

## CHAPTER 24

# GRADING AND EARTHWORK

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### INTRODUCTION

Grading is configuring the surface of the land by removing or adding earthen material to shape the land to best suit the project. It is accomplished with both large machines, such as bulldozers, pans, and dump trucks, and men wielding rakes and shovels. Grading is a major component of the function and success of a land development project (see Figure 24.1).

In this chapter, a general overview of the grading process will be followed by an explanation of how grading is represented and worked with on plans. A more specific breakdown of grading strategies and requirements follows, providing all the tools needed by the designer to produce an effective grading plan.

A good design integrates the natural landforms of the site with the proposed program to create an aesthetically pleasing, yet functional and cost-effective site plan. Because a grading scheme must consider function and utility, as well as aesthetics, it is both a science and an art. The grading of a site serves three basic purposes:

1. *Grading re-forms the land surface to make it compatible with the intended land use.* Subsequently, the relative elevations and gradients of streets, buildings, parking areas, and pedestrian/vehicle accesses must be mutually compatible if they are to function as a system. Similarly, they must be compatible with the surrounding existing terrain. Incompatibility with the existing terrain, which leads to excessive earthwork, the use of retaining walls, and drainage problems, increases construction costs.
2. *Grading establishes and controls the new drainage patterns.* In order to be cost effective, the grading de-

sign should allow for the efficient collection, conveyance, and detention of stormwater runoff. Proper grading prevents wet basements, damp crawl spaces, foundation damage, eroding hillsides, and muddy stream waters.

3. *Grading helps define the character and aesthetics of the site.* Site design is the foundation upon which many other elements of development depend. Proper grading should be cost-effective to the developer, appealing to the user, and responsive to the opportunities and restraints offered by the site. In this way, it enhances property values and contributes to the success of a land development project.

Often, the word “grade” refers to the slope, as in “the mountain road has a steep grade.” However, the word is also used as a reference to elevation, as in “what is the grade at the top of the driveway?” Both uses are correct, in that grading changes the ground elevation and, therefore, the inclination of the ground surface.

### CONTOUR GRADING

#### Description of Contour Lines

Contour lines are a method for depicting three dimensions on two-dimensional media, while maintaining a uniform scale in all directions. A contour line is an imaginary line connecting points of equal elevations and is formed by the intersection of a horizontal plane with the ground surface. The spacing and shape of contour lines indicate the shape and the inter-relationships of these land forms. A natural example of a contour line is the shoreline of a still body of water.



**FIGURE 24.1** Grading the site. (Photo Courtesy of Christer Carshult)

The vertical distance between successive contour lines is the contour interval. Most topographic maps, especially those associated with a land development project, have a constant contour interval. For instance, every contour may indicate a 2-ft change in elevation. Typically, the contour line at every fifth or tenth contour interval is shown as a heavier or darker line to make the map easier to read. In the rare instances where extremely flat areas and extremely steep slopes are shown on the same map, the addition or deletion of contour lines may be warranted. However, this depends on the scale of the drawing and the desired level of detail. The addition or deletion of intermediate contour lines results in an inconsistent contour interval for the map.

Topographic maps are an integral part of the design process of land development projects. The contour interval and level of detail depends on the purpose of the task and the scale of the drawing.

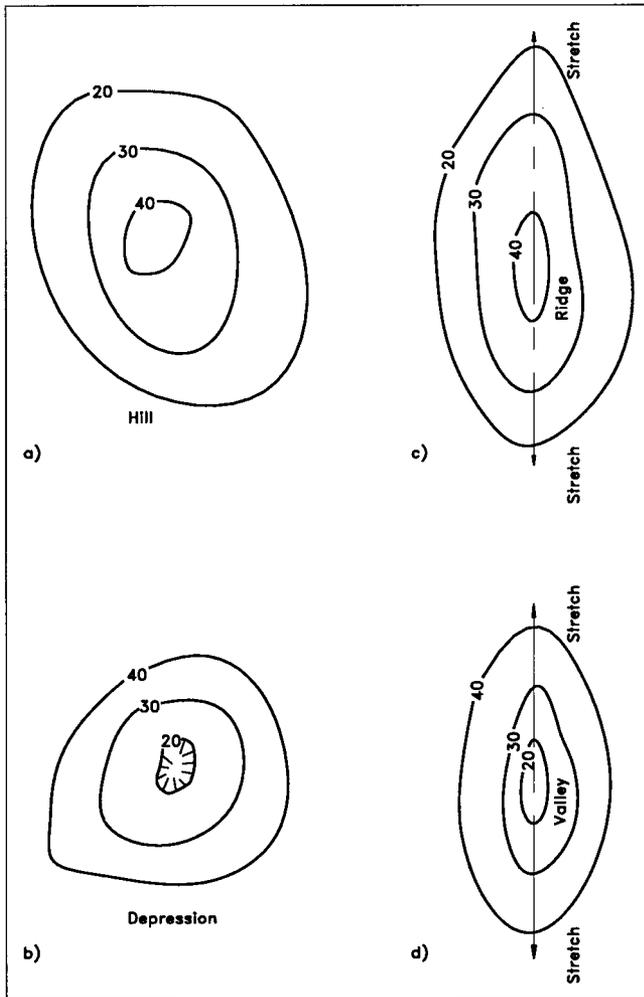
Large scale topographic maps, with 5 to 10-ft contour intervals, are usually available at a reasonable cost from government agencies and are used for feasibility studies of the project, where detailed information is not as critical. Because these maps are not constantly updated, their accuracy may be suspect, especially in areas of rapid development, so always qualify the information presented when using them.

Smaller scale maps, with 2-ft contour intervals, are used for final design and detailed studies. These maps are usually produced from recently collected data and provide a more accurate basis for design. State and local agencies, through ordinance and design standards, often require specific contour intervals for drawings submitted for review.

### Characteristics of Contour Lines

A key to conceptualizing and executing a grading plan is the ability to visualize the two-dimensional information depicted on the plan in three dimensions. In order to engineer a land development plan, the designer needs to have an understanding of contour lines and be able to recognize the land features associated with them. The following list briefly describes the fundamental characteristics of contour lines.

- *All contour lines eventually close on themselves if traced in their entirety.* Any apparent break in a contour line is due to the limitations of the map. Contour lines that extend beyond the limits of the subject area terminate at the map edge.
- *A series of contours that close on themselves within the mapped area indicate either a localized hill or localized depression.* Figure 24.2-a shows a hill and Figure 24.2-b shows a depression. In Figure 24.2-a, the elevations shown on the contour lines increase up to the summit. Conversely, in Figure 24.2-b, the elevations decrease towards the bottom of the depression.
- *Valleys and ridges are indicated by contour lines configured in V-shapes.* Imagine the contours of the hill in Figure 24.2-a being stretched in one direction. The result is an elongated hill, depicted by contours that are shaped like Vs at either end, as indicated in Figure 24.2-c. The tips of this V-shaped hill, when connected, depict a ridge. Stretching the contours of the depression of Figure 24.2-b creates the valley configuration of Figure 24.2-d. Both stretched figures are identical in



**FIGURE 24.2** Contour pattern: (a) for hills, (c) for ridges, (b) for depressions and (d) for valleys.

appearance except for the direction of increasing elevations. To distinguish the ridge from a valley, notice the direction of the apex of the V. On ridges, the V points down ridge (i.e., downhill), while the V points upstream (i.e., uphill) in valleys. Additionally, stream valley contours typically have a sharper V-shape, whereas ridges may be in a rounded U-shape.

- *Spacing of contours indicates general steepness of the ground.* While closely spaced contours indicate steep slopes, as the ground slope becomes flatter, the distance between the contours increases. Most natural hills and depressions are convex or concave in shape. A slope is convex-shaped if there is an increase in spacing between contour lines near the crest of the hill. Conversely, a slope is concave-shaped if there is an increase in spacing between the contour lines near the bottom of the slope.

- *Technically, contour lines never cross.* If a contour line represents a single elevation, then intersecting contour lines indicate two distinct elevations at the same point, a physical impossibility. However, in the case of

an overhanging cliff, where contour lines may appear to cross, this does not indicate dual elevations, since the two contours are actually in different horizontal planes.

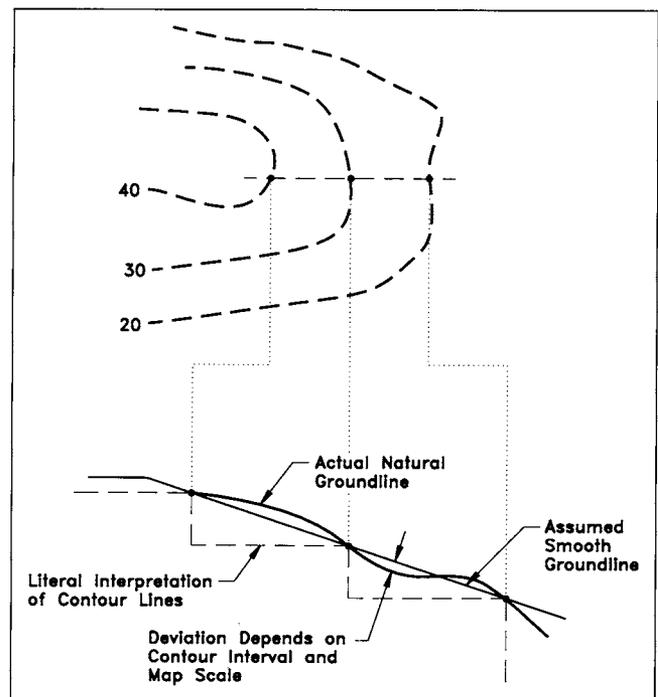
A contour line cannot split, nor can several lines join to form one line. This implies a knife-like edge, which is an unnatural occurrence.

In general, irregularly shaped contour lines designate rough, rugged landforms, while parallel, equally spaced contour lines indicate a smooth, uniform slope—often a machine-graded slope. Note: the steepest slope and also the path of flowing water is perpendicular to the contour lines, an important consideration when establishing drainage divides.

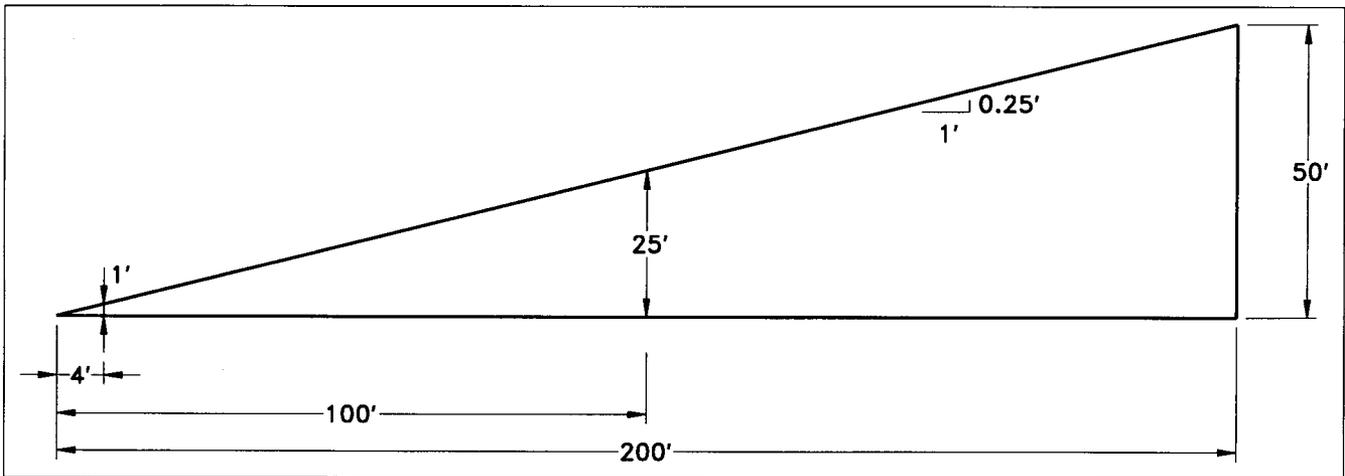
On a relatively large scale, the natural ground line is considered smooth and continuous. Relatively few ground features show sharp jagged or abrupt changes in ground relief. This smoothness is carried over to the concept of contour lines. Contour lines indicate distinct elevations, with the actual ground line between contour lines having local areas of irregular depressions and mounds, which may deviate (up to  $1 \pm$  ft) from the assumed smoothed ground line, as schematically shown in Figure 24.3. When determining an elevation between contour lines, the ground is assumed to be straight. Machine-graded slopes tend to be more uniform than natural ground and consequently have fewer irregularities.

### Ground Slope

Ground slope is the rate of change in elevation with respect to the horizontal distance, commonly expressed as either a



**FIGURE 24.3** Irregularities in natural ground.



**FIGURE 24.4** Various ways to denote slope gradients: (a) 4H:1V, (b) 25%.

percentage or a ratio. The percent slope describes the uniform change in elevation for a 100-foot horizontal distance. For example, if elevation changes 25 ft over a distance of 100 ft, the slope is expressed as 25%. Mathematically, this slope is defined as the ratio of  $\Delta v/\Delta x$ , where  $\Delta v$  is the change in vertical direction and  $\Delta x$  is the change in horizontal position (i.e., a distance,  $h$ ). A simple way to remember this basic tenant is in terms of “rise/run.” As a ratio, this slope would be expressed as 4 ft horizontal to 1 ft vertical, or simply “4h to 1v.” For example, the rate of change in elevation between two points that are 200 ft apart, with corresponding elevations of 100 ft and 150 ft (Figure 24.4), is

$$\begin{aligned} \text{rate of change in elevation} &= \frac{\text{change in elevation}}{\text{horizontal distance}} & (24.1) \\ &= \frac{\Delta v}{h} = \frac{150 - 100}{200} \\ &= 0.25 \text{ feet/foot} \end{aligned}$$

Hence, for every 1 ft of horizontal distance, the ground changes 0.25 ft in elevation. As a percentage, this equates to a slope of 25%; as a ratio this is equivalent to a 4h:1v slope (or 1v:4h). Figure 24.4 illustrates these various ways for designating slope gradients.

On most civil site drawings, the ratio is shown as horizontal to vertical,  $h:v$ . However, the order is sometimes reversed, (i.e.,  $v:h$ ) in other professional disciplines (e.g., architecture). Because of the significant difference between the two, always verify the order. To that end, it is good practice to include the  $h$  and  $v$  designation (e.g., 4h:1v) or indicate in a note on the plans the order of the  $h$  and  $v$  in the ratio.

The specific elevation of any point that lies between two points of known elevation is found by interpolation, assuming the ground slope between the two known points is linear. Hence, the newly determined elevation is based on the average ground slope between the two end points.

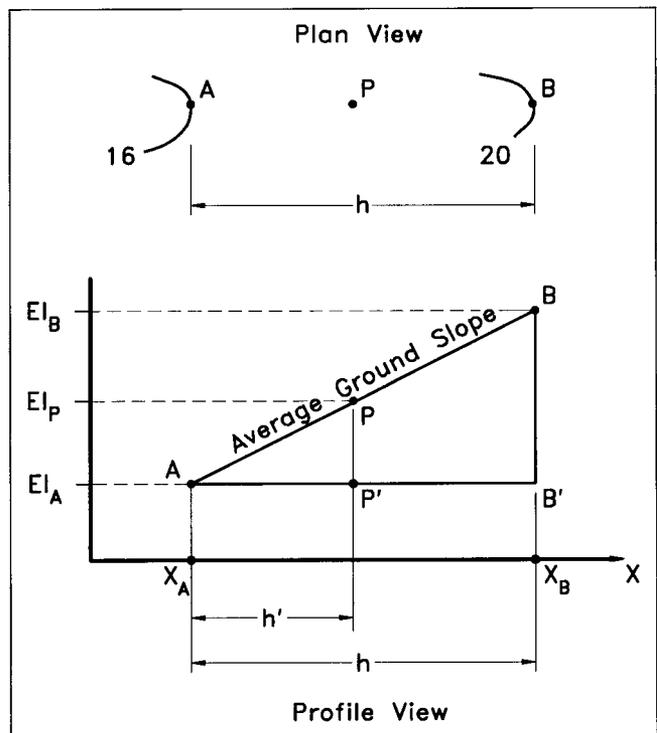
Given two end points (A and B) at positions  $x_A$  and  $x_B$  apart, with elevations  $El_A$  and  $El_B$ , the average ground slope,  $S_{avg}$ , between the two points is

$$S_{avg} = \frac{El_B - El_A}{x_B - x_A} = \frac{\Delta v}{\Delta x} \quad (24.2)$$

The distance  $\Delta x$  ( $h$ ) may be the scaled distance from the drawings, or it may be obtained through coordinate geometry if coordinates of points A and B are known.

$$El_P = El_A + (S_{avg} \times h') \quad (24.3)$$

In Figure 24.5, the elevation at any point P between A and



**FIGURE 24.5** Interpolation using similar triangles.

B and relative to point A is where  $h'$  is the horizontal distance from A to point P. The relative elevation of any point P along  $h$  is accounted for by the algebraic sign of  $S_{avg}$ , as determined by Equation 24.2. In this instance, the slope increases in going from A to B.

Another way to compute the elevation at any point P is to recognize that triangles APP' and ABB' are similar and the ratios of their corresponding sides is a constant, as shown in Figure 24.5. Hence from the following geometric ratios

$$\frac{h}{h'} = \frac{(BB')}{(PP')} \tag{24.4}$$

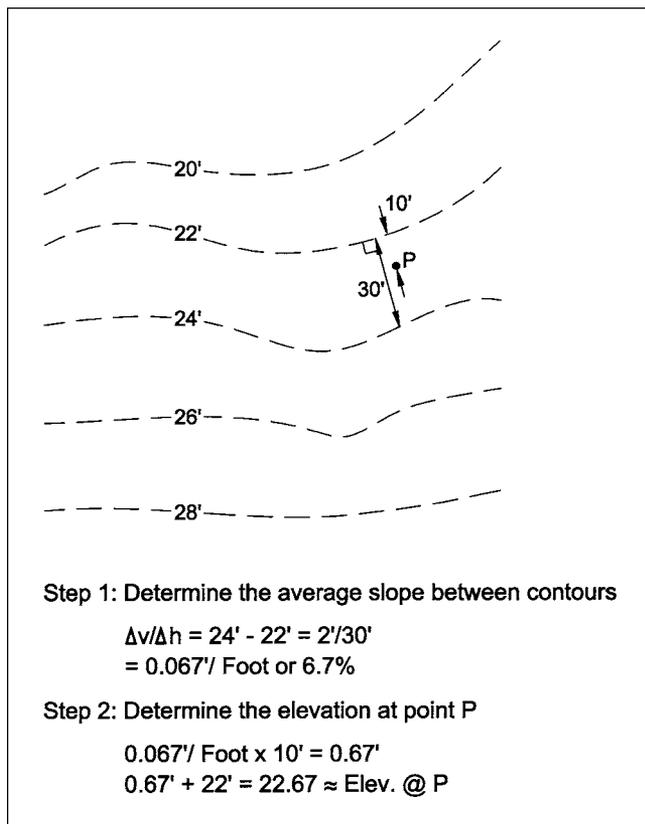
the elevation is found by adding (or subtracting depending on the relative slope) the distance PP' from the elevation.

Typically, the  $h$  measured is the shortest distance between the two points and, as a result, produces the steepest gradient between the two points. However, the horizontal distance measured between the two points may be more circuitous if the situation warrants. For instance, the average slope may be desired along a curb return or along a winding stream channel.

Figure 24.6 provides an example of interpolating between contours to determine the elevation of a point.

**Contour Line Patterns for Constructed Surfaces**

The concepts of contour lines can be applied to constructed surfaces just as easily as they are used on natural features.



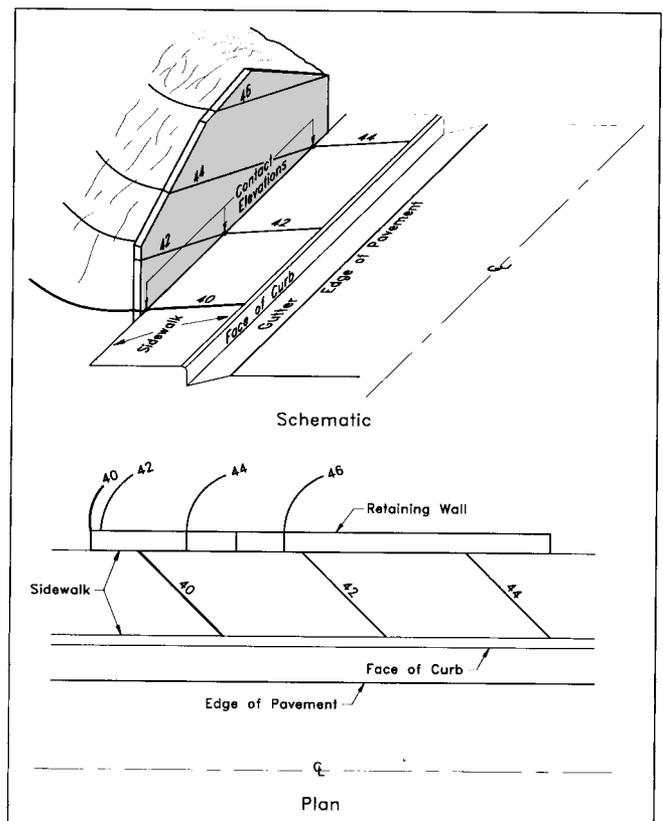
**FIGURE 24.6** Working with contours.

For instance, swales and mounds have distinct patterns similar to valleys and ridges. Reading the contours identifies important information such as drainage patterns and road gradients. The following discussion focuses on the contour line patterns of the most common types of constructed features.

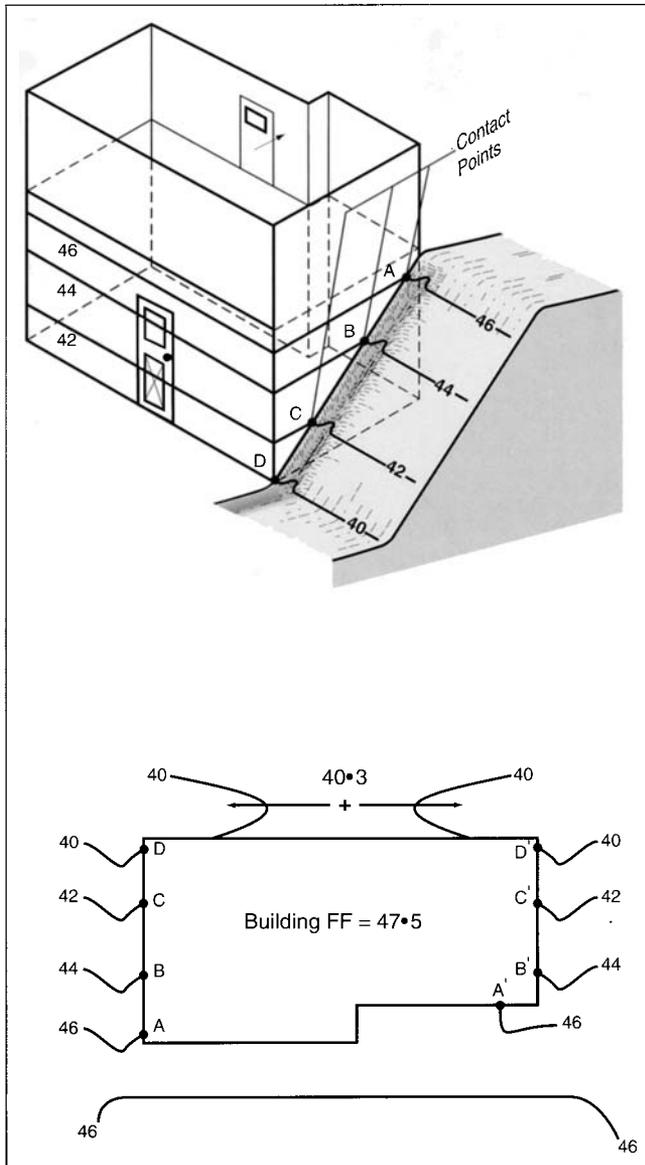
**Retaining Walls.** Although it is physically impossible for several contours to join and form a single contour line, retaining and exterior building walls can appear in plan view to do just this. A machine-graded uniform slope produces equally spaced, parallel contour lines. For the same contour interval, the spacing of the contour lines decreases (in the plan view) as the inclination of the slope increases. For a vertical slope (wall), the space between the contour lines disappears. Consider the face of a wall as a series of contour lines stacked one on top of another, as shown in Figure 24.7.

In tracing the contour line around a wall, the contour line intersects the wall at the contact elevation (i.e., where the ground meets the wall) and then continues along the face of the wall. The contour line leaves the wall where the wall intersects the ground at that elevation.

**Exterior Walls of Buildings.** These serve as earth retaining walls, as well as structural support. Similar to the conventional retaining wall, the contour line enters the wall where the ground surface intersects the wall at the prescribed elevation, shown as points A, B, and C in Figure 24.8. The



**FIGURE 24.7** Schematic and plan view of retaining wall with contour lines superimposed.



**FIGURE 24.8** Schematic and plan view of exterior building wall with contour lines superimposed.

contour line then follows the exposed face of the building wall until it reaches the point where the ground surface is the same elevation, shown as points A', B' and C' in the plan view of Figure 24.8. Since a contour line is continuous, if it "enters" the wall, it must "exit" the wall.

**Conveyance Channels.** Four frequently used conveyance channel sections are trapezoidal, V-ditch, rectangular, and semicircular. In the plan view of Figure 24.9, each of the channels is two ft deep. The depth of the channel is evident by comparing the elevation at the top of bank with the elevation at the bottom of the channel. On each type of channel section, point A, the top of bank, has an elevation of 06 ft. A line drawn perpendicular to the flow line, through the top of bank, intersects the flow line at elevation 04 ft, representing the elevation of the channel invert.

Hence, the depth of two ft. The V-ditch section shows the V-apex pointing upstream—a quick indication of the direction of flow. Direction of flow in the other channel sections is evident from inspection of the contour elevations.

Another indication of the depth of the channel is how far upstream the contour line runs. The spacing of the contour lines along the sides of the channel is an indication of the steepness of the bank. Figure 24.10 shows a 2-ft-deep and 4-ft-deep V-ditch with the same longitudinal slopes and the same top-widths,  $w$ . Note how the contour lines extend farther upstream for the 4-ft-deep channel as compared to the 2-ft-deep channel. Because the top widths are the same, the 4-ft-deep channel has steeper side slopes, evidenced by the contour line spacing on the sides of the channel.

