they permit greater flexibility in responding to changes in the tactical situation.

Flexible-pavement design procedures are different from airfield design procedures. This chapter is limited to flexible-pavement designs for roads. Chapter 12 of FM 5-430-00-2/AFPAM 32-8013, Vol 2 covers airfield flexible-pavement designs. TM 5-822-6 covers rigid-pavement designs.

Pavement Types and Uses

The descriptions, uses, advantages, and disadvantages of bituminous pavements and surfacing presented in TM 5-337 are applicable to TO construction except as modified in the following paragraphs. However, when surfacing for steel treads is necessary, use an asphalt cement with a penetration grade of 50-60 or 60-70, depending on the climate or season.

Special consideration must also be given to the design and construction of bituminous pavements that will be subjected to traffic of tanks and solid, rubber-tired vehicles. Most often the number of passes of tanks and solid, rubber-tired vehicles governs the bituminous-pavement design.

Hot-Mix, Bituminous-Concrete Pavements. Dense-graded, hot-mix. bituminous-concrete mixtures are well-suited for paving heavy-duty traffic roads with volumes of 3,000 vehicles or more per day. Where conditions warrant, use these mixtures to pave roads having traffic volumes of less than 3,000 vehicles per day. Select exact percentages of bituminous materials on the basis of design tests described in TM 5-337.

Cold-Laid, Bituminous-Concrete Plant Mix. Where hot-mix, bituminous-concrete mixtures are not available, use cold-plant, bituminous concrete to pave areas subject to pneumatic-tired traffic only.

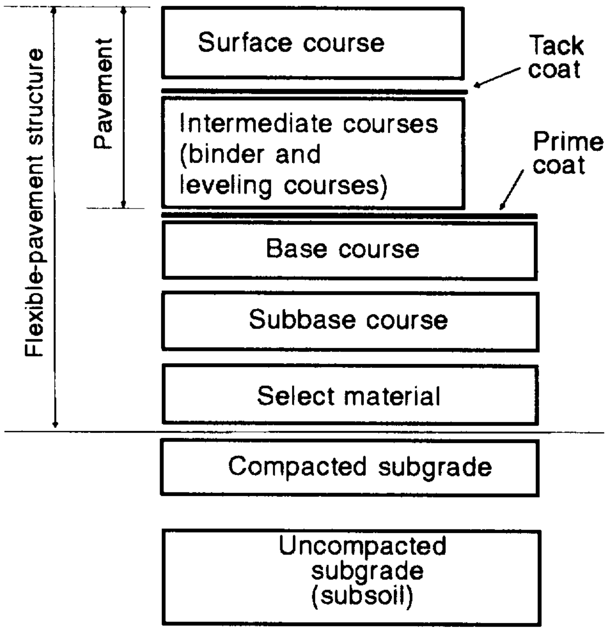
Sheet Asphalt, Stone-Filled Sheet Asphalt, Sand Asphalt, or Sand-Tar Mixes. Fine-aggregate mixes may be used for binder and surface courses of roads with traffic volumes of 2,000 or fewer vehicles per day when sand or other suitable fine aggregates are the only aggregates available. These mixes should not be used as surface or binder courses for roads or industrial-use pavements designed for solid, rubber-tired or steel wheels. In all cases, mixtures made with these aggregates should conform to the criteria for low-pressure tires (100 psi or less), based on laboratory tests.

Penetration Macadams. Do not use penetration macadam for paving any areas subject to traffic from tracked vehicles.

Bituminous Road Mix. Use road mix as a wearing course for TO roads or as the first step in stage construction for more permanent roads. When the existing subgrade soil is suitable or satisfactory aggregates are nearby, road mixing saves time in handling and transporting aggregates as compared with plant mixing. When properly designed and constructed, the quality of road mix approaches that of cold-laid plant mix. Road mix is used for binder and surface courses. It is generally considered inferior to plant-mix pavements manufactured in standard plants because of the less accurate control.

Flexible-Pavement Structure

A typical flexible-pavement structure is shown in Figure 9-53, page 9-70, and illustrates the terms used to refer to the various layers.



