CHAPTER 23

GRADING AND EARTHWORK

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GRADING 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 both with large machines, such as bulldozers, pans, and dump trucks, and with men, rakes, and shovels, and constitutes a major component of the function and success of a land development project. See Figure 23.1.

In this chapter, a general overview of the grading process is followed by an explanation of how grading is represented and utilized 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

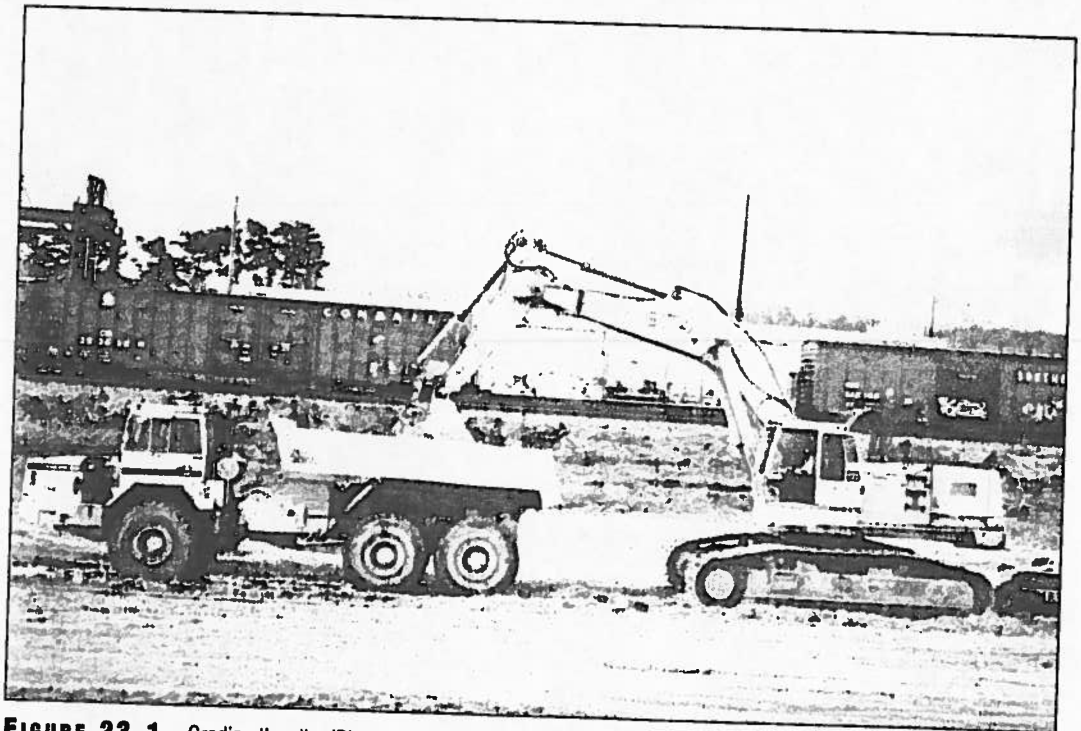


FIGURE 23.1 Grading the site. (Photo courtesy of Christer Carshult)

grading scheme must consider function and utility as well as aesthetics, it requires both science and art to create. 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.* 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 design 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 on 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 constraints offered by the site. In this way, it enhances property value 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 elevation 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 interrelationships of landforms. A natural example of a contour line is the shoreline of a still body of water.

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-foot 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 depending on the scale of the drawing and the desired level of detail.

While large-scale topographic maps, with 5- to 10-foot contour intervals, are suitable for feasibility studies, smaller-scale maps, with 2-foot 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.

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.

Spacing of contours indicates the general steepness of the ground. 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.

A contour line cannot split, nor can several lines join to form one line. This implies a knifelike 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 that the steepest slope and also the path of flowing water are 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 foot) from the assumed smoothed ground line, as schematically shown in Figure 23.2. When determining an elevation between contour lines, the ground is assumed straight. Machine-graded slopes tend to be more uniform than natural ground and consequently have fewer irregularities.

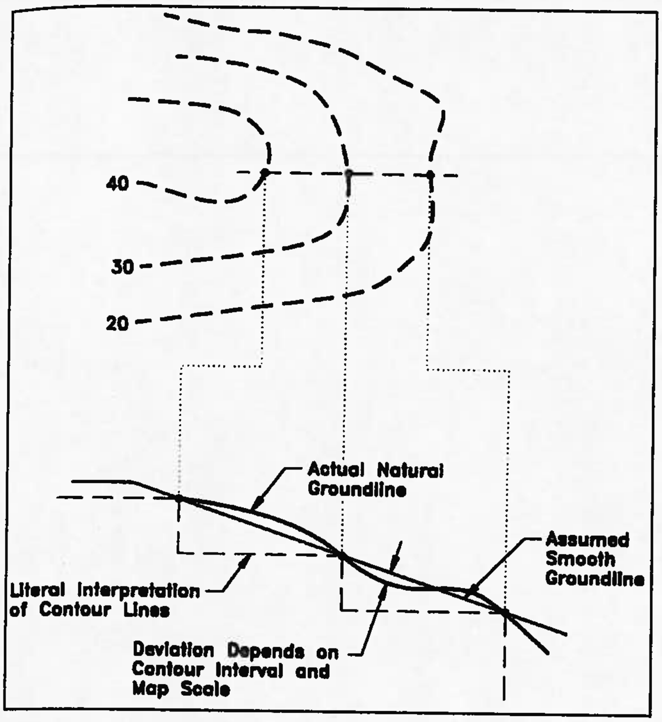


FIGURE 23.2 Irregularities in natural ground.

Contour Line Patterns for Natural Surfaces

Hills and Depressions. A series of contours that close on themselves within the mapped area indicate either a localized hill or a localized depression. Figure 23.3*a* shows a hill and Figure 23.3*b* shows a depression. In Figure 23.3*a* the elevations shown on the contour lines increase up to the summit. Conversely, in Figure 23.3*b* the elevations decrease toward the bottom of the depression.

Valleys and Ridges. Valleys and ridges are indicated by contour lines configured in V shapes. Imagine the contours of the hill in Figure 23.3*a* being stretched in one direction. The result is an elongated hill, depicted by contours that are shaped like V's at either end, as indicated in Figure 23.3*c*. The tips of this V-shaped hill, when connected, depict a ridge. Stretching the contours of the depression of Figure 23.3*b* creates the valley configuration of Figure 23.3*d*. Both stretched figures are identical in 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.

Overhanging Cliffs. 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.

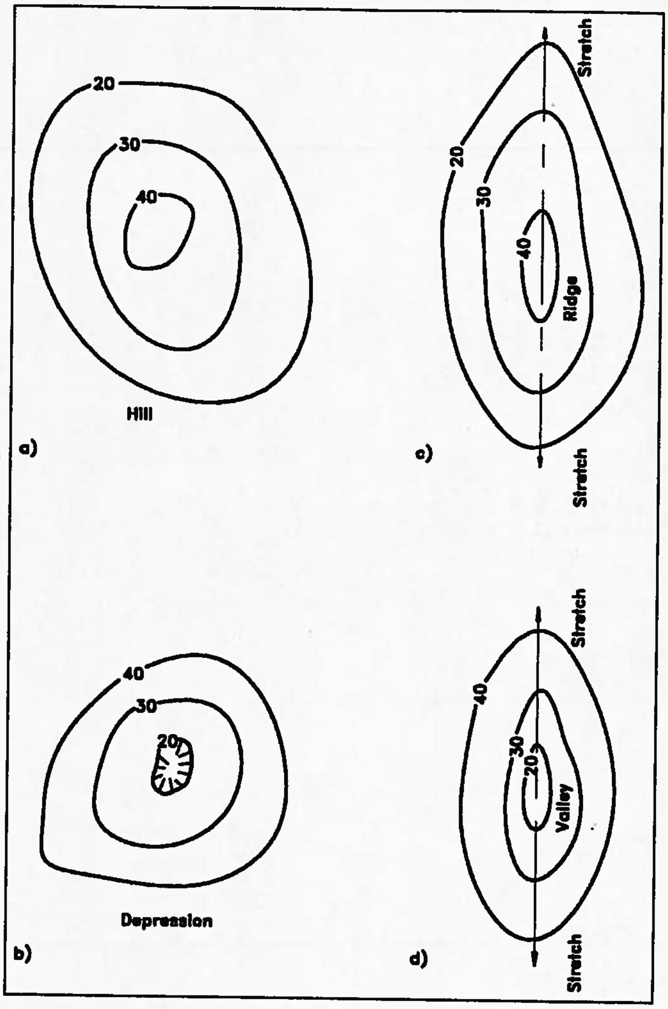


FIGURE 23.3 Contour patterns: hill, ridges, depressions, valleys.

Contour Line Patterns for Constructed Surfaces

Culverts (or Bridges). At the end of a culvert (or bridge) there are, for all practical purposes, two land surfaces to consider. One is at the level of the invert of the structure and the other is the *at grade* above the structure. Typically, the ground will slope up and away from a culvert opening and contours will be parallel and rather close together. In the case of a bridge, which would have a much more complex facial configuration—with possible wingwalls, piers, earth floor, and so on—the grade may not simply slope up and away from the structure as in the case of a culvert. So at the face of a bridge, the contours may appear to cross as two separate ground surfaces are being presented. Figure 23.4 illustrates this concept.

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. 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 23.5.