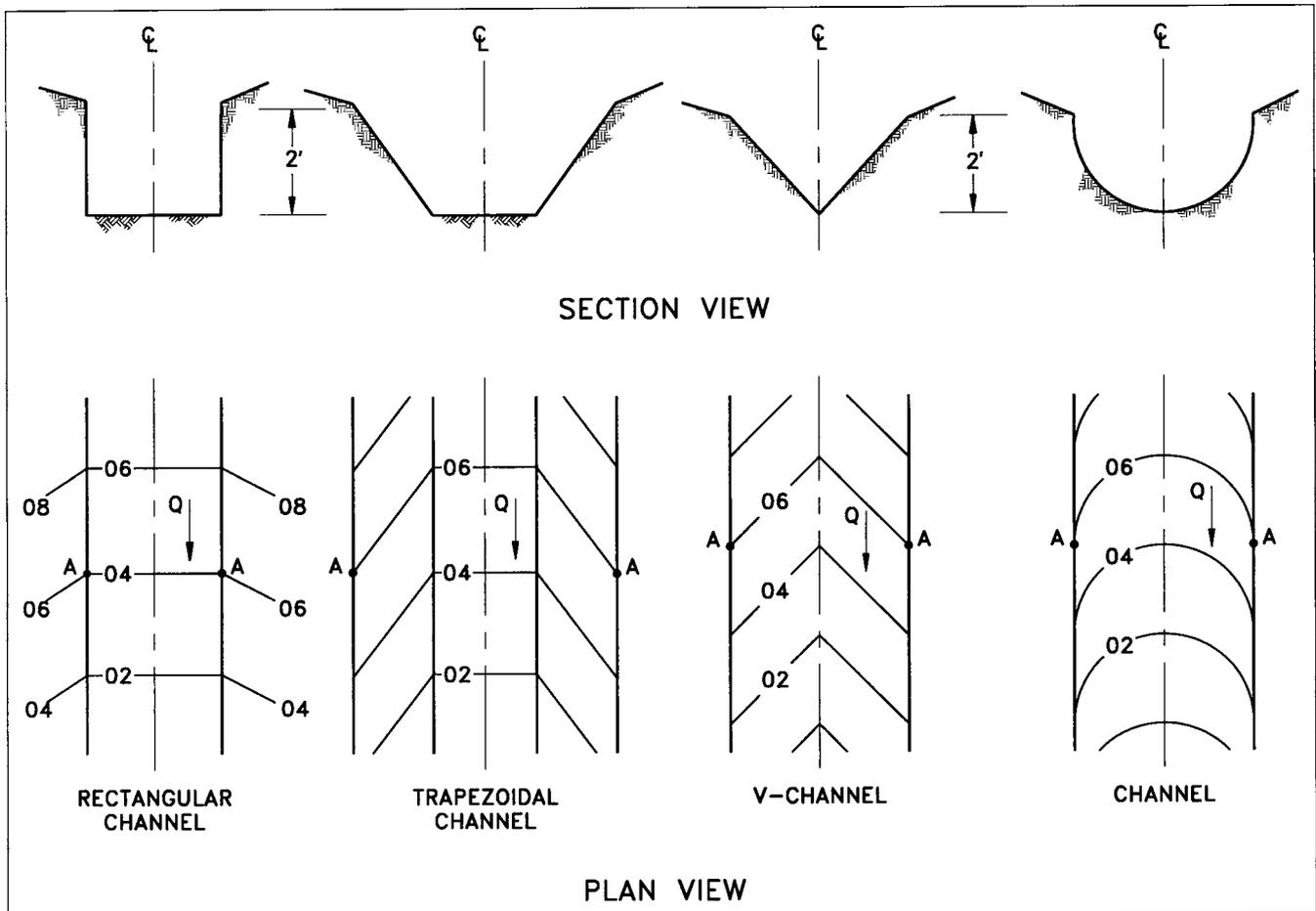
**Streets.** Two types of streets commonly used in development projects are the crown street with curb and gutter and the crown street with shoulder and ditch. Figure 24.11 shows the contour line pattern for a curb and gutter street section with longitudinal slope  $S$ . For a normal crown section street, the elevation decreases on a line perpendicular to the centerline due to the cross slope of the pavement. From the prescribed elevation on the centerline (point A), the contour line follows a straight line path that leads uphill until it meets a point at the edge of the gutter (point B) equal in elevation to the centerline elevation.

The break in the contour at the edge of the gutter (point B) results if the cross slope in the gutter pan differs from the cross slope of the street. From the edge of the gutter, the contour line continues uphill to the point on the flow line with the same elevation (point C). The contour line then follows the face of the curb downhill to the point on the top of the curb with the same elevation (point D). In the plan view, the contour line from C to D does not appear since the top of curb, the bottom of curb, and contour are all superimposed. The contour line intersects the outside edge of the sidewalk at the prescribed elevation. Typically, sidewalks are inclined towards the street. This is apparent from the contour line's downhill direction (points D to E) across the sidewalk. A similar trace of the contour line is shown in the shoulder/ditch type of street of Figure 24.12.

Knowing that water flows perpendicular to the contour line, it is easy to determine the direction of the longitudinal gradient for crown section streets from a quick glance of the contour pattern. Typically, surface drainage on the pavement flows toward the curb and gutter (or ditch); therefore, water flows in the direction perpendicular to the contour lines towards the curb or ditch.

### Plotting Street Contours

Knowing the concepts and mechanics for plotting contour lines is essential in land development design. Manual plotting of contour lines is rarely done for large street projects, given the technology of computers, software and digitizing. However, there is occasion to manually plot contours on short street sections and throughout other areas of the site.



**FIGURE 24.9** Contour line pattern for conveyance channels.

Typically, on a subdivision street with normal crown section, the crown is coincident with the centerline of the street. For this discussion, the focus will be on a straight segment of a crown section street with a uniform longitudinal slope.

The longitudinal reference line plotted in the profile view, identifying the design elevations of a street, is the profile grade line (PGL). The PGL may be the centerline, a line following the top of curb or median, or any other conveniently established line. The PGL is the reference line that has a known horizontal and vertical relationship to any other part of the street. For example, the top of curb elevation is known, given the pavement width and cross slope from the PGL centerline.

**EXAMPLE 1:** The PGL line is the centerline of a straight segment of a crown section street that has curb and gutter and sidewalk on the left side, and shoulder and ditch on the right side.<sup>1</sup> Figure 24.13 shows the typical section. From the profile view (not

given), the longitudinal slope of the street is  $-4.5\%$  in the direction of increasing stationing and the elevation of station  $10 + 50 = 125.50$  ft. Plot the contour lines at 2-ft intervals between stations  $10 + 00$  and  $11 + 50$ .

**SOLUTION:**

1. On the plan view, locate the stations for the elevations of the contour lines to be plotted along the PGL line. This can be done by mathematically calculating the elevations and their locations<sup>2</sup> or by scaling the location of the elevations<sup>3</sup> from the profile view. Depending on the longitudinal slope of the street, the scale of the plan and profile views and the desired precision, the latter may not be the acceptable method. The station of contour line 126 is determined by Eq. (24.2).

<sup>2</sup> Most engineers and designers have access to computer programs for hand-held calculators or microcomputers that provide elevations at incremental stations along the PGL.

<sup>3</sup> Scaling elevations is not recommended especially if the elevation can be obtained mathematically. Scaling is done only when a mathematical relationship is not known.

<sup>1</sup> This particular street section is used to illustrate the mechanics of plotting contour lines and is not a type of street section typically used in street design.

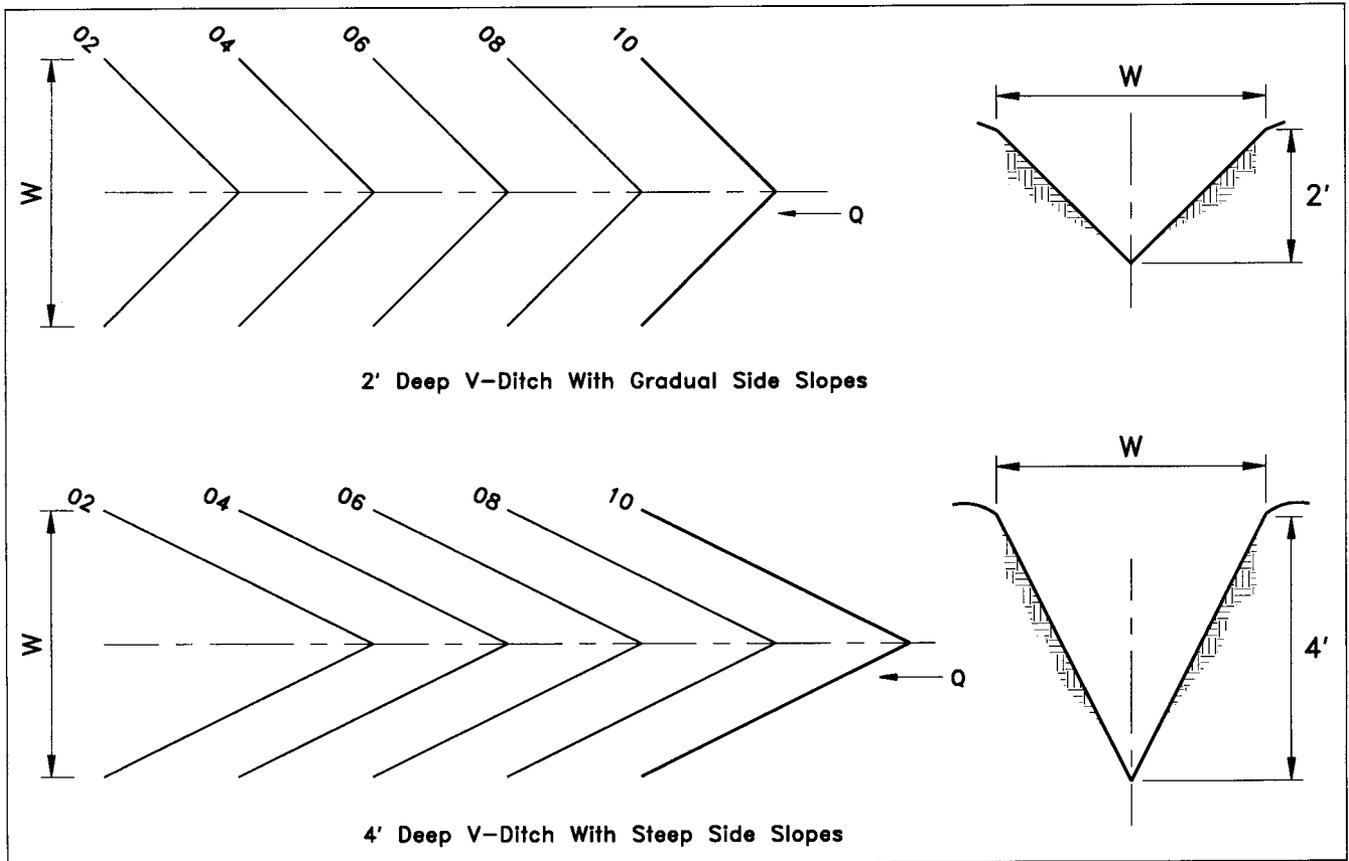


FIGURE 24.10 Example of 2-ft and 4-ft-deep channels with gradual and steep side slopes.

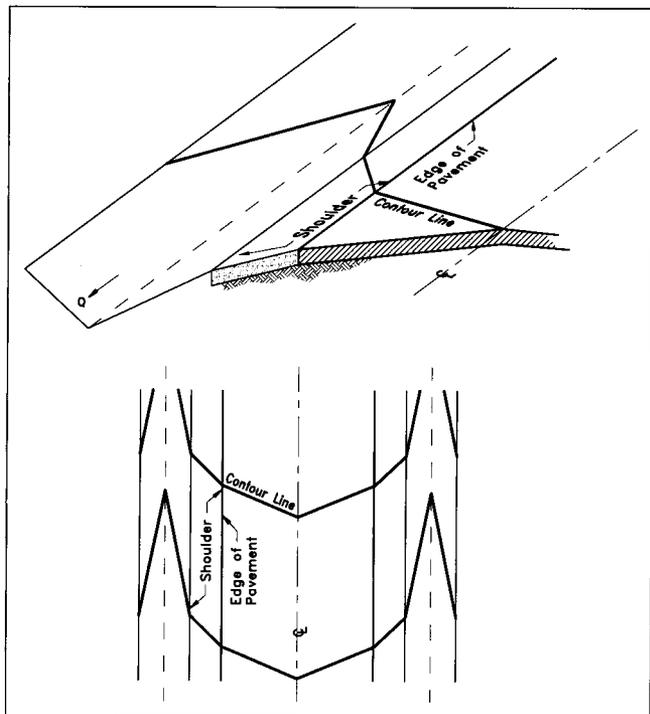


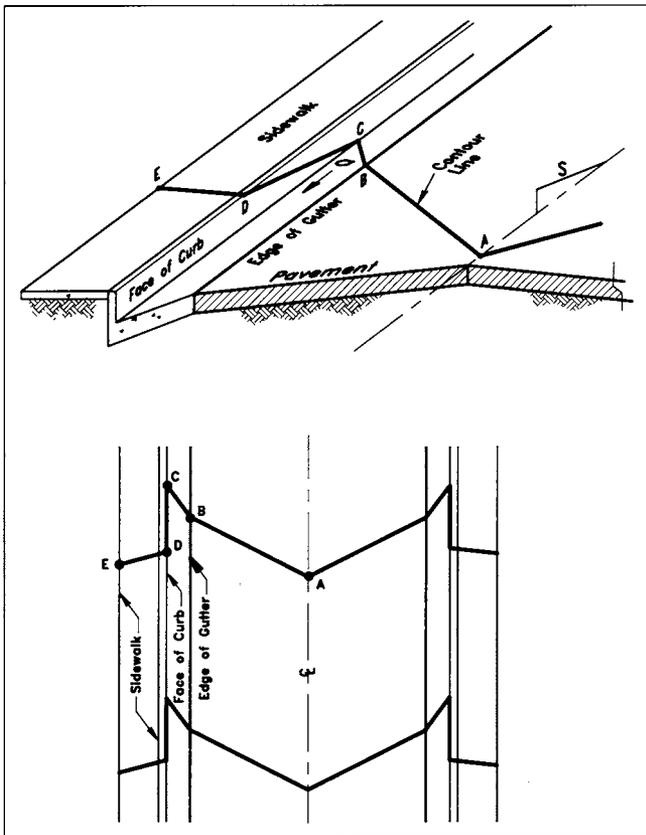
FIGURE 24.11 Contour line pattern for curb and gutter street section.

$$1050 - \frac{(126.0 - 125.5)}{0.045} = 1039 \quad (24.5)$$

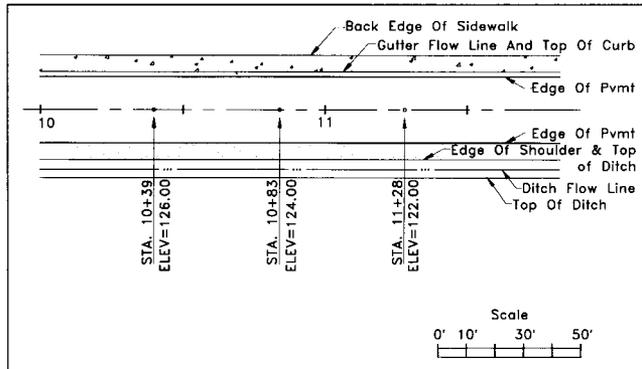
A uniform gradient of 4.5% corresponds to 2-ft change in elevation every 44.4 ft from Eq. (24.2). Therefore, contour lines 124 and 122 are located at stations 10 + 83 and 11 + 28 respectively (shown in Figure 24.14).

2. Calculate the elevation difference between the PGL and any other points of interest (e.g., the edge of pavement, the bottom and top of curb, and the back edge of the sidewalk). A 2% cross slope and 12-ft pavement width results in the edge of pavement being 0.24 ft lower than the PGL ( $0.02 \times 12 \text{ ft} = 0.24 \text{ ft}$ ). Table 24.1 lists the elevation difference for the other specific points.

3. Since the elevation difference between the PGL and edge of pavement is  $-0.24 \text{ ft}$ , elevation 124 at the edge of pavement is located at the station (on the PGL) where the elevation is 124.24, namely sta. 11 + 77.67. Mark the point on the edge of pavement that is perpendicular to the PGL from station 11 + 77.67. Similarly, the 124 contour at the flow line of the gutter occurs at the point perpendicular to the PGL point with elevation 124.41, namely sta. 11 + 92.33. The



**FIGURE 24.12** Contour line pattern for shoulder and ditch type of street.

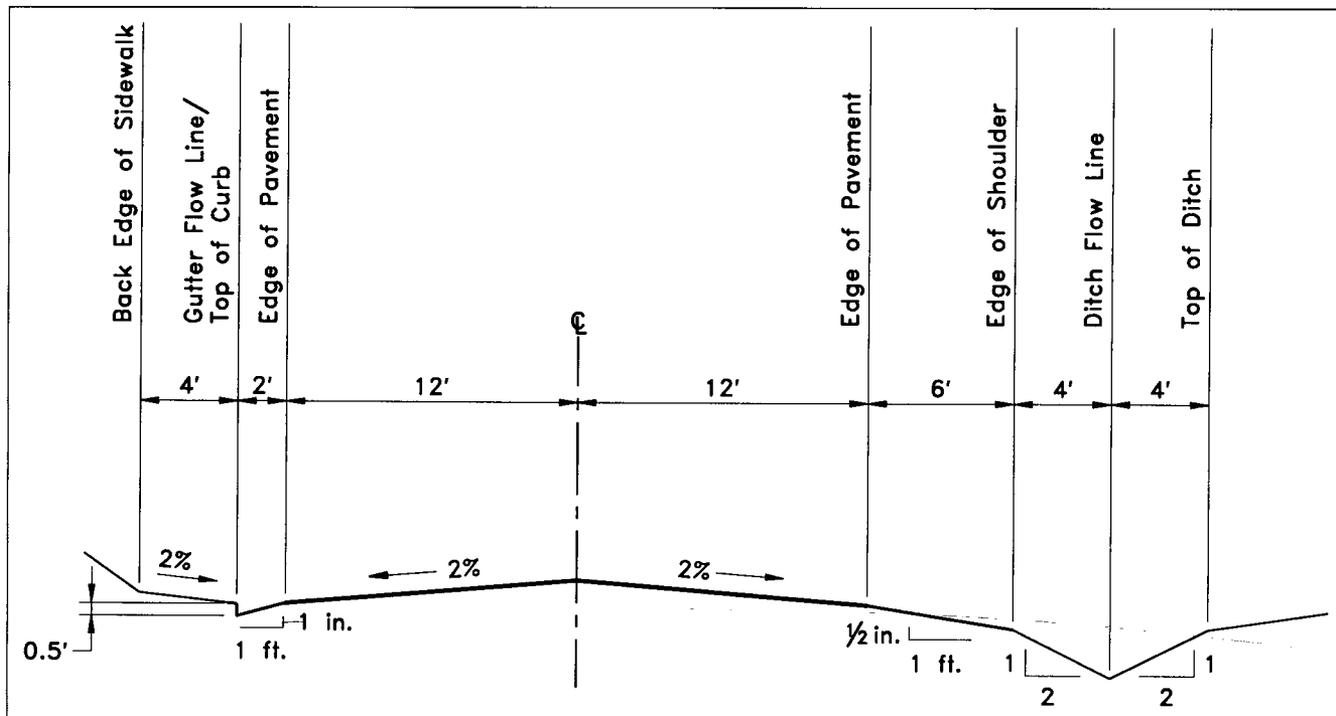


**FIGURE 24.14** STEP 1: Plot the location of the contour line elevations along the PGL.

124 contour at the top of curb will occur at a point perpendicular to the centerline point with elevation 124.09, namely sta. 11 + 30. This is done for all points of interest in the typical section (see Figure 24.15).

4. Connect all plotted points with a straight line. A constant longitudinal slope on a straight section of street results in uniformly spaced parallel contour lines (see Figure 24.16).

5. Since this straight section of street has a uniform longitudinal slope (i.e., it is not within a vertical curve), the other contour lines will all be parallel to this one. However, if the profile of the PGL is in a ver-



**FIGURE 24.13** Typical section for Example 1.

**TABLE 24.1 STEP 2: Compute Elevation Differences Between PGL and Points on Street Section**

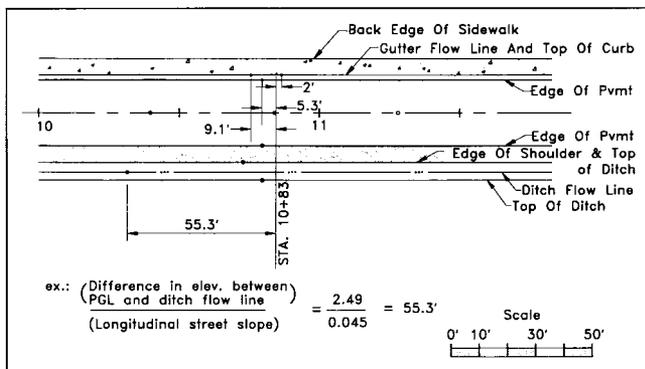
POINT ON STREET SECTION	ELEVATION RELATIVE TO PGL (FT)
Edge of Pavement/Gutter	-0.24
Gutter Flow Line	-0.41
Top of Curb	+0.09
Edge of Sidewalk	+0.17
Edge of Pavement/Shoulder	-0.24
Edge of Shoulder/Top of Ditch	-0.49
Ditch Flow Line	-2.49

tical curve, only steps 1 through 3 apply. Similarly, for streets with non-uniform cross slopes, new relative elevations need to be calculated (see Figure 24.17).

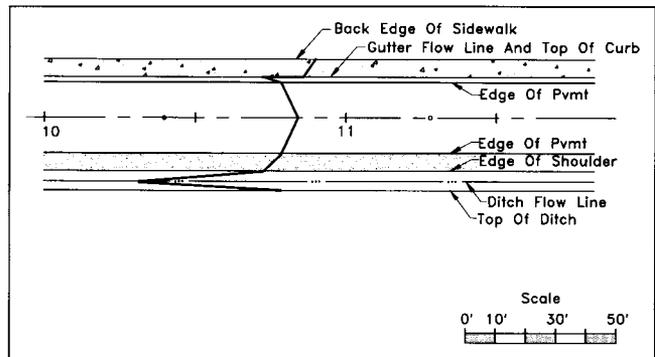
**Spot Elevations**

Often, contour lines alone cannot provide sufficient grading information to detail the existing ground conditions. As a result, the level of precision needed to construct the proposed features, detailed on land development plans, is not afforded by contours alone. Therefore, spot elevations are used to identify specific elevations at precise locations. For this reason, spot elevations take precedence over contour lines when determining grades.

A spot elevation is indicated in the plan view by a "+" symbol with the elevation written next to it. Spot elevations identify discontinuous or abrupt grade breaks in the ground surface, where straight-line interpolation between contours does not give the intended elevation. Therefore, spot elevations are used when the uncertainties associated with scaling distances and interpolating between contours cannot be tolerated.



**FIGURE 24.15** STEP 3: Plot location of the 124 contour lines at other points of interest on the street.



**FIGURE 24.16** STEP 4: Draw the contour line.

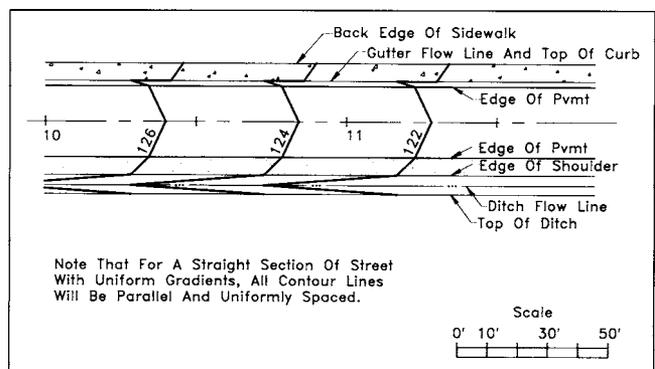
Typically, spot elevations are used for:

- Paved areas at points critical to construction, such as curb returns and parking lot corners
- Precise information regarding the tops of drainage and sewage structures
- Identification of high and low points in the grading scheme
- Description of retaining walls (i.e., top and bottom of wall elevations)
- Elevations at building entrances and corners

Note: spot elevations show up in a profile as an abrupt acute angle at the spot elevation location. The house-grading plan of Figure 24.30 illustrates the liberal use of spot elevations. Abbreviations are written next to the spot elevation when the elevation pertains to a specific feature, for instance, TC = 105.5. Selected abbreviations are given in Table 24.2.

**Cut and Fill**

The term "cut" refers to an area where soil is removed, while the term "fill" refers to the area where soil is added. Additionally, "excavation" refers to the removal of soil and material from an area, and "embankment" is used to reference



**FIGURE 24.17** STEP 5: Add the remaining contour lines following a similar procedure.

**TABLE 24.2 Spot Elevation Nomenclature**

ABBREVIATION	MEANING
TW/BW	Top/Bottom of wall
TC/BC	Top/Bottom of curb
FF El.	Finished floor elevation
BF El.	Basement floor elevation
HP/LP	High/low point
Inv. El.	Invert elevation
MH El.	Manhole elevation

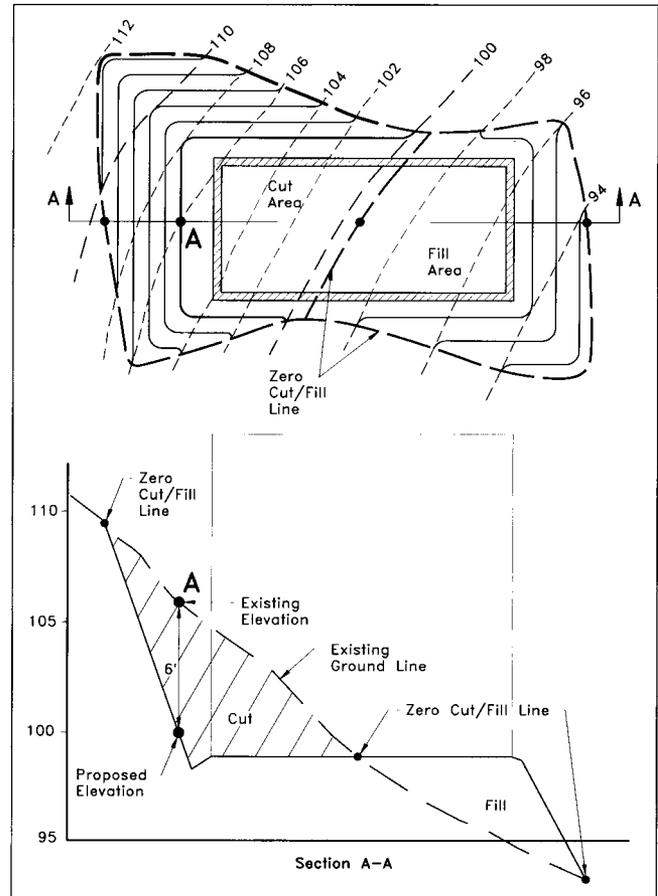
the addition of soil onto an area to bring it to grade. For example, a cut area is evident by the upward sloping ground along the sides of a road, while fill areas are evident as the downward slopes away from a building or street.

Cut and fill areas are indicated on the grading plan by comparing the existing contour lines to the proposed contour lines at a specific location. Where the proposed contour line elevation is higher than the existing contour line elevation, the area is a fill. Conversely, a cut area is one in which the proposed elevation is lower than the existing elevation.

Figure 24.18 shows a grading plan of a building with cut and fill areas. As an example of how to determine the depth of cut from comparison of contour lines, consider point A, where the existing 106 contour line intersects the proposed 100 contour line. The section view shows the 6-ft depth of cut at this point.

The left side of the building is a cut area and the right side is a fill area. The plan view shows a line around the cut and fill areas known as the zero cut/fill line. This line connects the points where no fill or cut occurs and separates the cut areas from the fill areas. Additionally, notice that the line also follows the points where the proposed contour lines connect to the existing contour lines around the perimeter of the graded area. Since the basement floor elevation has been established at elevation 99.0 ft, the zero line follows the existing 99.0-ft contour line through the center of the building. Although this grading plan shows only one cut and one fill area, other projects may have several areas of both types. The zero cut/fill lines are helpful for determining earthwork quantities, which will be discussed later in the chapter.

Consideration of cut and fill quantities is very important when developing a grading plan. For many reasons, a balance of cut vs. fill is usually desirable. Balance is achieved when the quantity of cut is roughly equal to the amount of fill. For example, in order to create a flat area on a hillside, it is most effective to cut into the hillside and use the excess



**FIGURE 24.18** Plan and section view showing cut and fill areas.

soil as fill on the lower portion of the site. This concept is illustrated in Figure 24.18.

One of the most compelling reasons to achieve a balance of earthwork is its effect on project cost. Moving soil around a site is less costly than either importing fill to the site or hauling excess cut from the site. Generally, importing fill onto the site costs more than hauling excess material away. Balancing the earthwork helps keep costs under control and often will help the finished site appear more in harmony with its surroundings.

