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Chapter 7

Horizontal Construction

Topics

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Overview

As the Department of Defense's construction force of choice, Seabees are often tasked with constructing roads and airfields, or portions of roads and airfields. As an Engineering Aid, you can expect to be involved. Your involvement may include assisting the engineering officer in the design, conducting surveying operations required before or during construction, performing soil sample analysis in the field or laboratory, providing on-site construction quality control by taking material or compaction samples, developing as-built drawings, or keeping a record of actual job progress as opposed to planned schedule. Whatever your involvement, to be effective you need to be familiar with the terminology, methods, and materials of road and airfield construction.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different methods of road construction.
2. Describe the different methods of airfield construction.
3. Describe the materials utilized in subbase and base course construction.

Prerequisites

None

1.0.0 ROADS

Definition: "A military road is any route used by the military for transportation of any type." This includes everything from a superhighway to a path through the jungle. For construction purposes, the type of road required will depend on the mission(s) of the unit(s) that use it. In forward combat zones, the most expedient roads usually meet the requirements, that is, roads that will get the job done with no attempt for permanency. However, rear zones usually require some degree of permanency and relatively high construction standards.

1.1.0 Nomenclature

As a senior EA, you may be assigned to the engineering division and help prepare working plans for constructing roads and airfields, for example, a two-lane earth, gravel, or paved-surface road. *Figures 7-1* and *7-2* show a road's basic parts.

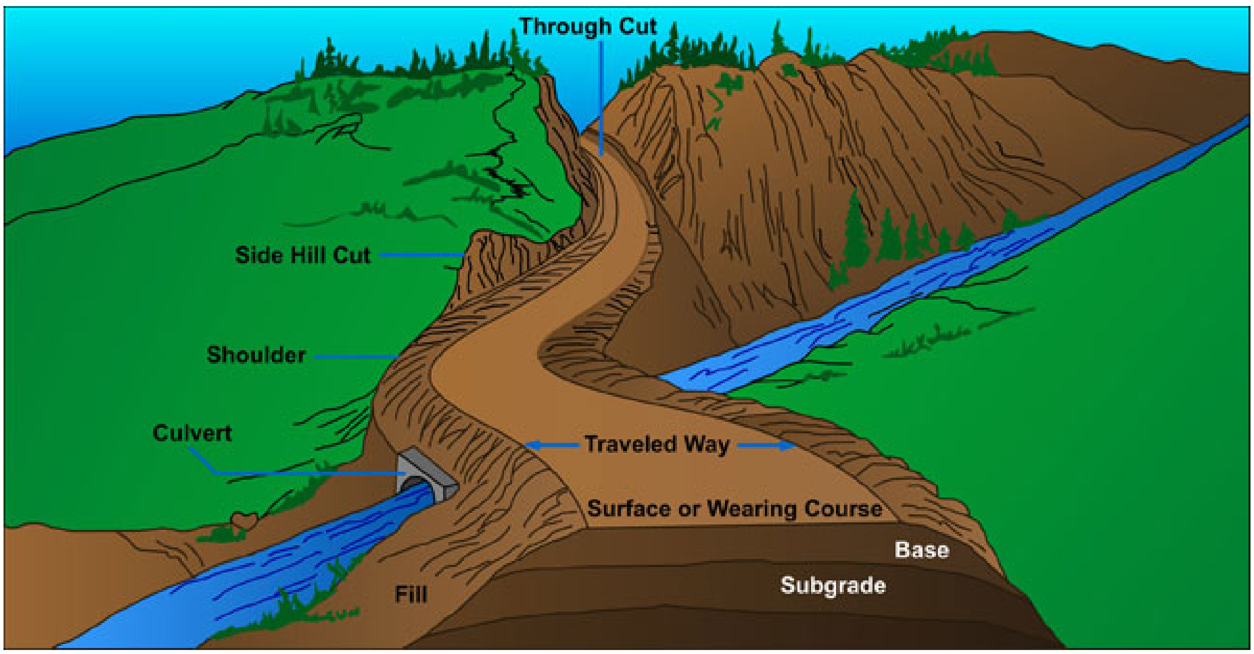


Figure 7-1 — Perspective view of road with road nomenclature.

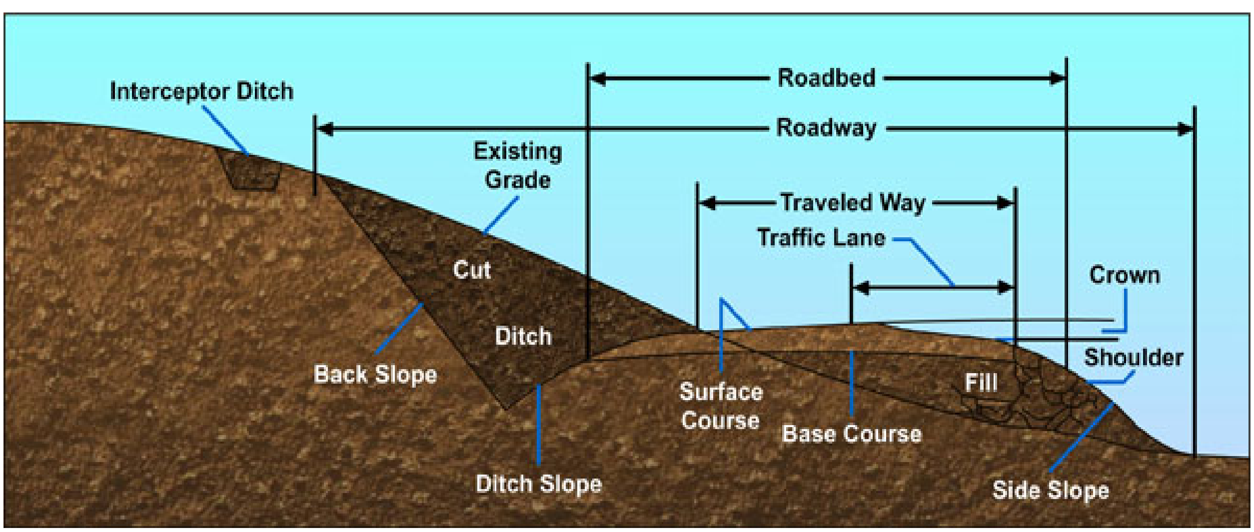


Figure 7-2 — Cross-section view of road with road nomenclature.

You are likely to use the following definitions when preparing working plans for a road:

- Back Slope — The slope from the top of the cut to the bottom of the ditch (sometimes called cut slope).
- Base — Select material (crushed stone, gravel, etc.) placed in a layer over the subgrade to distribute the load to the subgrade.
- Blanket Course — A 1- or 2-inch layer of sand or screening spread upon the subgrade to prevent the subgrade from mixing with the base.
- Centerline — The exact center, or middle, of the roadbed.
- Crown — The elevation difference between the centerline and the edge of the traveled way.
- Cut — Two connotations:
  - An excavation through which the road passes.
  - The vertical distance the final grade is below the existing grade.
- Ditch Slope — The slope that extends from the outside edge of the shoulder to the bottom of the ditch (sometimes called front slope or side slope).
- Existing Grade — The undisturbed earth before construction begins.
- Fill — Two connotations:
  - Earth that has been piled up to make the road.
  - The vertical distance the final grade is above the existing grade.
- Fill Slope — The slope from the outside edge of the shoulder to the toe of the fill (sometimes called front slope or side slope).
- Final, or Finished, Grade — The elevation to which the road surface is built.
- Interceptor Ditch — A ditch cut to intercept the water table or any subsurface drainage. Also, a ditch cut along the top of fills to intercept surface drainage.
- Roadbed — The entire width (including the traveled way and the shoulders) upon which a vehicle may stand or travel.
- Roadway — The entire width that lies within the limits of earthwork construction.
- Roadway Ditch — The excavation, or channel, adjacent and parallel to the roadbed.
- Shoulders — The additional width immediately adjacent to each side of the traveled way.
- Slope Ratio — A measure of the relative steepness of the slope, expressed as the ratio of the horizontal distance to the vertical distance.
- Station — A horizontal distance generally measured in intervals of 100 feet along the centerline.
- Station Number — The total distance from the beginning of construction to a particular point (for example, 4 +58 is equal to 458 feet).
- Subgrade — The foundation of a road, either undisturbed earth (for a cut) or material placed on top of the existing grade (for a fill).

- Superelevation — The elevation difference between the outside and inside edge of the traveled way in a horizontal curve.
- Surface — The portion of the road in direct contact with traffic.
- Toe of Slope — The extremity of the fill (where the existing grade intercepts the fill).
- Traffic Lane — The portion of the road surface over which a single line of traffic traveling in the same direction will pass.
- Traveled Way — The portion of the roadway over which all vehicles travel (both lanes for a two-lane road).
- Width of Cleared Area — The width of the entire area that is cleared for the roadway.

1.2.0 Survey

When a road is needed, the first and most logical step is to determine its route. Maps, aerial photographs, aerial reconnaissance, local intelligence, ground vehicle reconnaissance, walk-through reconnaissance, or any combination of these can be used to select a proposed route.

Once a route is chosen, an initial surveying crew makes a preliminary survey, which consists of a series of traverse lines connecting a series of traverse stations. Then a survey party stakes in each of the traverse stations and determines the bearing and distance of the connecting traverse lines.

This information instigates the following steps:

1. An EA draws the points of intersection (PI) and the connecting lines.
2. An engineer computes the horizontal curves at each point of intersection.
3. An EA draws the curves and marks the stationing.

This drawing is the proposed centerline drawing, which is then given to a final location party that will stake in the centerline and curves. With the engineer's approval, the party chief may make changes in alignment of the centerline to suit existing conditions, but the changes must be recorded.

Once the final location is determined, all information and pertinent changes are used to prepare a second and final drawing showing:

- final centerline location
- construction limits
- all curves and curve data
- station marks
- control points
- natural and man-made terrain features, trees, buildings
- anything else helpful in construction

This drawing is the road plan**,** a "bird's-eye view" of the road that shows a perspective from directly above. The road plan is drawn on the upper portion of plan-and-profile paper, using any scale desired. Composed of grid lines, the bottom portion of the plan-and-profile paper is reserved for drawing the road profile (*Figure 7-3*).

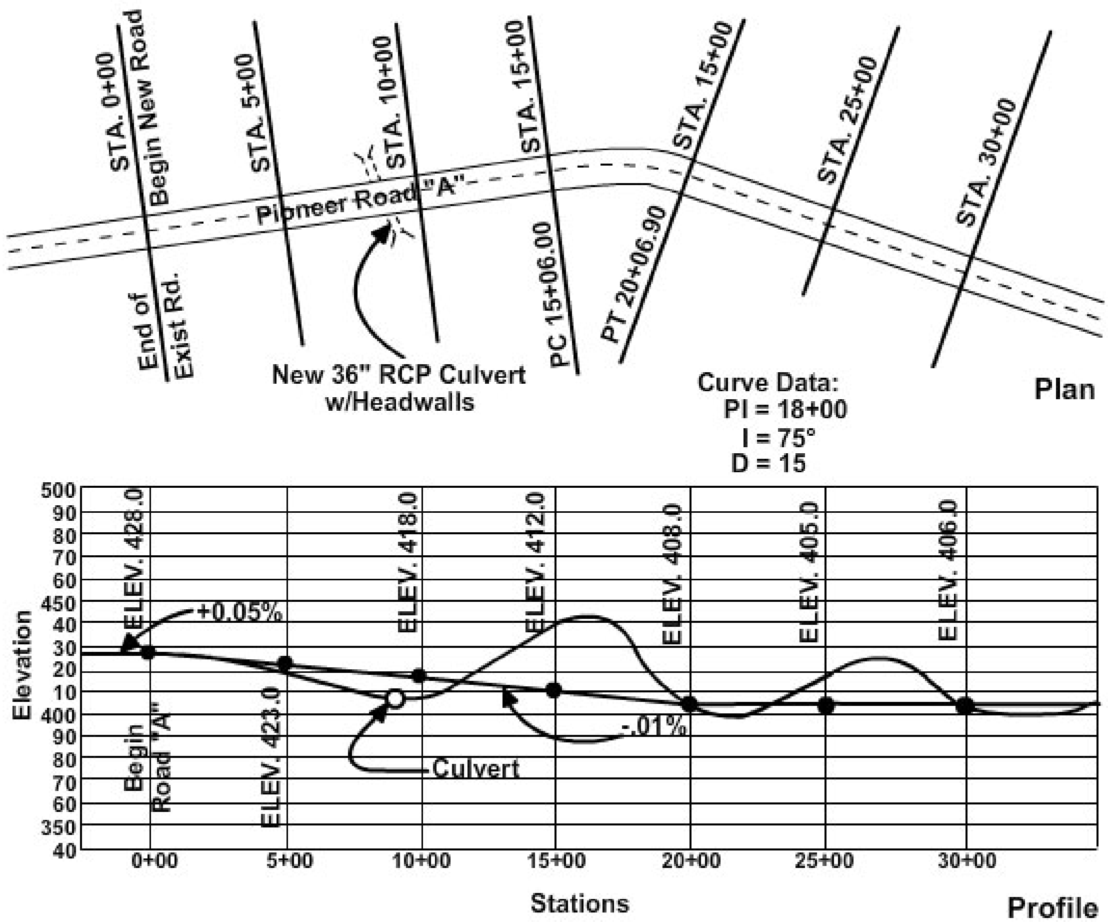


Figure 7-3 — Typical plan-and-profile drawing.