NOTE: Not all layers and coats are present In every flexible-pavement structure. Intermediate courses may be placed In one or more lifts. Tack coats maybe required on the surface of each intermediate course.

Figure 9-53. Flexible-pavement design

A bituminous pavement may consist of one or more courses depending on stage construction features, job conditions, and the economical use of materials. The pavement should consist of a surface course, an intermediate (binder) course, and a leveling course, when needed. These should be thick enough to prevent displacement of the base course because of shear deformation, to provide long life by resisting the effects of wear and traffic abrasion, to be waterproof, and to minimize differential settlements.

Sources of Supply

If time and conditions permit, investigate subgrade conditions: borrow areas; and all sources of select materials, subbase, base, and paving aggregates before designing the pavement. In determining subgrade conditions in cut sections of roads, conduct test borings deeper than the frost penetration depth. The minimum boring should never be less than 4 feet below the final grade.

Materials

Materials used in flexible pavements must meet the requirements as stated in Chapter 5 and in the following paragraphs:

Select Materials and Subbase

Select materials and subbases used in bituminous pavements must meet the same requirements as for aggregate-surfaced roads as indicated in Table 9-14, page 9-63.

Base Course

The base course used in bituminous pavements must meet the same requirements as for aggregate-surfaced roads as indicated previously. except as noted below.

Design CBR of Base Course. Where subbase material is used for base construction, the base course CBR must be at least 50 and the material must conform to the Atterberg limit requirement for a 50-CBR subbase as shown in Table 9-14. Otherwise, the design CBR of the base course must meet the requirements of Table 9-18.

Base Course Gradation Requirements. The gradation requirements of the base course are as indicated in Chapter 5 of this manual. The base course for a flexible pavement must meet the same gradation requirements of Table 5-4, page 5-12, since the flexible pavement will transfer most of the shear stress caused by the load directly to the base course.

Table 9-18. Assigned CBR ratings for base course materials - bituminous-surfaced road

Number	Type	Design CBR
1	Graded crushed aggregate	100
2	Water-bound macadam	100
3	Dry-bound macadam	100
4	Bituminous base course, central plant, hot mix	100
5	Lime rock	80
6	Bituminous macadam	80
7	Stabilized aggregate	80
8	Soil cement	80
9	Sand shell or shell	80

NOTE: It is recommended that stabilized-aggregate base-course material not be used for tire pressures in excess of 100 psi.

Minimum Base-Course Thickness. The minimum allowable thickness of the base course will be as shown in Table 9-19; except that in no case will the total thickness of pavement plus base for classes A through D roads be less than 6 inches.

Bituminous-Pavement Mix. Bituminous-pavement-mix design consists of selecting the bitumen and aggregate gradation, blending aggregates to conform to the selected gradation, determining the optimum bitumen (asphalt cement) content, and calculating the job mix formula. Bituminous-mix design is beyond the scope of this manual and is described in detail in Chapter 4 of TM 5-337.

Bitumininous-Pavement Thickness Requirement. Thickness design requirements are given in Figure 9-54, page 9-72, in terms of CBR and the design index determined. Minimum thickness requirements are shown in Table 9-19.

Note that each layered section must be checked to ensure that an adequate thickness of material is used to protect the underlying layer based on the CBR of the underlying layer.

Compaction Requirements

Compaction of the subgrade, subbase, and base course must meet the same requirements as for aggregate-surfaced roads. In addition, an asphalt base course and pavement must be compacted to CE-55 density of 98-100 percent. The compaction criteria and CBR requirements for a bituminous pavement are summarized in Table 9-20, page 9-73.

Bituminous-Pavement Design

Design Requirements. Flexible-pavement design must provide the following:

- Sufficient compaction and testing of the subgrade and each layer during construction to prevent objectionable settlement under traffic.
- Adequate drainage of the base course, when frost conditions are a factor, to provide for drainage of the base course during spring thaw.