The relationship between cut and fill is simple in concept, but other factors must be considered that complicate the equation. These factors include:

- Construction qualities of the specific soils on site. It cannot be assumed that on-site material may be used as fill, especially in areas where a load, such as a building or wall, is to be placed. The designer must verify the engineering characteristics of on-site soils rather than assuming they may be used as fill material. (See the chapter entitled *Soils* for further discussion).
- Soils generally shrink when used as fill, and the shrinkage factor can vary greatly between different soils. A grading plan that may appear to produce a

balance of materials may come up short on fill due to the shrinkage of the fill volume.

- A site developer may have several concurrent projects with different cut and fill needs. It may be desirable to produce intentionally a need for fill on one project in order to dispose of excess fill from another nearby project (hauling fill long distances is impractical due to high costs).

## DEVELOPING A GRADING STRATEGY

Now that the basics of grading, plan graphics, and grading mechanics have been discussed, it is time to combine these elements and develop a grading plan. Grading experience makes most of these considerations second nature, and enables the designer to concentrate on an overall strategy that produces the best possible plan.

### Grading and Drainage

Grading is necessary to enable a site to accommodate a proposed use. Perhaps the most important aspect of grading is to ensure proper drainage for the site. If a developed site traps water, causes it to flow to undesirable locations, or causes erosion, the grading has failed in its most basic requirement.

The designer must take into account the runoff that starts on the site as well as the runoff that flows onto the site from off-site areas. The drainage shed analysis serves as the basis for the design of all the proposed drainage structures and often influences the very layout of the site plan. For instance, the analysis may show that a large swale located on the site carries a considerable amount of water during a storm. The drainage structure required to convey the runoff underground proves to be too costly to construct; hence, the decision is made to leave the channel open and not construct site improvements over it.

The drainage study sets the basic parameters for the grading design. The following is a list of goals for a site-grading plan from a drainage perspective:

- Collect runoff and direct it safely to adequate outfall points at non-erosive velocities.
- Quickly convey runoff away from buildings to protect them from foundation damage and wet basements.
- Prevent the formation of unintentional wet areas that cause maintenance problems.

Experience and imagination both play a role in developing the final grading scheme. As the designer begins to work through the process, relationships between proposed improvements and existing conditions begin to coalesce. Important relationships begin to dictate patterns, such as existing elevations at site entry points compared to ground elevations at proposed building sites.

Drainage is conveyed either overland or underground. While the design of drainage facilities for concentrated

flows of runoff is covered thoroughly in the chapter entitled *Storm Drain Design*, this chapter will display a broader perspective, with a mixture of guidelines and rules, beginning with small flows.

Overland flow in its most benign form is called sheet flow, where little or no concentration of water exists as it moves across uniform, fairly level areas. Sheet flow is an ideal way to convey water because it helps absorption and is non-erosive. It is difficult to maintain sheet flow for large areas, however, due to water's tendency to concentrate. Left on its own, water quickly gathers into swales and ditches. The designer's job is to manipulate this transition from sheet flow artfully to shallow concentrated flow using sound engineering principles that accomplish the goal without obliterating the site. Although it may be possible to direct all runoff to its outfall points via overland flow, often it is advantageous to pipe it underground. Guiding the designer to either method are general rules-of-thumb that help simplify the process. A basic premise of grading is that a minimum slope of 2% needs to be maintained to drain runoff across non-paved areas. Decreasing the slope below 2% may result in sluggish drainage and standing water. It also can slow down the construction process. Very flat slopes are difficult to achieve in the field, even given the precision of modern construction equipment. Flat areas also remain wet for a longer time, and cause longer construction delays following rain. Yet, site constraints often require slopes of less than 2%. The use of flat slopes should be carefully considered and simply avoided if possible.

In some instances, the minimum desirable slope exceeds 2%, such as the grading adjacent to a building, where the objective is to move the water away quickly. The ground elevation at the building is referred to as the parge grade.<sup>4</sup> Dropping the proposed elevation at least six inches below the parge grade within ten ft of the building (5%) is ideal. Figure 24.19 shows the three basic methods for directing surface drainage away from a building. The ground beyond the parge grade directs the runoff to eventual points of collection. Although grades can vary beyond this point, a minimum slope of 2% helps prevent drainage problems.

Conversely, proposed grades that are too steep can lead to erosion and maintenance concerns. Steep slopes increase the velocity of water and therefore its energy, so that even relatively small amounts of runoff can erode large quantities of mulch or soil off a hillside. If grass is established on the slope, mowing is dangerous if slopes exceed 3h to 1v. While slope stability depends on many factors, they are all exacerbated with steeper slopes, especially in a fill condition. Local policy may also dictate the maximum (and minimum) slopes required for specific situations, and this makes a working knowledge of pertinent ordinances a valuable tool.

<sup>4</sup> A coat of masonry cement (parge) is applied to the part of the building walls below grade as a deterrent to moisture penetration. The parge grade is the elevation of the ground around the building sufficient to cover the parge coating.

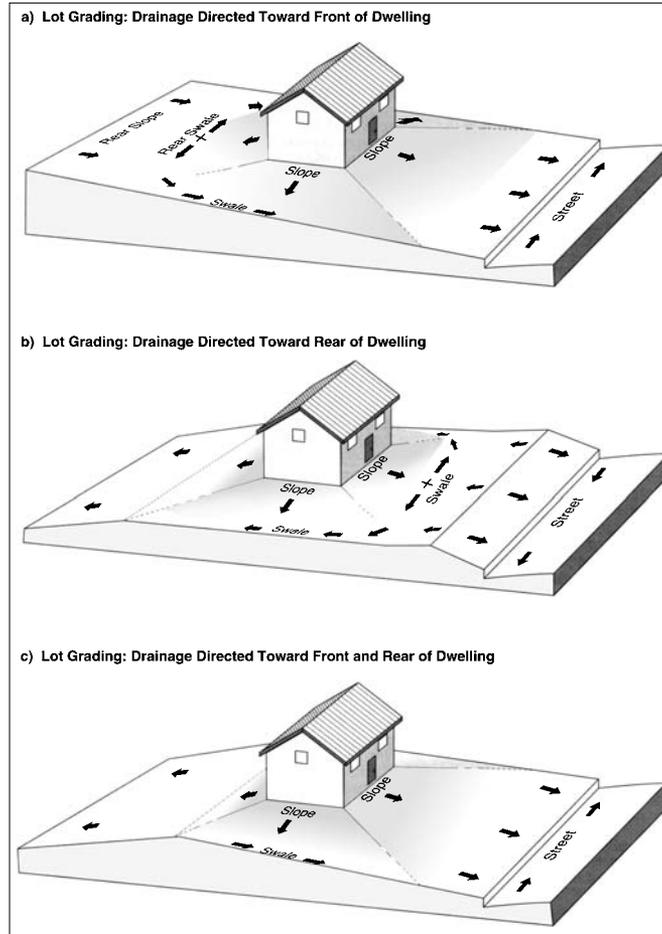


FIGURE 24.19 Schematic diagram for grading for drainage around a building.

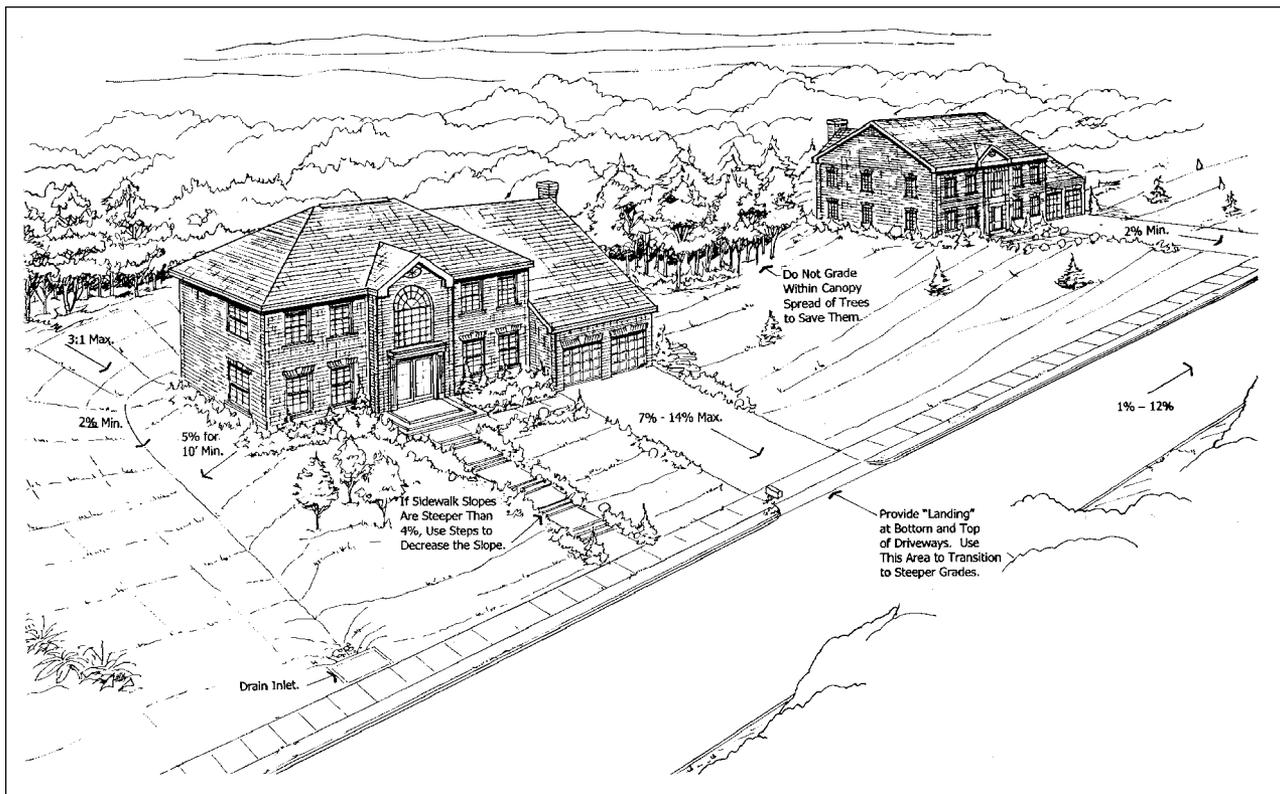


FIGURE 24.20 Illustration of grading strategies for subdivisions.

Minimum and maximum slopes are also an important consideration when designing roads, driveways, parking areas, sidewalks, and trails. Road design is a science unto itself, and the grading of roads is explained in the chapter entitled *Suburban Street Design*. More rules-of-thumb apply when planning for the movement of people across a site. Since the driveway entrance is the transition from the public or private road onto the site, the grading must facilitate its function. The following discussion explains grading for private and commercial driveways.

**Private Driveways.** A house set 25 to 35 ft from the street typifies the private driveway entrance. The slope of the driveway should be kept in the range of 2% minimum to about 7% to 14% maximum, depending upon whether the driveway is inclined up or down. The following points should be considered for driveway slopes exceeding about 5%:

- In snowy climates, steep driveways can become slippery and dangerous.
- If a walkway is proposed from the street to the house, a steep slope may require long flights of stairs, which are expensive to construct and can make the entrance to the house awkward.
- The transition from the street to the drive must be lengthened so that car bottoms don't drag.
- A landing with a slope of 2% should be provided in front of the garage that transitions to the steeper grade of the driveway.

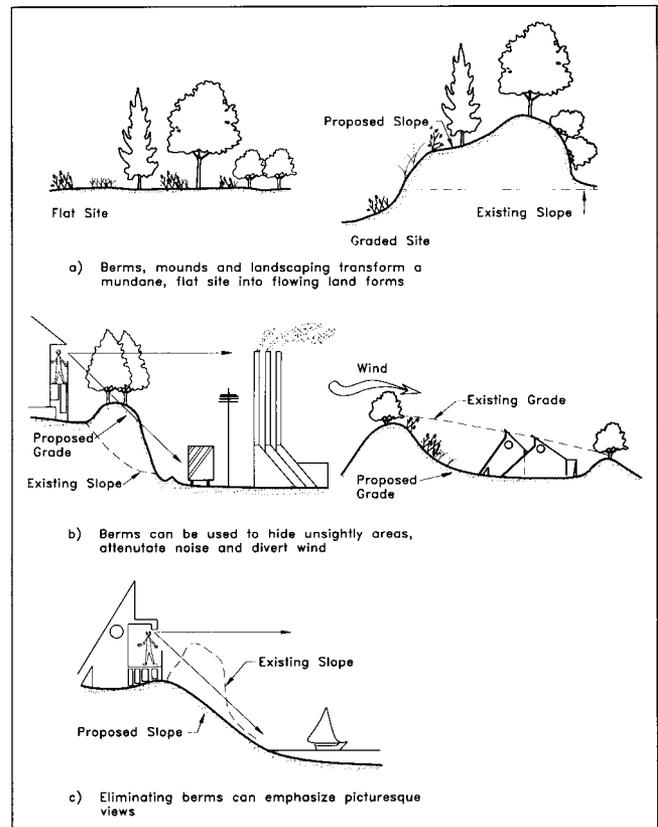
Such points of potential concern are illustrated in Figure 24.20.

**Public Driveways.** The higher traffic volumes encountered at public entrances dictate more conservative guidelines than private driveways. A landing at least 20 ft long with a maximum slope of 4% should be provided at the entrance. Grades on site should be in the 2% to 8% range. Local ordinances and requirements for access by physically challenged individuals (discussed below) must be incorporated into the plan.

### Grading and Aesthetics

Rules, regulations, and formulas have been discussed extensively above, and the mastery of the mechanics of grading will ensure a functionally sound site. But a functionally sound site is usually not enough in the competitive world of land development. A site must appeal to a user's aesthetic sense in order to be successful. Grading can transform a flat, featureless site into a visually pleasing series of rolling landforms that enhance the user's experience and create a higher demand for the property.

Figure 24.21 illustrates how grading can be used to enhance aesthetics. The grading itself can become the feature, as in the creation of landforms where none exist (24.21a). Grading can also be used to influence what we see by hid-



**FIGURE 24.21** Grading to improve aesthetics. (Courtesy of Nelischer, Maurice, ed., *Handbook of Landscape Architectural Construction* Vol 1, 2nd ed. Washington, D.C.: Landscape Architecture Foundation, 1985.)

ing a visually undesirable element, as shown in 24.21b, or opening up a view, shown in 24.21c. The landforms created for aesthetic reasons can simultaneously serve functional roles. The landform may aid in the balancing of earthwork by providing an on-site location to dispose of excess soil, or it may be used to direct wind away from buildings or outdoor-use areas.

However, using the grading to enhance the site aesthetically is not achieved by simply following formulas and rules; it must be coupled with a thorough knowledge of the site and the sensitivity to know what will work. Whereas a 20-ft berm on one site is appropriate, it might be totally inappropriate on another. Similarly, a small retaining wall used to help save a grove of trees may serve as the signature design element for a new project. Because most of these grading devices have an impact on project costs, the aesthetic gain must be compared to the extra construction expense. Sometimes the designer can justify the expense, but he/she must be prepared with lower cost solutions if the builder balks.

### Access for Disabled Individuals

Two legislative laws that may impact the grading scheme of certain types of construction are the Fair Housing Amend-

ments Act (FHA) of 1988 and the Americans With Disabilities Act (ADA) of 1990. Both acts deal with providing accessibility for individuals with disabilities. The FHA deals with multi-family housing of four or more dwelling units, and the ADA addresses accessibility to public places and commercial buildings such as hotels, stores, theaters, offices etc. Guidelines and standards adopted by the Department of Housing and Urban Development (HUD) for specific accessibility requirements of the FHA are given in Federal Register Vol. 56 No. 44 (March 6, 1991). Similar guidelines and standards for the ADA are developed by the Architectural and Transportation Barriers Compliance Board (ATBCB). The guidelines can be found in Federal Register Vol. 58 No.144 (July 26, 1991),

From the grading and site development perspective, HUD guidelines state that elevated buildings must have an accessible entrance on an accessible route, regardless of the terrain, unless site conditions and terrain make such accesses impractical. Because of the complexity of the requirements and its language, the reader is referred to the guidelines to make his or her own determination and interpretations. Local public works agencies are a good source of current requirements.

### Schematic Grading Analysis

Before detailed grading plans are underway, the designer should develop a schematic generalized grading scheme to determine any problem areas and get a feel for the type of limitations the site may have as design progresses. Developing a schematic grading plan consists of placing building footprints on the site and setting the building elevation, road grades, and parking area grades. Spot elevations and sketching the 5-ft, or sometimes 2-ft, contour lines helps determine the feasibility of the building elevations.

The road and parking area gradients for the schematic preliminary scheme are checked against any minimum requirements.

- Drainage patterns are analyzed
- Rough estimates of cut and fill quantities are calculated
- Steep slopes and retaining walls are identified
- Tree-save areas are identified

During this process, several grading schemes may result, each with its own advantages. Conferring with the client may help in establishing the favorable grading scheme.

### ESTABLISHING THE GRADING PLAN

A grading plan is established through refinement of different schemes through several trials. The first layout is rarely the best or accepted by the developer. During the first few trials, grades are adjusted to accommodate site constraints, earthwork, different building designs, and the preferences of the developer. The design is often done by hand on trac-

ing paper, but may be laid out in the computer in a digital format. The first few schemes may only involve siting the building, showing spot elevations at critical locations, and drawing several proposed contour lines. Additional detail is added to new iterations as the grading scheme is further refined. Once refined to the desired comfort level, the grading needs to be compiled in a reproducible format so that the designer can make work prints and distribute them to other members of the design team. Whether the grading was accomplished by hand drafting or through a digital application, it needs to adhere to general industry-wide graphic standards for both symbology and neatness to be effective.

In general practice, lighter, dashed lines are used for existing contour lines, while darker, solid lines are used to represent proposed contour lines. Note: the local jurisdiction may have specific graphic requirements for plans that should be considered as well. Additionally, drawing the existing contour lines on the back of the reproducible while placing the proposed contours on the front makes changing the proposed grading scheme easier. In a digital format, a variety of methods may be used to keep proposed information separate from existing. Either way, the goal is to create an easy-to-read plan that adheres to sound drafting principles.

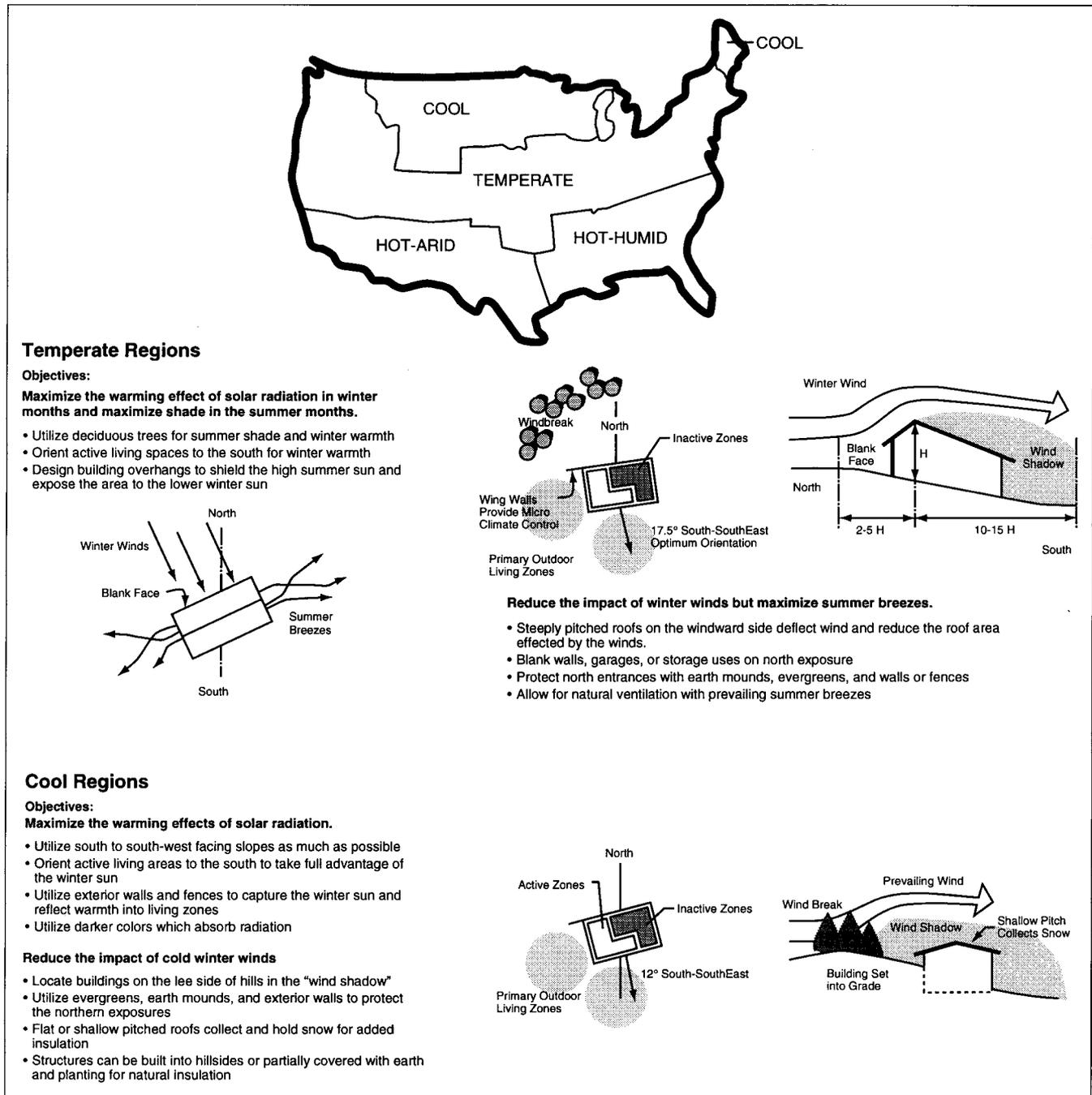
### Grading for Residential Purposes

Consumer appeal for a subdivision or a particular house type depends on numerous factors, one of which is appearance. The layout of the lots and houses, the style and type of house, as well as their spatial arrangement affect the overall appearance of the development and combine to form its character.

Frequently, residential land development projects incorporate several different house types and styles within a small price range. This practice is done for three reasons.

- The first reason is to accommodate the varying needs and the aesthetic tastes of buyers. The various house designs attract a wider range of consumers, thereby enhancing sales.
- The second reason is to take advantage of the varying topographical features of the lots. This provides the developer flexibility in the layout of the houses and reduces some of the construction costs.
- The third reason is for energy efficiency. Figure 24.22 identifies the considerations for room layout and house siting concerning climate conditions. Different house types offer varying responses to local climatic, slope, and orientation factors.

Professional and industry associations use different definitions in describing and categorizing houses. Some definitions overlap or conflict. Therefore, for the subsequent discussion the following definitions apply.



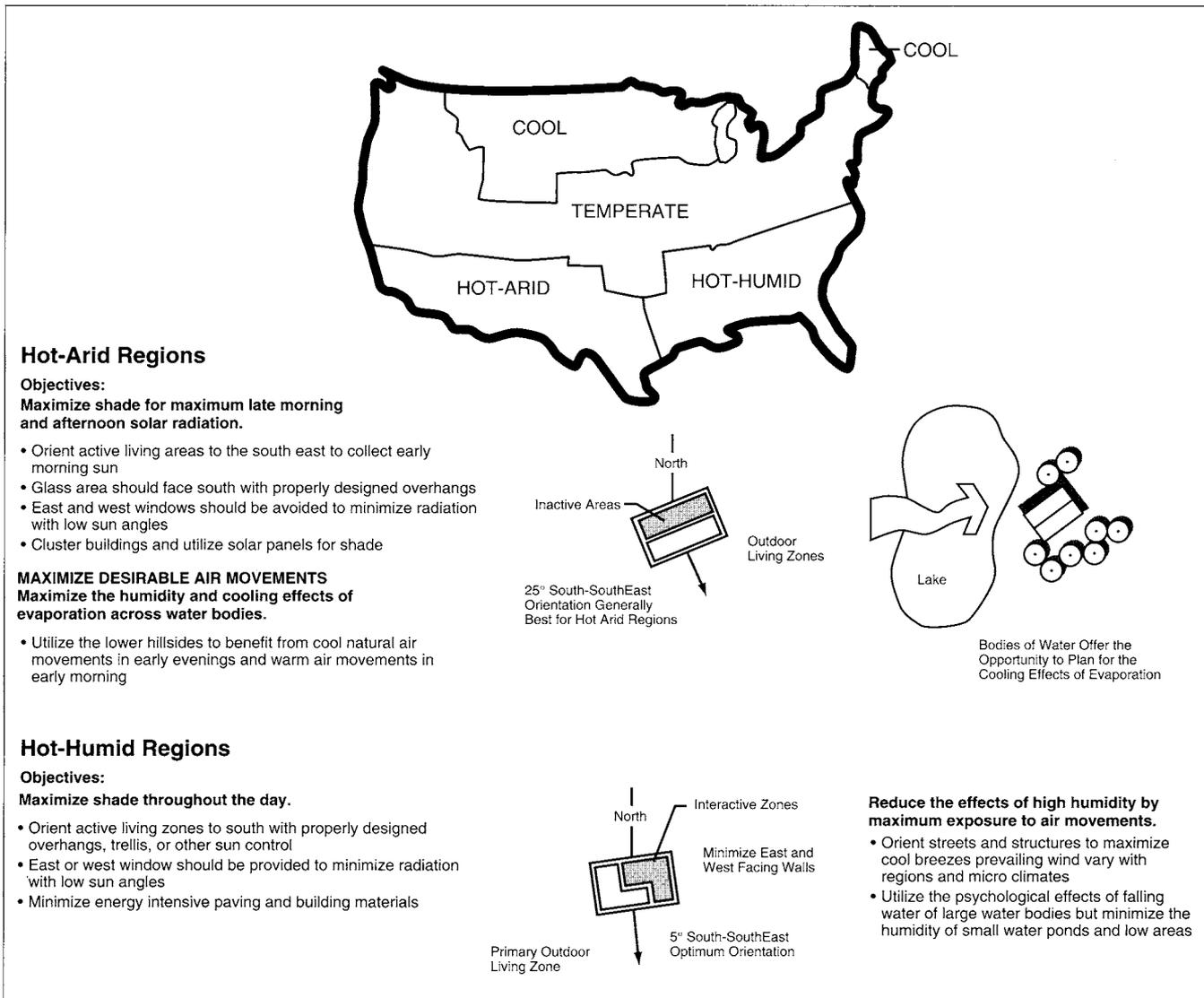
**FIGURE 24.22** Considerations for siting a building for different climate regions of the United States. (Courtesy of Robinette, Gary O., and Charles McClennon, *Landscape Planning for Energy Conservation*, New York: Van Nostrand Reinhold, 1983.)

**Architectural Style.** This is defined as the architectural features and configuration of a house that categorize it as belonging to a particular time period or region e.g., Colonial, Cape Cod or Victorian. (See Figure 24.25.)

**House Type.** This is the classification of a dwelling by the arrangement of floor elevations, location of entrances, location of walls, and property lines (e.g., 1-story, 2-story,

basement walkout and single-family attached and detached).

Not only is it imperative that the engineer developing the grading plan know the house types available in a subdivision, the engineer should also know the location and elevation of entrances, windows, garages, decks, patios, and roof lines. The engineer must consider each lot individually;



**FIGURE 24.22** (Continued) Considerations for siting a building for different climate regions of the United States.

however, he/she must also collectively consider the spatial arrangement of the houses along the street and within the development. In many suburban developments, the cost of land and the demand for greater living space forces the building of larger houses on smaller lots. The higher density produces a higher yield for the developer, and this in turn keeps housing costs down by reducing infrastructure costs on a per unit basis. However, smaller lots put houses in closer proximity, making house orientation a very important consideration. The designer must consider the views from one house to another, avoiding direct lines of site from one house into intimate areas of another house. For instance, no one wants to look out his front door and see into the dining area of the next house, or worse, to peer into the window of a second floor bedroom. Although grading can

be used to diminish the effects of poor siting, a good layout is paramount to a development's success.