1.3.0 Road Plan

A road plan shows the location and length of the road as measured along the centerline. By reading (or drawing) a road plan, you determine its length by station points, which are set at full station (100 feet or 100 meters apart), half station, or one-tenth station intervals (*Figure 7-4*).

Refer to *Figure 7-4*. Odd-station points are set at major breaks in the terrain (U. S. Route 90 crossings). Also, note how the beginning station (0 + 00), the full stations, and the partial stations are shown. From your previous studies, you know that the distance from the beginning station to the last full station shown (13 + 00) is 1,300 feet.

If they are in the right-of-way or construction limits, or can affect construction operations, man-made and natural objects (such as, buildings, fences, wells, trees, outcroppings, and so on) are also plotted on the plan. (Right-of-way is the land acquired for the road construction.)

The surveyor's notebook provides their identification and location by a station number and the distance from centerline. Unless otherwise noted, all measurements and distances are made perpendicular to the centerline.

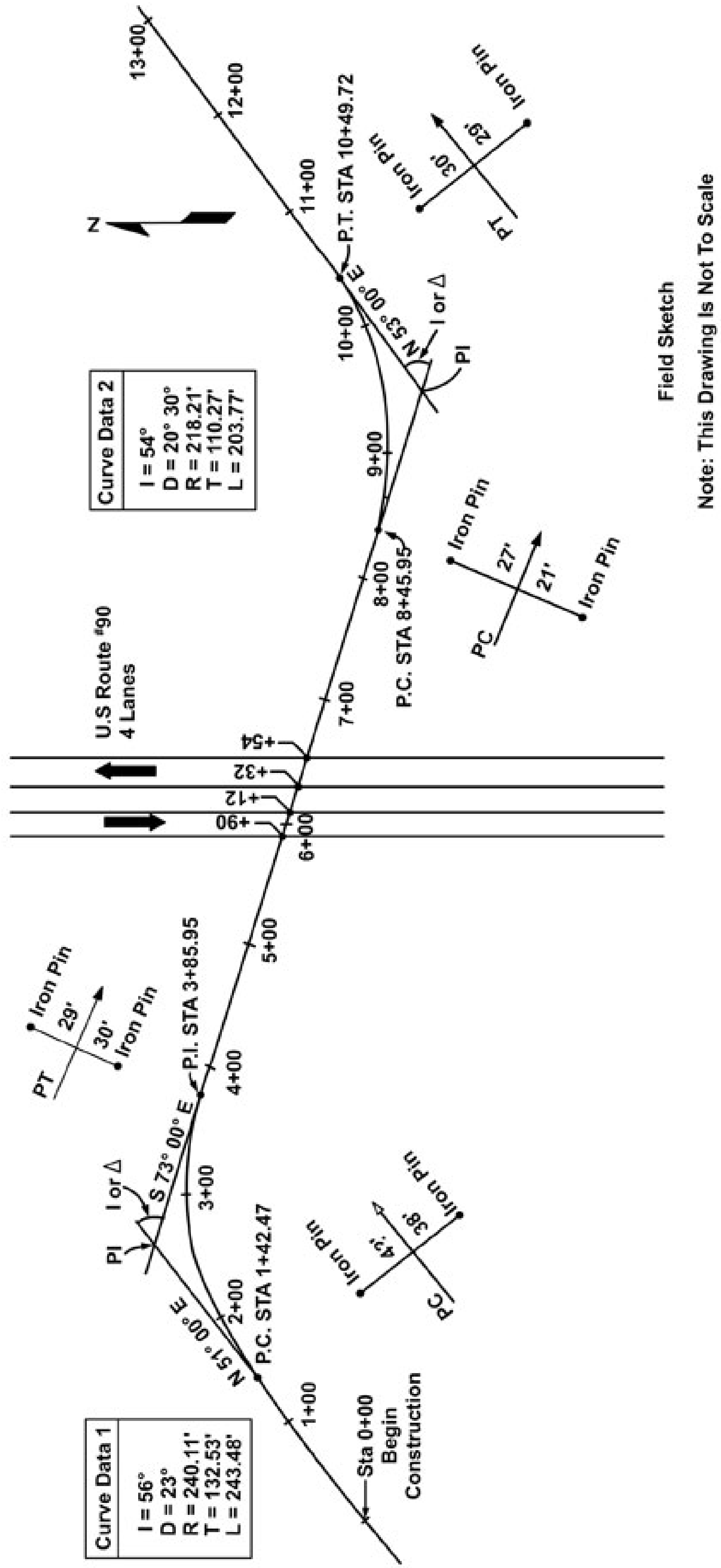


Figure 7-4 — Example of a road plan "bird's-eye view."

1.3.1 Horizontal Curves

A road centerline has both straight lines and curves. The straight lines are called tangents, and the curves are called horizontal curves; horizontal curves change the horizontal direction of the road. The engineer or the surveyor's notebook should furnish all the information necessary to draw a curve.

This necessary information is known as the curve data. Refer again to *Figure 7-4*.

The following is the curve data for curve No. 1 along with an explanation of the terms.

- $I \; or \; \Delta = 56^{\circ}00'$ — Δ (Delta), or I, represents the intersecting angle, which is the deflection angle made by the tangents where they intersect.
- $D = 23^{\circ}00'$ — D is the degree of curvature, or degree of curve, the angle subtended by a 100-foot arc or chord. (Refer to Chapter 3.)
- $R = 240.11'$ — R is the radius of the curve, or arc. The radius is always perpendicular to the curve tangents at the point of curvature (PC) and the point of tangency (PT).
- $T = 132.53'$ — T is the tangent distance, measured from the PI to the PC and the PT. The PC is the beginning of the curve, and the PT is the end of the curve.
- $L = 243.48'$ — L is the length of the curve measured in feet along the curve from the PC to the PT.

Typically, a horizontal curve is selected to fit the terrain, so some curve data will already be known.

There are definite mathematical relationships between the elements of the given data, and you can use the following formulas to compute the unknown quantities:

- To find R (radius), or D (degree of curvature), use the formula:

$$R = \frac{5729.58}{D}$$

- To find T (tangent distance), use the formula:

$$T = R \tan \frac{\Delta}{2}$$

- To find L (length of curve), use the formula:

$$L = 100 \frac{\Delta}{D} \left(D \; and \; \Delta \; in \; \deg rees \right)$$

Refer again to *Figure 7-4*. The PC and PT are designated on the plan by a small circle on the centerline with station numbers and a partial radius drawn at each point. Adding L (length of curve) from the curve data to the PC station gives you the PT station. Usually, the curve data is noted on the inside and between the partial radii of the curve to which it pertains (see Curve Data 2).

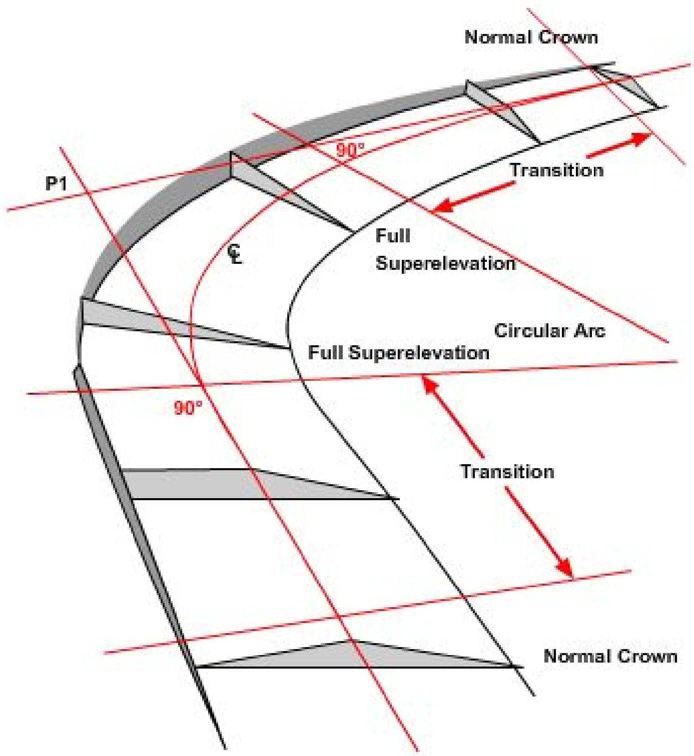


Figure 7-5 — Example of super elevation and transition.

Since most horizontal curves have superelevation (the outside edge of the traveled way is higher than the inside edge), there must be a transition distance where the shape of the road surface changes from a normal crown to a superelevated curve.

The transition length is generally 150 feet and starts 75 feet before the PC is reached.

The same is true in leaving curves. The transition begins 75 feet before the PT and ends 75 feet beyond.

Typically, the beginning and end of the superelevation are noted on the plan *(Figure 7-5)*.

1.3.2 Control Points

A control point may be a PT, PC, PI, or a point on tangent (POT). These control points are on or near the centerline and are very likely to be destroyed during construction. Therefore, you must reference them to other points farther from the activity. Common practice is to drive iron pins or other reference stakes on each side of the centerline at right angles to the control point. Then, measure and record the distance from the pins to the control point and if room allows, draw the references on the road plan opposite the control points, per the four examples in *Figure 7-4*. If space is unavailable in the road plan, create a separate reference sheet to show the control points.

1.4.0 Road Profile

A profile is the representation of something in outline. As applied to a road plan, this means that a road profile is a longitudinal-section view along the centerline, and is always viewed perpendicular to the centerline.

As you know, profile-leveling procedures are used to determine ground elevations at the station points along the centerline. Recorded in the surveyor’s notebook, draftsmen use these elevations to prepare a profile drawing, usually on the bottom portion of plan-and-profile paper, directly below the road plan (*Figure 7-6*).