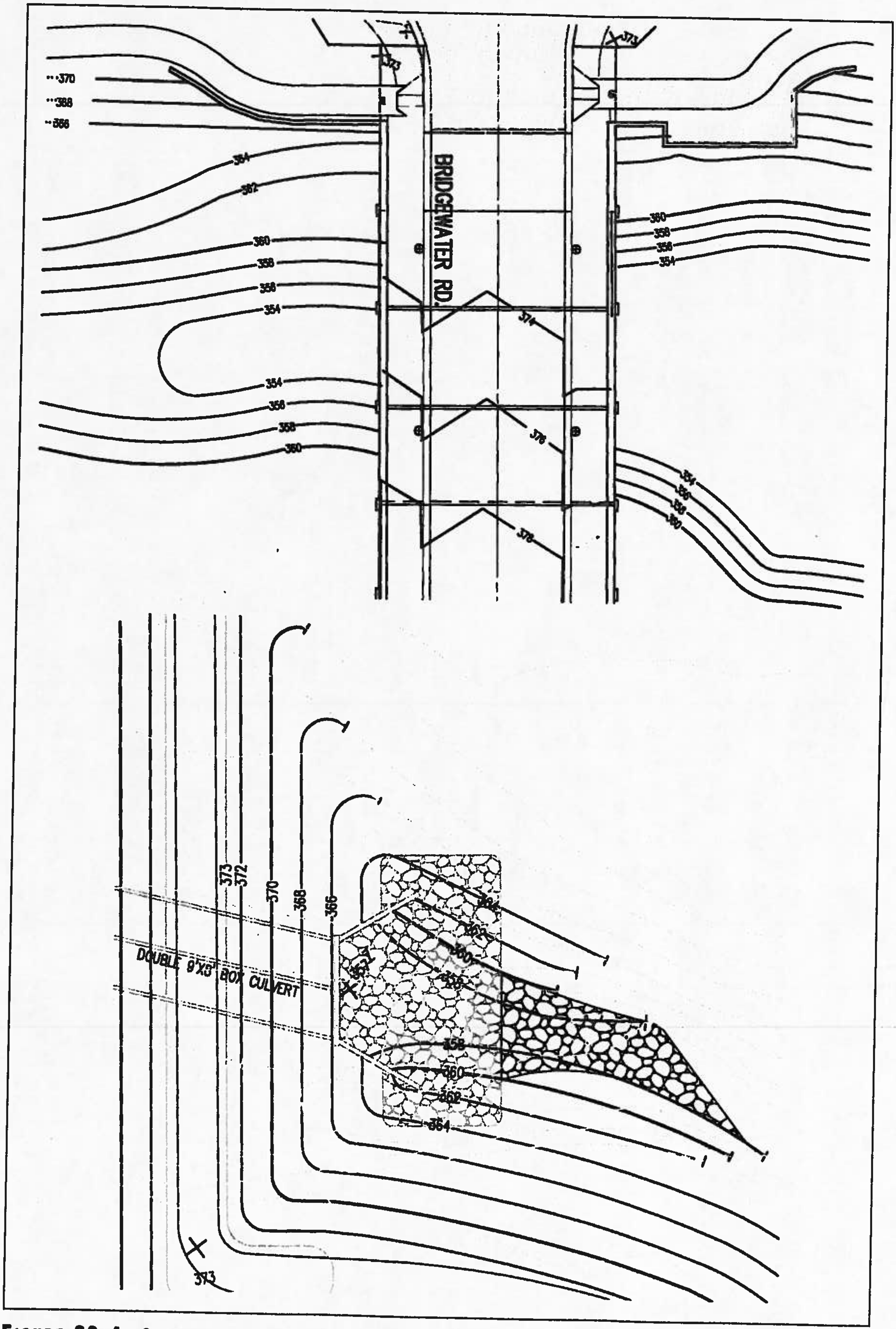


FIGURE 23.4 Contour patterns for culverts and bridges.

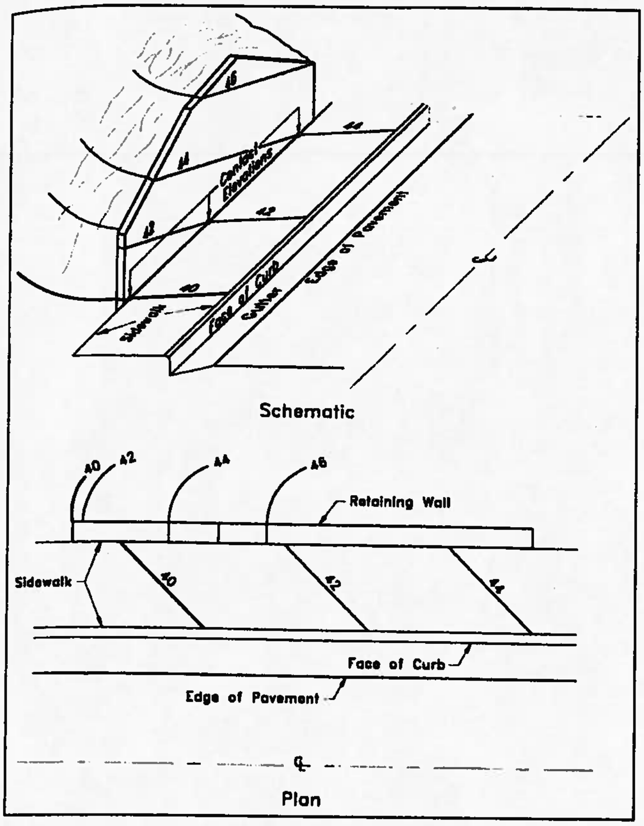


FIGURE 23.5 Schematic and plan view of retaining.

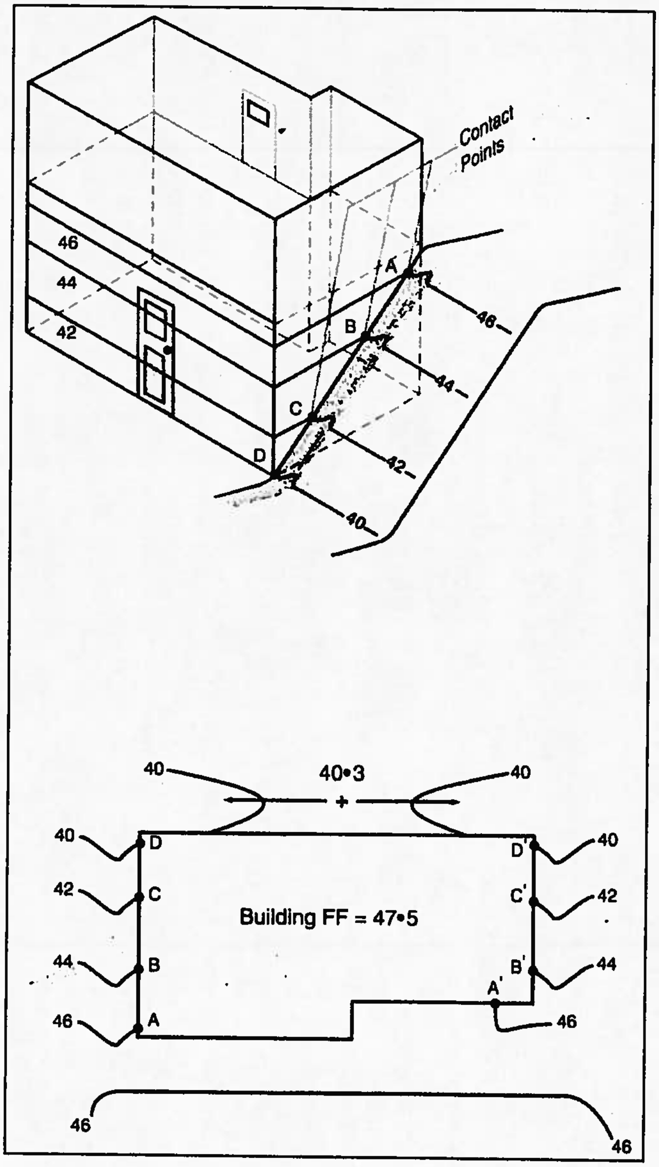


FIGURE 23.6 Schematic and plan view of exterior building.

In tracing the contour line around a wall, the contour line intersects the wall at the contact elevation, that is, 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. Exterior walls of buildings 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 23.6. The 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 23.6. 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 23.7, each of the channels is 2 feet deep. The depth of the channel is evident by comparing the elevation at the top of the bank with the elevation at the bottom of the channel. On each type of channel section, point A, the top of the bank, has an elevation of 6 feet. A line drawn perpendicular to the flow line, through the top of the bank, intersects the flow line at elevation 04 feet, representing the elevation of the channel invert. Hence, the depth of 2 feet. 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 23.8 shows a 2-foot-deep and a 4-foot-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-foot-deep channel as compared to the 2-foot-deep channel. Because the top widths are the same, the 4-foot-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

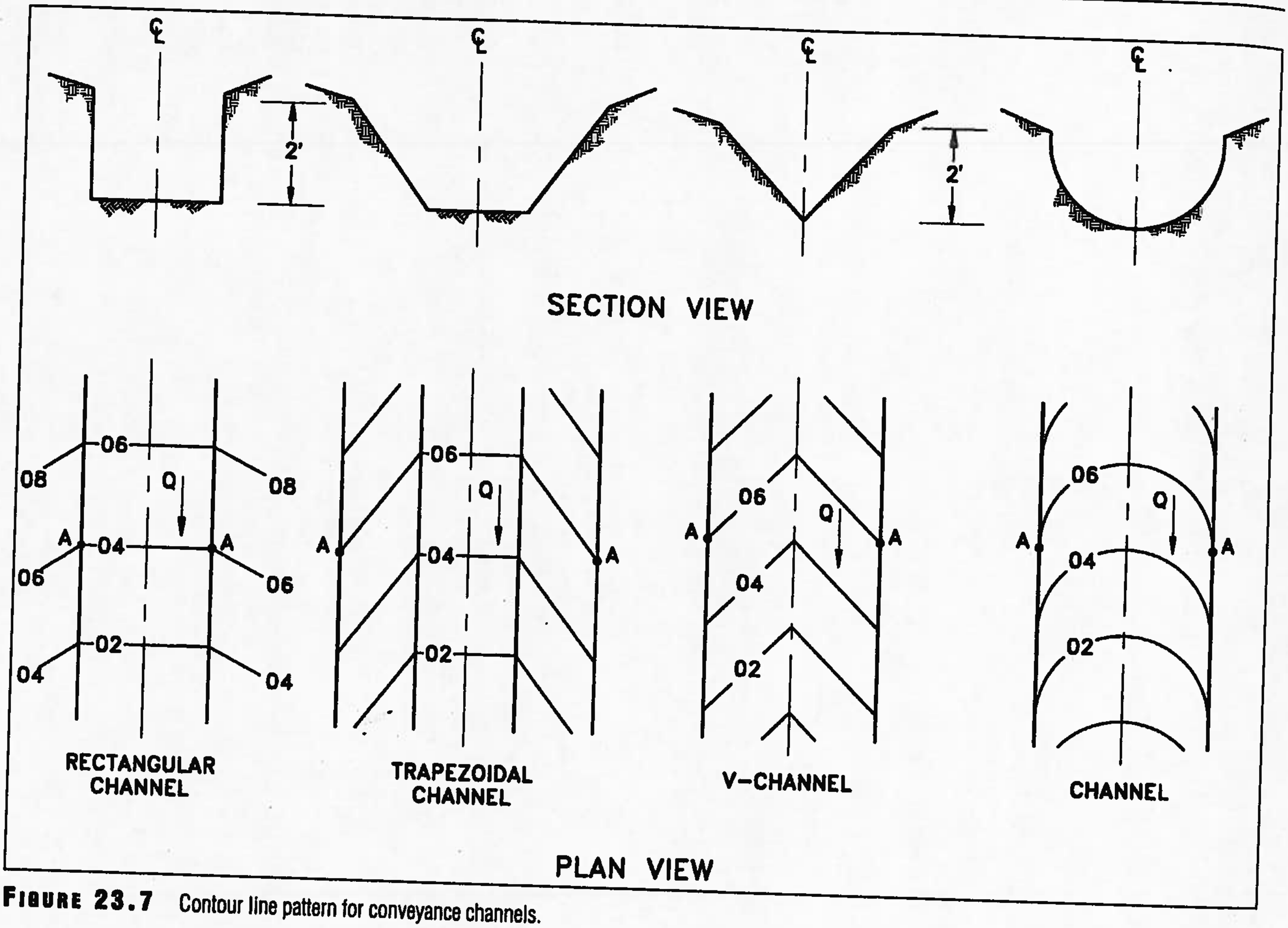


FIGURE 23.7 Contour line pattern for conveyance channels.

the crown street with shoulder and ditch. Figure 23.9 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 the contour are all superimposed. The contour line intersects the outside edge of the sidewalk at the prescribed elevation. Typically, sidewalks are inclined toward 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 23.10.