Table 9-19 Minimum thickness, in inches, of pavement and base for conventional pavements

CBR	100			80			50[a]		
Design Index	Pavement	Base	Total	Pavement	Base	Total	Pavement	Base	Total
1	ST[b]	4	4 1/2[c]	MST[d]	4	4 1/2[c]	2	4	6
2	MST[d]	4	5[c]	1 1/2	4	5 1/2[c]	2 1/2	4	6 1/2
3	1 1/2	4	5 1/2[c]	1 1/2	4	5 1/2[c]	2 1/2	4	6 1/2
4	1 1/2	4	5 1/2[c]	2	4	6	3	4	7
5	2	4	6	2 1/2	4	6 1/2	3 1/2	4	7 1/2
6	2	4	6 1/2	3	4	7	4	4	8
7	2 1/2	4	6 1/2	3	4	7	4	4	8
8	3	4	7	3 1/2	4	7 1/2	4 1/2	4	8 1/2
9	3	4	7	3 1/2	4	7 1/2	4 1/2	4	8 1/2
10	3 1/2	4	7 1/2	4	4	8	5	4	9

[a] In general, 50-CBR base course will only be used for classes E and F roads and streets.

[b] Bituminous surface treatment (spray application).

[c] Minimum total thickness of pavement plus base for classes A through D roads and streets will be 6 inches.

[d] Multiple bituminous surface treatment (spray application).