Spatial arrangement is part of what is known as the streetscape. Setbacks, rooflines, utility corridors, street trees and landscaping, sidewalk and trail locations, and signage further define the streetscape. These elements work with the grading to lend the development a uniform character and create a cohesive, unified design.

A residential lot can be categorized according to the direction of the ground slope using the front property line as reference. A downhill lot is one in which the ground slope falls away from the front property line. An uphill lot has ground sloping upwards from the property line, while a side-to-side lot has slopes across its width. Efficient land use includes the selection of a house type that is compatible

with the terrain. Proper design and siting of the house minimizes earthwork and reduces the disturbed area, and this helps the environment and saves on construction costs.

For grading purposes, it is useful to separate the myriad of housing styles into one of the three following categories. The main difference between them is how their foundations are set up to deal with site grading.

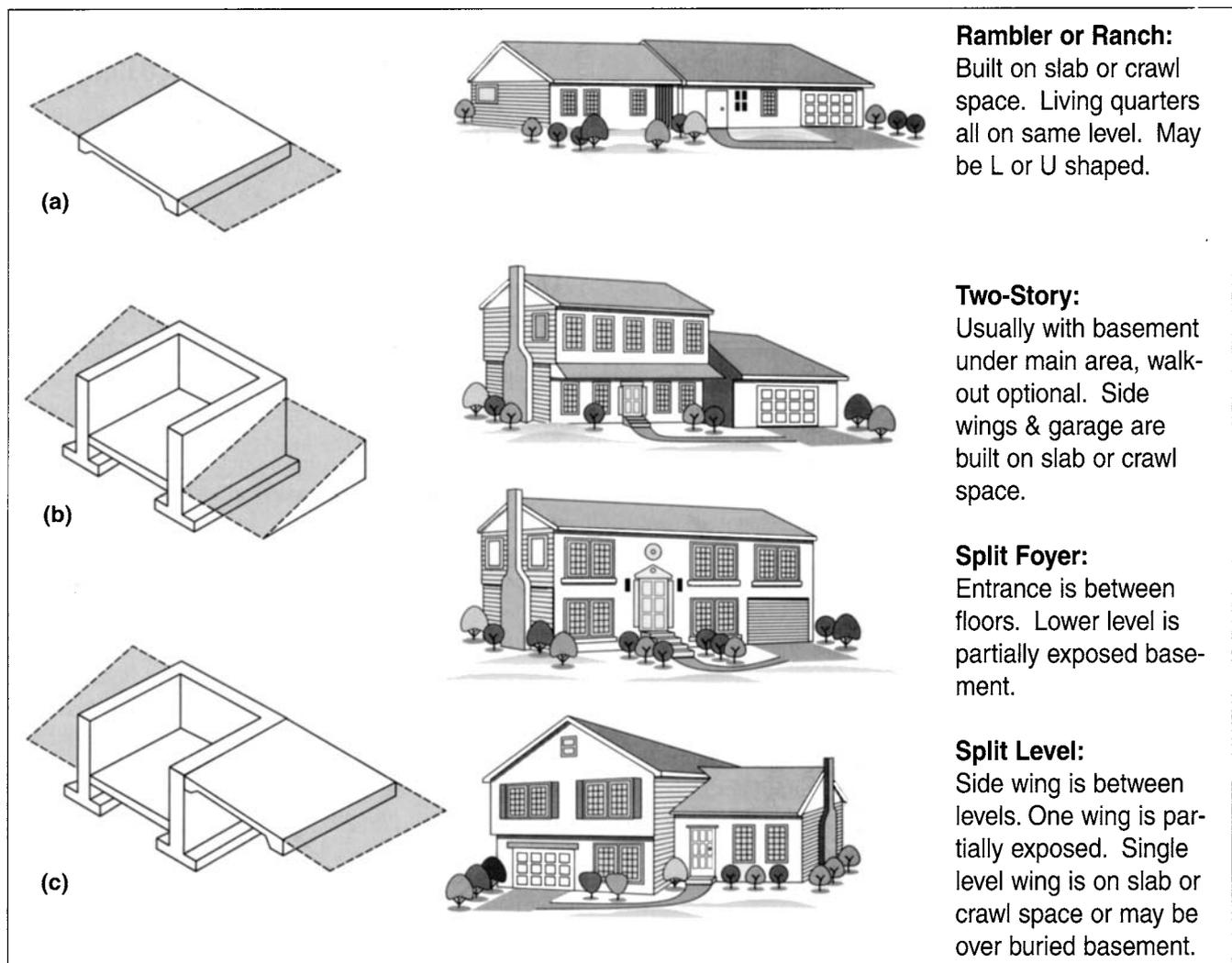
**No-Basement Units.** No-basement-type buildings are built on a concrete slab or crawl space and are best suited for flat areas with high water tables or where extensive rock lies near the surface. They are generally less expensive because of savings in excavation and construction costs. They are less suitable for hilly sites, since they require more grading to accommodate the building footprint. The no-basement unit is common in many regions of the country, and virtually every style of house can be constructed without a basement.

**Basement Units.** That part of the house that is wholly or partially buried is the basement. Basement units are useful on hilly lots because of their ability to accommodate grade

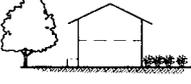
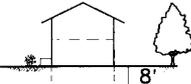
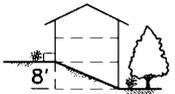
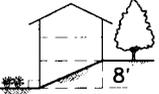
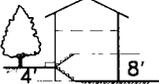
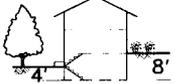
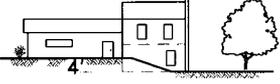
differences. For instance, the house shown in Figure 24.23b has a grade change of about 4 ft from front to back, and this may enable the proposed grade to tie-in with existing grade sooner, thereby reducing the disturbed area.

In addition to enabling the house to blend in with the site better, the use of basements can also generate small amounts of excess dirt that can be used elsewhere on a project. If a site is slightly deficient in fill dirt, basements can be incorporated to make up the deficiency. The use of basements also increases the living space of the house. This living space is enhanced by the presence of natural light, so often a partially buried basement that allows for window space is better than a completely buried basement. Another design element that enhances basements is the walk-out, which provides direct access outdoors from the basement. The typical site layout for a walkout is depicted in Figure 24.24.

**Split-Entry Units.** Floor elevations of a split-entry house are staggered such that their access from a preceding level is less than the full flight of stairs typical of the common



**FIGURE 24.23** Basic house types and their foundations.

HOUSE TYPE		COMMENTS
LEVEL UNIT		
 <p>2-Story House With Slab on Grade or Crawl Space</p>	 <p>2-Story House With Full Buried Basement</p>	1) Used on Flat or Mildly Sloping Lots.
FULL WALKOUT LOWER LEVEL (FRONT OR REAR)		
 <p>2-Story House With 8' Drop and Basement. Walkout From Rear</p>	 <p>2-Story House With Basement Entry from Front and 8' Rise to Rear of House</p>	2) Used to Make Up Grade Difference on Lots With Severe Front to Rear Slope Conditions.
SPLIT ENTRY UNIT ( $\pm$ 4' UP OR DOWN)		
 <p>2-Story Split Entrance With Rear Walkout From Lower Level</p>	 <p>2-Story Split Entrance With 4' Rise to Rear of House</p>	3) Used on Lots With $\pm$ 4' Fall or Rise Front to Rear
SPLIT LEVEL WITH SIDE TO SIDE DROP IN GRADE		
 <p>Side Split With Grade at One End of House 4' Higher Than the Other and Walkout From Lower Level</p>		4) Used on Lots With Side-to-Side Grade Differences of 2' to 4'

**FIGURE 24.24** Selection and location of building types that fit natural land forms.

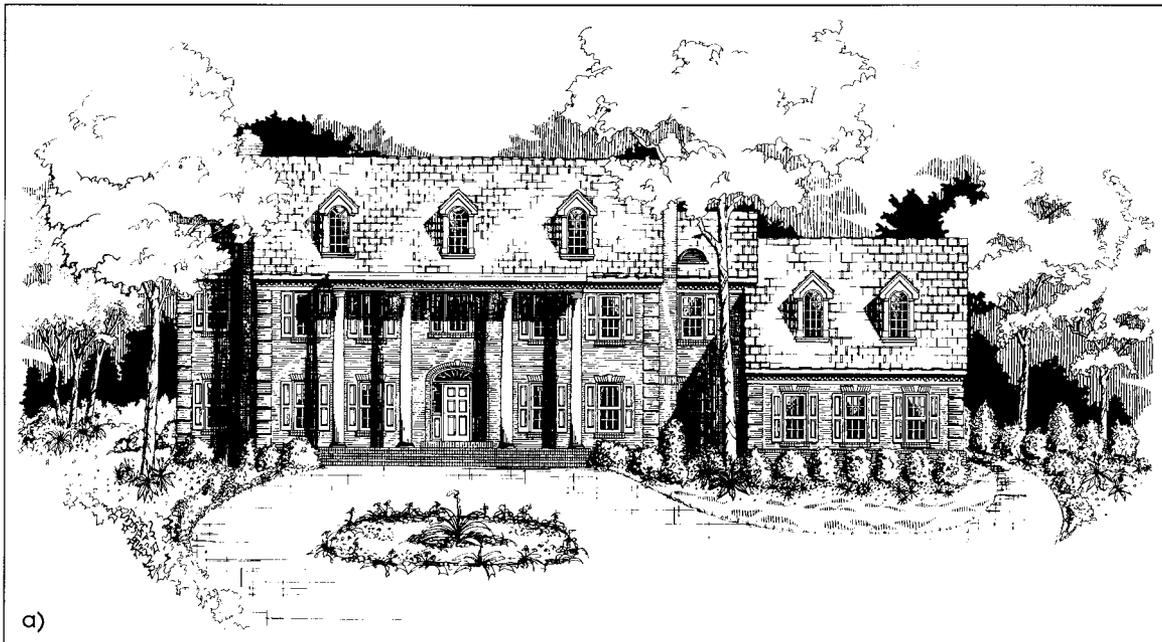
2-story unit. Split-entry houses and their variations are ideal for all types of hilly lots. These houses work best when the grade difference across the lot is 2 to 4 ft. Houses in this category are frequently referred to as split-levels and split-foyers. Split-level houses have a combined slab and basement foundation system as shown in Figure 24.23. Similarly, the basement of a split-foyer is partially exposed. Figure 24.23 shows the basic house types and their corresponding foundations. Figure 24.25 illustrates more contemporary examples of the basic house styles.

**Siting the House and Grading the Lot**

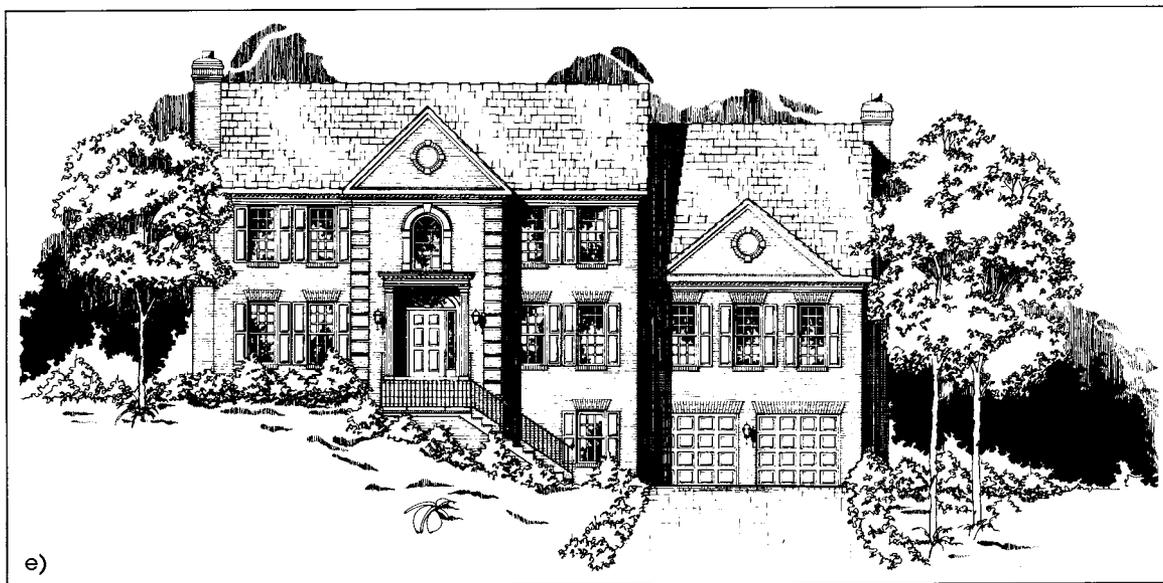
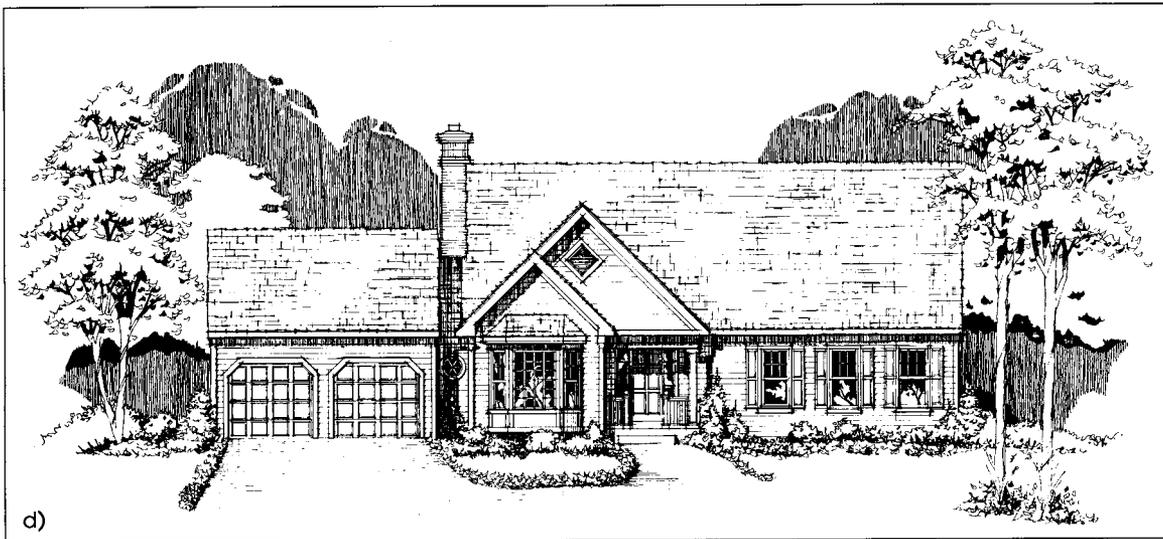
When siting a house on a lot, one must position the house horizontally and vertically in a manner harmonious with

the surrounding structures and terrain, while ensuring compliance with all appropriate codes and ordinances. In most residential, single-family-detached subdivisions of moderate density, siting a house is limited to the lot layout of the subdivision and the orientation of the street. Presumably, solar exposure and compass orientation was considered when the lot and street layout were established in the schematic design stages, since there is not much practicality in orienting the house for energy efficiency if it is in conflict with the street and lot layout.

The house type is selected based on the topography of the lot, adherence to all applicable setbacks, and any constraints by the client (see Figure 24.24). Using generic building footprints, the engineer produces the block-



**FIGURE 24.25** Examples of different house types: (a) Southern Colonial (b) Victorian (c) Tudor. (Courtesy of Sutton, Sullenberger Yantis Architects.)



**FIGURE 24.25** (Continued) Examples of different house types: (d) Rambler (e) Side-to-side/Uphill (f) Split Foyer.

grading plan, which defines the general grading patterns for groups of lots. This plan verifies the site's feasibility regarding a fairly specific program and is often used by a developer to market the land to builders. The goal is to produce finished lots that are then sold to the builder. The builder can then use the block-grading plan to check the feasibility of a very specific program. Usually, the engineer portrays an exact footprint of the builder's house on a proposed lot, precisely measures its distance to the property lines, and produces a lot-grading plan, the final step in siting a house on a lot.

The above scenario illustrates the two types of grading schemes: lot grading and block grading. Lot grading involves only one building and one lot. Grading is limited to the constraints at the boundaries of the lot, and any grading beyond the lot requires permission from the adjacent owner. Typically, lot grading applies to infill projects and commercial projects. Block grading involves grading a group of lots, a frequent occurrence in single-family residential projects. Block grading is not bound by the rigid constraints of lot grading since the whole group of lots is owned by one entity. Additionally, the spatial arrangement and the drainage pattern can be integrated much more easily.

In addition to the relationship of the house to its lot and surroundings, another relationship that affects the siting of a house is the elevation and location of the sanitary sewer. As shown in Figure 24.26, the house should be sited in

such a manner as to provide a gravity sewer for the lowest level of the house. A quick way to determine approximate finished floor based on the sewer line elevation is:

- Determine the invert of the sewer main at the connection point.
- Multiply the distance from the connection point to the farthest point of the house by  $0.0208 \times (1/4 \text{ in./ft})$ , and add to the invert elevation (the fall,  $f$ , in Figure 24.26).
- Add the diameter of the sewer main (distance  $d$  in Figure 24.26).
- Add an allowance for clearance under the foundation (shown as \* in Figure 24.26).

Typically, the house sewer runs under the footing for shallow footings and foundations. Therefore, the elevation of the lowest level should be raised an additional 6 in to 1.5 ft (depending on local construction practices) to allow for clearance beneath the footing and floors. In situations where it is not feasible to run the house sewer line under the footing, the house sewer line can be run through the footing. Figure 24.26 shows this concept.

When a basement, because of its depth related to the sewer main in the street, cannot be sewerred using a gravity line, the sewer is referred to as a hung sewer. A pump may be installed to eject sewage from the basement to the sewer

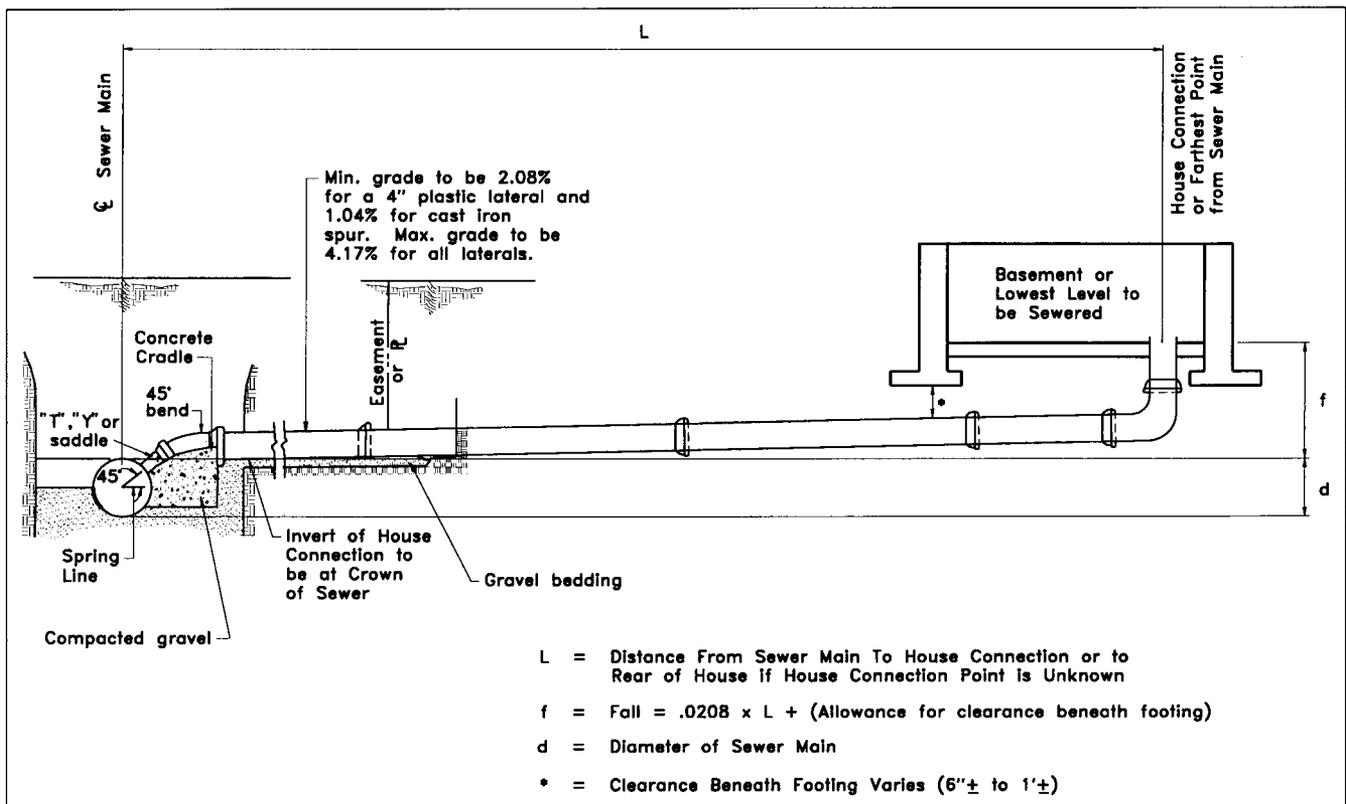


FIGURE 24.26 Sewer line from house to sewer main.

main if it will not flow by gravity, but this practice may come under special regulations in many jurisdictions. Other solutions, such as lowering the sanitary main, may be feasible, but the engineer must consider the impact of such a solution on the rest of the project. Careful planning while designing the grading plan will help avoid awkward situations such as basements that won't sewer by gravity.

Another controlling factor for setting the house elevation is the street elevation. Typically, the first floor elevation is above the street, but limitations on driveway grades, as discussed above, also control the maximum elevation of the house. The relationship of the house to the street is a major factor in its "curb appeal," and any deviation from general standards (e.g., a very steep driveway or slope that drains to the foundation of the house), looks out of place and lowers the curb appeal.

Finally, the development of any grading scheme includes the assimilation of other existing data and the constraints that data may impose. These existing constraints are combined with the data available on the proposed building structure. Ideally, these constraints are obtained from the approved<sup>5</sup> architectural and mechanical drawings. The location and relative elevations of doors, garages and windows, other appurtenances such as decks, patios, stoops, walkways, and any utility connections are necessary to develop an effective grading plan. This information becomes part of the constraints for grading. From this architectural information, develop a footprint or template of the building showing all entrances, windows and other appurtenances at or near the ground level that affect the grading. The relative elevations of these items with respect to the floor elevations are labeled on the template. Figure 24.27 depicts examples of house templates for three different house types used on a project. The building template is placed on the grading plan and oriented such that it best suits the topography, ordinance setback requirements, and utility constraints. The specific footprint of the desired house is then transferred onto the grading plan after the best orientation of the template is obtained. Since a typical subdivision has several house styles, the use of templates allows the designer to shuffle the house types around the lots for quick analysis.

Additionally, siting of buildings on corner lots must allow for site distances of the intersecting streets. This includes high walls and steep slopes resulting from the grading that might impede the required sight distance. However, in most cases the required zoning building setbacks and minimum radii of curvature allow for adequate sight distances.

The height of the earth fill around the house depends on the exterior surface and type of foundation system. Soil and accompanying moisture accelerates decay of some types

of construction materials and provides a haven for insects that can damage the house. Figure 24.28 shows the relationship of the exterior grade for selected foundation systems. The architectural plans should be consulted for the relationship of the flooring to the foundation wall, since setting the first floor elevation dictates the maximum ground elevation. The ground elevation around the perimeter of the house is adjusted to account for windows, doors, garages, and other architectural features, all of which are indicated on the house template.

Once the house is positioned on the lot, the elevations at all critical points are shown with spot elevations. Typically, stoop, patio and ground elevations outside of doors are six in (minimum) lower than the first floor elevation. Additionally, elevations are shown at windows located near ground level to ensure they are not buried. Walkways leading from the front door to the driveway or street should not be steeper than 5%. If walkways become too steep and steps cannot be used, then the overall house elevation may have to be raised or lowered to account for such constraints.

When grading out a rear yard, the designer should seek to provide an area sufficiently level as a place for lounging and family recreation. A space of 15 to 20 ft by 30 to 40 ft graded to a maximum of 5% to 6% slope immediately behind the house is reasonably adequate. In areas of steep slopes, where a flat yard of this size would require expansive fill slopes, the size of the back yard may be reduced, with perhaps a large deck proposed to provide the outdoor living space.

As shown in Figure 24.29, spot elevations and drainage direction arrows are used liberally on the grading plans to show the contractor the intentions of the engineer for the design. Note that the house types of Figure 24.27 correspond to the grading plan of Figure 24.29.

After all of the houses are set on the lots, the engineer should notify the developer of the proposed mix of house types since many developers know, from experience, what mix will be successful. In fact, sometimes the developer gives the engineer a range on the mix before any grading plan is started. Nonetheless, the engineer should verify the mix of house types to be sure no changes in the developer's program have occurred before proceeding with the project.

### Grading in Townhouse Development

Townhouse developments consist of parking areas, private streets, open space, and blocks of "attached" residential units. Typically, the blocks or sticks of residential units contain approximately three to nine homes. The interior units share a wall with either neighbor, while the end units have only one wall common with an adjoining unit. Typically, the property line runs down the center of the common wall.

Although a block of townhouses may have several house types, variations in architectural style and different lengths, usually they have a constant width. These variations help avoid the visual monotony that would occur if all the houses aligned and had the same style (see Figure 24.30).

<sup>5</sup> There are frequent changes in drawings during design and it is difficult to disseminate this information to all people involved in the design of the project in timely fashion. Final coordination of the architectural drawings with the civil site design must be checked when all plans are finalized.