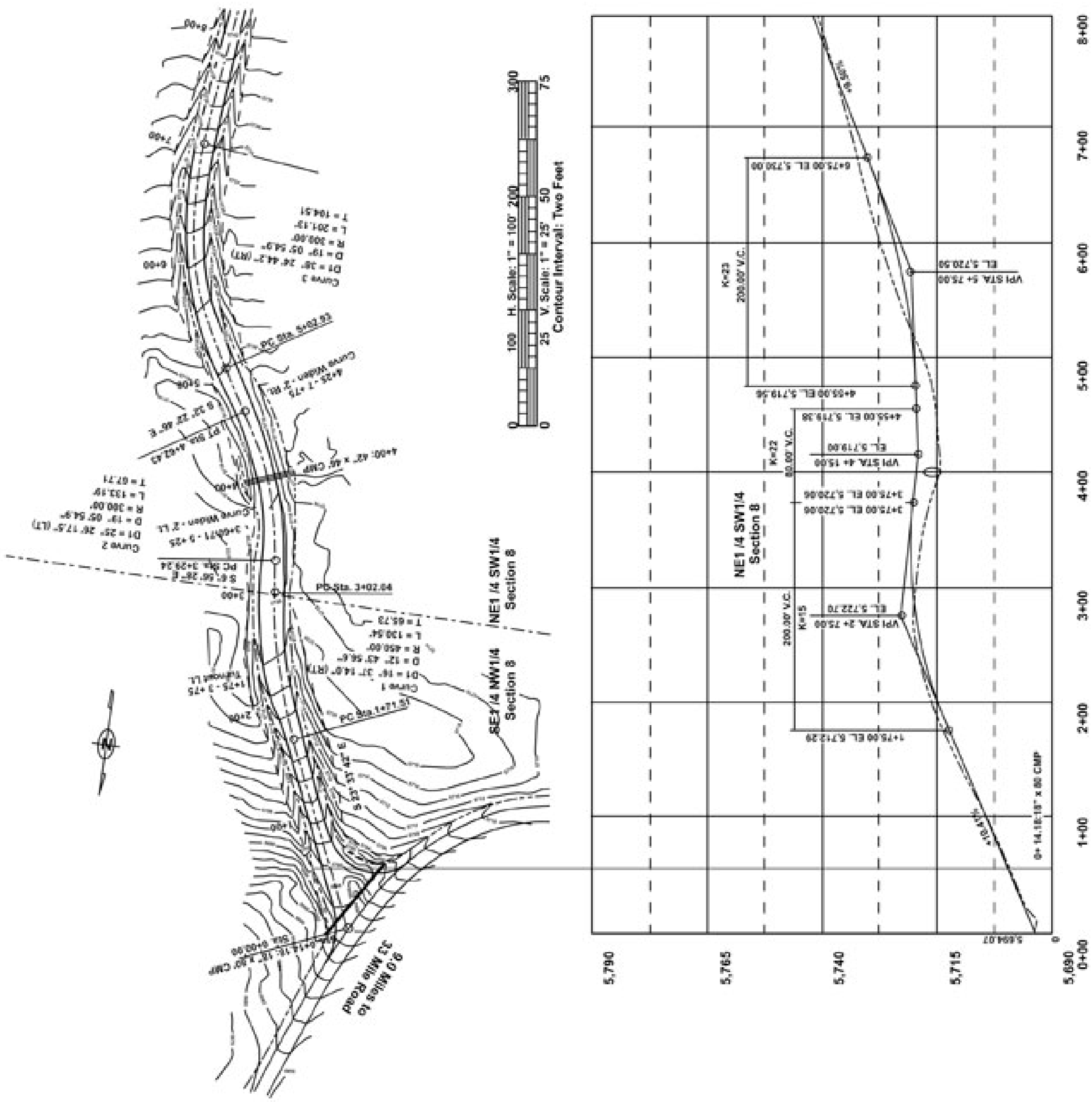


Figure 7-6 — Example of road profile and slope information.

A road grade line, represented by a heavy solid line, is also drawn on the lower portion of the plan-and-profile paper. Like the profile, the grade line is a longitudinal section taken along the centerline, and shows the elevations to which the road is built. Normally, the grade line is the centerline elevations of the finished surface, but on occasion it may be the centerline elevations of the subgrade. If you use the subgrade, you must make a special note of it.

The grade lines are a series of straight lines connected, where necessary, by curves (called vertical curves — the next topic). They may be level or sloped; if sloped upward, the grade is positive; if downward, the grade is negative.

The slopes are in reference to the direction of increasing stations. The amount of slope is lettered above the grade line and is usually indicated as the percent of slope. Note the slopes in *Figure 7-6*. In this example, the slopes continuously change from +10.41% grade at 175’, through a –2.64% at 375’ and then a slight rise of +0.94% at 415’ to a +9.50% grade increase at 675’. This means the centerline grade lowers or raises a total of 35.93 feet in a 675 foot horizontal distance.

At vertical curves, the straight lines are tangents that intersect at a point called the point of vertical intersection (PVI). This point is comparable to the PI of horizontal curves.

NOTE

Some agencies use similar but slightly different terminology, as shown in *Figures 7-6.*

For example:

VPI = Vertical Point of Intersection

VPC = Vertical Point of Curvature

VPT = Vertical Point of Tangency

1.4.1 Vertical Curves

To offer safe, comfortable driving conditions, the PVI should not break sharply. The length of the curve depends upon the steepness of the intersecting grades.

Note in *Figure 7-6* that the PVIs are centered on 200.00′, 80.00′, and 200.00′ V.C. (vertical curvatures). The station on which the curve begins and ends is called the point of vertical curvature (PVC) and point of vertical tangency (PVT), respectively.

Unlike the length of a horizontal curve (which is a measured distance following the curve), the length of a vertical curve is the straight-line horizontal distance from the beginning to the end of the curve or from PVC to PVT.

A vertical curve at the crest or top of a hill is called a summit curve, or oververtical; one at the bottom of a hill or a dip is called a sag curve, or undervertical.

Vertical curves may be symmetrical, meaning the tangent length from PVC to PVI equals the tangent length from PVI to PVT, though it is not necessary for the PVC and the PVT to be at the same elevation to have a symmetrical vertical curve.

However, some situations may dictate that an unsymmetrical vertical curve (a parabolic with no constant radius) will better satisfy constraints. An unsymmetrical curve is a curve in which the tangent length from PVC to PVI does not equal the tangent length from PVI to PVT. Therefore, the curves are plotted, usually in 50-foot lengths, by computing the offsets from the two tangents.

Definitions and formulas for symmetrical and unsymmetrical vertical curves can be found in EA Advanced, Chapter 3.

1.4.2 Drawing the Grade lines

Use the same horizontal and vertical scale to draw both the grade line and the profile; this allows the measurement of cuts or fills for a particular point. If the grade line is higher than the profile, fill is required; if lower, cut is required.

Refer again to *Figure 7-6*. Show the relative locations of drainage structures such as box culverts and pipes on both the profile and grade line drawings. However, use only the vertical scale to draw these structures. You can plot the heights of the structures accurately using the vertical scale, but you cannot draw the width of the structures to scale because of the exaggerated difference between the vertical and horizontal scales. Draw the width of the structures just wide enough to indicate the type of structure; show a box culvert as a high, narrow rectangle, and a round pipe as a high, narrow ellipse.

1.5.0 Road Dimensions

Dimensioning for road plans is a variation of standard dimensioning. In road dimensioning, numerical values for elevations, cuts, fills, and stations are also considered dimensions. Most road dimensions appear on the profile and grade line drawing, as shown in *Figure 7-7*.

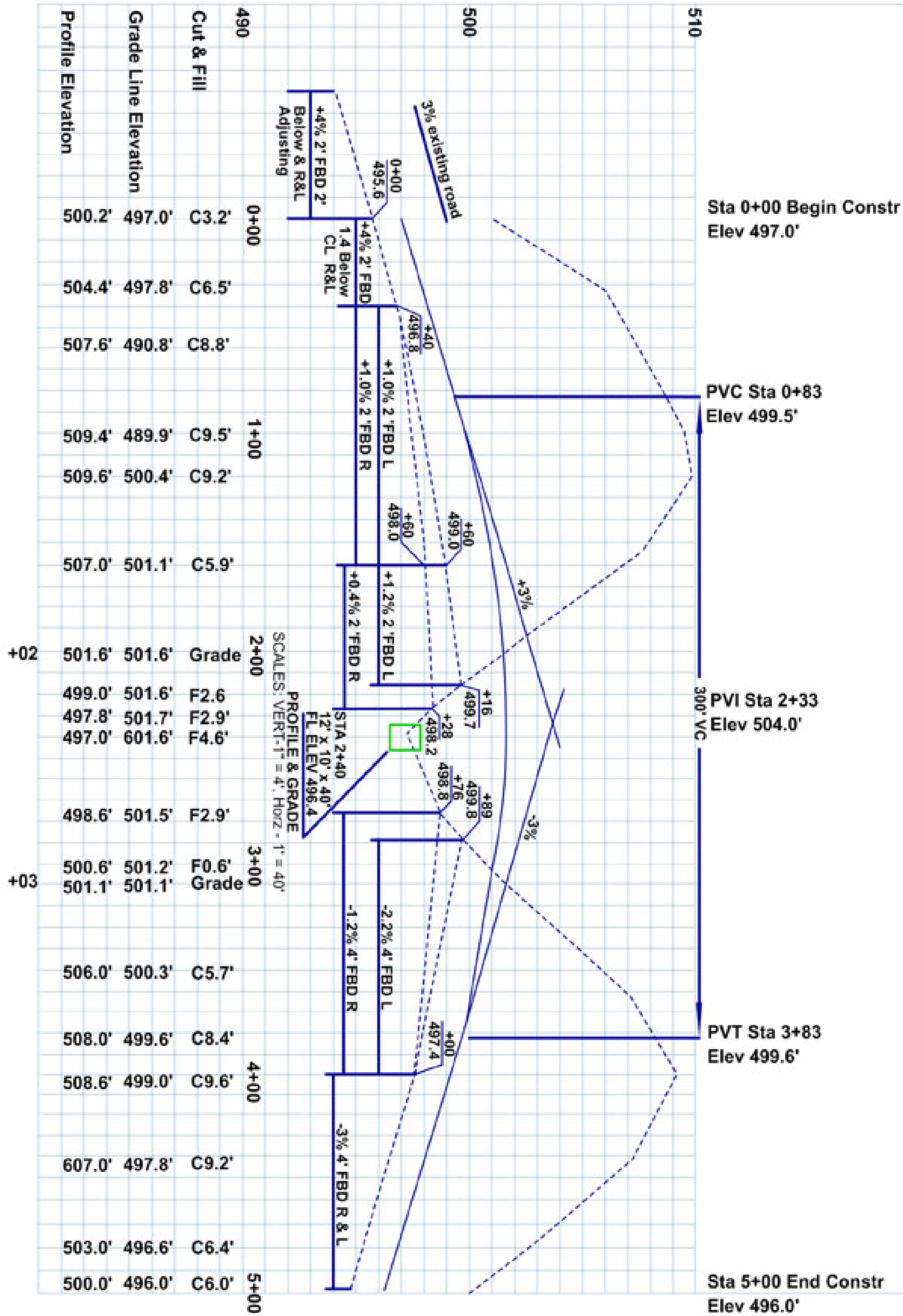


Figure 7-7 — Example of profile, grade line, with cut and fill calculations.

Refer to *Figure 7-7* for the following explanations and guidance:

- Station Numbers — Letter station numbers horizontally below profile and grade line, centered on the appropriate vertical grid line.
- Elevations (profile and grade line) — Letter elevations vertically at the bottom for each station.
    - Grade line elevations are lettered just above profile elevations. Any station numbers other than full stations are noted vertically as plus (+) stations just outside the bottom border.
- Cuts and Fills — Letter cuts and fills vertically at the bottom, above the profile and grade line elevations.
    - Indicate grade-points (where profiles cross grade lines) by the word *GRADE* lettered vertically above the grade-point station.
- Ditches — Dimensioning ditches requires two steps:
    1. Draw extension lines downward from the ends of a ditch or any point in the ditch where the ditch grade changes, and draw dimension lines with heavy arrowheads between them. These extension and dimension lines need to be drawn heavier than normal to be distinguished from grid lines.
    2. Letter the ditch's information above the dimension line; if crowded, use the space below the line. Furnish the following information:
        - Percent of grade
        - Depth relative to centerline
        - Type
        - Width
        - Elevation and station at ends and changes of grade
- Vertical Curves — Draw extension lines upward from the PVC and PVT, add a dimension line, arrowheads, and above, letter the length of the curve. Letter vertically the station and elevation of the PVC, PVI, and PVT.
- Correlation with Plan — Match all points on the profile and grade line with centerline points on the road plan, such as the beginning and ending of construction, with lettering indicating the elevations at these points.
- Drainage Structures — Dimension all drainage structures, such as pipes and culverts with notes providing station number, size of opening, length of pipe, and flow-line elevation.
- Title — In *Figure 7-7*, the title "PROFILE & GRADELINE," along with horizontal and vertical scales, is lettered below the drain structure and ditch dimensions.

1.6.0 Sequence of Construction

Construction crews follow a specific sequence when building a road.

Figure 7-8 — Example of clearing and grubbing.

1. Clear the road's through area of trees, stumps, brush, boulders, and other debris (known as clearing and grubbing), shown in *Figure 7-8*.

The width of the clearing varies greatly but should always be at least 12 feet greater than the roadway width, that is, 6 feet beyond the construction limit on each side.

2. Lay cross-drain pipes or culverts and commence grading operations by Equipment Operators (*Figure 7-9*).

In fill areas, bring grade up in successive layers with compaction.

In cuts areas, excavate until reaching subgrade, then compact.

Throughout this step, workers place culverts at the appropriate slopes when and where required according to the roadway plans.

Figure 7-9 — Example of placing pipe and grading.