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 toward the curb or ditch.

Berms (or Hills) and Ponds. Just as natural hills and depressions display contours that close in on themselves, berms and ponds also have concentric contours. However, manmade features of this nature are typically less irregular and the contours tend to be evenly spaced and/or parallel.

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 iden-

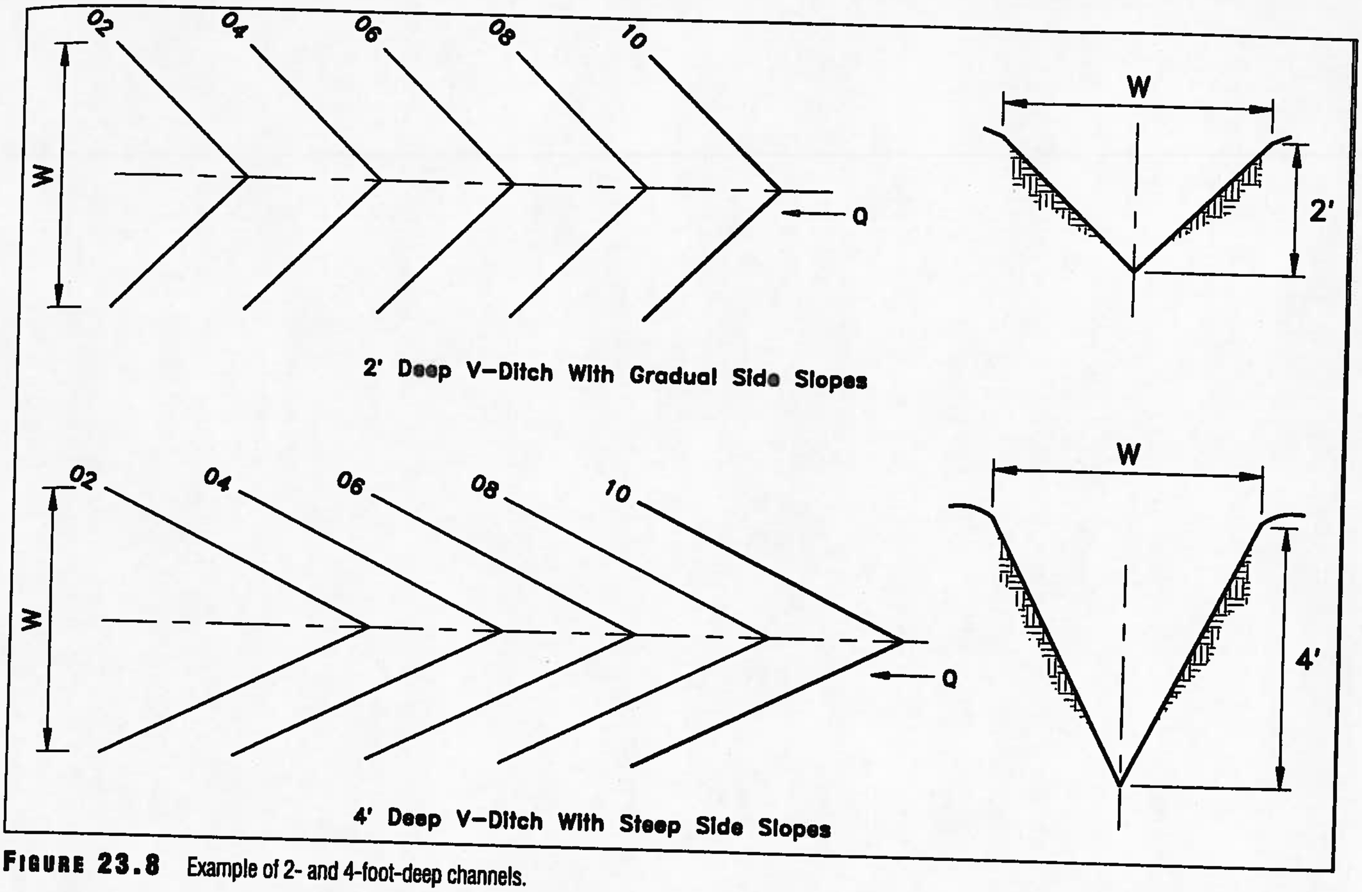


FIGURE 23.8 Example of 2- and 4-foot-deep channels.

tify 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.

Typically, spot elevations are used for:

- Precise information regarding the tops of drainage, sewage, and other utility structures
- Identification of high and low points in the grading scheme
- Description of retaining walls, that is, top and bottom of wall elevations
- Elevations at building entrances and corners

Note that spot elevations show up in a profile as an abrupt acute angle at the spot elevation location. The house-grading plan of Figure 23.11 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 23.1.

Ground Slope

Ground slope is the rate of change in elevation, with respect to the horizontal distance, commonly expressed as either a percentage or a ratio. The percent slope describes the uniform

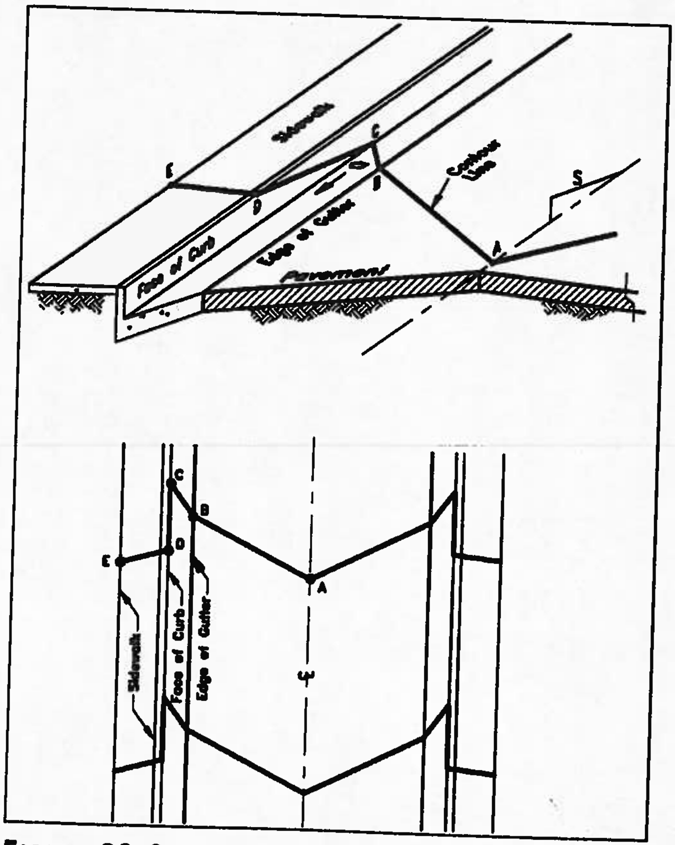


FIGURE 23.9 Contour line pattern for curb.

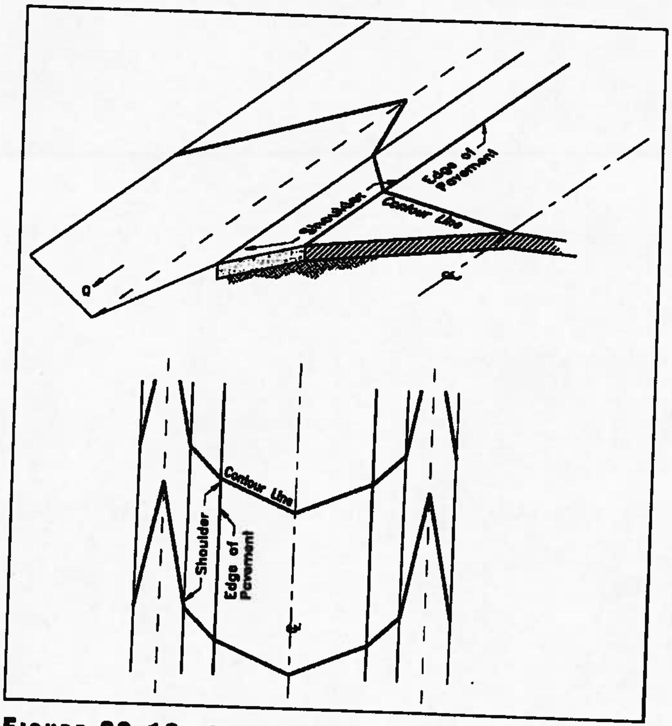


FIGURE 23.10 Contour line pattern for shoulder.

change in elevation for a 100-foot horizontal distance. For example, if elevation changes 25 feet over a distance of 100 feet, the slope is expressed as 25 percent. While mathematically this slope is defined as the ratio of $\Delta v/\Delta x$, where Δv is the change in vertical direction and Δx is the change in horizontal position, that is, a distance H. A simple way to remember this basic tenet is in terms of "rise/run." As a ratio, this slope would be expressed as 4 feet horizontal to 1 foot vertical, or simply "4H:1V." For example, the rate of change in elevation between two points that are 200 feet apart, with corresponding elevations of 100 feet and 150 feet (Figure 23.12), is:

$$\text{Rate of change in elevation} = \frac{\text{Change in elevation}}{\text{Horizontal distance}} \tag{23.1}$$

$$= \frac{\Delta V}{H}$$

$$= \frac{150-100}{200} = 0.25 \text{ feet/foot}$$

Hence, for every 1 foot of horizontal distance, the ground changes 0.25 feet in elevation. As a percentage, this equates to a slope of 25 percent; as a ratio, this is equivalent to a