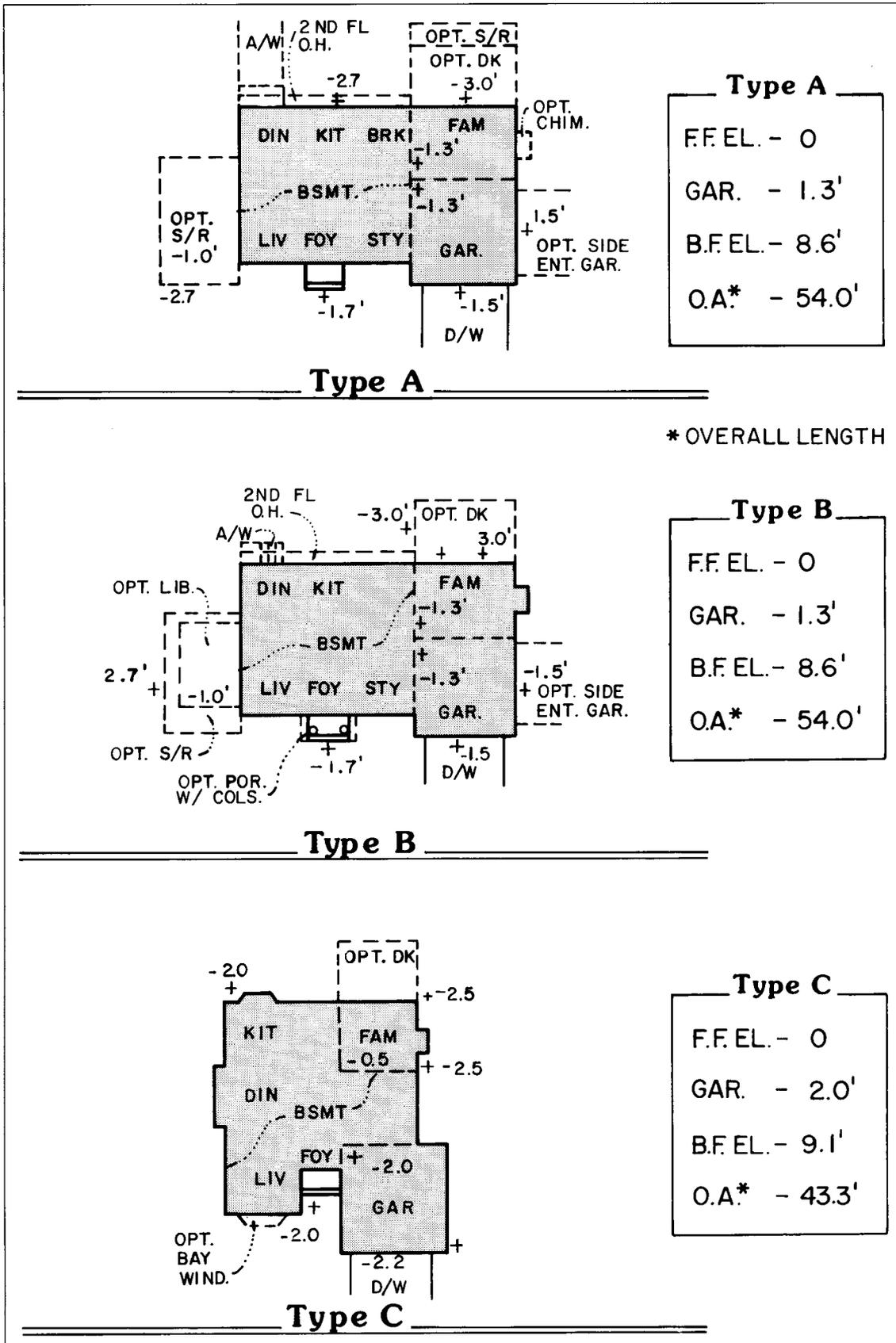
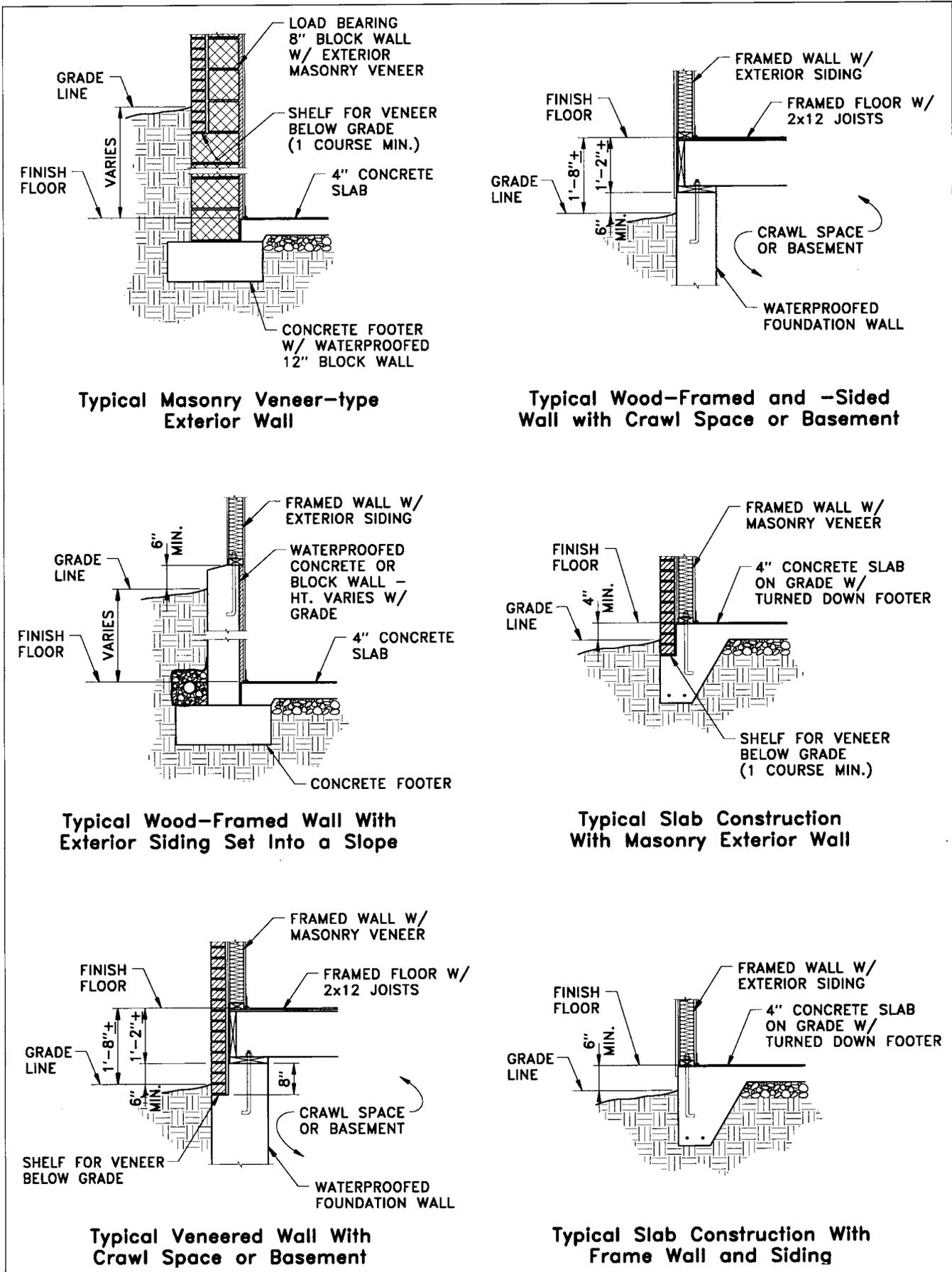
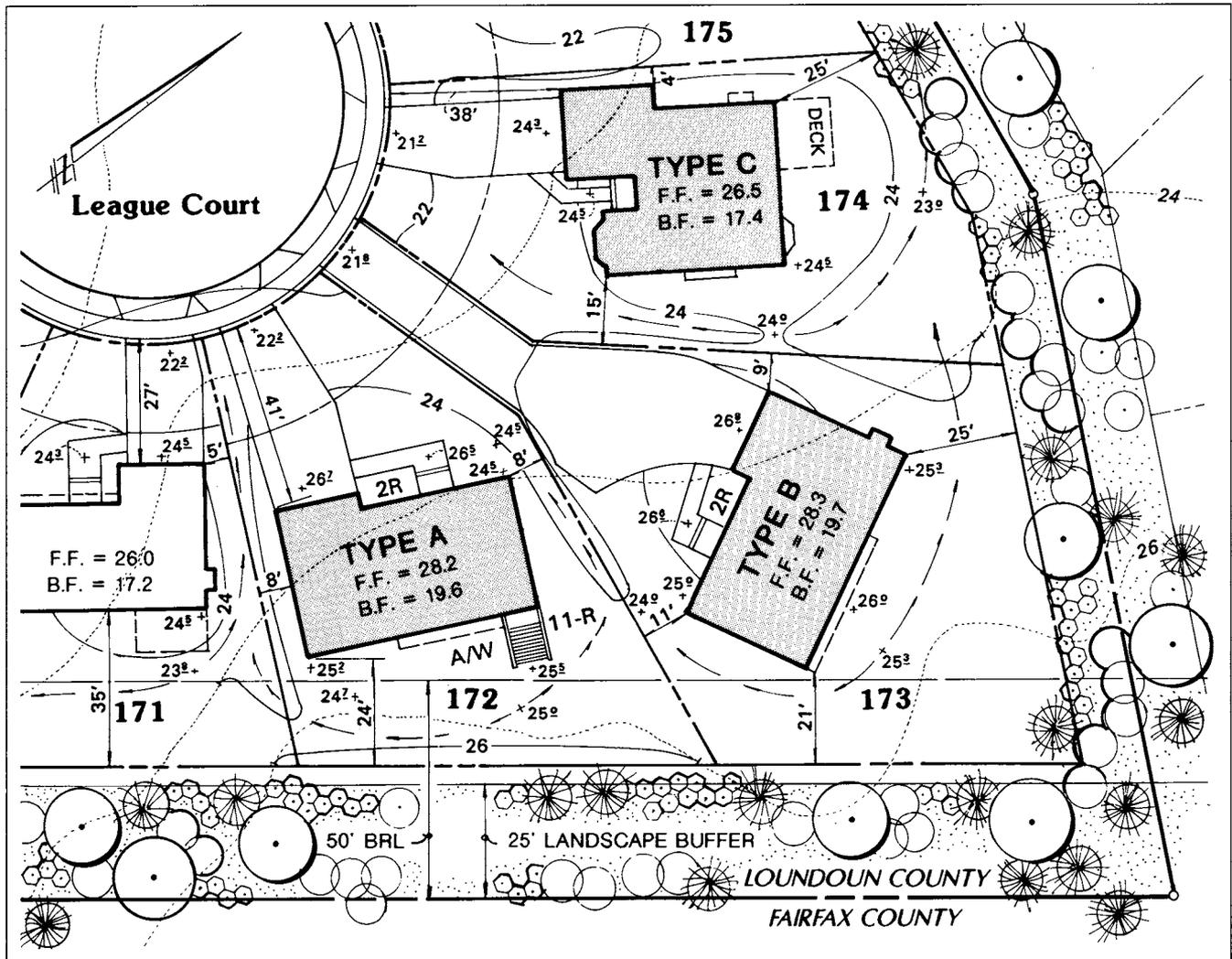


FIGURE 24.27 House template.



**FIGURE 24.28** Foundation systems, exterior surfacing and grading. (Reprinted with permission of C. Harris and N. Dines, 1988, *Time Saves Standards for Landscape Architecture*. New York: McGraw-Hill.)



**FIGURE 24.29** House grading plan.

Other variations include vertical and horizontal staggering, which provides flexibility in the layout and helps the sticks conform to sloping sites.

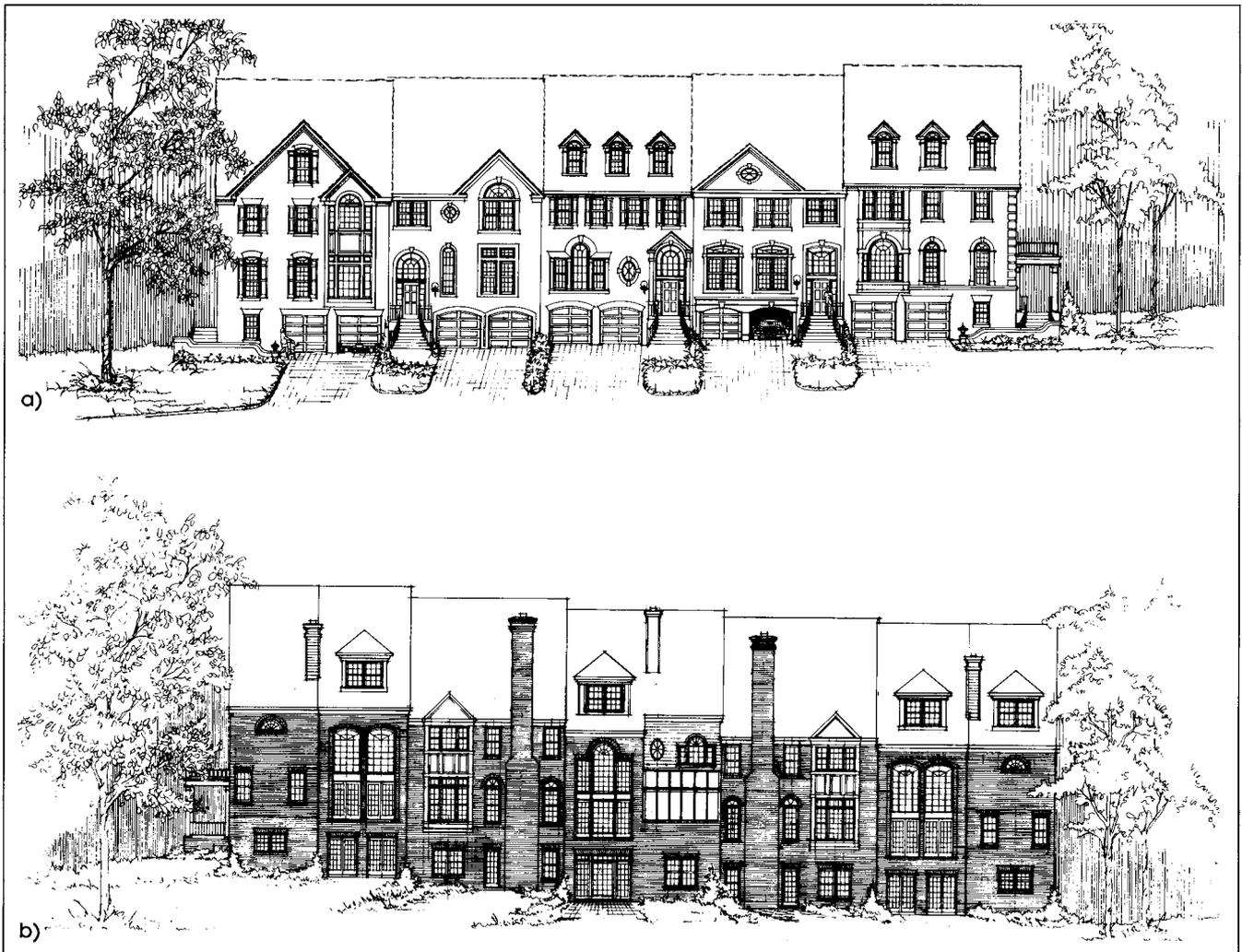
Since each unit is attached to another unit within a block, there must be coordination in the structural design with adjacent units (e.g., roof lines, wall framing, etc.). The minimum or maximum variations in horizontal and vertical relationships may be dictated by local ordinance and building codes. Certainly, restrictions on staggering and vertical orientation will be limited to the structural and architectural design.

From an engineering aspect, the units have to coincide with the site constraints. Yet, from a sales perspective the units have to be appealing to the consumer. For this reason, the layout and design of a townhouse project requires extensive communication and coordination between the site designer, developer, and architect.

During the preliminary phase of design, the site designer obtains general criteria regarding the size, limitations on horizontal and vertical placement, location of garages, pat-

ios, decks and other constraining information about the units, all of which impacts the grading design. During the preliminary-design phase, several layouts and rough grading plan designs might be necessary to optimize the site. The preliminary lot layout provides information on the number of blocks, the number of units in each block, and a rough idea of the vertical arrangement of the units. From these preliminary studies, the architect develops the final arrangement of the units. During final design, the site designer determines the floor elevations of the units. The architect's drawings guide the site designer in setting the floor elevations.

Some refinement of the elevations shown on the preliminary plan is necessary at the final design stage. Whereas the preliminary study may have shown elevations to the nearest foot or half foot, final design drawings show floor elevations to the nearest hundredths of a foot. Therefore, deviations from the preliminary design are expected. In addition, the architect's drawings may also have to be refined during final engineering design. Occasionally, the architect



**FIGURE 24.30** Townhouse block showing vertical staggering to accommodate the longitudinal slope: (a) Front elevation; (b) Rear elevation. (Courtesy of Sutton Sullenberger Yantis Architects.)

allows some flexibility in adjusting the vertical and horizontal orientation of the units. Adjusting units several inches or even a foot or two may present no critical dilemma. When vertical separation between units is two ft or more, small retaining walls are required.

Setting the floor elevations for townhouses is more involved than single-family detached houses. A certain limited structural relationship, evident from the architectural plans, exists among the units of a block. In some townhouse designs, there is flexibility in adjusting the stagger distance and the vertical relationship of floor elevations of adjacent units. This flexibility is needed to allow for better coordination between the housing units and the site conditions.

To set the townhouse elevations properly, the engineer needs a complete and current set of architectural plans. From these plans, the site designer determines the relative location of the units in a block. As with single-family homes, a template of the townhouse block may simplify the process. This template shows the relative floor elevations of

the units and the location of stoops, patios, decks and other appurtenances. When vertical adjustment between units is necessary, it is recommended, and usually mandatory with brick veneer, to raise or lower floor elevations in eight-in increments. This recommendation is based on the dimensions of masonry units used for construction. Using 8 in. or a multiple of eight simplifies the construction while still providing flexibility to the designer.

Depending on the experience of the site designer and architect, the site designer may be the one who sets the pad elevations and staggers the setbacks. This information is then sent to the architect, who then develops the block designs. Whether the site designer suggests the initial unit requirements to the architect first, or vice-versa, communication between the site designer and architect (through the developer) is imperative to exchange the interdisciplinary information necessary for design.

Another problem encountered in setting townhouse elevations is the number of risers (steps) from the street to

the door. The site designer needs to verify the horizontal and vertical distance necessary to accommodate the full run of the stairs. Zoning ordinances may not allow the steps and stoop to encroach into the building setback limits. The site designer must verify that the vertical distance from the door (or stoop) to the ground, and the horizontal distance from the door (or stoop) to the property line, is capable of accommodating the required number of risers. A safe assumption is to allow a tread width of 1 ft; therefore, if ten risers are needed, the minimum setback to the stoop is 10 ft. Furthermore, additional distance may be needed between the sidewalk and the start of the steps. Although riser heights can vary with the maximum height typically limited to  $7\frac{1}{2} \pm$  in., building codes require the riser height to be constant for the run of steps. Therefore, the vertical distance from the sidewalk/street to the entrance must be a multiple of the riser height.

### Grading in Commercial Sites

Commercial projects (e.g., high and low rise offices, retail plazas, houses of worship, and schools) mainly consist of buildings, parking areas, and access points. Due to the high premium rates for commercial land, rarely are there large areas of natural ground to allow for extensive flexibility in the grading scheme. On residential projects, groups of lots are worked on simultaneously, and the grading can extend beyond the limits of a single lot, since the group of lots has only one owner. On commercial projects, rarely does one owner develop several parcels simultaneously; therefore, the limits of the grading cannot extend off site. Grading on an adjacent parcel, with a different owner, requires permission in the form of a letter of agreement or an off-site grading easement, either of which is often difficult and expensive to obtain. Therefore, assume that proposed grades must tie-out at the property line. When this practice requires expensive retaining walls or severely curtails the development program, then it is appropriate to explore the off-site permission. On small sites, this limitation makes developing a grading plan more challenging, especially when steep slopes exist.

The controlling factors for grading commercial sites are basically the same as other sites, and include drainage, slopes in parking and pedestrian areas, and access points to the building structures. From an aesthetic point of view, the grading concept for commercial sites is often tied to the visual goals that the architect (and developer) set for the proposed building.

The necessity for large expanses of paving on commercial projects leads to rules-of-thumb somewhat unique to this genre. Remember the requirements for commercial entrances discussed above. From the entrance, the recommended pavement slope in the travel lanes varies from 1% to 5%. The pavement is sloped to direct runoff to curb inlets, sump areas, or ditches off the edge of pavement. Placement of all drainage structures should take into consideration the movement of pedestrians and vehicles. Inlets

should not be placed in areas of heavy pedestrian use, such as crosswalks and curb-cut ramps. Additionally, the designer should locate inlets in areas where people can access their vehicles without stepping around the inlet. Figure 24.31 shows recommended placement of inlets in parking areas.

Another rule-of-thumb is that long runs of sheet flow on steep slopes in parking areas should be avoided, especially in colder climates where the sheet flow can freeze and create hazardous conditions for pedestrians and drivers. Additionally, runoff should be directed away from sidewalks and pedestrian travelways, as this not only makes it easier for walking but also reduces the splash from passing traffic.

When devising the grading scheme in larger parking areas, consideration should also be given to paving operations. Parking areas that have extensive wash-board effects are difficult to pave, especially if there are numerous grade breaks and relatively steep slopes.

Many commercial buildings have ramps that lead to underground parking or to loading areas. The grading should direct the runoff away from the ramp areas, while inlets at the bottom of the ramps carry the small amount of runoff that does fall in the ramp and loading area.

### Grading and Software

The process of grading explained in this chapter has developed over many years; most of the concepts presented have been in use long before the advent of computers. These concepts change very little, and they must be thoroughly understood before trying to grade a site. Only when the designer has this understanding should tools such as computer programs be employed.

Both AutoCAD and Microstation have software packages designed to perform many tasks associated with site grad-

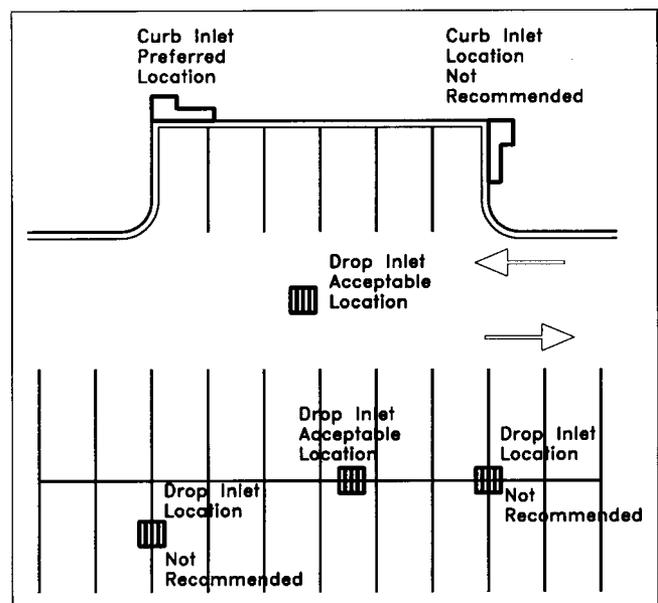


FIGURE 24.31 Recommended inlet locations in parking areas.

ing. By assigning a third dimension to the two-dimensional line, a  $z$  value, a three-dimensional entity is created, and this allows grading to be accomplished in the digital world. The use of computers theoretically leads to increased precision and productivity.

Most of the more mundane tasks associated with grading have been automated. Today, programs are available that not only aid in site grading but may actually design the site grading. Despite the level of sophistication within these programs, it is still imperative that the person applying the technology know what to tell the machine and what the machine is telling him. Only then can the grading plan truly represent the best solution.

### Conclusion

The person designing the site grading plan must combine several skills to accomplish the task. Knowledge of plan graphics and the mechanics of grading provides the means to represent the scheme on paper. Identifying the natural and manmade constraints and knowing how to work with them ensures feasibility. Manipulating the grades so that the proposed uses are facilitated and enhanced contributes to the plan's viability. Creation of an attractive site that is enhanced by the grading helps marketability. Accomplishing all of the above requires a combination of art and science rarely equaled in any other aspect of the site development process.

### EARTHWORK

Calculating the amount of displaced material is referred to as an earth take-off (ETO). Although rarely the case, the ideal scenario is to have a balance of earthwork, where all of the required excavation is used to backfill and to bring the lot to finished grade. In order to attain any semblance of an earthwork balance, the excavated material must be of adequate quality to be reusable. In projects with excessive rock, loam soils, or expansive soils, an earthwork balance, in all likelihood, is unattainable. If a balance cannot be attained, the next best alternative is to have excess soil, since hauling the excess away from the site is typically less expensive than hauling in borrow material.

A grading plan may have to go through several iterations before an acceptable earthwork balance is obtained. Frequently, a rough grading plan is developed as a first approximation. This rough grading plan shows the buildings, streets, and parking areas with spot elevations at critical points and contours lines with 2- or 5-ft contour intervals. An ETO is performed to determine the net earthwork quantity. Since this rough grading plan serves as an unpolished first guess for design, the earthwork analysis cannot be extraordinarily detailed. As the rough grading plan is refined and approaches final design, the detail and accuracy of the earthwork analysis increases.

Most earthwork calculations are performed with the aid of earthwork software, although occasion does arise when manual methods are more effective. Of the several methods

presented herein, the one selected depends on the type of site and the way the project is set up. For many projects, the ETO is developed from the contour grading plan, or in the case of roads, the cross-section drawings. Of major interest to the developer or contractor is the net amount of cut and fill material. Therefore, in order to get a final quantity, cut and fill values must be adjusted for such things as topsoil, pavement thicknesses, undercut, large conduits, soil shrink-swell, and other factors. Many of these factors are fully discussed in Chapter 40, Soils.

### Cross-Section Method

The cross-section method is used to calculate earthwork quantities for roads, utility trenching, and other projects when the length is greater than the width. A contour grading plan is not necessarily needed to use this method since cross sections for streets and prismatic channels can be obtained from the typical section and the profile. Street cross sections are easily plotted manually, although computer software is available to produce street cross sections more easily.

If the cross-section method is used for a building site, the grading plan is used to develop the cross sections. A baseline or reference line is drawn on the plan. Although the location is arbitrary, it is usually down the center or along one edge of the project. The baseline does not need to be straight. Slight curvature or angles can be used when the situation warrants. Lines perpendicular or radial to the baseline are drawn where the cross sections are desired and the sections are then plotted. Distortion of the topography as it appears on the cross-section plot increases when the section line is significantly skewed relative to the prevailing land slope. This, in turn, contributes to errors in the cut and fill values. On the other hand, the distance is not uniform between two section lines if they are not perpendicular to the baseline, and this also adds to the error in the ETO. Judgment and experience dictate the orientation of the section line relative to the baseline and prevailing land slope in order to obtain reasonably precise ETO quantities.

Section lines do not have to be at constant intervals. They are located where the cut and fill does not substantially change and at points where there is an abrupt change between cut and fill. For example, cross sections located before and after foundation walls will not account for the excavated volume. Additional cross sections should be included just inside of the foundation walls. Precision of the ETO depends on judicious selection of the cross-section locations and their orientation to the baseline.

Once the existing and proposed grades are plotted on the cross sections, thicknesses for pavement, concrete slabs, and subbase depths are then added to the drawings. The gross cut and fill quantities are adjusted according to these depths. The cut and fill areas of each section are determined by using a planimeter, geometry or grids. The latter way is tedious, has inherent errors (e.g. estimating partial segments of the squares), but can be effective for very rough esti-

mates. If the measured area from the cross-section drawing is in square inches, the conversion to actual square feet based on the horizontal and vertical scale is

$$SF_{act} = A \times H_{scale} \times V_{scale} \quad (24.6)$$

where  $SF_{act}$  = actual square feet,  $A$  = measured area in square inches,  $H_{scale}$  = horizontal scale in feet per inch, and  $V_{scale}$  = vertical scale, also in feet per inch.

$$V_{inc} = \frac{A_i + A_{i+1}}{2} \times L \quad (24.7)$$

The incremental volume of cut and fill between successive cross sections is equal to the averaged area of the cut or fill multiplied by the (average) length between the cross sections as given in Eq. (24.7), where  $V_{inc}$  is the incremental volume of material between two consecutive cross sections,  $A_i$  and  $A_{i+1}$  are the areas of cut or fill on the two consecutive cross sections, and  $L$  is the average horizontal distance between the sections. Summation of the incremental cut and fill volumes determines the total cut and fill.

The volume from the average end area (Eq. (24.7)) significantly overestimates the volume at the two end sections. As shown in Figure 24.32, the solid segment bounded by station 10 + 60 and station 11 + 00 is wedge-shaped. The volume for a wedge (pyramid) is

$$V_w = \frac{A}{3} \times L \quad (24.8)$$

where  $A$  is the area of the first cross section, in this case station 11 + 00. A comparison of the volumes for the

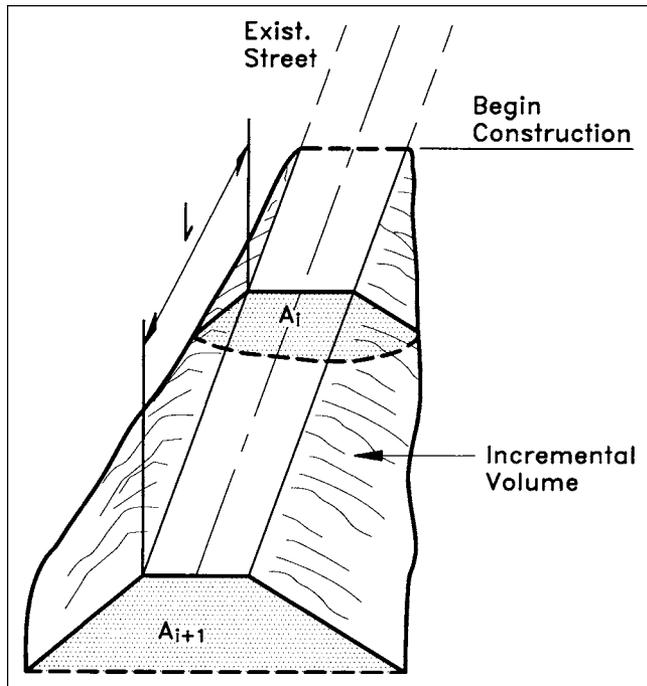


FIGURE 24.32 Wedge-shaped volume and prismatic volume.

wedge segment as computed by the average end area and the wedge equation shows that the average end area volume is 50% greater. The volume due to this error in this segment must be weighed against the total volume of earthwork. Since the error applies only to the two end segments, it is left to the judgment of the engineer which equation is used for the wedge-shaped segments.