3. Place a base course on the subgrade. The base course material can be gravel, sand, crushed stone, or more expensive and permanent materials (*Figure 7-10*).
4. Place a surface course over the base. This material can be sand, asphalt, blacktop, concrete, or similar materials.

Figure 7-10 — Example of placing a base course of crushed stone.

Depending on the location and intended permanency of the road, traffic may be allowed to travel over the subgrade itself. In other instances, traffic may require only a gravel or stone surface. However, a high-speed road requires a base and a hard, durable surface.

1.7.0 Sections

A section is a view of an object cut by a plane perpendicular to the line of sight. For road design and construction, a section is perpendicular to the roadway centerline.

Sections are used for a variety of purposes during road design and construction, two of which are to define the materials to be used, and communicate the design configuration of the completed road. Sections are also used to stake out roads, determine earthwork requirements, and provide quality control in determining how the completed road conforms to its original design.

1.7.1 Typical Section

The shape and features of a road should be as uniform as possible while still meeting the project's conditions and requirements. Typical sections establish that standard of uniformity. The typical sections of a road show exactly what the road should look like in appropriate segments upon completion. It includes the type and thickness of the base and surface materials, the crown, superelevation, ditch slope, cut slope, fill slope, and all horizontal widths of components, such as surface, shoulders, and ditches (*Figure 7-11*).

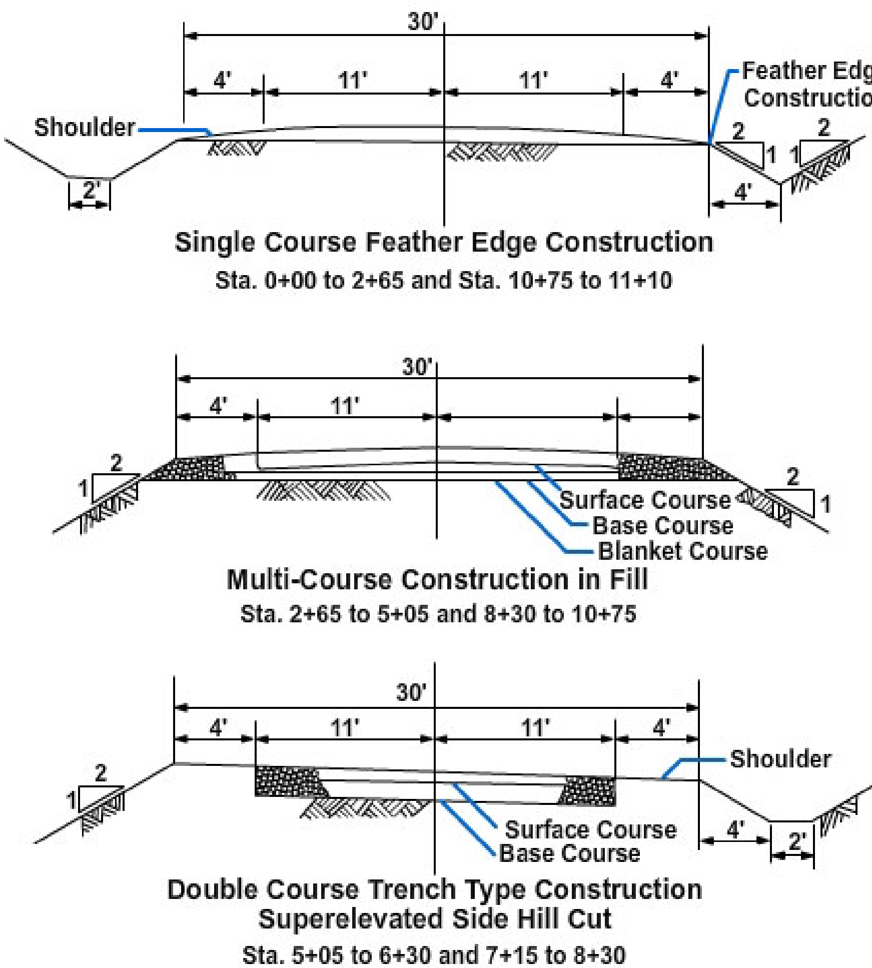


Figure 7-11 — Example of a typical section.

Slight deviations will occur during construction, and tolerances are allowed. However, the shape and construction of the road should conform as closely as possible to the typical section. Refer to United Facilities Criteria UFC 3-250-12N, *Design: Pavements*, and UFC 3-250-1FA, *Pavement Design for Roads, Streets, Walks, and Open Storage Areas* for additional information on general provisions and design criteria.

The roadbed for the curved portion differs from the roadbed for the straight portion, so typical sections are prepared for both. A typical section for a curve will show the pavement as a plane surface instead of crowned, and it is usually superelevated to account for centrifugal force encountered in curves. The outside shoulder slope is the same as the superelevated pavement slope, but the inside shoulder slope (closest to the center of the arc) is either the same or a greater slope.

Most curves are also widened on the inside to allow for the “curve straightening” effect of long wheelbase vehicles. On a tractor-trailer rig, the trailer’s wheels do not follow the tracks of the tractor’s wheels. They run closer to the inside edge on the inside lane, and closer to the centerline on the outside lane, presenting a safety hazard when two vehicles meet on curves. Curve widening partially relieves this hazard. *Figure 7-12* shows a superelevated section with curve widening. You can find specific guidance for curve widening in the previously mentioned UFCs.

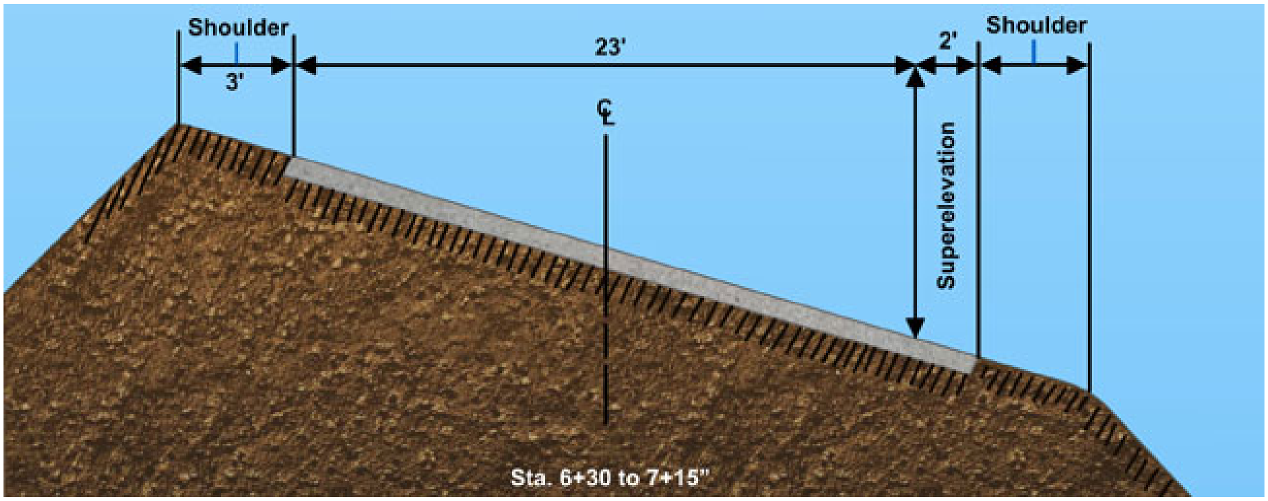
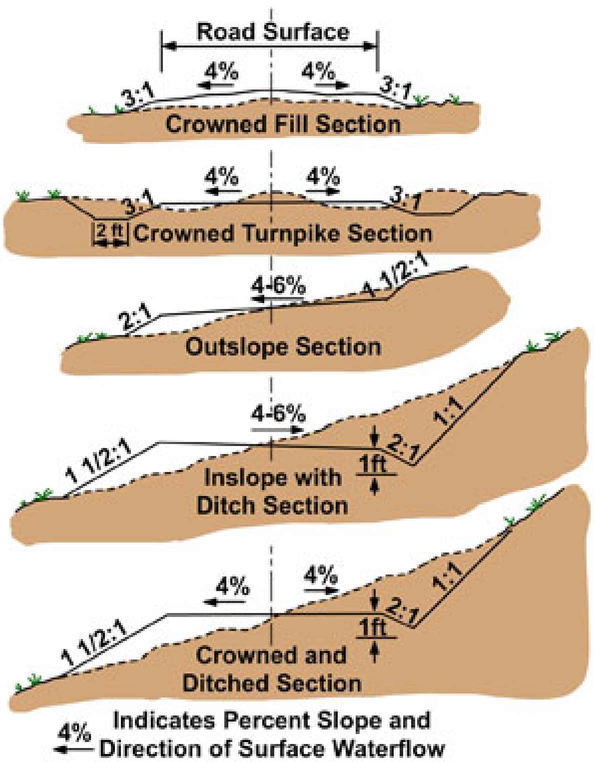


Figure 7-12 — Example of typical curve section.

1.7.2 Preliminary Cross Section

Preliminary cross sections are sectional views of existing terrain at station points along the centerline of the proposed route. These sections are usually drawn after the roadway has been cleared but may be drawn before.



If drawn before, the thickness of the sod to be stripped off is normally deducted from the elevations.

Preliminary cross sections show elevations of the natural, or original ground.

By superimposing these preliminary sections over the designed finished roadbed sections, road builders can study various alignments of the road before commencing preliminary earthwork estimating (*Figure 7-13*).

Figure 7-13 — Typical preliminary cross section.

1.7.3 Final Cross Section

When the vertical and horizontal alignments of the road are fairly well fixed, final design is commenced, and drafters can prepare final construction drawings including the final cross sections. For a refresher on procedures for plotting cross sections, review Chapter 15 of EA Basic.

From these final cross sections, crews can set slope stakes at each station along the centerline of the road. They show the actual shape of the road, the horizontal width of components, their distances from the centerline, finish elevations, and the extremities of the cut and fill. They also show the slopes of the roadbed surface, ditches, and shoulders.

The term final cross section also applies to the as-built sections established after the road is completed.

1.8.0 Drainage

Drainage can be a major problem in the location, construction, and design of roads.

A route should never be located where drainage cannot be handled or would be too costly to handle (*Figure 7-14*).

Swamps, underground springs, flash floods, and seasonal high floodwaters that can cover the road are causes to relocate a proposed route, and provide good reasons for planning alternate routes.

A route may also have to be relocated because local material is insufficient to build a particular type of road.

Figure 7-14 — Example of road with major drainage problem.

To prevent standing puddles on the roadway during construction, some surface drainage problems can be solved by slanting the worked surface so water will run off quickly, or by cutting ditches, called bleeders, so the water is carried away.

Solving subsurface drainage problems requires either raising the grade line of the road or lowering the water table. In either case, the elevation difference between the water table and the top of the subgrade should be as great as possible.

One way to lower the water table is to dig deep, open ditches that are set back beyond the roadway limits. These deep ditches allow groundwater to seep through the sides, intercepting and directing the flow out to the end of each ditch.

Another way is to dig a deep trench exactly where the finished roadway ditch will be, backfill it to a designated depth with rocks or large gravel of varying sizes (larger sizes at the bottom), cap the rocks with a layer of branches or straw, and finish with soil backfill and compaction. This type of drain is a french drain (*Figure 7-15*).