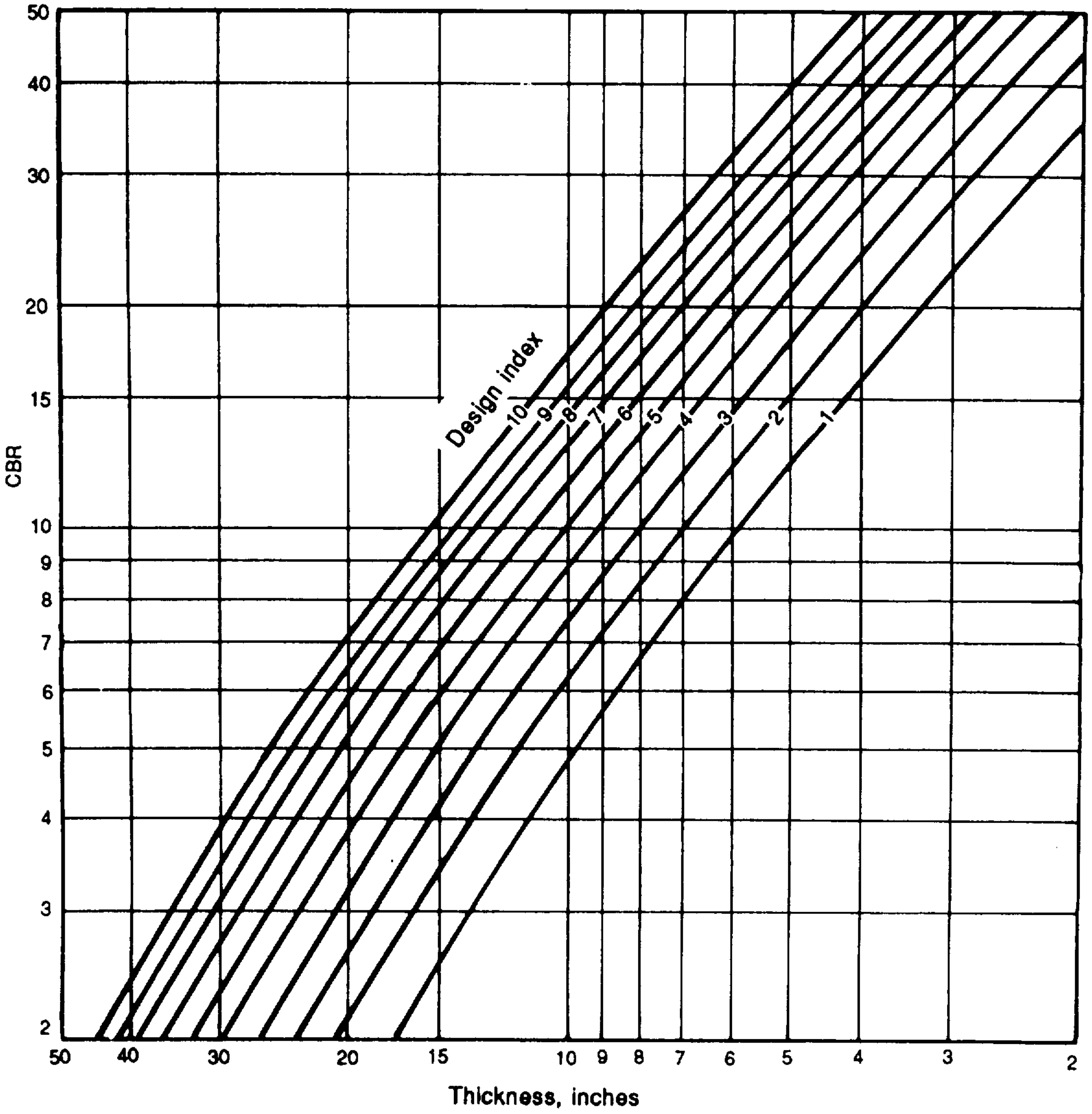


Figure 9-54. Thickness design requirements for flexible pavements

Table 9-20. Compaction criteria and CBR requirements for a flexiblew-pavement structure

CBR requirements	Layer	Compaction requirements
	Pavement	98 - 100%
50, 80, 100	Base course	Asphalt: 98 - 100% Soil: 100 - 105%
20 - 50	Subbase course	100 - 105%
0 - 20	Select material	Cohesive: 90 - 95% Cohesionless: 95 - 100%
	Design subgrade (SCIP)	Cohesive: 90 - 95% Cohesionless: 95 - 100%
	Uncompacted subgrade	

NOTES:

1. All lifts (excluding the pavement) in an Army flexible pavement must be at least 4 inches.

2. A cohesive soil is one with a PI above 5.

3. A cohesionless soil is one with a PI of 5 or less.

4. Percent Compaction is compared to CE 55 compactive effort.

- Adequate thickness above the subgrade and above each layer together with adequate quality of the select material, subbase, and base courses to prevent detrimental shear deformation under traffic and, when frost conditions are a factor, to control or reduce the effects of frost heave or permafrost degradation.
- A stable, weather-resistant, wear-resistant, waterproof, nonslippery pavement.

Design Steps.

1. Estimate the number of passes of each type of vehicle expected to use the road on a daily basis.

2. Select the proper road class based upon the traffic intensity from Table 9-8, page 9-59.

3. Determine the traffic category based upon the traffic-composition criteria given previously.

4. Determine the design index from Table 9-10, page 9-59, or 9-12, page 9-60.

5. Check soils and construction aggregates using standard criteria in Tables 5-9, page 5-12; 9-14, page 9-63; and 9-18, page 9-70.

6. Use Table 9-16 or 9-17, page 9-66, to determine compaction depth of the subgrade.

7. Determine the total road-structure thickness and cover requirements.

a. Enter Figure 9-54 for each layer of soil or aggregate with the following information:

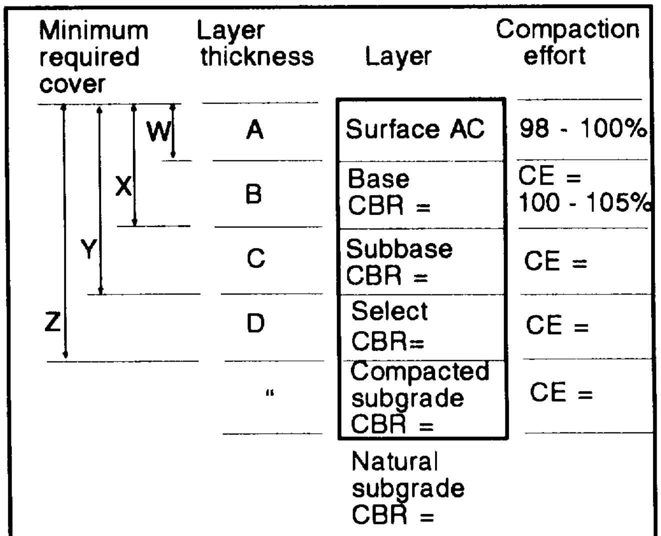
- Design index.