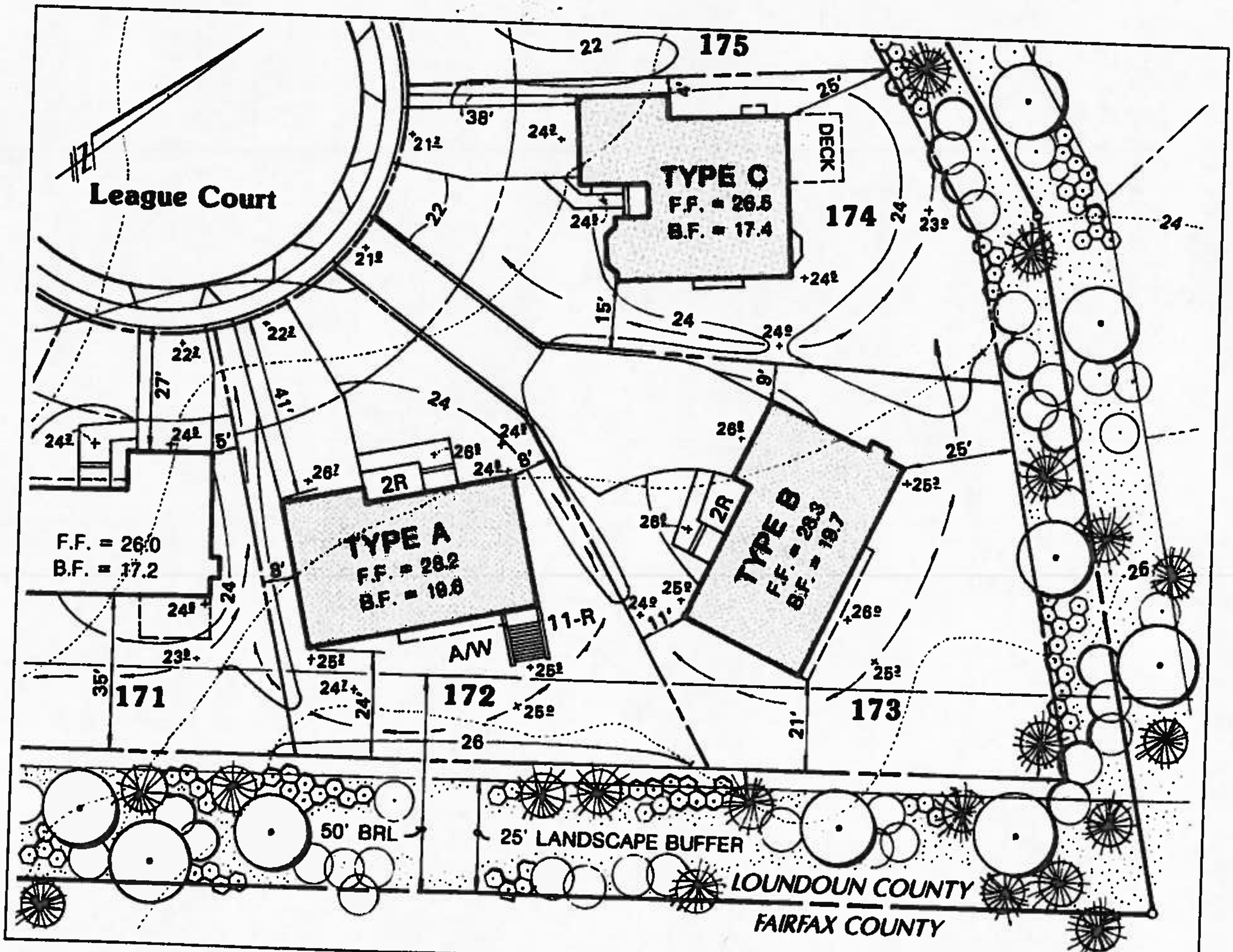


FIGURE 23.11 House grading plan.

TABLE 23.1 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

4H:1V slope (or 1V:4H). Figure 23.12 illustrates these various means of designating slope gradients.

On most civil site drawings, the ratio is shown as horizontal to vertical, H:V. However, the order is sometimes reversed, V:H, in other professional disciplines (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—for example, 4H:1V—or indicate in a note on the plan the correct order.

The specific elevation of any point that lies between two points of known elevation is found by interpolation, presuming 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:

$$S_{avg} = \frac{El_B - El_A}{x_B - x_A} = \frac{\Delta v}{\Delta x} \qquad (23.2)$$

The distance Δx (h) may be the scaled distance from the drawings or obtained through coordinate geometry if the coordinates of points A and B are known.

$$El_P = El_A + (S_{avg} \times h') \qquad (23.3)$$

In Figure 23.13, the elevation at any point P, between A and 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 23.2. In this instance the slope increases 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 23.13. Hence, from the following geometric ratios:

$$\frac{h}{h'} = \frac{(B'B)}{(P'P)} \qquad (23.4)$$

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

ESTABLISHING THE GRADING PLAN

A grading plan is established through refinement of different schemes over the course of 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.

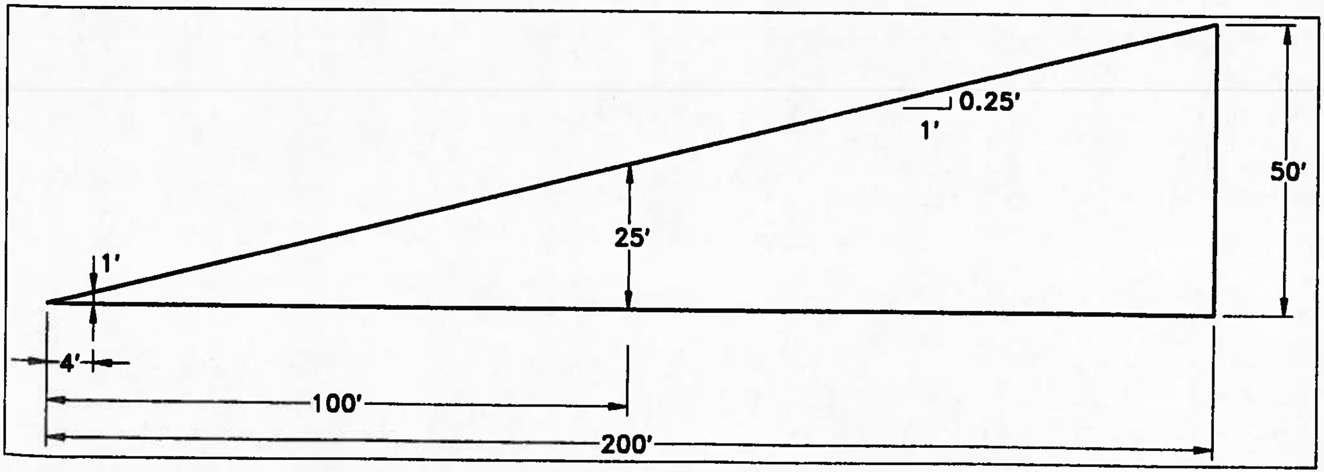


FIGURE 23.12 Various ways to denote slope gradients.

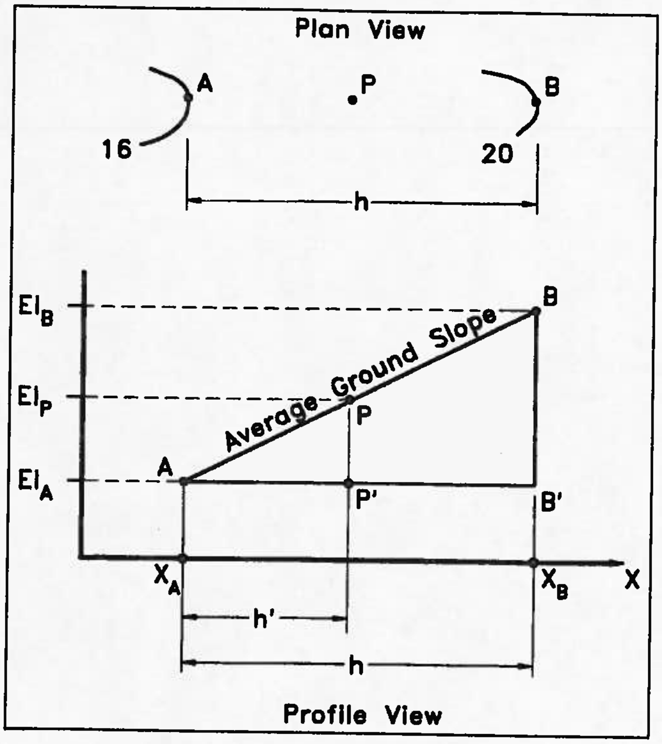
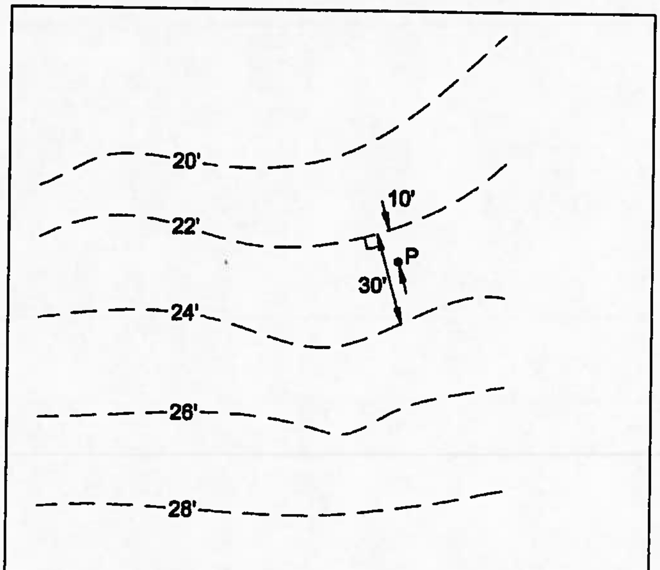


FIGURE 23.13 Interpolation using similar triangles.



Step 1: Determine the average slope between contours

$\Delta v/\Delta h = 24' - 22' = 2'/30'$
$= 0.067'/$ Foot or 6.7%

Step 2: Determine the elevation at point P

$0.067'/$ Foot $\times 10' = 0.67'$
$0.67' + 22' = 22.67 \approx$ Elev. @ P

FIGURE 23.14 Working with contours.

At the very beginning of the project it should be determined whether the site will be designed to meet LEED certification criteria. Although many of the U.S. Green Building Council's recommendations apply to building construction, there are specific credits that apply to site work. Credit 5.1: Protect or Restore Habitat is one such requirement that may be met with a well-designed grading plan. The concept of this credit is to minimize the amount of native soil disturbed when developing a site, or in the case of redevelopment, existing impervious areas would be reduced and native plant material would be reintroduced to the site. To achieve this credit, the designer would need to supply very specific limits of work for the proposed grading. For example, no grading would be permitted farther than 40 feet from the main building.

During the schematic phase of design, the site designer obtains general criteria regarding the size; limitations on horizontal and vertical placement; location of garages, patios, decks, and loading docks, and other constraining information about the main structures that impact the grading design. During preliminary engineering, several layouts and rough grading plan designs might be necessary to optimize the site. For residential sites, 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 main building(s) or housing units. The architectural 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 hundredth 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 allows some flexibility in adjusting the vertical and horizontal orientation of individual housing units. Adjusting units several inches or even a foot or two may present no critical dilemma. When vertical separation between units is 2 feet or more, small retaining walls are required.

The design is often done by hand on tracing paper, but may be laid out in the computer in a digital format. The first few schemes may involve only 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 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 practice, lighter, dashed lines are used for existing contour lines, while darker, solid lines are used to represent proposed contour lines. Note that 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 (Mylar or other hand-crafted formats) 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 principals.