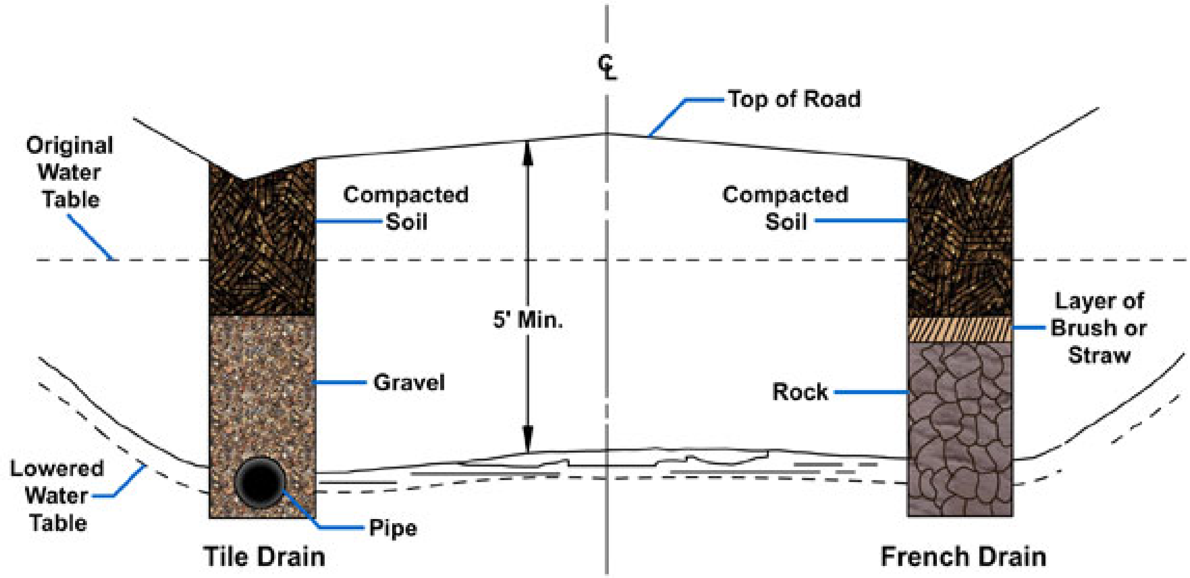


Figure 7-15 — Examples of subsurface drainage systems.

Figure 7-15 also shows a similar drain system, a tile drain. With a tile drain, place a perforated pipe in the bottom of the trench (minimum pipe grade is 0.3 percent), fill with gravel to the desired depth, and finish with soil backfill and compaction.

Managing surface drainage involves water from direct precipitation, surface runoff (rainfall not absorbed by the soil), rivers, and streams.

Figure 7-16 — Example of an uncrowned traveled way.

Rainfall has an immediate effect on a roadway; if allowed to stand, it would be a safety hazard or could cause weak spots (*Figure 7-16*).

Water falling upon a traveled way (road surface) should be drained away by crowning, that is, constructing the traveled way so that the middle is higher than the edges.

Superelevating the traveled way provides the drainage on curves; the inside edge of the curve is constructed lower than the outside edge.

Water draining from the surface continues over the shoulders; shoulders should always have a slope greater than or equal to the surface slope. This slightly increases the speed of the draining water and corresponding rate of drainage. The water then flows from the shoulder down the side of the fall in a fill section, or into a roadway ditch in a cut section. Roadway ditches are not normally used in a fill section.

1.8.1 Roadway Ditches

There are three main types of ditches used in road and airfield construction: side (or roadway), interceptor, and diversion.

A properly functioning roadway ditch is the most important factor in roadway drainage.

Running alongside the traveled way, if the ditch is inadequate for the volume of water or becomes obstructed, the overflow can flood the roadbed to block traffic, and/or wash away surface and shoulder material (*Figure 7-17*).

Figure 7-17 — Example of an inadequate ditch eroding shoulder material.

You need to consider a number of factors in determining the size and type of roadway ditches, such as:

- volume of water to be carried
- slope of the back slope
- soil types
- “lay of the land”
- maximum and minimum ditch grades

The slopes of the surface, shoulders, and back slopes affect the volume. A steep slope increases the rate of runoff, which causes a greater instantaneous volume of water in the ditch. A shallower slope decreases the rate of runoff, but exposes more surface area on the back slope, which increases the amount of runoff.

However, other factors predominately affect the choice of slope:

- Is additional excavation needed?
- If so, what type of soil would form the ditch?

If the ditch cut will be in sand, it will require a lesser slope than if in clay or rock. All soil types have different amounts of runoff; runoff from sandy soil is small, while runoff from clay soil or solid rock is large.

The usual back slope is 1½:1 (1½ foot horizontal: 1 foot vertical), but may be decreased for sandy soil or greatly increased for rock cuts. The usual front, or ditch slope from the shoulder to the bottom of the ditch is 3:1.

Another important design factor is the grade of the ditch itself, which can range from 0.5 — 4%, but 2% is the desired slope; steeper grades tend to cause excessive erosion from the greater velocity of water. A moderate velocity (peak velocity flow above 3 feet/second) is generally desirable to prevent excessive erosion from too much velocity, and to offset such effects as saturation and sedimentation from water moving too slowly.

The water velocity in a channel can be reduced by decreasing the slope. However, except for local variations, building ditches at slopes other than that of the surrounding ground is impractical.

One method for decreasing the slope is to install check dams or weirs, as shown in *Figure 7-18*, when the slope ranges between 2 and 8 percent. Channels with slopes of 2 percent or less generally do not require extensive erosion controls; in excess of 8 percent, it is usually more economical to pave the ditch with asphalt or concrete than to build check dams.

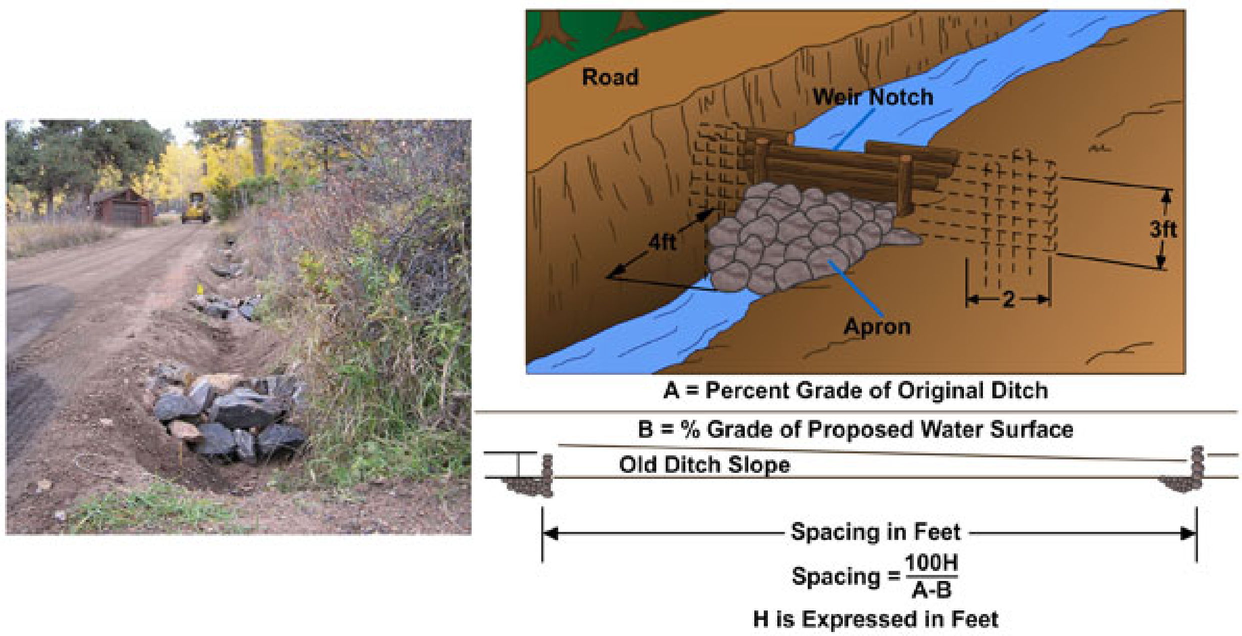


Figure 7-18 — Examples of a stone and a wooden check dam.

Correct spacing between check dams can be determined by using the following formula:

$$S = \frac{100\ H}{A - B} \quad \text{where —}$$

- *S* = spacing, in feet, between check dams. (This value should not be less than 50 feet.)
- *H* = height from the channel bottom to the lower edge of the weir notch. (This value should not be greater than 3 feet unless the dam is to be structurally designed. To prevent unnecessary work, the practical lower limit for H is 1 foot.)
- *A* = slope of the original ditch in percent.

- *B* = desired slope in percent. (This value should be set at 2 percent. This is the maximum slope that will not require additional erosion control.)

Example: Original slope = 6%, Desired slope = 2%, Height = 3 ft, Find S = spacing

$$S = \frac{100\ H}{A - B} = \frac{100(3)}{6 - 2} = \frac{300}{4} = 75\ feet$$

Rainfall itself, of course, is the one factor involving water volume that cannot be controlled; the more intense the rainfall or the longer the duration, the greater the volume of water the ditch has to carry.

However, gathering information from local residents and observing high-water marks along streams can help the engineer determine the heaviest rainfall to expect in a particular area.

In addition to considering soil type, slopes, and volume of water as factors, the engineer must also consider available equipment and traffic usage when designing the type of ditch to use. A grader is best suited to cut “V” or triangular ditches, while a scraper is best suited for an expedient wide, flat bottomed or trapezoidal ditch. Besides inviting excessive erosion, sidewalls designed and cut too deep can turn minor “off the road” accidents into something more serious by a vehicle overturning and entrapping the occupants.

The two most common types of ditches are the V-bottom and the flat bottom, or trapezoidal, ditches. Under similar conditions, water flows faster in a V-bottom ditch than in a trapezoidal ditch. The most common ditches and their typical side slopes are shown in *Figure 7-19*. For a trapezoidal ditch, the flat bottom is generally 2 feet wide but can range anywhere from 1 foot to scraper width.

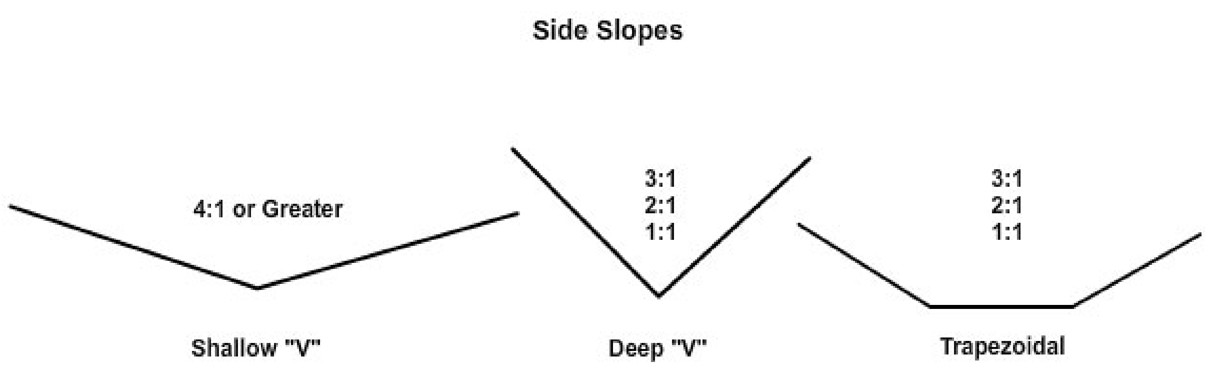


Figure 7-19 — Example of the most common types of ditches and slopes.

1.8.2 Interceptor Ditches

Interceptor ditches can decrease the volume of water draining into a roadway ditch. These are shallow ditches dug around the top of the cut to intercept and redirect the water draining from the original ground toward the roadway.

Figure 7-20 shows an interceptor ditch 10 to 12 feet above the back slope limits. The quantity and size of needed interceptor ditches will depend on the original ground slope, runoff area, type of soil, vegetation, and any other factors related to runoff volume.

1.8.3 Diversion Ditches

Refer again to *Figure 7-20* for an example of a diversion ditch. Diversion ditches redirect and relieve loading on the side ditches. Water from the roadway ditches cannot be allowed to pond on the side or against the roadway fill as it leaves the cut, so diversion ditches need to be dug to carry the water away from the roadway to natural drains. These natural drains can be rivers, streams, gullies, sinkholes, natural depressions, or hollows.