Ž Design CBR values for subgrade, select, and subbase materials.

b. Determine the minimum cover thickness, in inches, for each layer of the road structure through Figure 9-54 and Table 9-19, page 9-71.

8. Determine the required percent compaction in terms of CE 55 for each layer from Table 9-20.

9. Draw the section of the bituminous-pavement road structure. (See below.)



A = W

B = X - A

C = Y - A - B

D = Z - A - B - C

W = Minimum cover over base (Table 9-18)

X = Minimum cover over subbase (Figure 9-54)

Y = Minimum cover over select (Figure 9-54)

Z = Minimum cover over compacted subgrade (Figure 9-54)

Total thickness above subgrade = A + B + C + D

NOTES:

1. All layer depths, <u>except</u> for the surface AC, should be rounded up to the next full inch for construction purposes.

2. After all possible design sections are determined, the final section used should be determined on the basis of an economic analysis.

Example (Bituminous-Pavement Design):

Design the most economical bituminous pavement for a 3-year design life capable of sustaining the following traffic:

Vehicle	Average Daily Traffic
M998 HMMWV	1,000
M35A2 2 1/2-ton truck (dual axle)	500
M113A3 (13 tons)	40
M1A1	20

The soils data are—

Subgrade:
CL material, PI = 12, W = 14 percent
Natural CBR = 5
Compaction at 90- to 95-percent CE 55, CBR = 7

Borrow:
CBR 30 at 90- to 95-percent CE 55
W = 8 percent, LL = 15, PI = 5
40 percent passing No. 10 sieve, 12 percent passing No. 20 sieve

CBR 35 at 100- to 105-percent CE 55
W = 8 PERCENT, LL - 15, PI = 5
40 percent passing No. 10 sieve, 10 percent passing No. 20 sieve

Base: GP material at CBR 50 (meets gradation)

Solution:

1. Total average daily traffic = 1,560 (given).

2. Select road class E from Table 9-8, page 9-59, based upon average daily traffic of 1,560.

3. Select traffic category VII based upon the presence of the M1A1 tank.

4. Select design index 9 from Table 9-12, page 9-60. Notice that the number of vehicles per day (20) in this table refers to the M1A1 only, since the M113A3 is considered as a Group 3 vehicle because of its weight.

5. Check soils and construction aggregate.

a. Where can the CBR 30 material be used? Table 9-14, page 9-63, indicates this material can be used only as a select material (CBR 20) because the PI exceeds 5.

b. Where can the CBR 35 material be used? Table 9-14 indicates that this material can be used as a subbase with a CBR 30 design because of the percent passing the No. 10 sieve.

6. The required depth of subgrade compaction = 15 inches.

7. Determine the total thickness and cover requirements.

a. From Figure 9-54, page 9-72, the required cover for each layer is determined for design index of 9.

Layer	Required Cover	After Rounding
Compacted subgrade, CBR 7	18"	18"
Select, CBR 20	**8 1/4"**	**9"**
Subbase, CBR 30	**5 3/4"**	**6"**
Base, CBR = 50	**4"**	**4"**

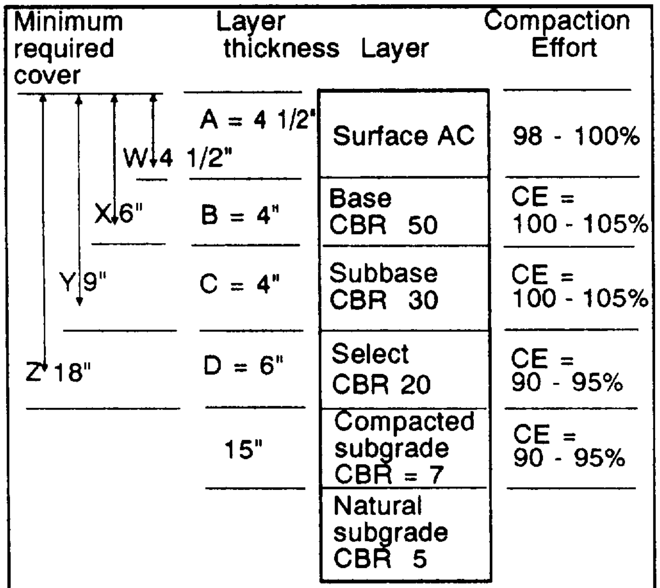
b. From Table 9-19, page 9-71, the required minimum thickness for the base course and surface asphalt is determined for design index of 9.