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 the houses, 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:

1. To accommodate the varying needs and the aesthetic tastes of buyers. The various house designs attract a wider range of consumers, thereby enhancing sales.
2. To take advantage of the varying topographical features of the lots. This provides the developer flexibility in the layout of the houses, which reduces some of the construction costs.
3. For energy efficiency (see Chapter 11, Figure 11.06. Different house types offer varying responses to local climatic, slope, and orientation factors.

After all 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 change to the developer's program has occurred before proceeding with the project.

House Type and Foundation Type. The architectural features and configuration of a house categorize it with a particular time period or region—for example, Colonial, Cape Cod, or Victorian. Classification of a dwelling by the arrangement of floor elevations, location of entrances, location of walls, and relationship to property lines (e.g., one-story, two-story, basement walkout, and single-family attached and detached) is also common.

Not only is it imperative that the engineer developing the grading plan know the house types available in a subdivision, but he or she must know the location and elevation of entrances, windows, garages, decks, patios, and roof lines. The engineer must consider each lot individually as well as collectively to determine the optimal 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 results in building larger houses on smaller lots. The higher density produces a higher yield for the developer, which 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, 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.

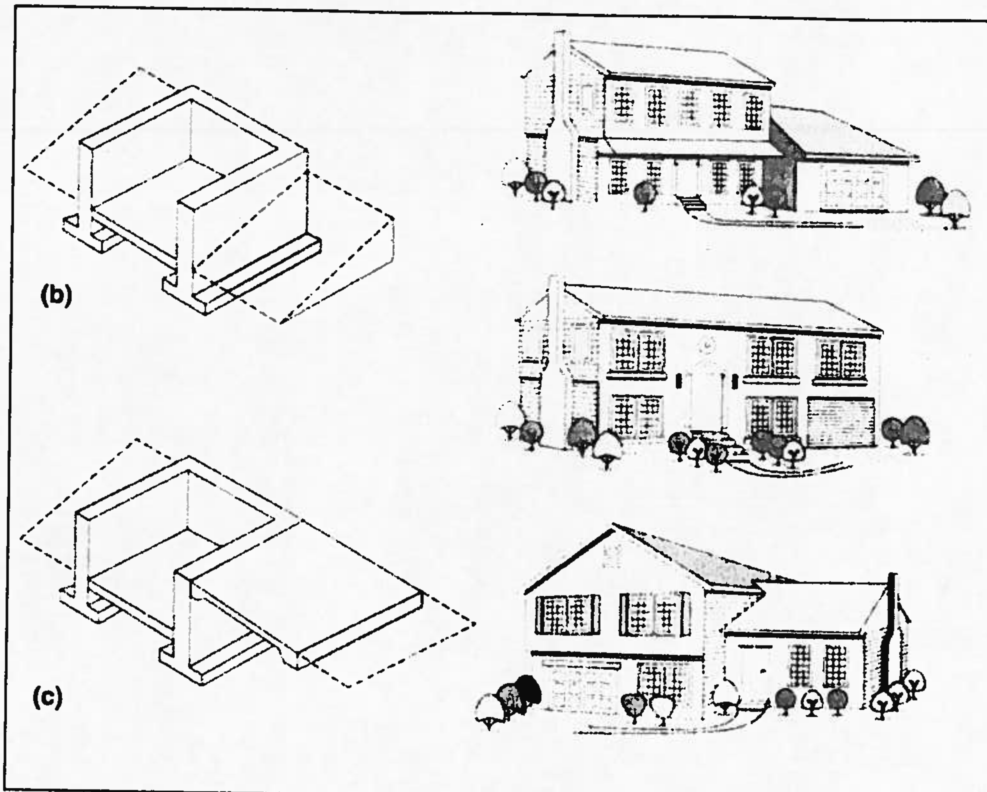
Spatial arrangement is part of what is known as the *streetscape*. Setbacks, rooflines, utility corridors, street trees and landscaping, sidewalk and trail locations, and signage further define the streetscape. These elements work with the grading to lend the development a uniform character and create 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 upward 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, which helps the environment and saves on construction costs.

For grading purposes, it is useful to categorize the myriad of housing styles by asking the following three questions: (1) Is the unit single-level or split-level? (2) Does the unit have a basement? (3) Is it a single unit or are several units attached (town houses)? The answers to these questions help determine how the lot(s) will be graded.

Single-Level or Split-Level. A single-level unit is constructed so that the finished floor elevation is the same everywhere. 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 two-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 feet. 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 23.15. Similarly, the basement of a split-foyer is partially exposed. Figure 23.15 shows the basic house types and their corresponding foundations.

No-Basement or Basement. No-basement types of buildings are built on a concrete slab or crawl space and are best



Two-Story:
Usually with basement under main area, walk-out optional. Side wings & garage are built on slab or crawl space.

Split Foyer:
Entrance is between floors. Lower level is partially exposed basement.

Split Level:
Side wing is between levels. One wing is partially exposed. Single level wing is on slab or crawl space or may be over buried basement.

FIGURE 23.15 Basic house types and their foundations.

suited for flat areas with high water tables or where extensive rock lies near the surface. They are generally less expensive due to 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.

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 23.15*b* has a grade change of about 4 feet from front to back, which may enable the proposed grade to tie in with the existing grade sooner, thereby reducing the disturbed area.

In addition to enabling the house to better blend in with the site, 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 walkout, which provides direct access outdoors from the basement. The typical site layout for a walkout is depicted in Figure in 23.16.

Town Houses. Town house developments consist of parking areas, private streets, open space, and blocks of attached residential units. Typically, the blocks, or sticks of residential units, contain 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 town houses may have several house types, variations in architectural style, and different lengths, usually they have a constant width. These variations help prevent the visual monotony that would occur if all the houses aligned and had the same style (see Figure 23.17). 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., rooflines, 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 are 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 consumers. For this reason, the layout and design of a town house project requires extensive

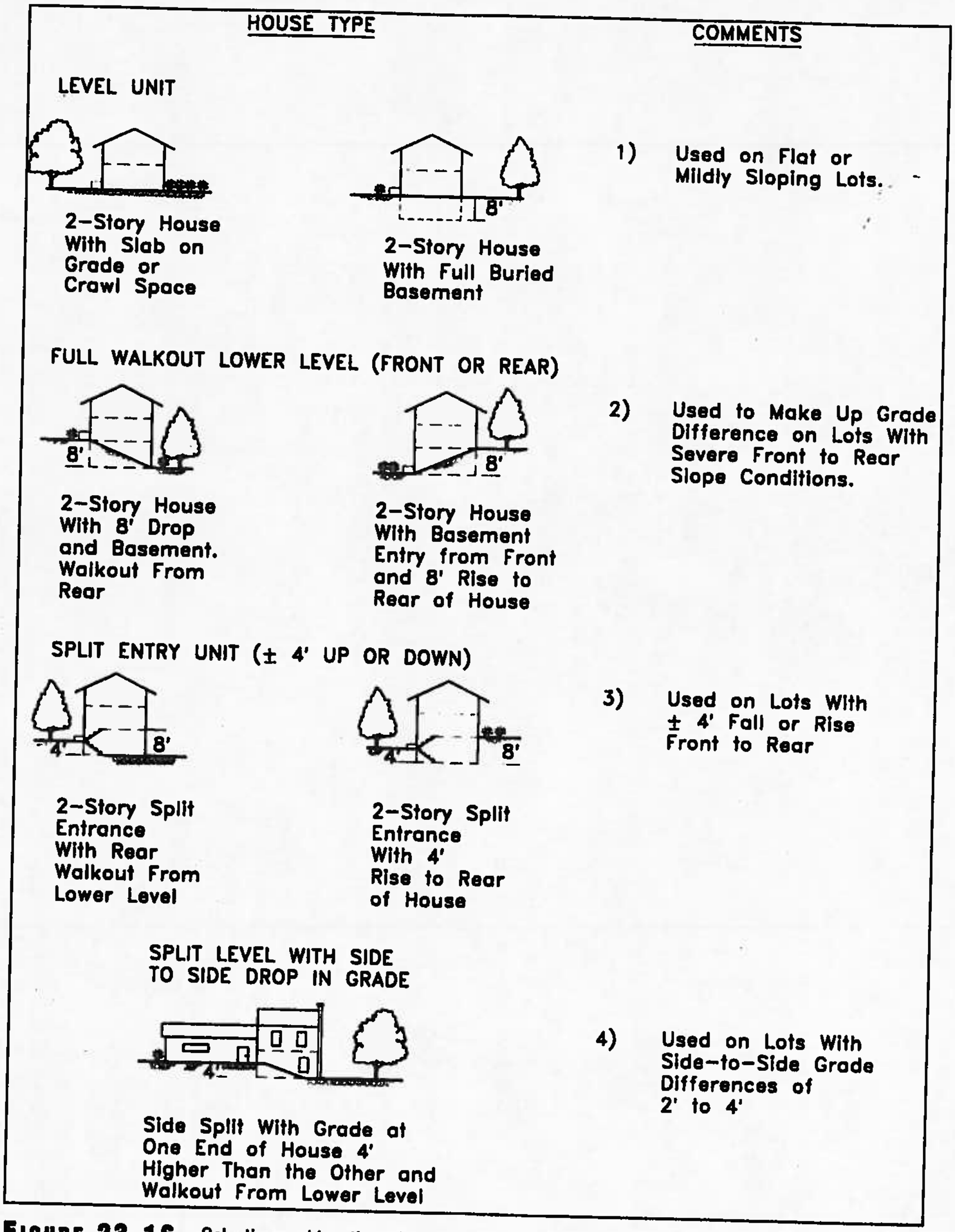


FIGURE 23.16 Selection and location of building types to fit natural landforms.

communication and coordination among the site designer, developer, and architect.