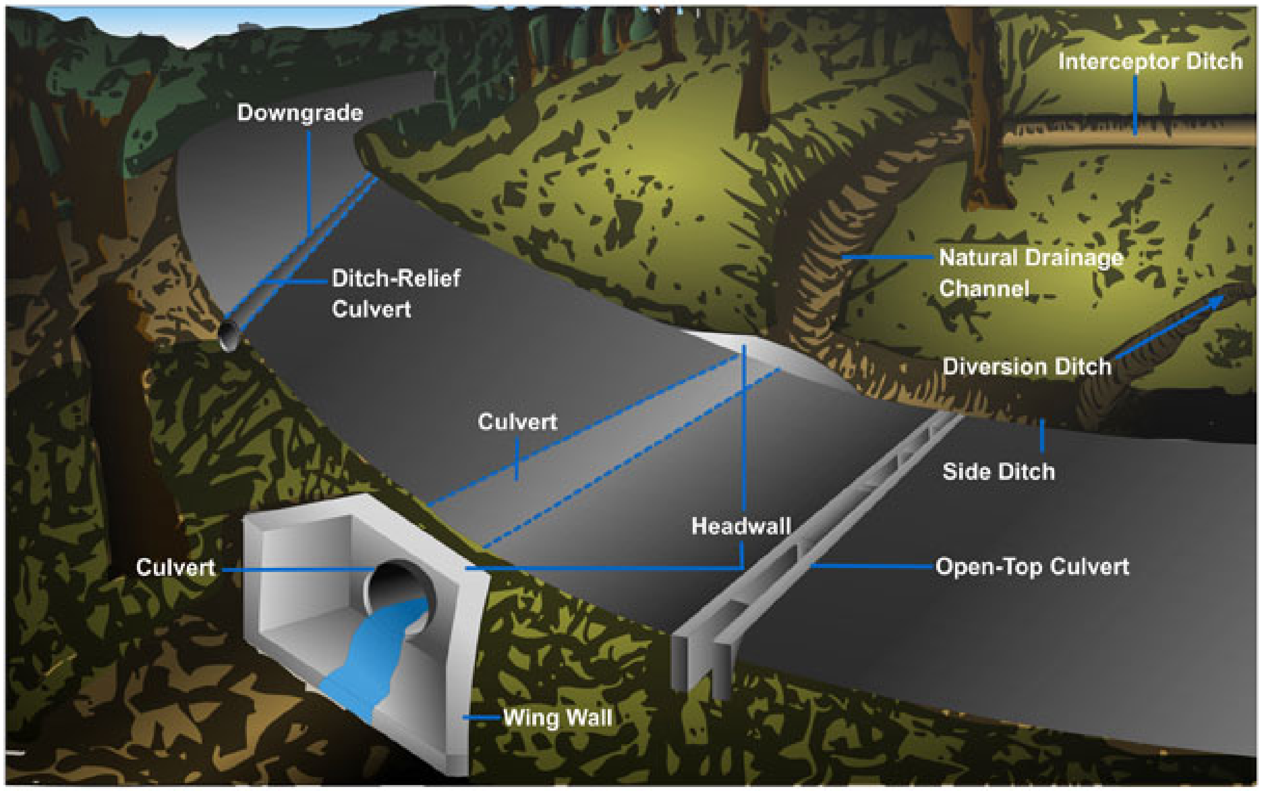


Figure 7-20 — Example of drainage systems and their terminology.

1.8.4 Culverts

Sometimes you need to use a cross-drain to allow the water to flow from one side of the road to the other, or the road must cross a small stream. If these cross-drains are 10 feet wide or less, they are called culverts (*Figure 7-20*). Over 10 feet wide, they are called bridges.

Culverts can be made of many materials, such as corrugated metal, reinforced concrete, concrete pipe, timber, logs, and even open-ended oil drums (*Figure 7-21*). Material selected for a culvert will depend upon various factors, one of which is the type and life expectancy of the road.

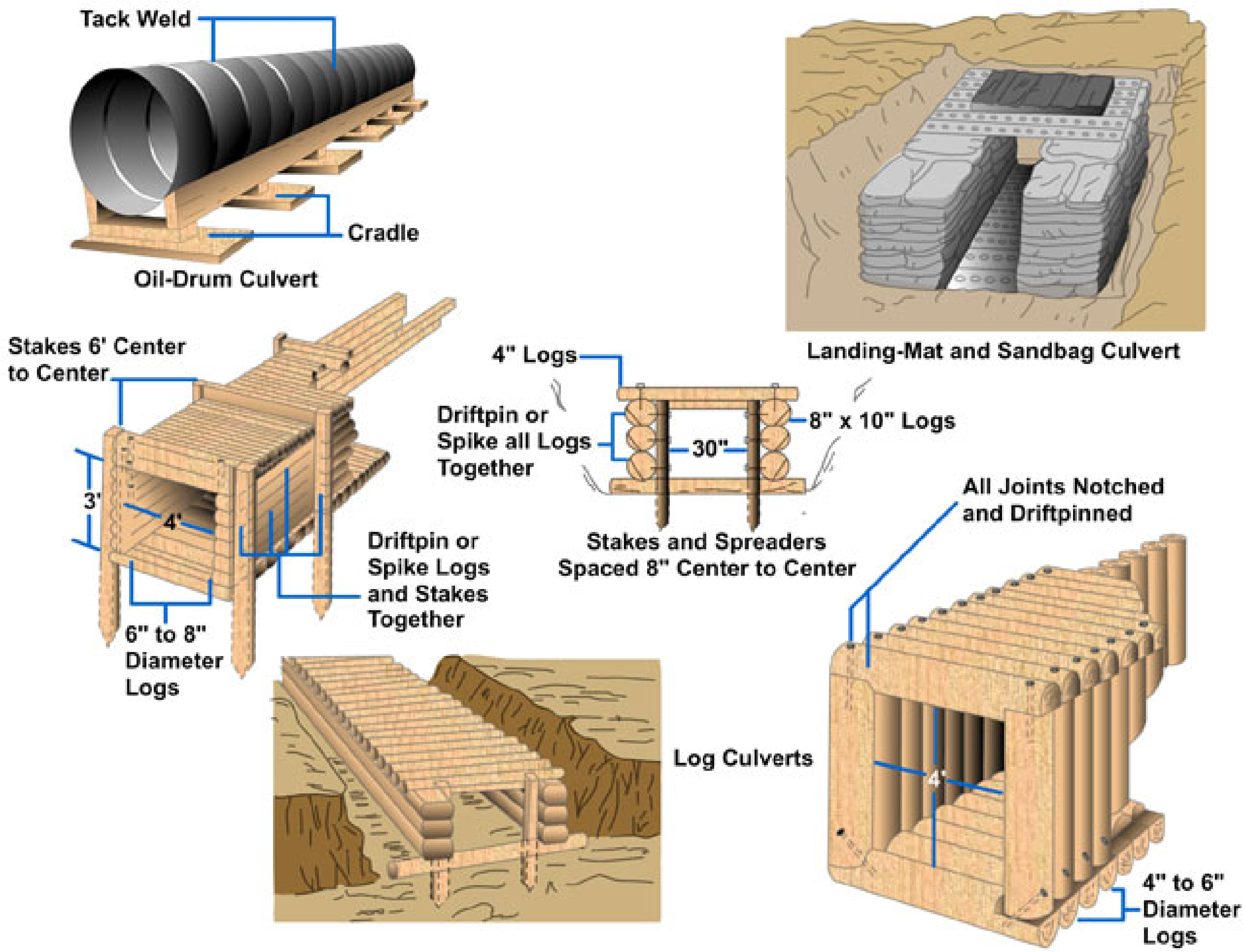


Figure 7-21 — Examples of expeditionary culverts.

For permanent roads and highways with concrete or asphalt paving, reinforced concrete or concrete pipe should be used. Concrete pipe is one of the strongest and most durable materials used in manufacturing culverts. The pipe diameter is in direct proportion to the shell thickness and length: the larger the diameter, the thicker the shell, and the longer the section availability. Pipe diameters are nominal inside dimensions.

For semi-permanent and temporary or expeditionary roads, the design engineer may choose to use materials such as or similar to those shown in *Figure 7-21*.

Test your Knowledge (Select the Correct Response)

1. As a senior EA, your involvement in road construction can include ________.

   A. conducting surveying operations
   B. assisting in the design
   C. providing on-site construction quality control
   D. all of the above

2.0.0 AIRFIELDS

Road construction and airfield construction are similar in methods, equipment, and sequence of operations; both require a subgrade, base course, and surface course. Clearing and grubbing, cutting and filling, grading and compacting, surfacing: all these basic evolutions are common to both types of projects.

Since the engineering officer is also responsible for designing and laying out an airfield, as a senior EA, you can expect to be involved in this project as well.

This section will introduce you to airfields and airfield terminology.

2.1.0 Airfield Terminology

Figure 7-22 is a plan view of a small advanced-base airfield constructed for operational use in a combat area. *Figure 7-23* is a plan, section, and perspective view of a runway approach zone. This airfield is not intended for permanent occupancy since it contains a minimum of servicing facilities.

However, the terminology is typical to all airfields, and you can refer to *Figure 7-22* and *Figure 7-23* often to relate a specific area to the following definitions.

- Approach Zone — A trapezoidal area established at each end of a runway. The approach zone must be free of obstructions on the plane of a specific glide angle.
- Apron — A stabilized paved or metal-planked surface area designed for temporary parking of aircraft other than at hardstands. Aprons are classified as service, warm-up, and parking.
- End Zone — A cleared and graded area that extends beyond each end of the runway. The dimensions of the end zone depend upon the safety clearances specified by the design criteria for advanced-base airfields.
- Glide Angle — The angle between the flight path of an airplane during a glide for landing or takeoff and a horizontal plane fixed relative to the runway. The glide angle is measured from the outer edge of the end zone.
- Hardstand — A stabilized, paved, or metal-planked surface parking area of sufficient size and strength to accommodate a limited number of aircraft. Hardstands are usually dispersed over the ground area beyond the safety clearance zones of a landing strip. They provide protection for aircraft on the field by dispersal, concealment, and revetment.
- Landing Area — The paved portion, or runaway, of the landing field. The landing area should have unobstructed approaches and should be suitable for the safe landing and takeoff of aircraft under ordinary weather conditions.

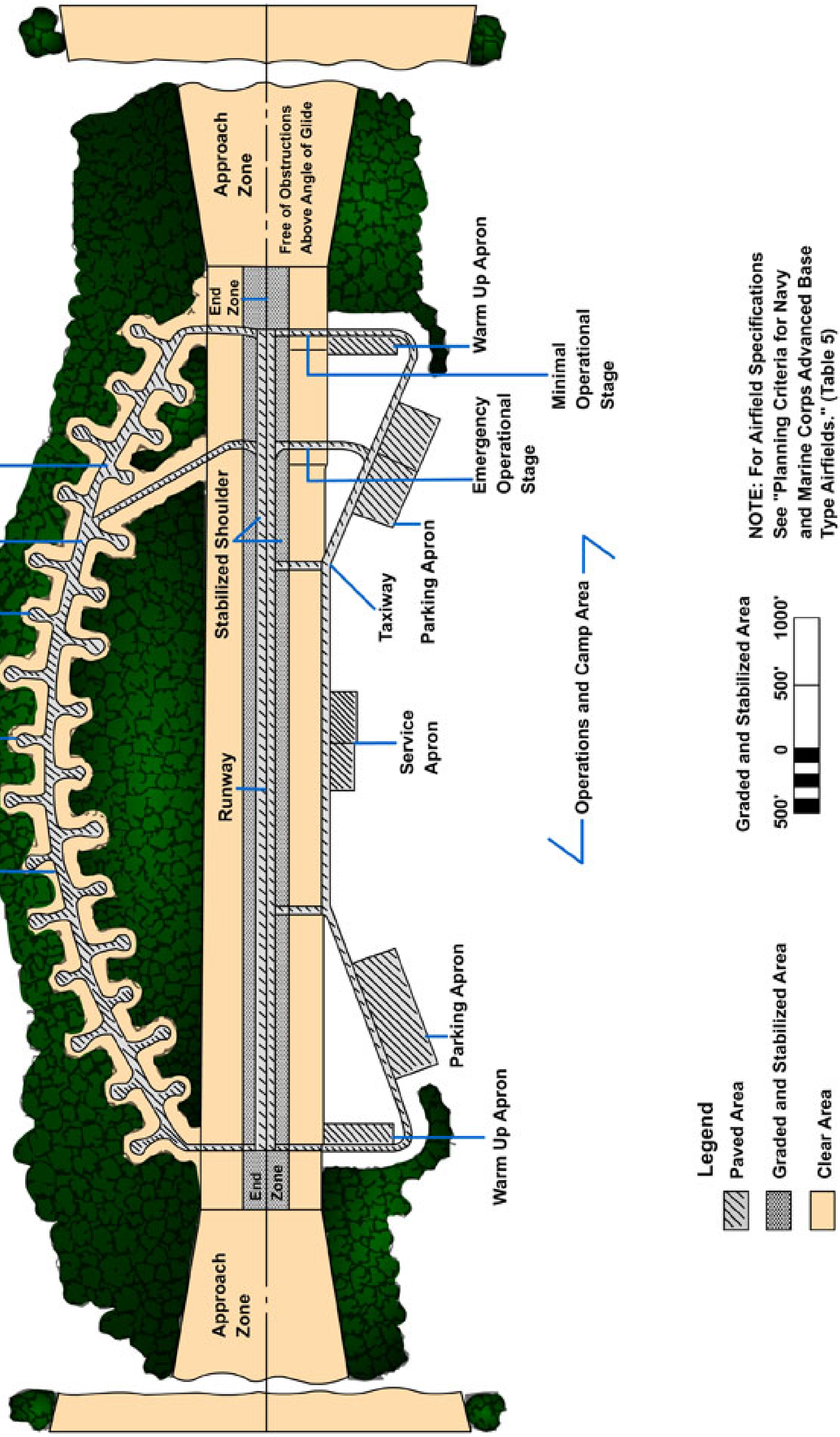


Figure 7-22 — Example of an advanced-base airfield and terminology.