**EXAMPLE 2:** Figure 24.33 shows three cross sections of a roadway where C and F designate the cut or fill area on the cross section. Table 24.3 shows the tabular organization of the data to determine the earthwork quantities using the cross-section method. (Assume stations 0 + 50 and 2 + 50 are the begin and end points of construction.)

The accuracy of this method is determined by the variation of cut or fill areas of subsequent cross sections. Although most cross sections are taken at constant intervals, intermediate cross sections may be necessary. If one cross section is in total fill and the following cross section is in total cut, an intermediate cross section is necessary for a higher degree of accuracy. The intermediate cross section is located where the fill section transitions to the cut section; this is the point where the cut and fill areas are nearly zero. The accuracy of this method can be increased if the interval length is reduced. The trade-off for this increased accuracy is the time to evaluate more cross sections. Another factor affecting accuracy is the cost

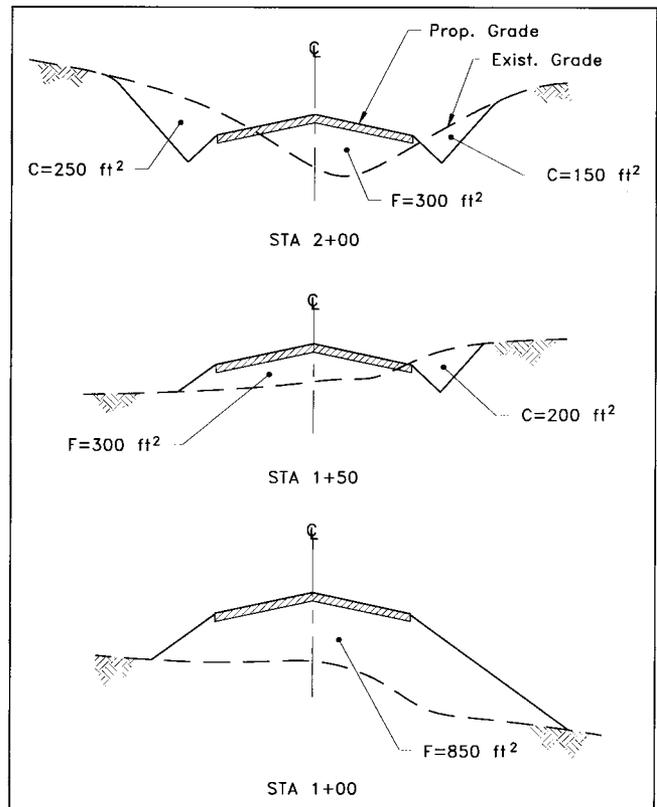


FIGURE 24.33 Earthwork example: cross-section method.

**TABLE 24.3 ETO by Cross-section Method**

(1) STATION	(2) LENGTH (FT)	(3) AREA (FT <sup>2</sup> )	(4) AVERAGE AREA (FT <sup>2</sup> )	(5) INCR. VOLUME (FT <sup>3</sup> )	(6) ACCUM. VOLUME (FT <sup>3</sup> )
FILL					
0 + 50		0			0
	50		425	21,250	
1 + 00		850			21,250
	50		575	28,750	
1 + 50		300			50,000
	50		300	15,000	
2 + 00		300			65,000
	50		150	7,500	
2 + 50		0			72,500
CUT					
0 + 50		0			0
	50		0	0	
1 + 00		0			0
	50		100	5,000	
1 + 50		200			5,000
	50		600	15,000	

Column 1: STATION—the stationing along the street that identifies the location of the cross section.

Column 2: LENGTH—the length between the two cross sections. Notice this value is written on a line between the two cross sections of column 1.

Column 3: AREA—the total area of the cut or fill for the section. The first and last stations are the stations where the grading begins and ends. Here the cut and fill areas are zero.

Column 4: AVERAGE AREA—the average of the cut or fill area as determined by equation (24.7).

Column 5: INCR. VOLUME—the volume of cut or fill between the two cross sections. This is equal to column 2  $\times$  column 4.

Column 6: ACCUM. VOLUME—the accumulated volume of cut or fill. Equal to the preceding value of column 6 added to the current value of column 5. The last value in this column is the total cut or fill for the total number of cross sections.

for cut and fill. An extremely high cost associated with the cut or fill operations will necessitate that the computed earthwork quantity be considerably more accurate. Consideration for additional cross sections through a curve is necessary if the length parameter is longer than the arc length of the curve. In general, the average end area equation tends to overestimate volumes.

A variation of the average end area method considers the average the areas within a closed contour loop. The average area is multiplied by the difference in elevation between the contour lines to obtain a volume. This method is best suited for computing volumes of lakes and mounds.

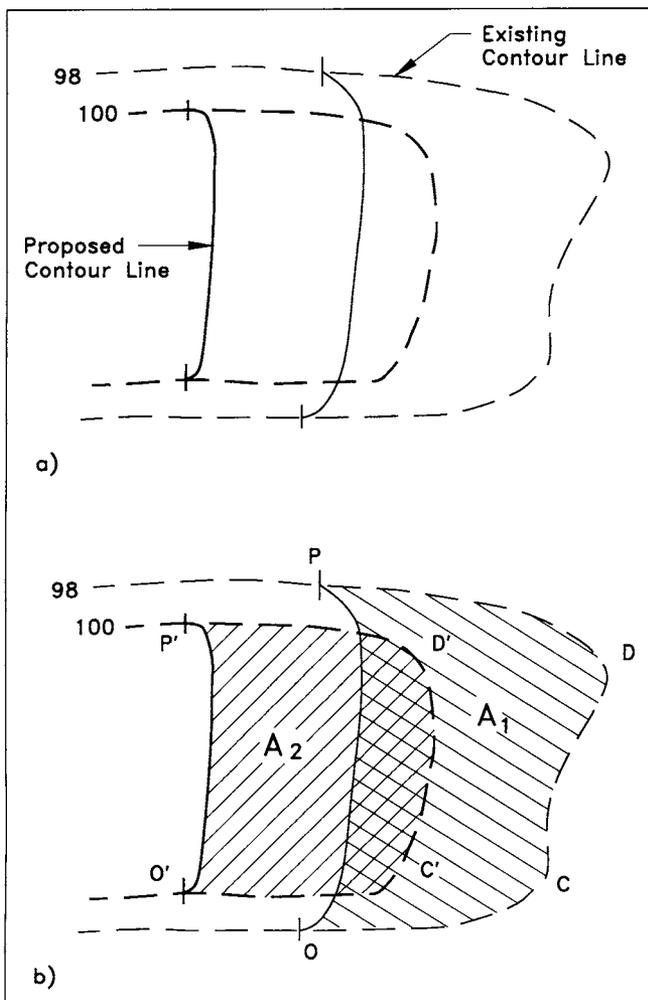
**EXAMPLE 3:** Table 24.4 organizes the data for calculating the volume of the depression in Figure 24.34. The values for the area (shown in column 2) represent the plane area contained within the contour line. Column 4,  $ht$ , is the difference between the elevations of the contour lines.

### The Contour Method

The contour method requires a contour grading plan. The amount of cut or fill material is determined by averaging the change in areas due to grading on two successive horizontal planes. This area is contained within the loop of the existing contour line and the proposed contour line. This averaged area is multiplied by the distance between the two

**TABLE 24.4 Contour Method: ETO for Fill Area**

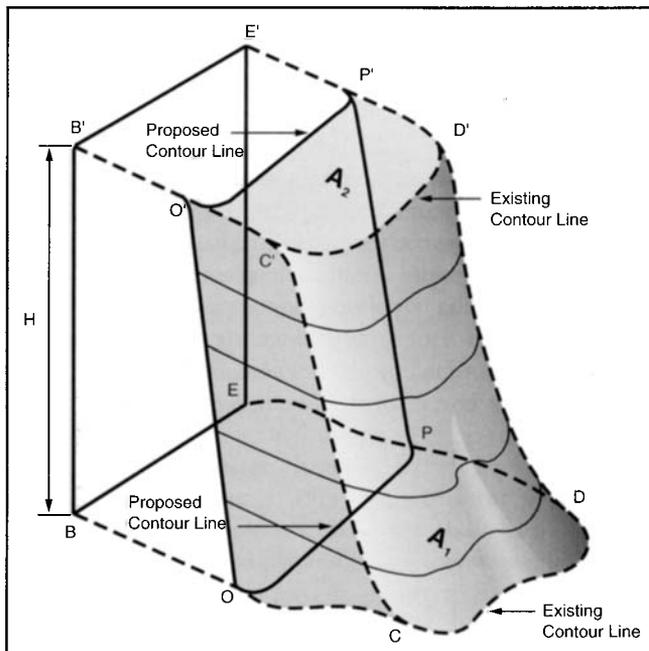
(1) ELEV. (FT)	(2) LOOP AREA (FT <sup>2</sup> )	(3) AVG. AREA (FT <sup>2</sup> )	(4) DIFF. IN ELEV. (FT <sup>2</sup> )	(5) INCR. VOL. (FT <sup>3</sup> )	(6) ACCUM. VOL. (FT <sup>3</sup> )
413	0				0
		2714	1	2714	
414	5428				2714
		7348	2	14,696	
416	9268				17,410
		5529	2	11,058	
418	1789				28,468
		895	1	1790	
419	0				30,258



**FIGURE 24.34** (a) Portion of a graded area; (b) change in surface areas.

plane areas to obtain a volume. To illustrate this point, Figure 24.35-a shows a portion of a contour grading plan where the graded area is in cut. Figure 24.35-b shows the change in plane areas resulting from the new grading. Each area is bounded by a loop comprised of the existing contour line and the proposed contour line.

In the three-dimensional figure, lines BCDE and B'C'D'E' are the existing contour lines representing the two planes. Lines OP and O'P' are the proposed contour lines



**FIGURE 24.35** Three-dimensional representation of the graded area.

on each plane. The change in surface areas from the existing to the proposed conditions are the loops OPDC and O'P'D'C', which enclose areas  $A_1$  and  $A_2$  respectively. The volume of material is the prism of material between the horizontal planes of  $A_1$  and  $A_2$  and the inclined surfaces of O'P'PO and C'D'DC. This volume,  $V$ , is given as

$$V = \left( \frac{A_1 + A_2}{2} \right) \times H \quad (24.9)$$

The procedure for performing an ETO using the contour method is:

1. Delineate on the grading plan the limits of the cut areas and fill areas. These limits are identified by a closed loop that connects the points where proposed contour lines connect to the existing contour lines, essentially where the cut and fill is zero. These loops are identified as the zero loops and the number of zero loops depends on the grading scheme. All grading within a zero loop is either all cut or all fill. All lines on the drawing representing zero loops should be drawn in the same color. On the plan view, these points are indicated where the proposed contour line ties into the existing contour line or where a cut area changes to a fill area. In Figure 24.36 points A and C are where the proposed contour lines tie to the existing contour lines. Point B is where the cut area changes to a fill area. The zero lines are indicated in the plan view of Figure 24.37.
2. For each contour line within a zero loop, there are other loops comprised of part of an existing contour and a proposed contour. Each of these loops outline the change in area between the existing and proposed conditions for that contour plane. On projects where extensive grading is required, the loops will overlap, as shown in Figure 24.38 and Figure 24.39. The basic procedure for delineating a loop is: (1) on the grading plan, find where the proposed contour line meets the existing contour line; (2) from this point using a colored pencil, trace the proposed contour line to the point where it joins the existing contour again; (3) then trace the existing contour line back to the original point; (4) do this for each contour within the zero loop; (5) identifying individual loops with lines of alternating colors helps when tracing the planimeter around the loop. If a loop cannot be completely closed—that is, the proposed contour does not meet the existing contour within the bounds of the zero line—the zero line is not drawn correctly.
3. The incremental volume is the averaged areas of the two loops multiplied by the difference in elevation between the two contour lines.

After all loops have been outlined, the area of each loop is determined for each cut and fill area. After all loop areas

have been determined and compiled into tabular format (see Tables 24.4 and Table 24.5), the table is completed by following through with the calculations of each column. If one table is used for each cut and fill area, a quick inspection of the tables will identify areas of the site where an adjustment can be made to balance the cut and fill.

**EXAMPLE 4:** Use the contour method to determine the amount of cut and fill for the grading plan of Figure 24.36.

The first step in the procedure is to determine the zero lines. For the grading plan example, some of these points along the zero line where the proposed contour lines tie into the existing contour lines are shown as points a, b, c, d, e and f in Figure 24.37. The line c-g-h-d separates the fill area from the cut area. It is analogous to the line in Figure 24.36 that runs through the center of the graded area to divide the cut and fill areas.

Figure 24.38 shows the change in graded areas for the contour lines for elevations 414 ft, 416 ft, and 418 ft within the zero line for the fill area. For example, beginning at point "J," a loop is made that follows the proposed contour line to point "K," then along the existing contour back to point "J." Similarly, the areas for the loops MQM and the NOPN are measured.

The loop areas for each contour line in the fill areas are measured and entered into a computation table (Col. 2) as shown in Table 24.5. The following calculations complete the table.

COL 3: The average area for the first two consecutive contour lines (e.g., for the 413-ft and 414-ft contour lines), is

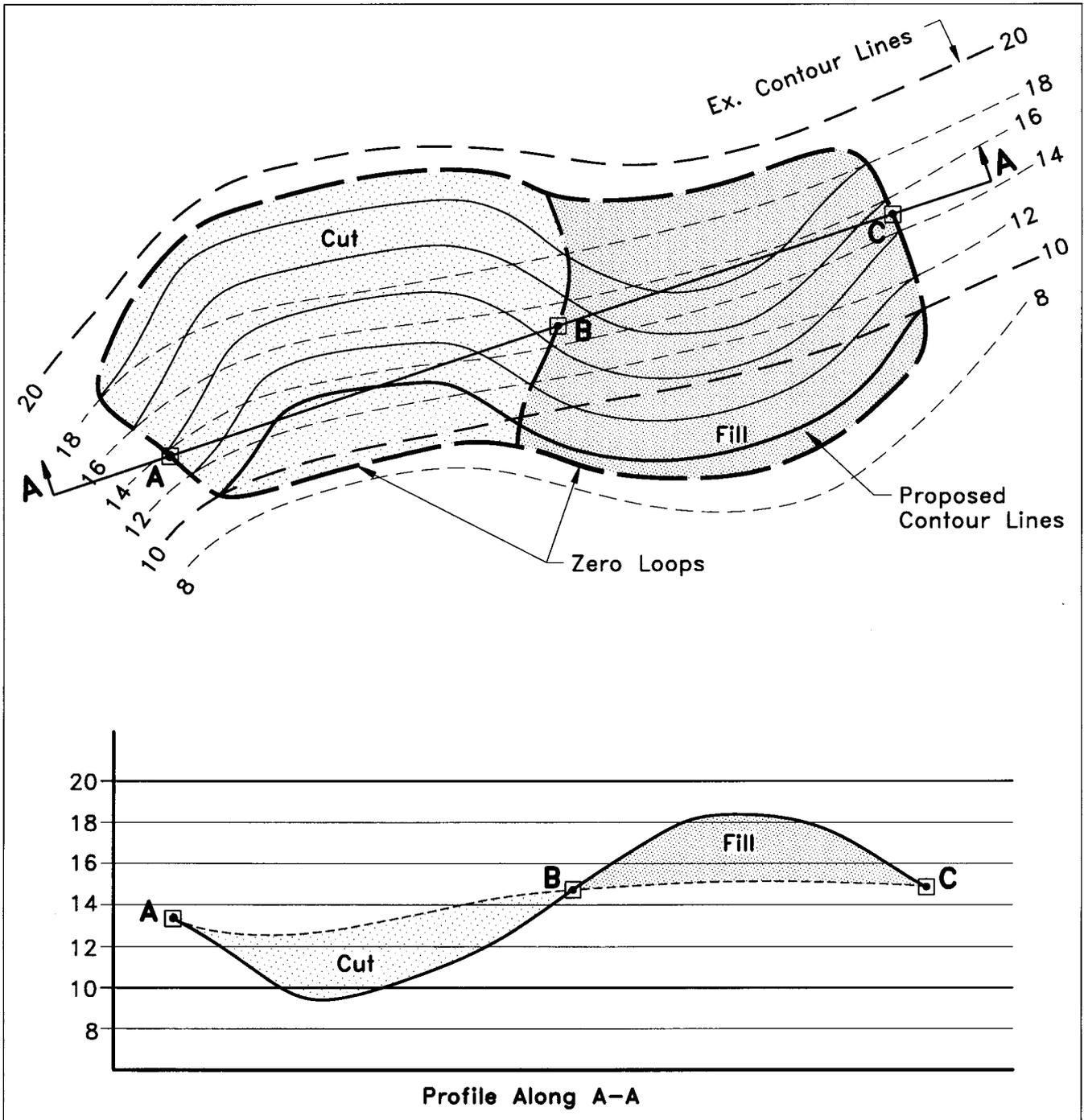
$$\frac{8823 + 11,453}{2} = 10,138 \text{ ft}^2 \quad (24.10)$$

COL 4: The incremental volume is the volume of material cut or filled corresponding to the two consecutive contour lines. It is the averaged area (Col. 3) multiplied by the elevation difference between the two consecutive contour lines.

COL 5: The accumulated volume is the preceding incremental volume added to the current incremental volume.

$$2 \times (416 - 414) \times 10,138 \text{ ft}^2 = 20,276 \text{ ft}^3 \quad (24.11)$$

Similar loop areas are obtained for the contour lines within the zero loop of the two cut areas as shown in Figure 24.40. One detail that must be pointed out involves the cut area around the building. A common error is to trace the building with the planimeter in the wrong direction. The path indicated as abcdef is the correct loop (see discussion on Contour Patterns for Buildings and Retaining Walls). The other loop areas around the building have not been shown for clarity.



**FIGURE 24.36** Schematic diagram showing zero lines.

The total volume of material of cut and fill is

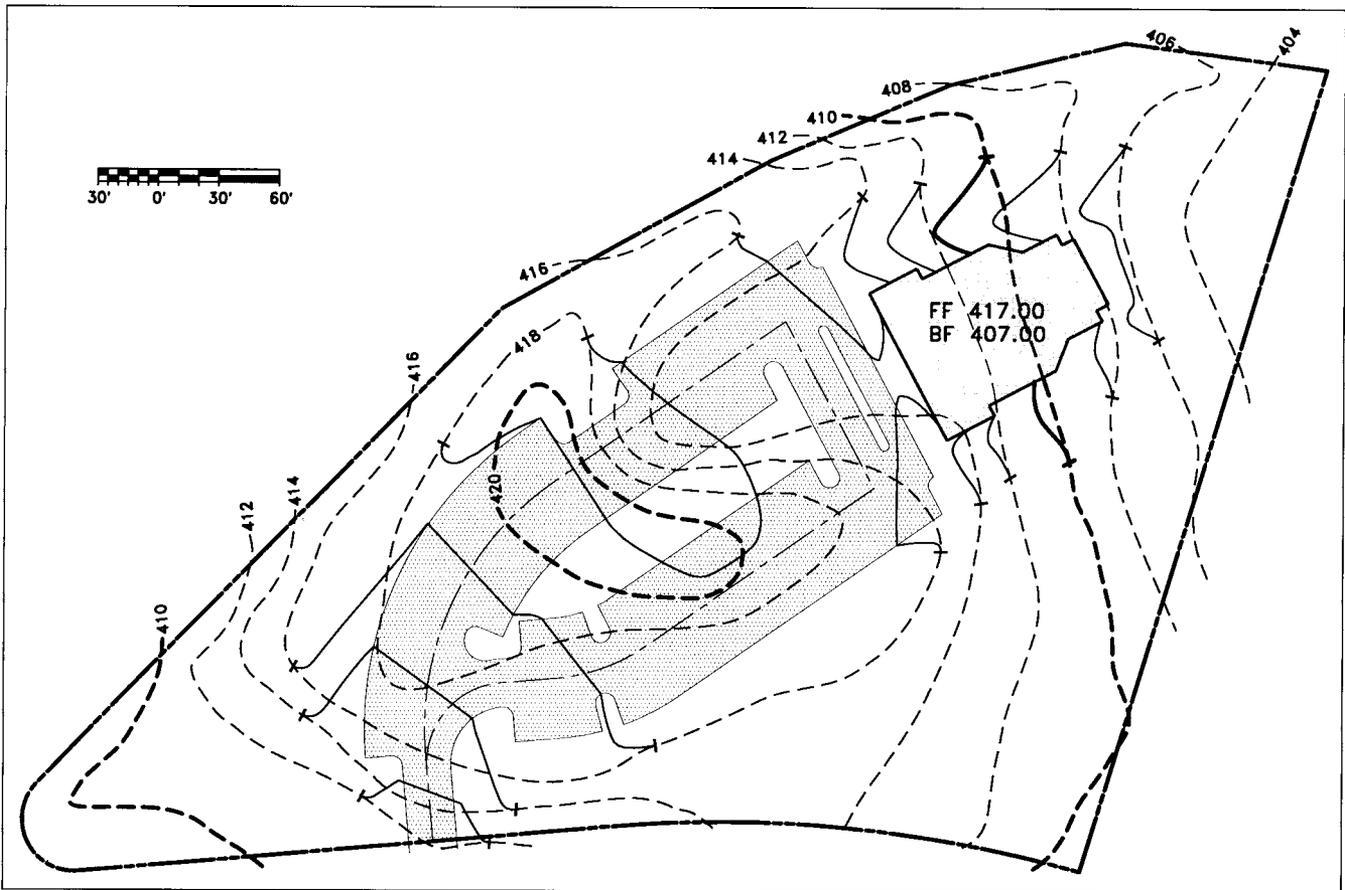
$$\begin{aligned} \text{Total Volume of cut} &= \frac{62,556 + 38,439 \text{ ft}^3}{27 \text{ ft}^3 \text{ per yd}^3} \quad (24.12) \\ &\approx 3740 \text{ yd}^3 \end{aligned}$$

$$\begin{aligned} \text{Total Volume of fill} &= \frac{35,662 \text{ ft}^3}{27 \text{ ft}^3 \text{ per yd}^3} \\ &\approx 1321 \text{ yd}^3 \end{aligned}$$

However, these volumes must be adjusted for topsoil, allowance for concrete and pavement thicknesses, and shrink and swell.

**Equal Planes Method**

Another method for estimating earthwork considers the volume based on averaging incremental depths of cut or fill. Each specific depth extends up or down from the proposed ground to the original ground line. The resulting configu-



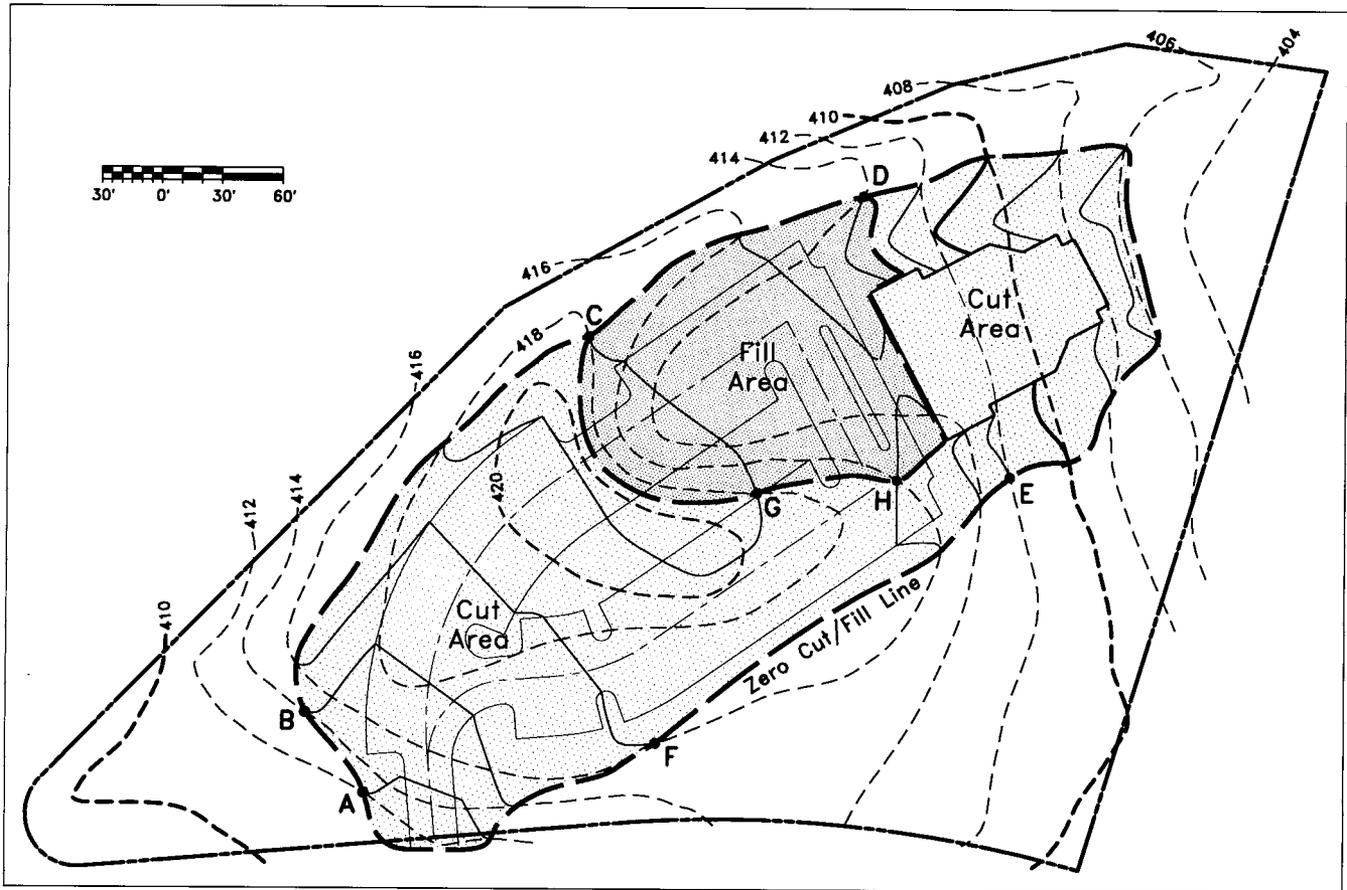
**FIGURE 24.37** Grading plan.

ration is a series of concentric nested rings of uniform depths and variable widths. The height of each ring represents an incremental depth of cut or fill. The width of each ring represents the difference in area between two successive cut or fill contour lines. Whereas the contour and cross-section methods average the cut and fill *areas* on successive planes, the equal planes method averages the depths of cut or fill of successive rings.

To illustrate the incremental volumes of the equal planes method, consider an 8-ft high mound built up from level ground. Imagine that the 8-ft elevation is represented by a ring of a specific radius,  $r_8$ , as shown in Figure 24.41. The outer edge of the ring is formed by the 8-ft contour line. The volume of earth in this initial “ring” is that of a right circular cylinder =  $8(\pi r_8^2)/4$ . Next, consider a ring formed by the 6-ft contour line with radius  $r_6$ , ( $r_6 > r_8$ ), concentric with the 8-ft-high cylinder. The incremental volume in this ring is  $6\pi(d_6^2 - d_8^2)/4$ . Note that the volume between the ground line and the horizontal planes of the successive rings as shown in the triangle PQS of Figure 24.41 is not included in the calculations. This error is reduced by computing the incremental volumes by averaging the depths of fill (or cut) on two successive rings as indicated by triangles TUV and T'U'V on the left side of Figure 24.41.