Setting the floor elevations for town houses is more involved than for single-family detached houses. A certain limited structural relationship, evident from the architectural plans, exists among the units of a block. Some town house designs allow for the flexibility to adjust 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 town house elevations properly, the engineer needs a complete 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 town house 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 8-inch increments. This recommendation is based on the dimensions of masonry units used for construction. Using 8 inches or a multiple of 8 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

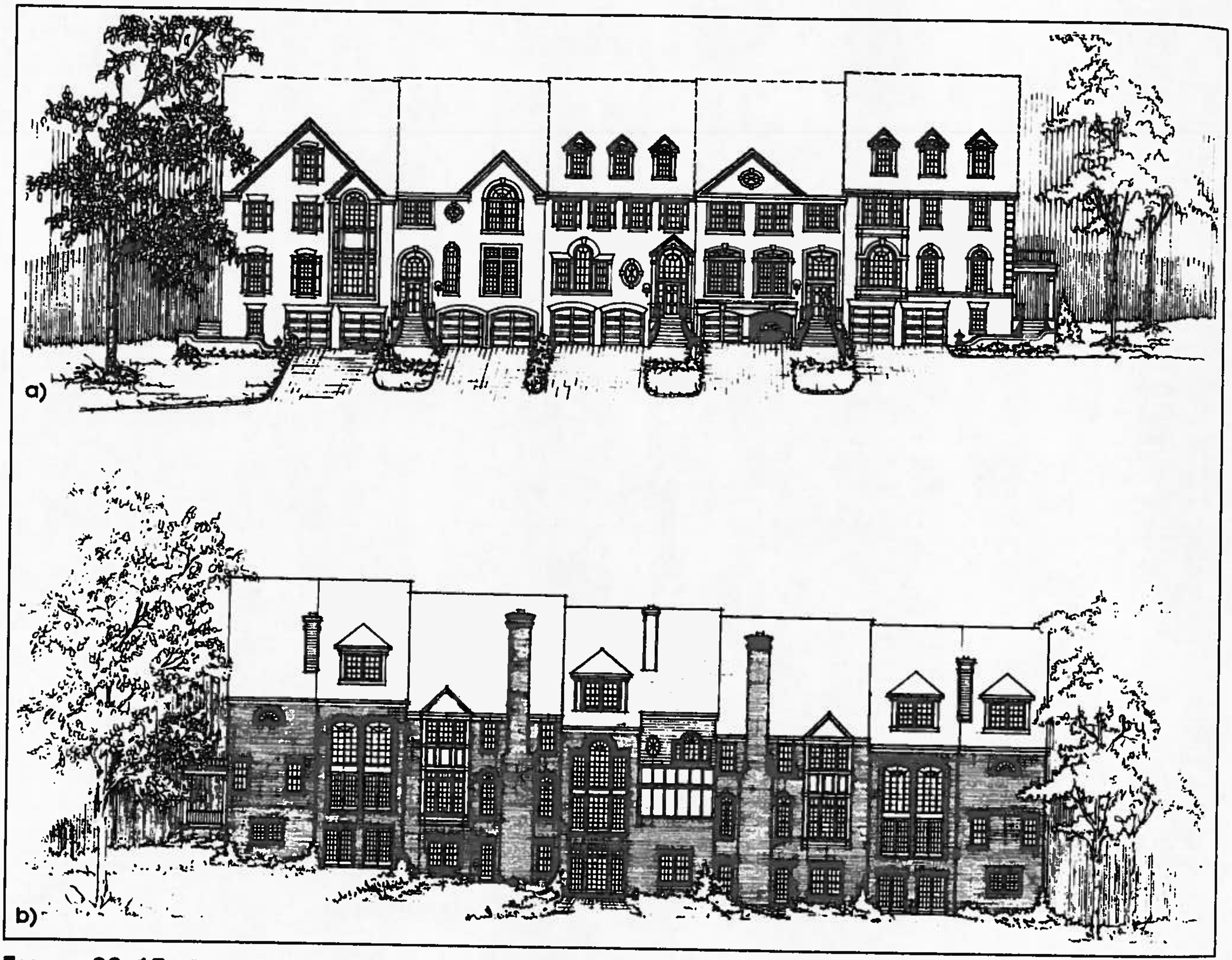


FIGURE 23.17 Town house block showing vertical stagger. (Courtesy of Sutton Sullenberger Yantis Architects)

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 the architect (through the developer) is imperative to exchange the interdisciplinary information necessary for design.

Another problem encountered in setting town house 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 foot; therefore, if 10 risers are needed, the minimum setback to the stoop is 10 feet. Furthermore, additional distance may be needed between the sidewalk and the start of the steps. Although riser heights can vary, the maximum height is typically limited to 7½± inches; 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.

Siting the House. 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.

Character of the Site. 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 were considered when the lot and street layout were established in the concept and schematic design stages, since there is not much practicality in orienting the house for energy efficiency if it contradicts with the street and lot layout.

Further, the topography of the lot and any (aesthetic) constraints by the client play a part in selecting a house type (see Figure 23.16).

Property Lines and Setbacks. In addition to size and the type of lot (corner, flag, etc.), its applicable setbacks play a part in how a house is sited. 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.

Grading the Lot. There are 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 that 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 easier.

Using generic building footprints, the engineer produces the block 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 lots to builders.

Drainage. 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 next, may 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, such as a very steep driveway or slope that drains to the foundation of the house, looks out of place and lowers the curb appeal. Generally, lots are graded such that drainage is directed away from the structure toward the street or other runoff conveyance systems such as swales or channels that may be incorporated into the proposed grading plan.

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

- 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 percent 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 23.18.

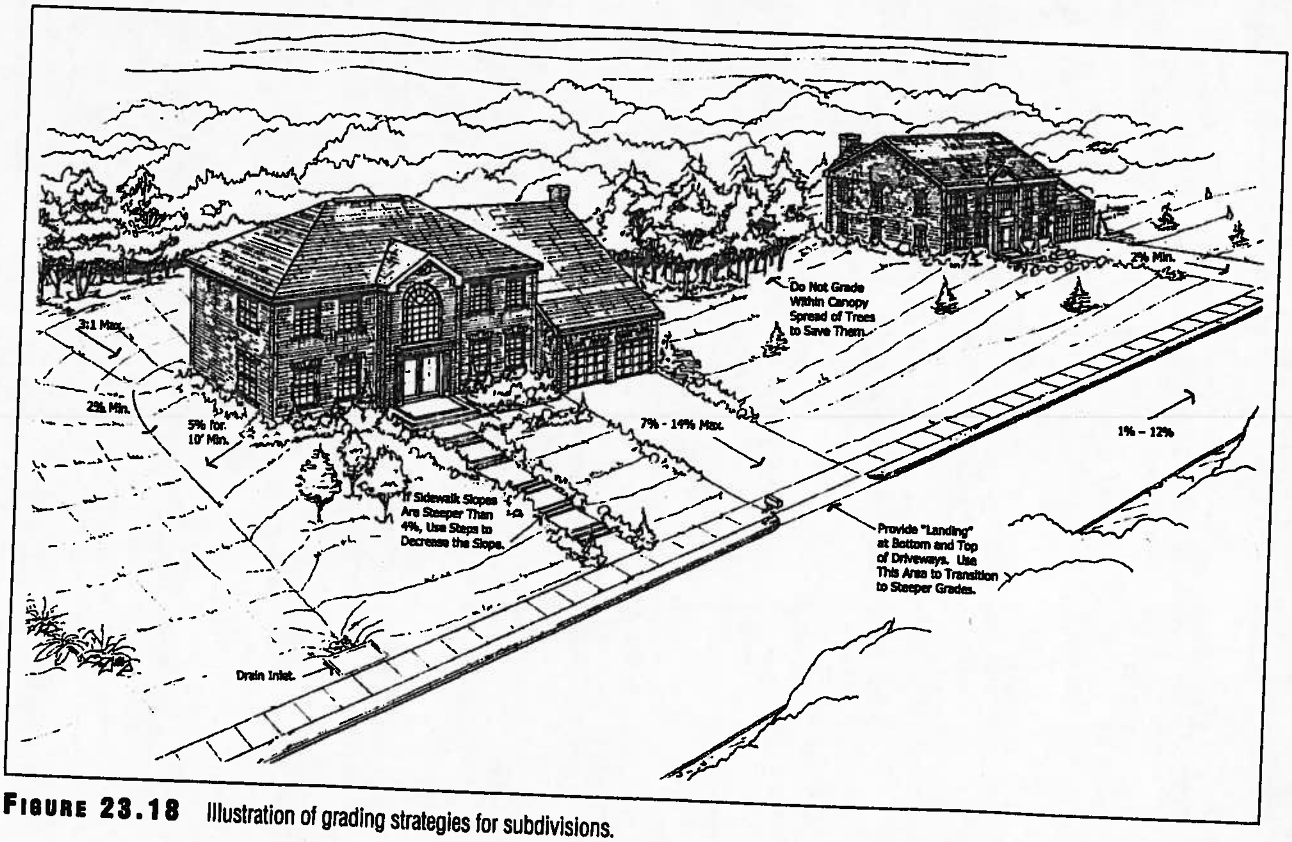


FIGURE 23.18 Illustration of grading strategies for subdivisions.

Utility Services. In addition to the relationship of the house to its lot and surroundings, another relationship that affects the siting of a house is that of the elevation and location of the sanitary sewer. As shown in Figure 23.19, 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 as follows:

1. Determine the invert of the sewer main at the connection point.
2. Multiply the distance from the connection point to the farthest point of the house by 0.0208 (¼ in/ft), and add to the invert elevation (the fall *f* in Figure 23.19).
3. Add the diameter of the sewer main (distance *d* in Figure 23.19).
4. Add an allowance for clearance under the foundation (shown as * in Figure 23.19).

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 inches to 1.5 feet (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.

When a basement, because of its depth related to the sewer main in the street, cannot be sewered 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 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, might 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 helps prevent awkward situations such as basements that won't sewer by gravity.

Grading around the Unit. Finally, the development of any grading scheme includes the assimilation of other existing data and identification of the constraints it imposes. These existing constraints are combined with the data available on the proposed building structure. Ideally, these constraints are obtained from the approved 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 of the building showing all entrances, windows, and other appurtenances at or near the ground level that affect the grading, often called a *template.* The relative elevations of these items with respect to the floor elevations are labeled on the template. Figure 23.20