Layer	Minimum thickness
Base, CBR 50	**4"**
Surface AC	**4 1/2"**

8. From Table 9-20, page 9-73, the required compaction is determined for each layer.

Layer	Compaction Effort
Compacted subgrade PI > 5 (cohesive)	**90 - 95 percent**
Select, CBR 20	**90 - 95 percent**
Subbase, CBR 30	**100 - 105 percent**
Base, CBR 50	**100 - 105 percent**
Surface AC	**98 - 100 percent**

9. Draw the section of the bituminous-pavement road structure.



A = W
= 4.5"

W= Minimum cover over base (Table 9-18, page 9-70)
= 4.5"

B = X - A
= 4"

X = Minimum cover over subbase (Figure 9-54, page 9-73)
= 6" (B cannot be < 4" lift)

C = Y - A - B
= 4"

Y = Minimum cover over select (Figure 9-54)
= 9" (C cannot be < 4" lift)

D = Z - A - B - C
= 6"

Z = Minimum cover over compacted subgrade (Figure 9-54)
= 18" (D cannot be < 4" lift)

Total thickness above subgrade = A+B+C+D

Shoulders and Similar Areas. These areas are provided only for the purpose of minimizing damage to vehicles using them accidentally or in emergencies; therefore, they are not considered normal, vehicular traffic areas. Normally only shoulders for class A roads will be paved. Others will be surfaced with soils selected for their stability in wet weather and will be compacted as required. Dust and erosion control will be provided by means of vegetative cover, anchored mulch, coarse-graded aggregate, or liquid palliative. Shoulders will not block base-course drainage, particularly where frost conditions are a factor. Where paving of shoulders is deemed necessary, the shoulders will be designed as a class F road or street.

Special Considerations for Open Storage Areas. In the design of open storage areas, consideration will be given to any special requirements necessary because of the use of a particular area. In repair yards, for instance, the final-surface texture will be one that will promote quick drying and will not contribute to the easy loss of nuts, bolts, and tiny parts. Mixtures in such areas will contain approximately 50 percent coarse aggregate. Areas subject to an appreciable amount of foot traffic will be designed to avoid the occurrence of free bituminous material on the surface.

SPECIAL DESIGN CONSIDERATIONS

Special design considerations include frost design, stabilized-base design, and geotextile design.

Frost Design

Normally, frost effects are not considered as part of the design in TO road construction. However, in the event that extremely severe host conditions exist or that frost design is directed, an outline of the frost-design procedure is included in Appendix G of this manual.

Stabilized-Soil Design

The use of stabilized-soil layers (as described in Chapter 5 of this manual and in FM 5-410) within a road structure provides the opportunity to reduce the overall thickness required to support a given load. To design a road containing stabilized-soil layers requires the application of equivalency factors to a layer or layers of a conventionally designed pavement.

To qualify for application of equivalency factors, the stabilized layer must meet appropriate strength and durability requirements. An equivalency factor represents the number of inches of a conventional base or subbase which can be replaced by 1 inch of stabilized material. Equivalency factors are determined as shown on Table 9-21, page 9-76, for bituminous-stabilized materials and from Figures 9-55 and 9-56, page 9-76, for materials stabilized with

Table 9-21. Thickness criteria

Material	Equivalency Factors Base	 Subbase
All-bituminous concrete	1.15	2.30
GW, GP, GM, GC	1.00	2.00
SW, SP, SM, SC	--	1.50

cement, lime, or a combination of fly ash mixed with cement or lime. The selection of an equivalency factor from the tabulation is dependent upon the classification of the soil to be stabilized. The selection of an equivalency factor from Figures 9-55 and 9-56 requires that the unconfined compressive strength (as determined according to the American Society of Testing and Materials Standatd (ASTM) D1633) be known. The equivalency factors from Figure 9-55 are for subbase materials, and those from Figure 9-56 are for base materials.