The height of a ring represents a layer that is a constant depth above (for fill) or below (for cut) the original ground line. The constant distance is measured along the vertical direction from the ground surface. Although the equal planes method is predicated on layers of uniform depth of cut or fill parallel to the ground surface as shown in the profile of the mound (Figure 24.43-a) the projection of these surfaces onto the plan view assumes these surfaces to be parallel to a horizontal plane as shown in Figure 24.42-b.

Figure 24.43 shows a profile view of the mound and the corresponding contours in plan view. The profile shows the underlying surfaces in increments of 2 ft. The first layer under the original ground represents a cut depth equal to 2 ft. In plan view, this layer appears as a loop where the difference in elevation between the existing grade and proposed grade is two ft. Likewise, successive layers of 4, 6, 8, . . . -foot cuts are identified by loops where the difference in elevation between the existing and proposed grades are 4, 6, 8, . . . etc. ft respectively. Each loop is identified on the plan view illustration. A loop represents the inner edge on one shape and the outer edge of the subsequent inner shape. Hence, the difference in area between successive loops is the incremental area used to determine the volume



**FIGURE 24.38** Grading plan showing zero cut/fill lines and cut and fill areas.

of one of the rings. Summation of all incremental volumes is the estimated earthwork volume.

The basic procedure for using the equal planes method on a grading plan is:

1. Delineate all loops representing equal cut or fill layers beginning with the zero loop. This loop identifies the plane where the grades tie out—essentially where the difference between proposed grade and existing grade elevations are zero. There could be more than one cut or fill area on a project. The zero loop isolates these individual cut and fill areas.
2. From each zero loop work inward. Decide the next level for which a plane will be identified. The easiest way is to keep the planes at the same increment as the contour interval. If the contour interval is 2 ft, the next plane would be at a depth/height of 2 ft. Inside the zero loop, locate the points where an existing contour intersects a proposed contour where the elevation difference between the two contours is 2 ft, as indicated by points A and A' in Figure 24.43. A loop that connects these points and all points where the proposed elevation is 2-ft higher/lower than the existing elevation outlines a plane that is 2 ft higher/lower than the zero plane. A loop will cross contours only where the existing contour and proposed contour intersect—unless there is a retaining wall or other structure.
3. Decide the next plane. Again, if the contour interval is 2 ft, the next plane is at a depth/height of 4 ft. Draw a loop that connects all points 4 ft higher/lower than the existing elevation (points B and B' in Figure 24.42). Continue this procedure inside all zero loops until all loops have been drawn for the site. The plan becomes more readable if two colors are used to draw the loops—one color for cut areas and another color for fill areas. Very light shading of alternate rings in the same color enhances the cut and fill areas. Large numbers written on the loops identify the depths/heights of cut/fill areas.
4. For each cut and fill area, a table keeps a record of the individual quantities and the accumulated earthwork, as shown in Table 24.6. The area of each loop is determined and entered into column 2. Column 3 is the difference between the current loop and the preceding loop. Column 4 is the average of the current depth and the preceding depth. Column 5 is the prod-

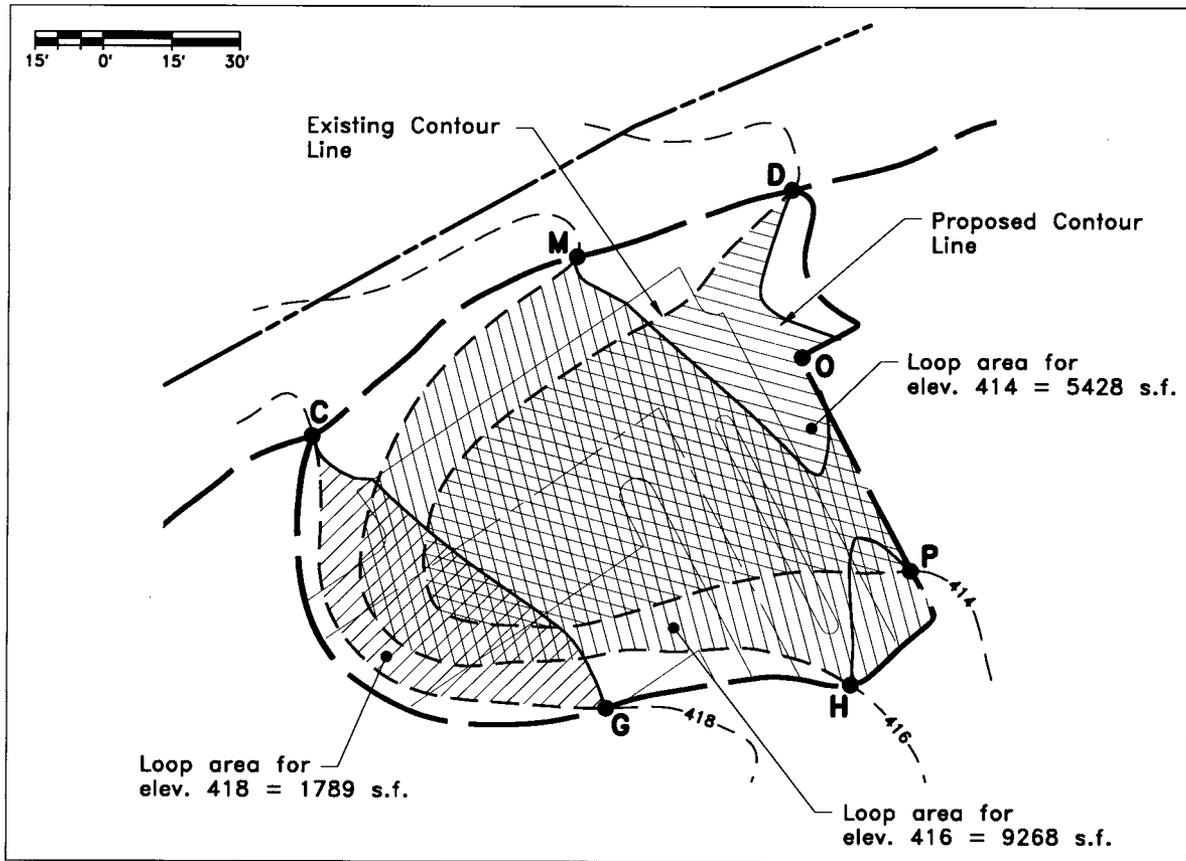


FIGURE 24.39 Contour method: loops for fill area.

uct of column 3 and column 4. Column 6 is the accumulated earthwork of column 5.

**EXAMPLE 5:** Using the same grading plan as the previous example, perform an ETO using the equal planes method. Figure 24.44 shows the grading plan with the zero lines, and the 2-ft, 4-ft and 6-ft depths of cut loops and depths of fill loops.

The area of each loop is determined and entered into column 2 of Table 24.6. Column 3 of this table is the difference in area between two consecutive loops. Column 4 is the averaged depth of cut or fill, and column 5 is the incremental volume = col. 3  $\times$  col. 4.

The main advantage to using the equal planes method is that the final plan view shows the cut and fill areas and how deep these areas are. Any adjustments to the site grades to adjust the ETO can be limited to specific areas.

### Grid Method (Borrow Pit Method)

The grid method for computing earthwork quantities averages the cut or fill depths over a unit area. The product of the averaged depths with the unit area is the net incre-

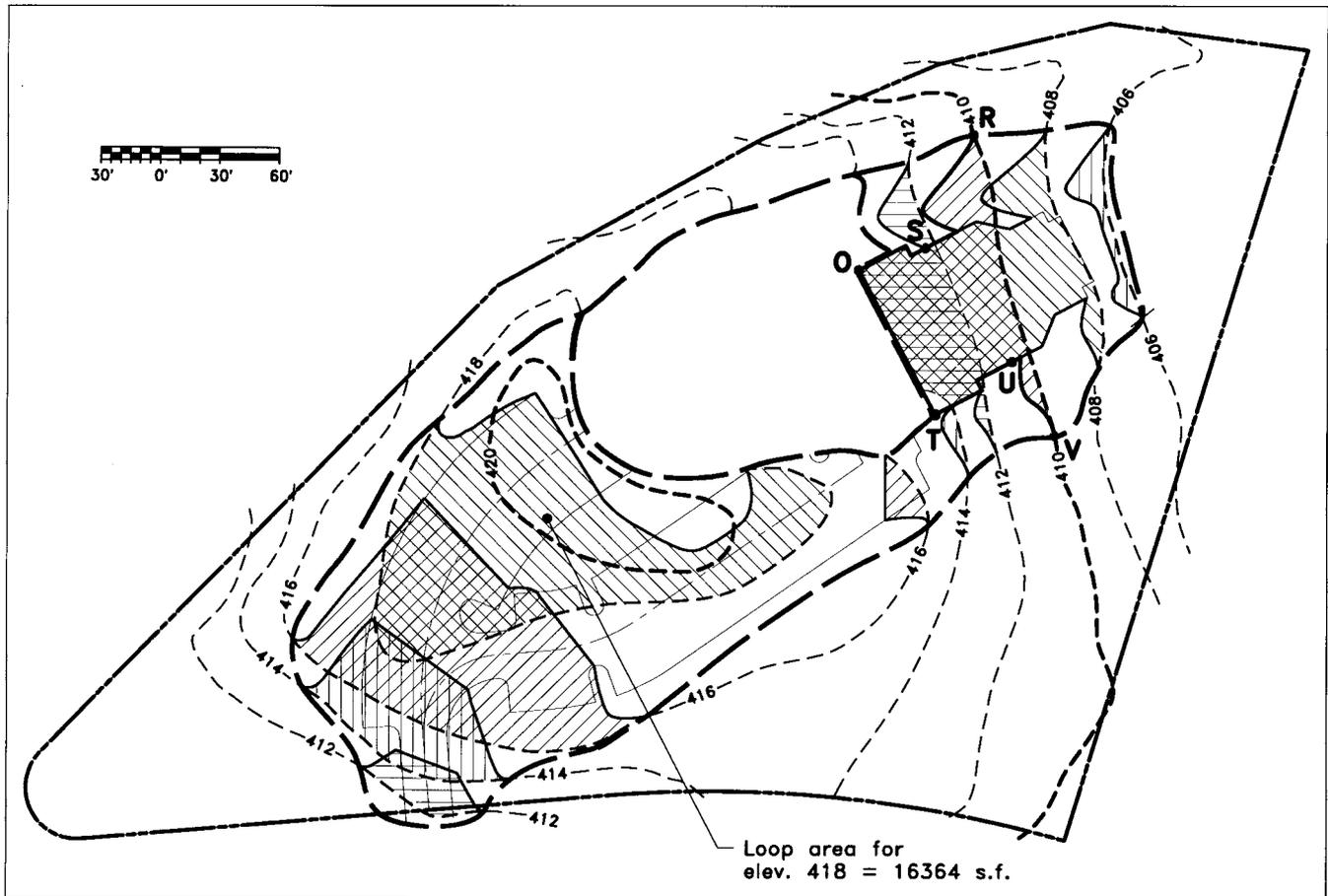
mental volume of cut or fill. A summation of all incremental fill volumes and cut volumes gives the total for the site.

Figure 24.45 shows a proposed ground surface and the existing ground surface for a unit area. (Note that the intersection of the two surfaces establishes the zero cut and fill line.) The depth of cut or fill is written at each corner of the unit area. For this particular unit area, the average cut/fill is zero. That is, the volume of material in the cut area is equal to the volume of material in the fill area.

However, as shown in Figure 24.46, the computations presume that the actual ground surface is a plane representing a linear ground surface. The areas that contribute to the error in the actual volume are shaded. The accuracy of the computed volume is a function of the size of the unit area and how close the representative planes for the existing and proposed ground approximate the true ground surface. As the undulations of the actual ground surface increase in number and deviate from the straight line approximation, the precision of the computed volume decreases. To compensate for the irregular topography, the unit area can be reduced to increase precision. The penalty for this is the increase in number of grids and the computing time to perform the method. In some instances, decreasing the unit area may not be the solution either. On extremely flat sites,

**TABLE 24.5 Contour Method: ETO Quantities for Cut Area**

(1) ELEV. (FT)	(2) LOOP AREA (FT <sup>2</sup> )	(3) AVG. AREA (FT <sup>2</sup> )	(4) DIFF. IN ELEV. (FT <sup>2</sup> )	(5) INCR. VOL. (FT <sup>3</sup> )	(6) ACCUM. VOL. (FT <sup>3</sup> )
<b>PARKING AREA</b>					
411	0				0
		680	1	680	
412	1360				680
		2829	2	5658	
414	4298				6338
		8468	2	16,936	
416	12,638				23,274
		14,501	2	29,002	
418	16,364				52,276
		8182	1	8182	
419	0				60,458
<b>BUILDING AREA</b>					
405.4	0				0
		324	0.6	194	
406	648				194
		4336	2	8672	
408	8024				8866
		7186	2	14,372	
410	6348				23,238
		5168	2	10,336	
412	3988				33,574
		2055	2	4110	
414	122				37,684
		61	0.4	24	
414.4	0				37,708



**FIGURE 24.40** Contour method: loops for cut area.

decreasing unit area size decreases the precision. For each unit area, an interpolation between contours is necessary to determine the elevations at each corner. Each interpolation calculation has an error associated with it. The propagation of this error contributes to the precision of the volume. In these extreme cases, the grid method may be abandoned in favor of an earthwork method that is more accommodating.

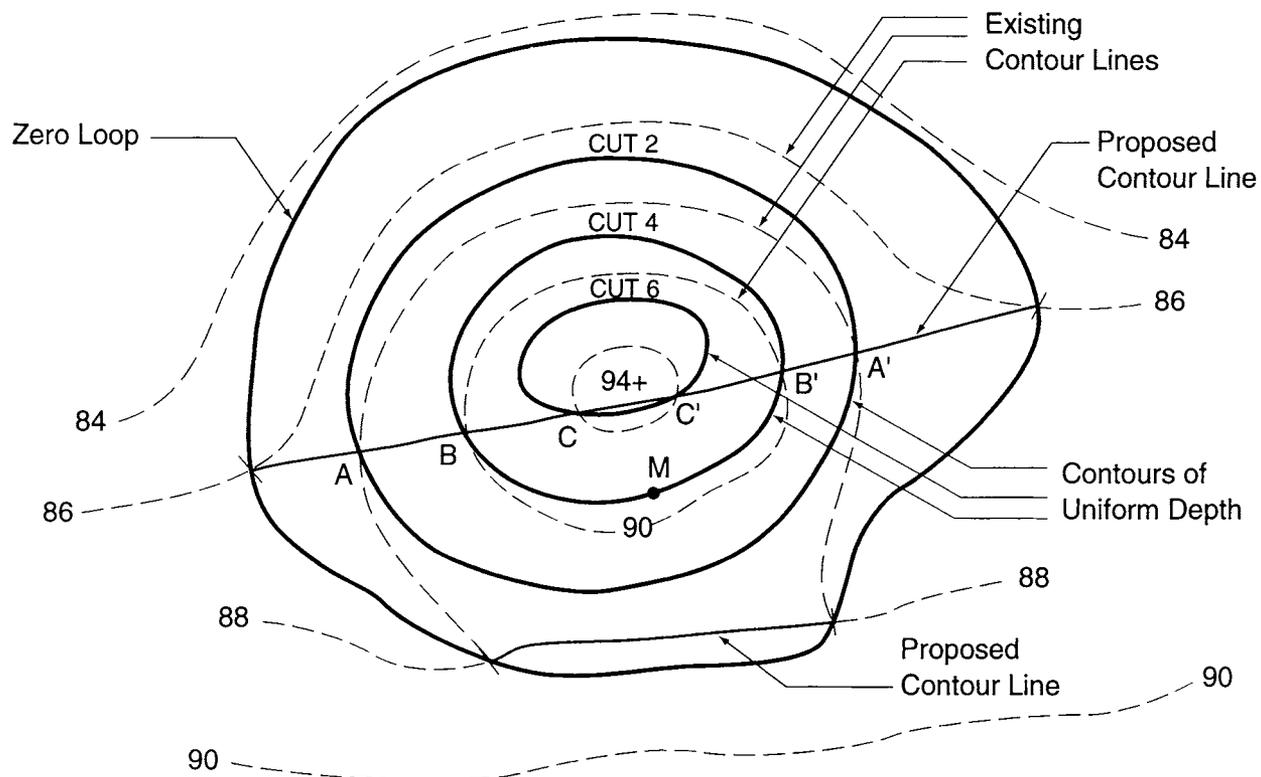
The mechanics of the method are:

1. Obtain the grading plan of the site and create a grid of uniform-sized squares over the graded area. The procedure is facilitated if the grid is created on transparent material and overlain on the grading plan. For reasonably precise earthwork quantities, the grid squares should be 1-in. squares for plans with scales of 1 in. = 100 ft and larger.
2. The grid is overlain on the grading plan. At each corner of a square, a value is entered to identify the amount of cut or fill at that point. A positive value indicates fill and a negative value indicates cut.
3. For each square, the cut/fill values are averaged and written in the center of the square. The incremen-

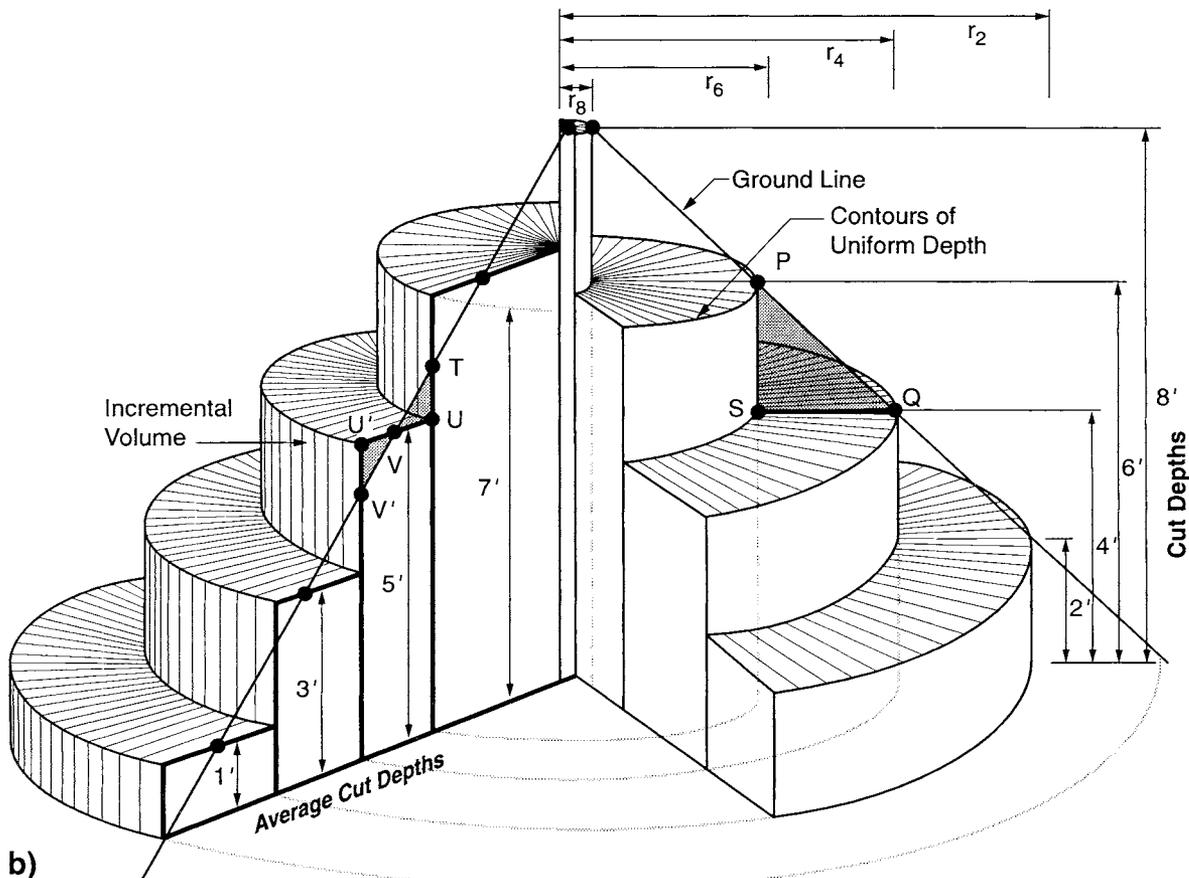
tal volume is the averaged cut/fill depths multiplied by the grid area. Only the corners of grid squares within the grading limits are used to obtain the average cut/fill values.

4. Any corner outside the grading limits is not included in the computational process. The incremental volume is the averaged cut/fill of these grid corners in the graded area multiplied by the fraction of the area of the grid within the grading limits.
5. Summing all averaged values within the grid squares is the net amount of excess/deficient dirt. Summing all positive and negative numbers separately is the amount of cut and fill respectively.

Figure 24.46 shows the grid method for the same grading plan with 1-in. grids. The cut or fill depths are written at the corners of each square (negative values indicate cut, positive values indicate fill). The value written in the center of the grid is the average cut or fill depth for that grid (i.e., the sum of the values at the corners divided by the number of summed values). The volumes of cut or fill for each grid are determined by the product of the averaged cut or fill

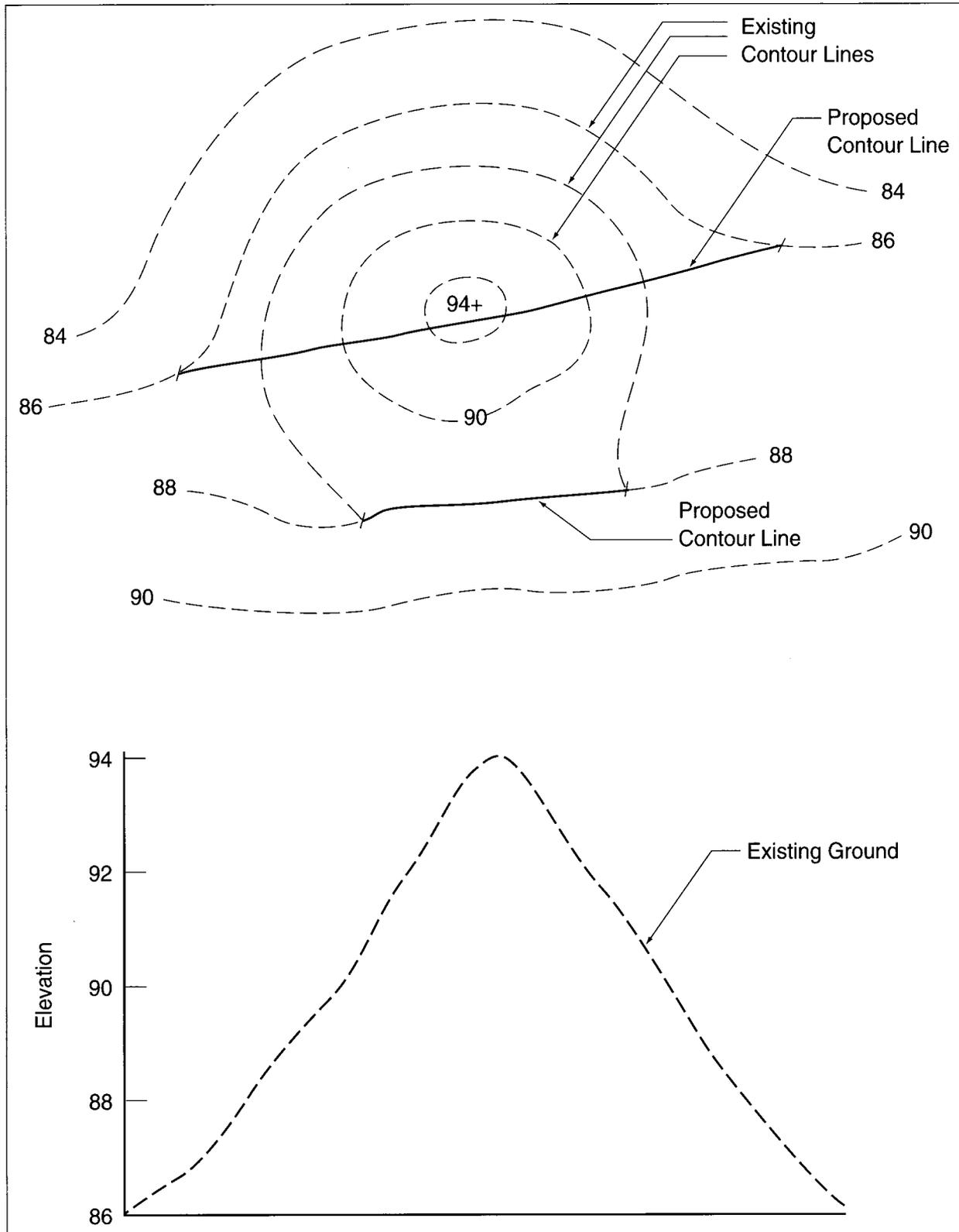


a)



b)

FIGURE 24.41 Contours of uniform depth for the 8-foot-high mound a) plan view b) schematic.



**FIGURE 24.42** Plan and profile view of a mound showing layers of equal depths.

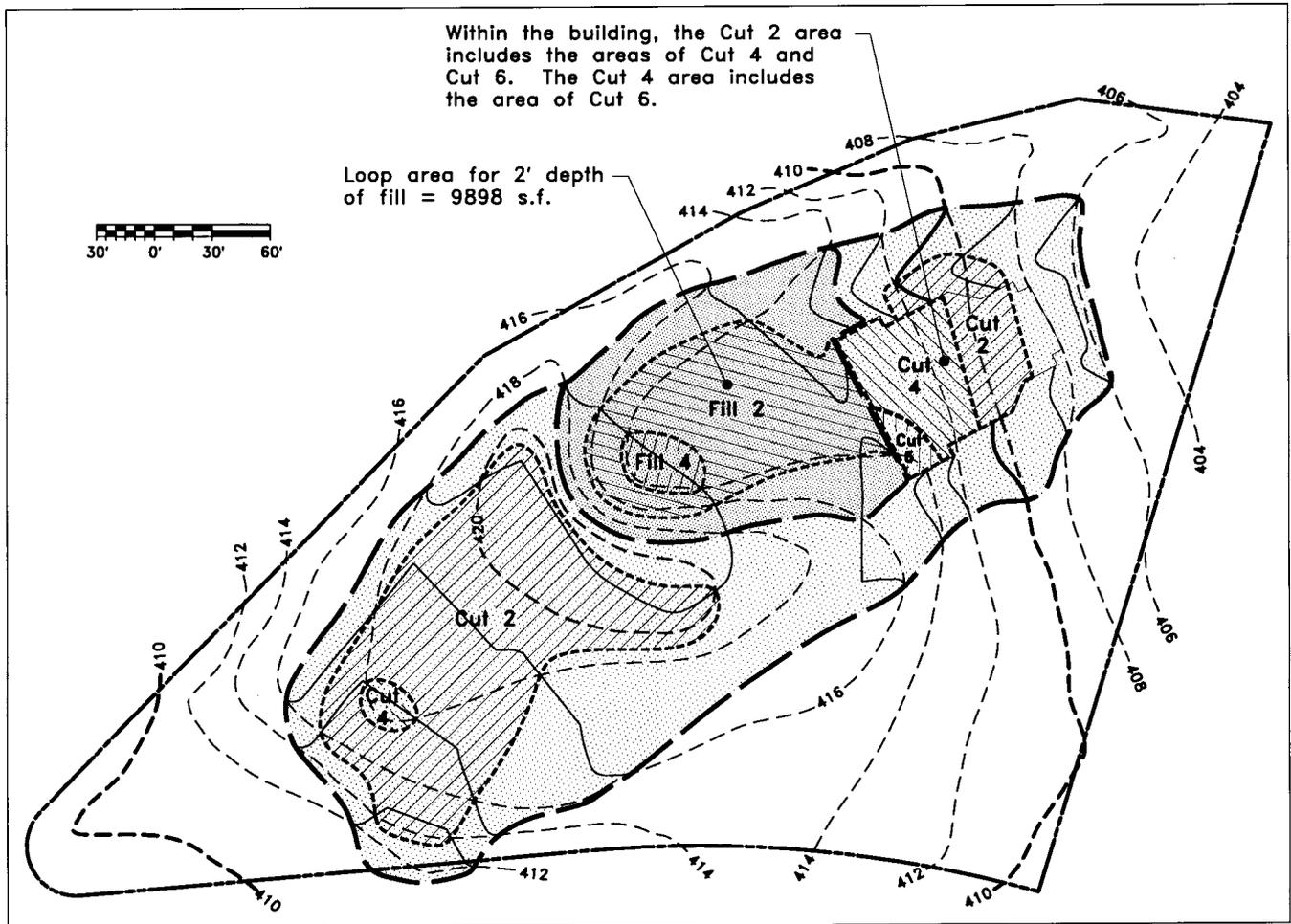


FIGURE 24.43 Cut and fill loops for the equal-planes method.

and the area of each grid. Some squares are not entirely within the grading area. The volume of cut or fill for these squares is found by multiplying the averaged cut or fill depth by the fraction of the area of the grid within the grading area. An “eyeball” estimate of the fractional area should suffice in most cases.