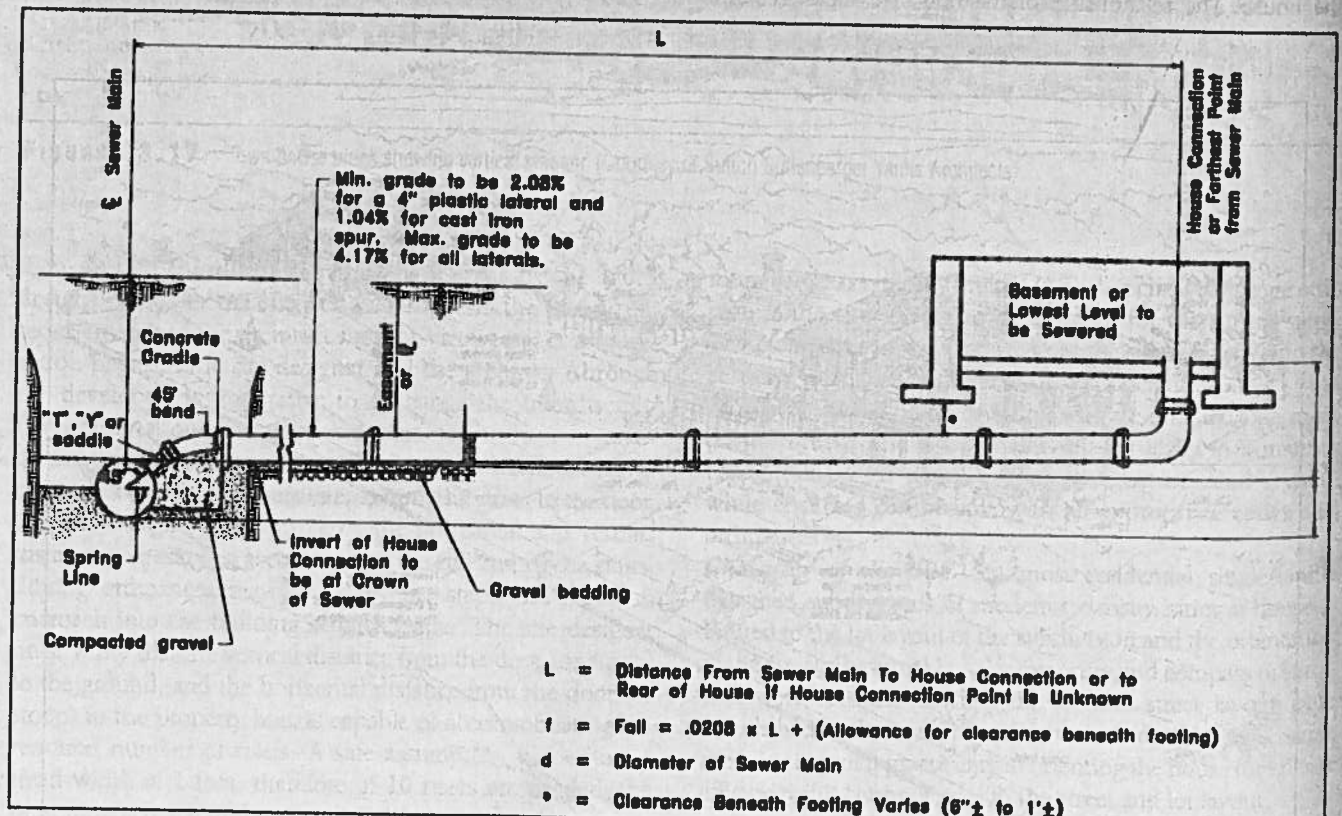


FIGURE 23.19 Sewer line from house to sewer main.

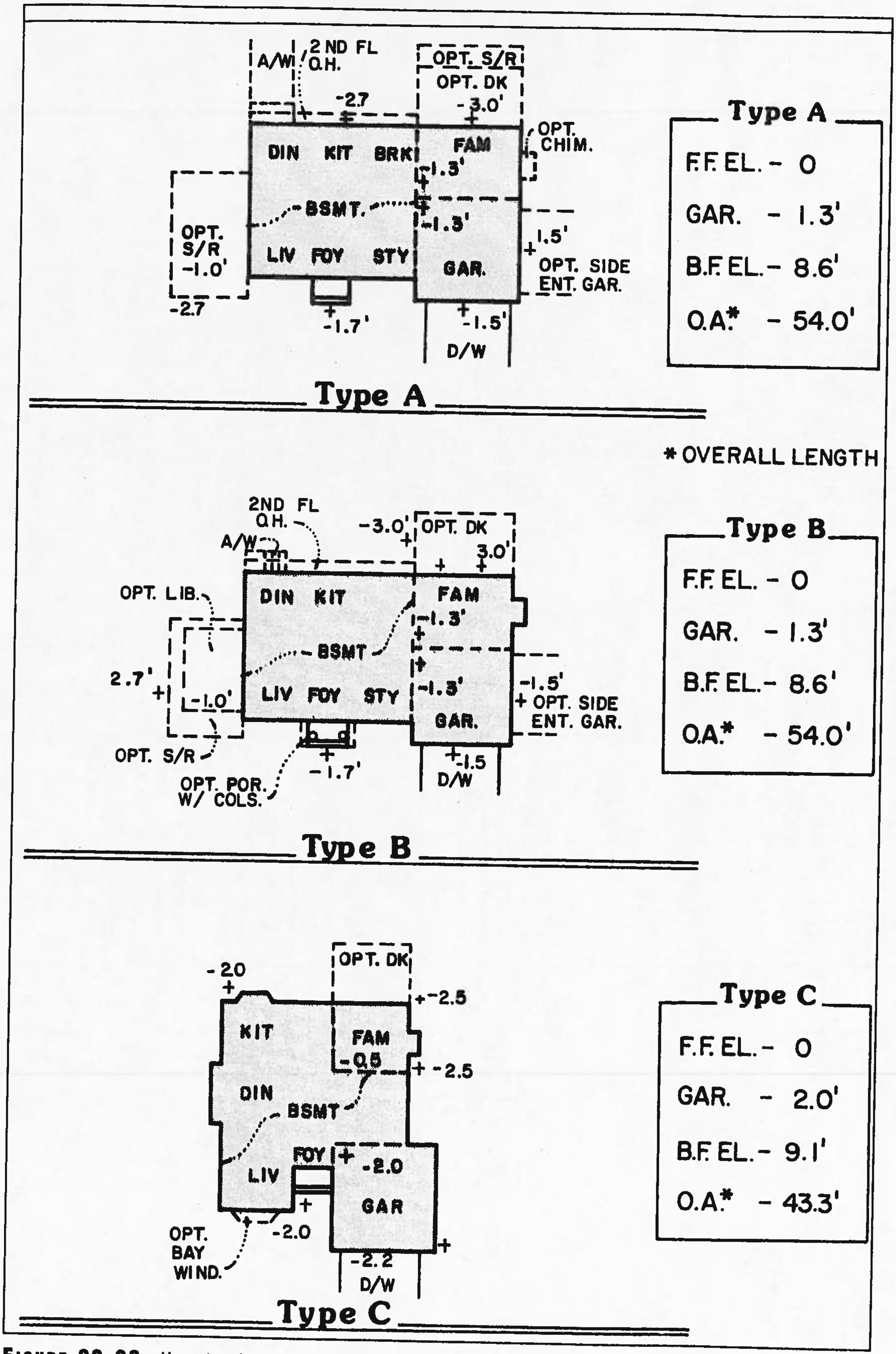


FIGURE 23.20 House template.

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 sight 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 setbacks and minimum radius 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 accelerate decay of some types of construction materials and provide a haven for insects that can damage the house. Figure 23.21 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 6 inches (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 percent. 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.

Rear Yard. 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 feet by 30 to 40 feet, graded to a maximum of 5 to 6 percent 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 backyard may be reduced, with perhaps a large deck proposed to provide the outdoor living space.

Mass Grading. In the case of subdivisions, typically only the infrastructure—roadway, underground utilities, and special features such as berms and drainage ponds or swales—is constructed by the developer. At this point, no homes are built and the individual lots are generally graded slightly lower than final grade. This is referred to as *mass grading*. When a lot is sold and a home is built, spoil from the excavated basement is spread on the lot to raise it to final grade. This not only eliminates the need to remove excess soil from the site when the home is constructed but also prevents adding fill to the site unnecessarily. Therefore, the grading plan for a subdivision should include mass grade elevations for each unit in addition to finished grade elevations.

The process of determining how much lower than final grade a lot should be constructed is one of trial and error. A given drop in grade is chosen and then the volume of spoil and the amount of fill required to bring the lot up to grade are calculated and compared. Several drop values need to be evaluated to determine the ideal drop—the one that results in the volume of spoil and required fill being the closest to equal. Mass grade elevation is determined by Equation 23.5.

$$\text{Mass grade} = \text{Finished grade} - \text{Ideal drop} \tag{23.5}$$

When calculating the volume of basement spoil, the designer needs to consider how the lot is to ultimately be graded. More specifically, will the grade get lower around the rear of the unit to provide a walkout or half-walkout basement? Both of these instances will result in less spoil, as less of the basement will be buried. When calculating the volume of spoil, it is important to remember that the depth of the basement (depth that the basement will be buried when final grades are achieved) needs to be adjusted by the amount of drop being considered. Approximate spoil volume can be determined by using one of the following equations.

a. Non-walkout (23.6)

$$SV = (D_B - \text{Drop}) \cdot A$$

b. Half walkout

$$SV = \left[\frac{1}{2} \cdot (D_B - D_{B1} - \text{Drop}) \cdot A\right] + (D_{B1} \cdot A)$$

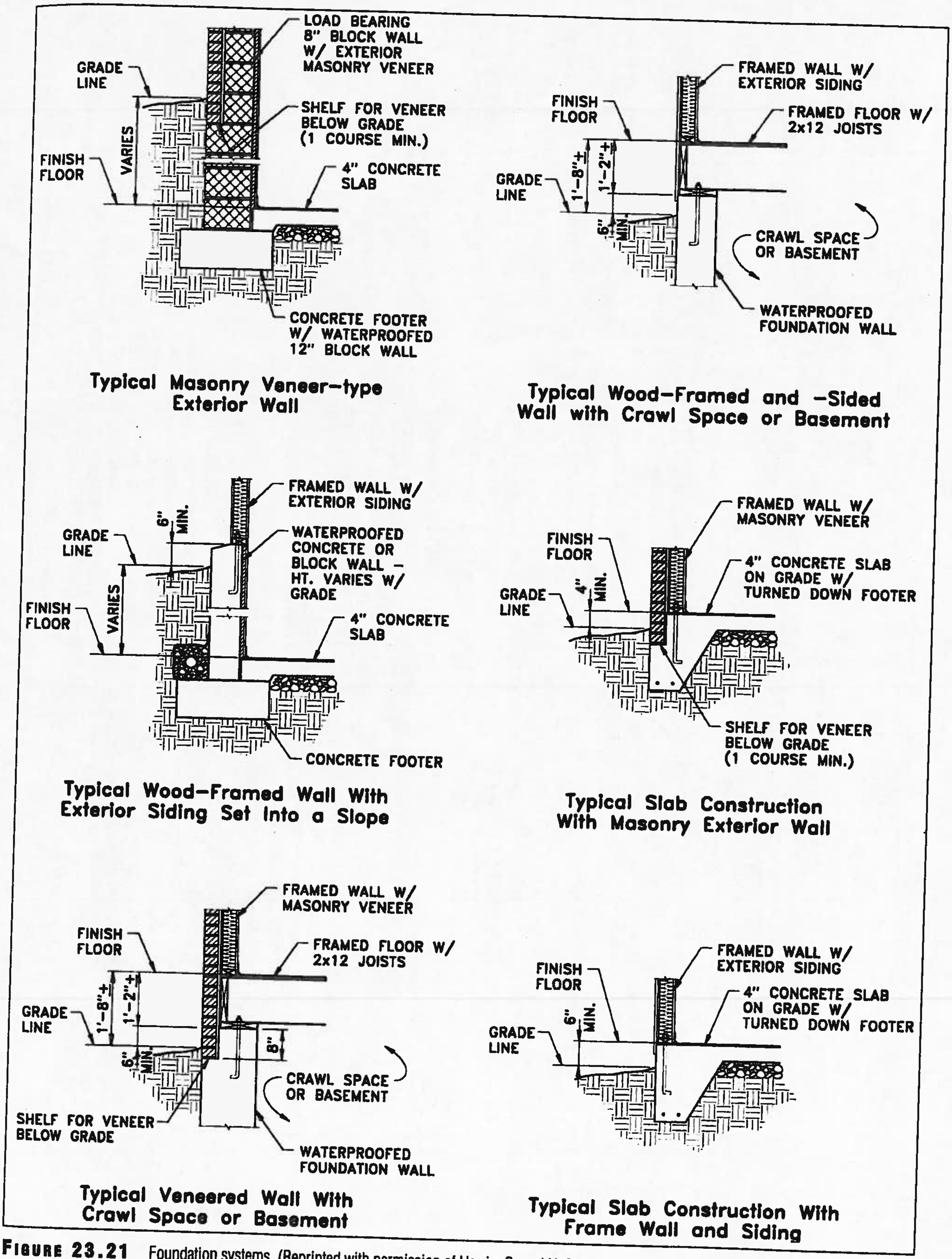
c. Walkout

$$SV = \frac{1}{2} \cdot (D_B - \text{Drop}) \cdot A$$

where SV = volume of spoil, D_B = full buried depth of basement (portion of full basement buried at final grade), A = area of basement, and D_{B1} = half-buried depth of basement (portion of half basement buried at final grade).