Minimum Thickness. The minimum thickness requirement for a stabilized base or subbase is 4.0 inches. The minimum thickness requirements for an asphalt pavement are the same as shown for convention pavements in Table 9-19, page 9-71.

Application of Equivalency Factors. The use of equivalency factors requires that a road be designed to support the design-load conditions. If using a stabilized base or subbase course, the thickness of a conventional base or subbase is divided by the equivalency factor for the applicable stabilized soil. The following are examples for the application of the equivalency factors:

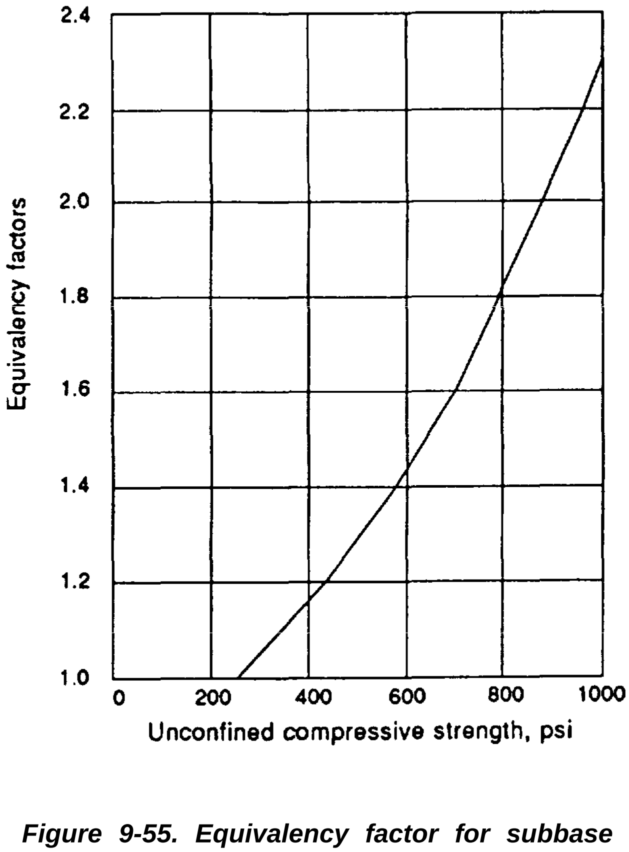


Figure 9-55. Equivalency factor for subbase soils stabilized with cement, lime, or cement and lime mixed with fly ash

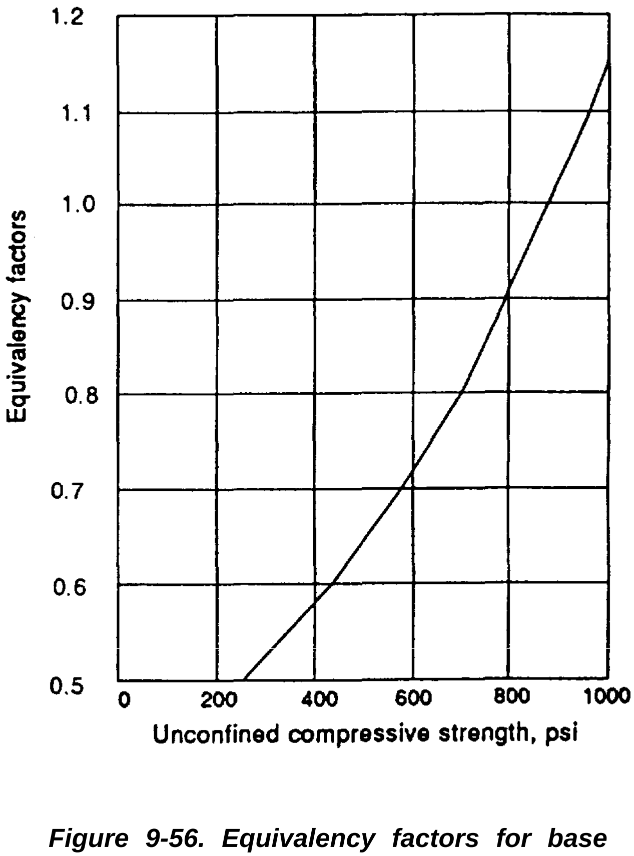


Figure 9-56. Equivalency factors for base soils stabilized with cement, lime, or cement and lime mixed with fly ash