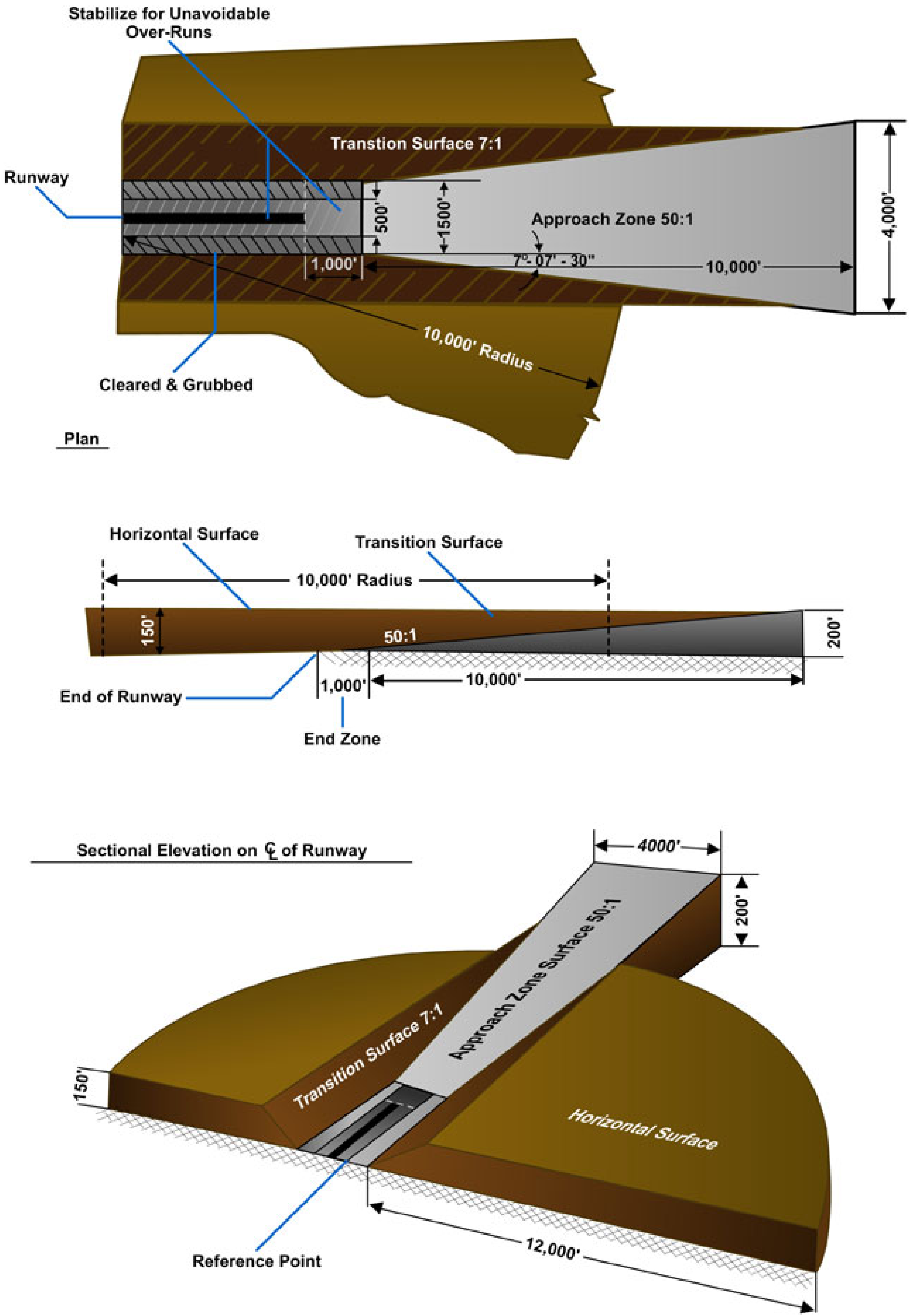


Figure 7-23 — Example of a runway approach zone and terminology.

- Landing Strip — The area that includes the landing area, end zones, shoulders, and cleared areas.
- Revetment — A protective pen usually made by excavating into the side of a hill or by constructing earth, timber, sandbag, or masonry traverse around the hardstands. Such pens provide protection against bomb fragments from high-altitude bombing but provide little protection against ground strafing. They may actually draw this type of fire if not well concealed.
- Runway — The portion of the landing strip, usually paved, used for the landing and takeoff of aircraft.
- Shoulder — The graded and stabilized area adjacent to the runway or taxiway. Although it is made capable of supporting aircraft and auxiliary equipment (such as crash trucks) in emergencies, its principal function is to facilitate surface drainage.
- Taxiway — A specially prepared area over which aircraft may taxi to and from the landing area.
- Transition Surface — A sloping plane surface (about 1 foot rise to 7 feet run) at the edge of a landing strip. Its function is to provide lateral safety clearances for planes that accidentally run off the strip.

2.2.0 Planning an Airfield

Planning for aviation facilities requires special consideration:

- type of aircraft to be accommodated
- physical conditions of the site
  - weather conditions
  - terrain
  - soil
- availability of construction materials
- safety factors
  - approach zone obstructions
  - traffic control
- provision for expansion
- defense

Wartime conditions also require tactical considerations. All of these factors affect the number, orientation, and dimensions of runways, taxiways, aprons, hardstands, hangars, and other facilities.

For additional information about airfield planning and construction, refer to the Unified Facilities Criteria UFC 3-260-XX series: *—01 Airfield and Heliport Planning and Design, —02 Pavement Design for Airfields, —03 Airfield Pavement Evaluation.*

3.0.0 SUBBASE and BASE COURSE

Pavements (including the surface and underlying courses) may be divided into two classes—rigid and flexible. The wearing surface of a rigid pavement consists of Portland cement concrete with strength that enables it to act as a miniature beam to bridge over minor irregularities in the base or subgrade material.

All other pavements are classified as flexible. Distortions or displacements in the subgrade reflect into the base course and upward into the surface course.

Under traffic loading, the layered courses tend to conform to the same shape. Flexible pavements are used almost exclusively in the theater of operations for road and airfield construction; they are adaptable to nearly all situations and any construction battalion in the Naval Construction Force (NCF) can build them.

3.1.0 Flexible Pavement Structure

Flexible pavements on airfields must be limited to those pavement areas not subjected to detrimental effects of fuel spillage, severe jet blast, or parked aircraft. Jet blast damages bituminous pavements when the intense heat is allowed to impinge in one area long enough to burn or soften the bitumen so that the blast erodes the pavement.

Hot-mix asphaltic concretes generally will resist erosion at temperatures up to 150 degrees Celsius (300 degrees Fahrenheit). Temperatures of this magnitude are produced only when aircraft are standing and operated for an extended time, or with afterburners operating. Fuel spillage leaches out the asphalt cement in asphaltic pavements.

In an area subject to casual minor spillage, the leaching is not serious, but where spillage is repeated in the same spot at frequent intervals, the leaching will expose loose aggregate. Flexible pavements are generally satisfactory for runway interiors, secondary taxiways, shoulders, paved portions of overruns, or other areas not specifically required to have a rigid pavement surfacing.

Figure 7-24 shows a typical flexible pavement construction, although not all layers shown are present in every flexible pavement design. For example, a two-layer structure consists of a compacted subgrade and a base course only.

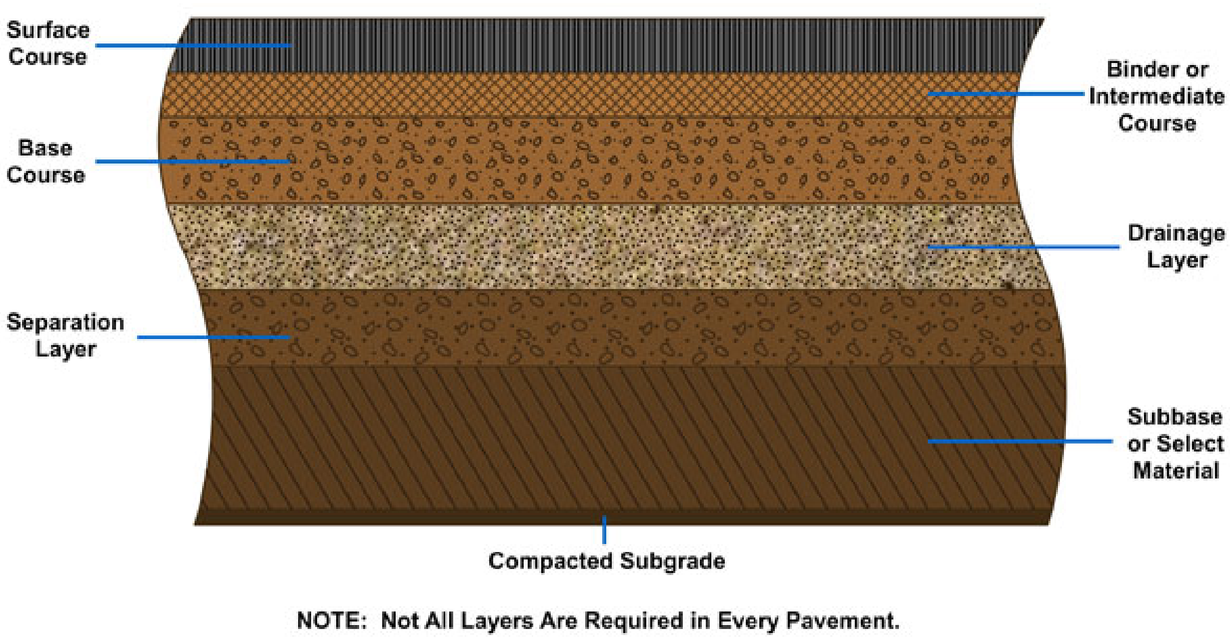


Figure 7-24 — Typical flexible pavement structure.

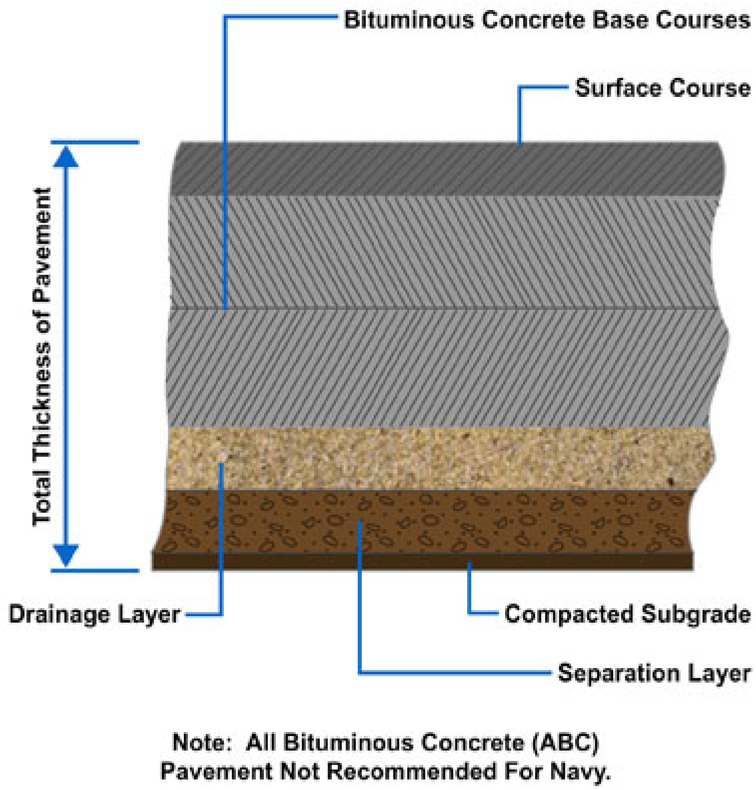


Figure 7-25 — Typical all-bituminous concrete pavement.