The grid on Figure 24.46 has four rows and eight columns. The incremental volume for each grid is given in Table 24.7.

Summing all of the fractions of the cut values and all of the fill values multiplied by the area of a grid gives the total volumes. The sum of the fractions of the cut and fill are 38.3 and 3.2 respectively. This corresponds to

$$\frac{38.3 \text{ ft} \times (60 \text{ ft} \times 60 \text{ ft})}{27 \text{ ft}^3 \text{ per yd}^3} = 5,100 \text{ yd}^3 \text{ of cut} \quad (24.13)$$

$$\frac{3.2 \text{ ft} \times (60 \text{ ft} \times 60 \text{ ft})}{27 \text{ ft}^3 \text{ per yd}^3} = 430 \text{ yd}^3 \text{ of fill}$$

The unusual low value for the fill volume (430 yd<sup>3</sup>) is

due to the large grid size relative to the small fill area of the plan.

### ADJUSTMENTS TO EARTHWORK QUANTITIES

The ETO methods previously explained calculate the gross quantity of cut and fill. That is, the quantities are computed based on the existing topography and the proposed finished grades. Computing final earthwork quantities includes adjustments to the gross values of cut and fill to account for soil characteristics, topsoil, sub-base allowance, foundations and other items that affect the amount of displaced soil. Since earthwork is a major expense for a project, the adjustments are necessary, considering that the adjustments may affect the computed gross quantity by 10% to 30%. Frequently the client requests the adjustment quantities separate from the gross quantities. These adjustments are shown as separate volumes in a tabulated format. This can be helpful when determining causes for excess or deficient volumes. After all adjustments are made, the results are the net volumes of cut and fill.

**TABLE 24.6 ETO Computations for the Equal-Planes Method**

(1) CUT DEPTH	(2) LOOP AREA (FT <sup>2</sup> )	(3) DIFF. IN AREA (FT <sup>2</sup> )	(4) AVG. DEPTH (FT)	(5) INCR. VOLUME (FT <sup>3</sup> )
0	57,580			
		35,360	1	35,360
2	22,220			
		18,222	3	54,666
4	3998			
		3618	5	18,090
6	380			
		380	6.5	2470
7	0			
				TOTAL = 110,586 ft <sup>3</sup> = 4,096 yd <sup>3</sup>
FILL DEPTH				
0	17,468			
		7570	1	7570
2	9898			
		8930	3	26,790
4	968			
		968	4.2	4066
4.4	0			
				TOTAL = 38,426 ft <sup>3</sup> = 1423 yd <sup>3</sup>

### Topsoil

Before any major grading operations begin, the site is stripped of the topsoil. The topsoil is stockpiled and used for planting and landscaping purposes when the project is nearly complete. In high-density residential projects and many commercial sites, very little area is available for landscaping. The resulting excess topsoil must be either hauled away or disposed on site.

Topsoil depths generally range from 6 to 18 in. Estimates for topsoil depths can be determined from the soils report and the soil boring logs of the site. If the soils report indicates a nearly uniform depth of topsoil, calculate the topsoil volume assuming a constant depth over the graded area. Some sites may have a large variation in topsoil depth

over the site. The engineer decides whether to use a uniform depth or to divide the site into areas of nearly uniform topsoil depth for calculations. The topsoil volume is the estimated depth multiplied by the graded area. In most of the cases the earthwork quantity will not be adversely affected if the topsoil depth is assumed to be uniform over the entire graded area. Another, more time-consuming method is to actually draw the topsoil depth on the cross-section drawings and calculate the topsoil quantity using the average end-area method. This procedure is done when cross sections of the site are available and the topsoil depth is highly variable.

The gross volume of topsoil to be stockpiled is equal to the topsoil stripped from both the cut and fill areas. The

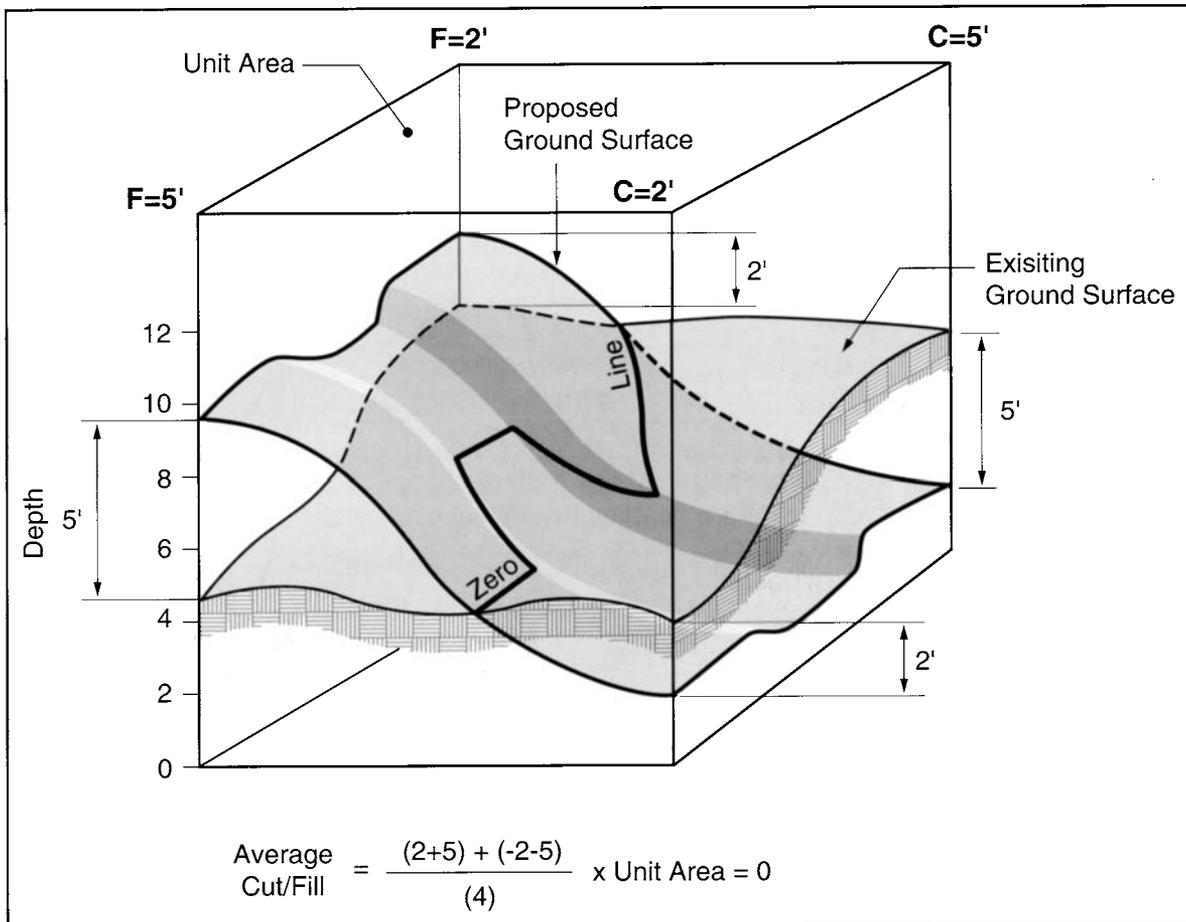


FIGURE 24.44 Ground surfaces for unit area of the grid method.

stripped volume of topsoil from the cut areas is *subtracted* from the gross cut volume.

Conversely, the volume of topsoil stripped in the fill areas is *added* to the gross fill volume. The sum of these two values is the volume of stockpiled topsoil. Topsoil reused in vegetated areas is replacement topsoil. The vegetated areas are determined for both the cut and fill areas of the site. Calculated replacement topsoil volumes in the vegetated areas of the cut areas are added to the gross cut quantity, and the replacement topsoil volumes in fill areas are subtracted from the gross fill quantity. The stockpiled topsoil volume less the replacement topsoil volume is the net topsoil remaining.

Referring back to the grading plan used in the ETO examples, the area of topsoil to be considered is that contained within the zero loops. The area of the zero loop for the cut area is 58,268 ft<sup>2</sup>. An assumed uniform topsoil depth of 6 in equates to approximately 1100 yd<sup>3</sup> of topsoil. Likewise, within the fill area loop of 18,711 ft<sup>2</sup>, the approximate topsoil volume is 350 yd<sup>3</sup>. The vegetated area in the cut area is 26,200 ft<sup>2</sup> and in the fill area is 8000 ft<sup>2</sup>.

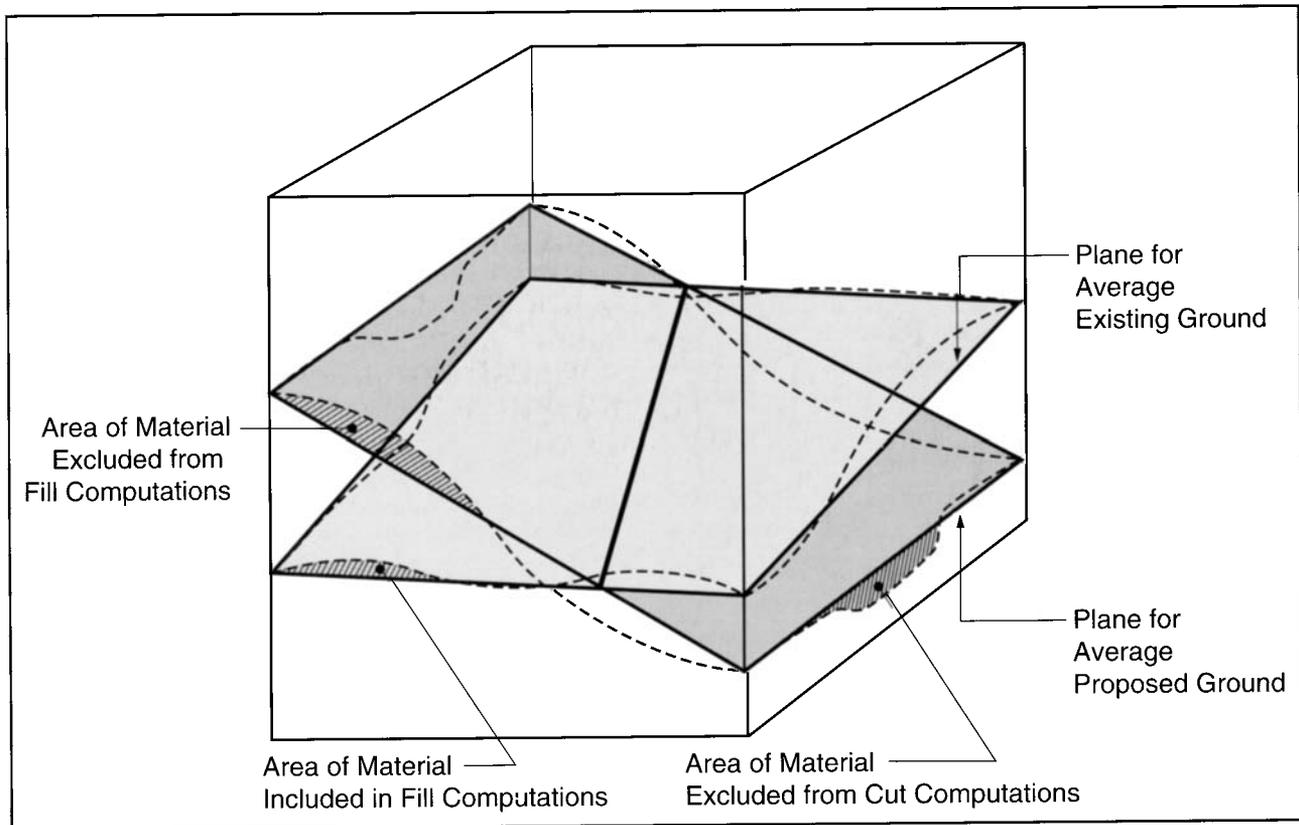
Using a replacement topsoil depth of 14 ± in. results in using all of the stockpiled topsoil tabulated in Table 24.8.

### Subbase and Concrete Pads

Roads, concrete slabs, and building pads consist of different layers of gravel, coarse aggregate, concrete and wearing surface. The total thickness of these layers depends on the bearing capacity of the soil and the type of structure and ranges from eight in to 2 ft in typical situations. In extreme cases the thickness may be double these depths. Concrete pads and the subbase for residential houses has a thickness of 8 to 12 in. Concrete pads and subbase for parking structures and high rise commercial buildings typically are 18 to 24 in. thick. The pavement structure for roads may be 12 to 18 in. thick.

To account for subbase and concrete thickness the earthwork quantity is based on the subgrade<sup>6</sup> elevation rather

<sup>6</sup> In cut areas, the subgrade is the original soil lying below the concrete pad, pavement and gravel layers. In fill areas, the subgrade is the controlled fill placed over the existing ground to bring the area to grade at the subgrade elevation.



**FIGURE 24.45** Average ground surface by linear approximation.

than the finished grade elevation. Therefore, in cut areas the base volume of cut must be increased by the total volume of the subbase, pavement, and concrete. In fill areas, the pavement and subbase volumes are subtracted from the base value of the fill volume.

Following through on the ETO example problem, assume the combined pavement and subbase thickness is 10 in. The area of pavement in the cut area and fill area is determined (by planimeter) to be 25,000 ft<sup>2</sup> and 10,000 ft<sup>2</sup> respectively. The building pad has combined concrete and coarse aggregate layer thickness of 12 in. and a footprint area of 7000 ft<sup>2</sup>. The adjusted earthwork volumes for these items are shown in Table 24.9.

### Undercut

Another adjustment to the ETO must account for the inadequate bearing capacity of the underlying soil or other bad soil conditions (e.g., high shrink/swell characteristics) or underlying rock layers. Although a thorough subsurface investigation performed during early planning stages usually alerts the design team to these undesirable conditions, small pockets of poor soil conditions and rock layers may not become evident until excavation exposes them during construction. Nonetheless, the removal (undercut) and replacement of this unsuitable material must be accounted

for in the earthwork quantities. If such conditions cover wide areas and extend to great depths, the removal and replacement with acceptable material becomes costly.

The undercut quantity is added to the cut volume as well as the fill volume.

### Utilities

Accounting for soil volume for relatively narrow shallow trenches is not typically done. For example, the volume of a trench 6 ft deep and 3 ft wide is equal to 0.67 yd<sup>3</sup> per linear foot. The volume of a 15-in. conduit with 6 in. of bedding material is 0.10 yd<sup>3</sup> per linear foot. If a 15% shrinkage factor is assumed, then the additional amount of soil required for backfill is compensated for by the volume of conduit and bedding.

However, when the sizes of the trenches become larger or deeper than the shallow example described above, the amount of trench backfill should be accounted for. The backfill volume is the volume of the trench less the volume of conduit and bedding plus allowance for shrinkage.

### Shrinkage

Soil volume increases when it is displaced from its natural state due to the increase in the amount of voids. Relative to soil in a natural state, soil used as compacted fill has a

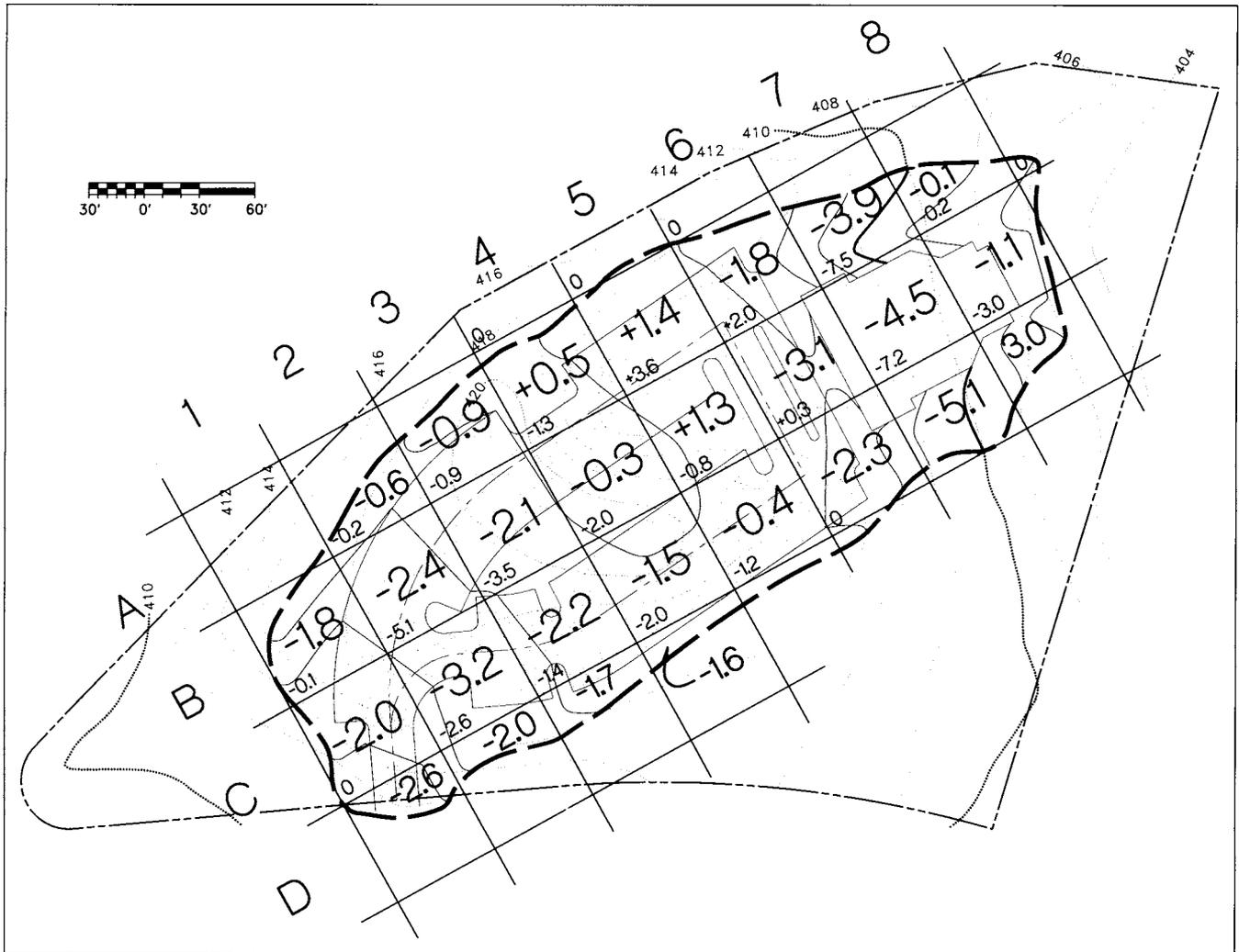


FIGURE 24.46 Grid method for ETO.

higher in-place density in most cases. If the same dirt excavated from a 1-ft<sup>3</sup> hole is placed back into the hole without any compaction efforts, there will be excess dirt. Later a depression appears in the hole area due to natural settlement. If the dirt is placed back into the hole at a density higher than its natural state, there will not be enough dirt to fill the hole. With the added compaction, the amount of voids are less than the amount of voids of the naturally consolidated soil. Hence, the reason for the deficiency in excavated soil volume. This apparent decrease in volume of excavated soil is referred to as shrinkage. The ratio of the remaining volume of the excavated hole after the original dirt has been replaced (with compaction) to the total volume of the hole is the shrinkage factor. The amount of shrinkage can be measured relative to the volume of excavated material or relative to the volume of required fill.

To illustrate this last statement, consider a soil with a density of 90 lbs per ft<sup>3</sup> with 21.2% water content in its natural state. Laboratory test results show that this same

soil has a maximum density of 110 lbs per ft<sup>3</sup> at optimum moisture content (OMC).

(a) If a site requires 10,000 yd<sup>3</sup> of fill at maximum density, how much borrow material should be excavated?

To compute soil volumes in going from borrow to fill or fill to borrow, recognize that density is inversely proportional to volume,  $D \propto (1/V)$ . The relative ratios of the borrow and fill densities and volumes can be expressed as

$$\frac{D_b}{D_f} = \frac{V_f}{V_b} \tag{24.14}$$

where the *b* and *f* subscripts refer to borrow or fill. Therefore, the required borrow volume is

$$\frac{90 \text{ pcf}}{110 \text{ pcf}} = \frac{10,000 \text{ yd}^3}{V_b} \text{ or } V_b \approx 12,200 \text{ yd}^3 \tag{24.15}$$

(b) How much volume will 10,000 yd<sup>3</sup> of borrow material occupy if placed at maximum density?

**TABLE 24.7 Incremental Cuts and Fills for ETO Grid Method Example**

GRID (ROW × COLUMN)	AVG. CUT OR FILL DEPTH	FRACTION OF GRID	FRACTION OF CUT OR FILL	GRID (ROW × COLUMN)	AVG. CUT OR FILL DEPTH	FRACTION OF GRID	FRACTION OF CUT OR FILL
(A,1)	0	0	0	(A,5)	+1.4	1	+1.4
(B,1)	-1.8	0.8	-1.4	(B,5)	+1.3	1	+1.3
(C,1)	-2.0	1	-2.0	(C,5)	-0.4	1	-0.4
(D,1)	-2.6	0.5	-1.3	(A,6)	-1.8	0.8	-1.4
(A,2)	-0.6	0.4	-0.2	(B,6)	-3.1	1	-3.1
(B,2)	-2.4	1	-2.4	(C,6)	-2.3	0.9	-2.1
(C,2)	-3.2	1	-3.2	(A,7)	-3.9	0.6	-2.3
(D,2)	-2.0	0.4	-0.8	(B,7)	-4.5	1	-4.5
(A,3)	-0.9	0.7	-0.6	(C,7)	-5.1	0.7	-3.6
(B,3)	-2.1	1	-2.1	(A,8)	-0.1	0.3	-0.3
(C,3)	-2.2	1	-2.2	(B,8)	-1.1	0.6	-0.7
(D,3)	-1.7	0.4	-0.7	(C,8)	-3.0	0.3	-0.9
(A,4)	+0.5	0.9	+0.5				
(B,4)	-0.3	1	-0.3				Σ Cut = 38.3 ft
(C,4)	-1.5	1	-1.5				Σ Fill = 3.2 ft
(D,4)	-1.6	0.2	-0.3				

**TABLE 24.8 ETO Values Adjusted for Topsoil Depth**

ADJUSTMENT	CUT VOL. (YD <sup>3</sup> )	FILL VOL. (YD <sup>3</sup> )
Gross	4096	1423
Strip Topsoil (6")	-1100	+ 350
Replacement Topsoil (14")	+1130	- 345
ADJUSTED VOLUME =	4126	1428

**TABLE 24.9 ETO Values Adjusted for Subbase, Pavement and Concrete Thickness**

ADJUSTMENT	CUT VOL. (YD <sup>3</sup> )	FILL VOL. (YD <sup>3</sup> )
Gross	4096	1423
Strip Topsoil (6") Replacement	-1100	+ 350
Topsoil (14")	+1130	- 345
Building Pad (12")	+ 260	- 0
Pavement (10")	+ 770	- 310
ADJUSTED VOLUME =	5156	1118

TABLE 24.10 Tabulated ETO Values

ADJUSTMENT	CUT VOL. (YD <sup>3</sup> )	FILL VOL. (YD <sup>3</sup> )
Gross	4096	1423
Strip Topsoil (6") Replacement	1100	+ 350
Topsoil (14")	+1130	- 345
Building Pad (12")	+ 260	- 0
Pavement (10")	+ 770	- 310
Undercut	+ 0	+ 0
Large Conduits & Structures	+ 0	—
SUBTOTAL =	5156	1118
Shrinkage (20%)		+ 224
NET FILL VOL. =		1342
NET CUT VOL. =	3814	

$$\frac{90 \text{ pcf}}{110 \text{ pcf}} = \frac{V_f}{10,000 \text{ yd}^3} \text{ or } V_f \approx 8200 \text{ yd}^3 \quad (24.16)$$

(c) What is the relative change in volume in parts a and b?

Part a:

$$\frac{12,200 \text{ yd}^3 - 10,000 \text{ yd}^3}{10,000 \text{ yd}^3} = 22\% \quad (24.17)$$

Part b:

$$\frac{12,200 \text{ yd}^3 - 10,000 \text{ yd}^3}{12,200 \text{ yd}^3} = 18\%$$

Part (c) shows that relative to the required fill volume, 22% more borrow material is required, and relative to a given borrow volume, the material reduces only 18% in volume when placed at maximum density. Notice that the borrow volume reduces by the same amount in both cases (i.e.  $(12,200 - 10,000)/12,200 \approx 18\%$  and  $(10,000 - 8200)/10,000 \approx 18\%$ ). The point here is to recognize that careful attention is warranted when specifying volumes for fill and excavation projects. Payment for fill dirt is typically based on the amount required to fill the hole (as shown in part a above) and not the volume of the hole itself. However, in most cases, the cost of doing the work is based on the amount of soil excavated. Since the density of excavated soil is less than its natural-state density, allowances must be made for computing haul quantities.

Typical shrinkage factors may range from 10% to 30% depending on the type of soil, the amount of compaction

and the amount of losses expected in hauling. In the previous example, the natural soil density is known. In most cases, the natural soil density is unknown and the engineer must use judgment in estimating the shrinkage to make an adjustment. This adjustment is typically made by increasing the amount of fill that is reusable. This accounts for the increased amount of soil required as a result of compaction.

Referring back to the ETO example, the assumed shrinkage factor is 20%. The measured fill volume is 1095 yd<sup>3</sup>. This will require  $1.2(1095) = 1314 \text{ yd}^3$ . Assuming the cut volume is adequate for use as compacted fill, the resulting excess is  $4560 - 1314 = 3246 \text{ yd}^3$ . This can be hauled away to be used as compacted fill elsewhere. The remaining  $3246 \text{ yd}^3$  of excavated material will convert to  $0.8(3246) \approx 2600 \text{ yd}^3$  of fill material.

Table 24.10 shows the final tabulation to account for earthwork adjustments.

### SUMMARY

Grading and siting buildings for a project requires the site designer to consider many issues when developing a grading plan that is cost-effective to the builder and appealing to the consumer. Issues such as saving trees, optimizing grading, streetscape and roof lines, house type, drainage, zoning ordinances and the rest are all integrated into the design. Although each item may be addressed separately, the important concern is that they must be analyzed collectively after the design is complete. Many times the designer will adjust a site to address a single issue. In doing so, several other issues undoubtedly will be affected—usually adversely. The designer must collectively reanalyze

the site to be sure that the small, single adjustment does not cause a conflict with any other item.

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