Example 1:

Assume an aggregate-surfaced road has been designed which requires a total thickness of 14 inches above the CBR 6 subgrade. The minimum thickness of the 80 CBR base is 7 inches and the 15 CBR subbase is 7 inches. It is desired to replace the base and subbase with a lime-stabilized gravelly soil having an unconfined compression strength of 950 psi.

Solution:

From Figure 9-55 the equivalency factor for the subbase is 2.20. From Figure 9-56, the equivalency factor for the base is 1.10. Therefore, the thickness of the stabilized subbase is 7.0 inches/2.20 = 3.18 inches, and the thickness of the stabilized base is 7.0 inches/1.10 = 6.36 inches. However, since the minimum lift thickness is 4 inches, the stabilized subbase must be 4.0 inches instead of 3.18 inches. In addition, the stabilized base lift must be rounded up to the nearest full inch, so 6.36 inches is rounded up to 7 inches. Therefore, the final thickness is 7.0 inches of base + 4.0 inches of subbase = 11.0 inches of lime-stabilized gravel.

Example 2:

Assume a conventional flexible pavement has been designed which requires a total thickness of 16 inches above the subgrade. The minimum thicknesses of the asphalt concrete and the base are 2 and 4 inches, respectively, and the thickness of the subbase is 10 inches. It is desired to replace the base and subbase with a cement-stabilized, gravelly soil having an unconfined compressive strength of 890 psi.

Solution:

From Figure 9-55, the equivalency factor for a subbase having an unconfined compressive strength of 890 is 2.0: and from Figure 9-56, the equivalency factor for the base is 1.0. Therefore, the thickness of the stabilized subbase is 10 inches/2.0 = 5.0 inches, and the thickness of the stabilized base course is 4 inches/1.0 = 4.0 inches. The final section would be 2 inches of asphalt concrete and 9 inches of cement-stabilized, gravelly soil. The base-course thickness of 4.0 inches would also have been required due to the minimum thickness of the stabilized base. The subgrade still has an equivalent cover of 16 inches within the newly designed 2 inches of asphalt concrete and 9 inches of cement-stabilized, gravelly soil.

Example 3:

Assume a conventional flexible pavement has been designed which requires 2 inches of asphalt-concrete surface, 4 inches of crushed stone base, and 6 inches of subbase. It is desired to construct an all-bituminous pavement.

Solution:

The equivalency factor from data in Table 9-21, for a base course is 1.15 and for a subbase is 2.30. The thickness of asphalt concrete required to replace the base is 4 inches/ 1.15 = 3.5 inches and the thickness of asphalt concrete required to replace the subbase is 6 inches/2.30 = 2.6 inches. Therefore, the total thickness of the all-bituminous pavement is 2 + 3.5 + 2.6 or 8.1 inches, which would be reduced to 8.0 inches.

Geotextiles

The term geotextile refers to any permeable textile used with foundation, soil. rock, earth, or any other geotechnical, engineering-related material as an integral part of a human-made project, structure, or system. Geotextiles are commonly referred to as geofabrics, engineering fabrics, or just fabrics. They serve four prlmary functions:

- Reinforcement.
- Separation.
- Drainage.
- Filtration.

In many situations, the use of these fabrics can replace soil, saving time, materials, and equipment costs. In TO construction, the primary concern is with separating and reinforcing low load-bearing soils to reduce construction time.

Geotextile design is an emerging technology. As such, each geotextile manufacturer uses its own design procedure, and a general design procedure using the design criteria established in previous sections has yet to be established. Nonetheless, Appendix H of this manual outlines a typical geotextile design procedure. Note that Appendix H describes only one design procedure, and the particular geotextile used in construction may require alterations to this procedure. Additional details on geotextiles and their use are in Chapter 11 of FM 5-410.