Figure 7-25 shows a typical all-bituminous concrete pavement.

However, UFC 3-26-02, *Pavement Design for Airfields* does not recommend this type of pavement for Navy airfields.

Figure 7-26 shows a typical flexible pavement using stabilized layers.

As mentioned previously, flexible pavements are generally satisfactory for runway interiors, taxiways, shoulders, and overruns.

NOTE

The word *pavement,* when used by itself, refers only to the leveling, binder, and surface course, whereas *flexible pavement* refers to the entire pavement structure from the subgrade up.

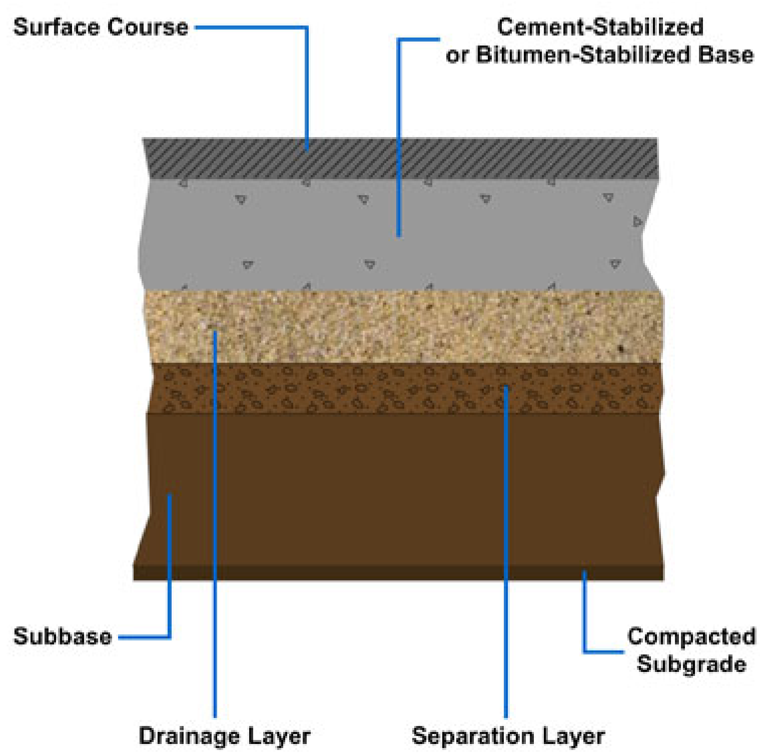


Figure 7-26 — Typical flexible pavement with stabilized base.

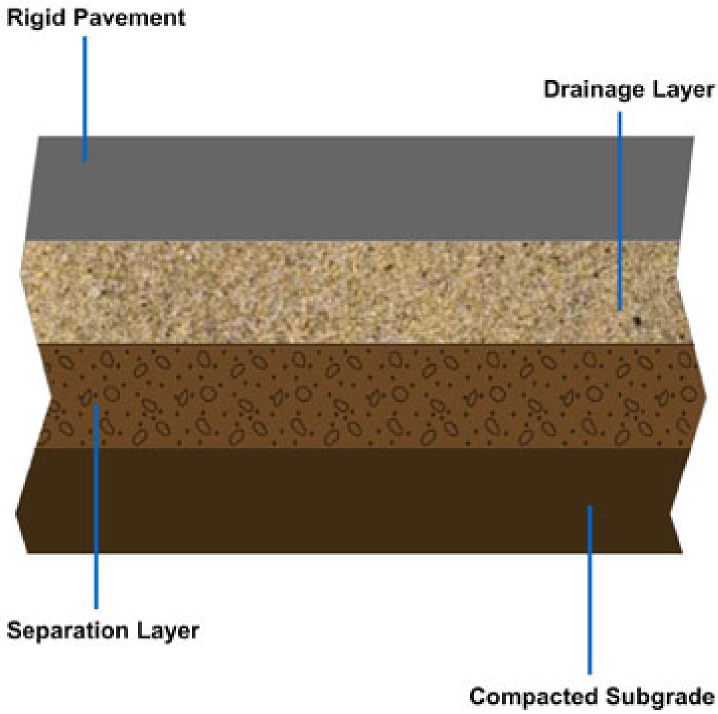


Figure 7-27 — Typical rigid pavement structure

Figure 7-27 shows a typical rigid pavement structure.

The following pavements will be rigid pavement:

- all paved areas on which aircraft or helicopters are regularly parked, maintained, serviced, or preflight checked on hangar floors and access aprons
- specific runway ends
- any other area where it can be documented that flexible pavement will be damaged by jet blast or by spillage of fuel or hydraulic fluid

3.2.0 Materials

Select materials will normally be the locally available coarse-grained soils, although in certain cases the design may call for fine-grained soils. When they are economically available on the local market, the designing officer may consider lime rock, coral, shell, ashes, cinders, caliche, disintegrated granite, and other like materials.

3.2.1 Subbase

Subbase materials may consist of naturally occurring coarse-grained soils or blended and processed soils. When they meet area specifications or project specifications, the previously mentioned materials may be used as subbases.

In certain instances, it may be more economical to use materials stabilized with commercial admixes for subbases. Portland cement, cutback asphalt, emulsified asphalt, and tar are commonly used for this purpose.

3.2.2 Base Course

A base course's material design may call for a wide variety of gravels, sands, gravelly and sandy soils, or other natural materials, either alone or blended. Some natural materials may only need crushing or removal of the oversize fraction to maintain gradation limits, while others may require mixing crushed and pit-run materials to form material for a satisfactory base course.

Many natural deposits of sandy and gravelly materials make satisfactory base materials, but they vary widely in their relative proportions of coarse and fine material and in the character of their rock fragments. Often, however, blending materials from two or more deposits can produce satisfactory base materials.

To support heavy loads, you can use a base course made from sandy and gravelly material with its high-bearing value, but you should not use uncrushed, clean-washed gravel. Clean-washed gravel is not satisfactory for a base course since the fines, which act as the binder and void filler to the coarse aggregate, have been washed away.

Alluvial deposits in thickness from 1 to 20 feet may contain sand and clay in a natural mixture, but typically there are great variations in the sand/clay proportions from the top of a pit to the bottom.

Do not confuse unacceptable deposits of partially disintegrated rock with fragments of rock, clay, and mica flakes with acceptable sand-clay soils. Mistaking such material for sand-clay soil is often the reason for a base course failure, the reduced stability caused by the mica content. Nevertheless, with proper proportioning and construction methods, sand-clay soil can achieve satisfactory results; it is excellent material for construction where a higher type of surface will be added later.

Processed materials are prepared by crushing and screening rock, gravel, or slag, and a properly graded crushed-rock base can make the highest quality of any base material providing it is produced from sound, durable rock particles.

Almost any rock hard enough to require drilling, blasting, and crushing can produce a satisfactory crushed-rock material. The usual resources for raw processing material are existing quarries, ledge rock, cobbles and gravel, talus deposits, coarse mine tailings or other similar hard, durable rock fragments.

Do not use materials that crumble on exposure to air or water. Nor should you use processed materials when gravel or sand-clay is available, except when the project requirements make it necessary, or when studies show that processed materials will save time and effort.

Bases made from processed materials can be divided into three general types: stabilized, coarse-graded, and macadam.

- Stabilized base — All material ranging from coarse to fine is intimately mixed either before or as the material is laid into place.
- Coarse-graded base — Composed of crushed rock, gravel, or slag, this base may be used to advantage when necessary to produce crushed rock, gravel, or slag on site, or when commercial aggregates are available.
- Macadam base — Coarse, crushed aggregate is placed in a relatively thin layer and rolled into place; then fine aggregate or screenings are placed on the surface of the coarse-aggregate layer and rolled into the coarse rock until it is thoroughly keyed in place. Water may be used in the compacting and keying process; then the base is a water-bound macadam.

  Crushed rock used for macadam bases should consist of clean, angular, durable particles free of clay, organic matter, and other objectionable material or coating. Any hard, durable crushed aggregate is usable, provided the coarse aggregate is primarily one size and the fine aggregate will key into the coarse aggregate.

3.2.3 Other Materials

In a theater of operations where natural deposits of sand, gravel, or sources of crushed rock are unavailable, base courses can be developed from materials not normally considered, such as coral, caliche, tuff, rubble, lime rock, shells, cinders, iron ore, and other select materials. Some are primarily a soft rock that is crushed or degraded under construction traffic to produce a composite base material; others develop a cementing action resulting in a satisfactory base. The following describes the characteristics and usage of some of these materials.

3.2.3.1 Coral

Uncompacted and poorly drained coral often results in an excessive moisture content and loss of stability. Coral's greatest asset as a construction material is its bonding properties, but those properties can fluctuate greatly with a number of variables:

- quantity of volcanic impurities
- proportion of fine and coarse material
- age
- length of exposure to the elements
- climate
- traffic
- sprinkling
- method of compaction

However, with additional attention to proper moisture control, drainage, and compaction methods, coral can obtain satisfactory results.

3.2.3.2 Caliche

Caliche is another variable material consisting of sand, silt, or even gravel. Its variability in content (limestone, silt, and clay) and in degree of cementation make it essential that caliche be obtained from deposits of good uniform quality, and that it be compacted at optimum moisture. When properly saturated with water, compacted, and allowed to settle, caliche can be made into high-quality base courses, especially caliches that are cemented with lime, iron oxide, or salt.

3.2.3.3 Tuff

Tuff is a porous rock, usually stratified and formed by consolidation of volcanic ashes, dust, and other cementatious materials of volcanic origin. It may be used for constructing base courses the same as other base courses, except that after tuff is dumped and spread, the oversize pieces need to be broken and compacted with sheepsfoot rollers. The surface is then graded, compacted, and finished.

3.2.3.4 Rubble

Debris or rubble from destroyed buildings may also be used to advantage in constructing base courses. Depending on theater operations, multiple goals may be achieved by reusing building materials: clearance of building rubble, disposal of accumulated rubble, resource for a base course; non-use or minimized use of other natural resources. If debris or rubble from destroyed buildings is designated for use, jagged pieces of metal and similar objects must be removed.

3.2.4 Bituminous Base

When an asphalt mixing plant and bituminous materials are readily available, bituminous base courses may be used to advantage if locally available aggregates are relatively soft or of relatively poor quality. Bituminous mixtures are frequently used as base courses beneath high-type bituminous pavements when the design calls for a relatively thick surface course for traffic, particularly for rear-areas, which carry heavy traffic.

Generally, a bituminous base course may be considered equal to other types of high-quality base courses on an inch-for-inch basis, but if a bituminous base course is used, it must be placed in lifts not exceeding 3 1/2 inches in thickness. Additionally, if using a bituminous base, the binder course may be omitted and the surface course may be laid directly on the base course.

Summary

Whether the construction involves military roads or airfields, you can expect to be a participant in one of the many roles an Engineering Aid may be tasked with during a unit's project. You can best serve yourself and your unit by knowing and understanding the general methodology of horizontal construction, the terminology of both roadway and airfield construction, and the use and development of resource materials to construct both.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Iowa Department of Transportation, Office of Design, *Design Manual, Vertical Curve Design Alignments,* January 2004

Subcourse Number EN 5465, *Drainage Engineering Edition A* United States Army Engineer School Fort Leonard Wood, MO 65473, April 1994

Unified Facilities Criteria, UFC 3-250-12N, *Design: Pavements*, 8 June 2005, Naval Facilities Engineering Command (Preparing Activity)

Unified Facilities Criteria, UFC 3-260-01, *Airfield and Heliport Planning and Design*, 17 NOVEMBER 2008, Air Force Civil Engineer Support Agency (Preparing Activity)

Unified Facilities Criteria, UFC 3-260-02, *Pavement Design for Airfields*, 30 June 2001 U.S. Army Corps of Engineers (Preparing Activity)

Unified Facilities Criteria, UFC 3-260-03, *Airfield Pavement Evaluation*, 15 April 2001, U.S. Army Corps of Engineers (Preparing Activity)

US Army Correspondence Course, *Engineer Construction Course 052 D55*, United States Army Engineer Course, Fort Leonard Wood, MO 65473