The process for determining the volume of fill required to raise the lot to final grade is as follows:

1. Draw three contours on the lot. Draw the first (referred to as the *0.0 contour*) just inside the property line or edge of disturbance. The depth of fill is equal to 0 feet in this location, as this is where the finished grade meets existing. However, the mass grade elevation at this location is assumed to be 0.5 feet below the finished grade elevation for the purpose of these calculations. The purpose of making this assumption is to account for



Typical Masonry Veneer-type Exterior Wall

Typical Wood-Framed and -Sided Wall with Crawl Space or Basement

Typical Wood-Framed Wall With Exterior Siding Set Into a Slope

Typical Slab Construction With Masonry Exterior Wall

Typical Veneered Wall With Crawl Space or Basement

Typical Slab Construction With Frame Wall and Siding

FIGURE 23.21 Foundation systems. (Reprinted with permission of Harris, C. and N. Dines. 1988. *Time Saver Standards for Landscape Architecture.* New York: McGraw-Hill) the depth of topsoil that will be spread on the lot. Draw the second (referred to as the *0.5 contour*) midway between the 0.0 contour and the house footprint. At this location, the fill depth will be equal to one-half the difference between the considered drop (at the unit) and the 0.5-foot assumed drop at the 0.0 contour. Draw the third (referred to as the *1.0 contour*) just outside the perimeter of the house footprint. At this location, the fill depth will be equal to the considered drop. Figure 23.22 illustrates the placement of the 0.0, 0.5, and 1.0 contours.

2. Measure the area within each contour. For the area of the 0.0 and the 0.5 contours, the entire internal area and not just the area from one contour to the next should be measured. However, the area of the basement footprint is excluded from each measurement because no fill will be spread in this location.

3. Use Equation 23.7 to calculate the required fill volume.

$$F_v = \left[\frac{1}{2}A_{0.0} + A_{0.5} + A_{1.0}\right] \cdot \text{CI} \qquad (23.7)$$

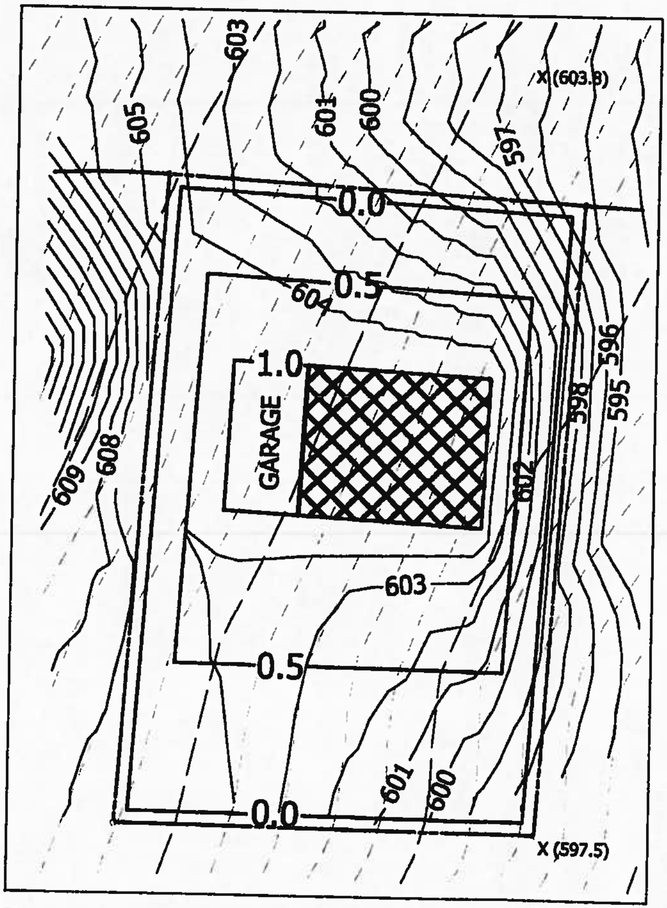


FIGURE 23.22 0.0, 0.5, and 1.0 contours for mass grading calculations.

TABLE 23.2 Contour Intervals for Mass Grade Calculations

DROP	CONTOUR INTERVAL (CI)
1.0	0.25
1.5	0.50
2.0	0.75
2.5	1.00

*Note: Both drop and contour interval have the same unit associated with them (e.g., a 1-foot drop has a 0.25-foot CI, etc.).

where F_v = required fill volume, $A_{0.0}$ = area inside the 0.0 contour (minus the area of the basement), $A_{0.5}$ = area inside the 0.5 contour (minus the area of the basement), $A_{1.0}$ = area inside the 1.0 contour (minus the area of the basement), and CI = contour interval, as shown in Table 23.2.

Grading in Commercial Sites

Commercial projects (e.g., high- and low-rise office, retail plazas, houses of worship, and schools) consist mainly 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 can be 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.

Siting the Building and Other Structures. When siting the building(s) and any other structures on the property, one must position them in a manner that optimizes the area, promotes public safety, is harmonious with the adjacent properties, and ensures compliance with all appropriate codes and ordinances. In most cases the lot layout is created during preliminary design. Refer to Chapter 11 for a complete discussion on laying out a commercial property.

Type of Site. Each type of commercial development has its own features and needs associated with those features. The following items are examples of special grading needs based on the type of site:

- A fast-food restaurant might require the design of a drive-through facility, which would require that fairly steady grades are held around the building.
- Commercial developments usually have some type of Dumpster pad/enclosure located on the lot. Features such as Dumpsters are typically screened by means of landscaping. In some cases, aesthetic grading is used in conjunction with landscaping.
- Commercial sites, by nature of being public, have a certain amount of space that must maintain suitable grades to provide accessibility for disabled persons, according to the ADA Accessibility Guidelines. In cases such as senior living facilities, these areas may be wider and occur at more frequent intervals.

Property Lines and Setbacks. Siting the building parallel to at least one property line is usually the preferred method. To provide enough room for parking areas, it is common for the building to be situated as close to one or two of the property lines as possible. In general, required setbacks are applied to the building(s) and structures. However, some municipalities also have separate setback requirements for pavement such as parking lots. Setback requirements are typically determined in the preliminary design phase when the building is sited. The important thing to remember is to leave enough room between the property lines and the structures to allow the proposed grades around them to transition appropriately to meet the existing grades along the property boundary.

Grading the Site. The controlling factors for grading commercial sites are basically the same as for 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 the architect (and developer) set for the proposed building.

Drainage. As in residential developments, the topography of the lot plays a big part in laying out the lot. For example, the lot would be configured such that stormwater facilities would be located at a lower point of the property for ease of drainage. Further, it is desirable to have the building on higher ground. In general, the building elevation is set above the street.

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

Parking Lots. 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 previously. From the entrance, recommended pavement slopes in the travel lanes vary from 1 to 5 percent. 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 23.23 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 washboard 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.

Utility Services. In the discussion of residential developments, it was noted that it is best to set the building elevation to provide for gravity drainage to an existing sanitary sewer. The same is true in commercial applications. This is because gravity drainage of the site's wastewater is the most economical solution.

Grading around the Building(s). The grades around the perimeter of a commercial building typically do not vary

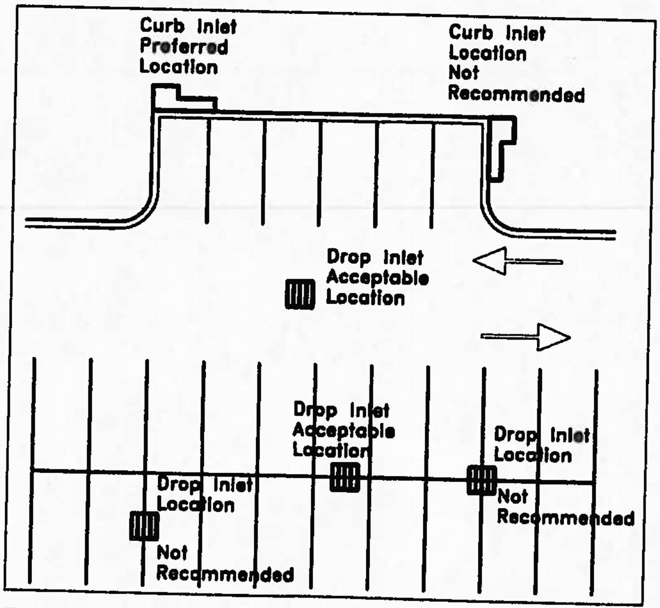


FIGURE 23.23 Recommended inlet locations.

unless the existing terrain has slopes that dictate it. Figure 23.24 illustrates a possible grading scenario around a commercial building. Following are examples of areas around the building that may require special grading:

- *Entrances:* In lieu of steps, walkways may be graded toward the building to meet the finished floor elevation.
- *Loading docks:* Pavement ramps (with possible walls) may need to be designed/graded to provide access to either raised or lowered entries to the building.
- *Drive-throughs:* Special care must be given when grading a drive-through where an access road has its edge of pavement/curb almost touching the face of the building. It is usually easy enough to grade away from the building. But it might be more difficult to grade the road to provide drainage, as it is constrained by the grades along the perimeter of the building.

GRADING AND DESIGN SOFTWARE

The process of grading as 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 electronic tools commonly offered through computer programs be employed.

Moreover, it should be remembered that, in many ways, grading is an art. Therefore, computers—no matter how sophisticated they become—will never be able to produce a grading plan better than a human being can. Computers should be considered a valuable grading tool but not a substitute for the designer's experience and skill.

Smart Drawings

Computer-aided design (CAD) software, such as AutoCAD by Autodesk, Inc., and MicroStation by Bentley Systems,

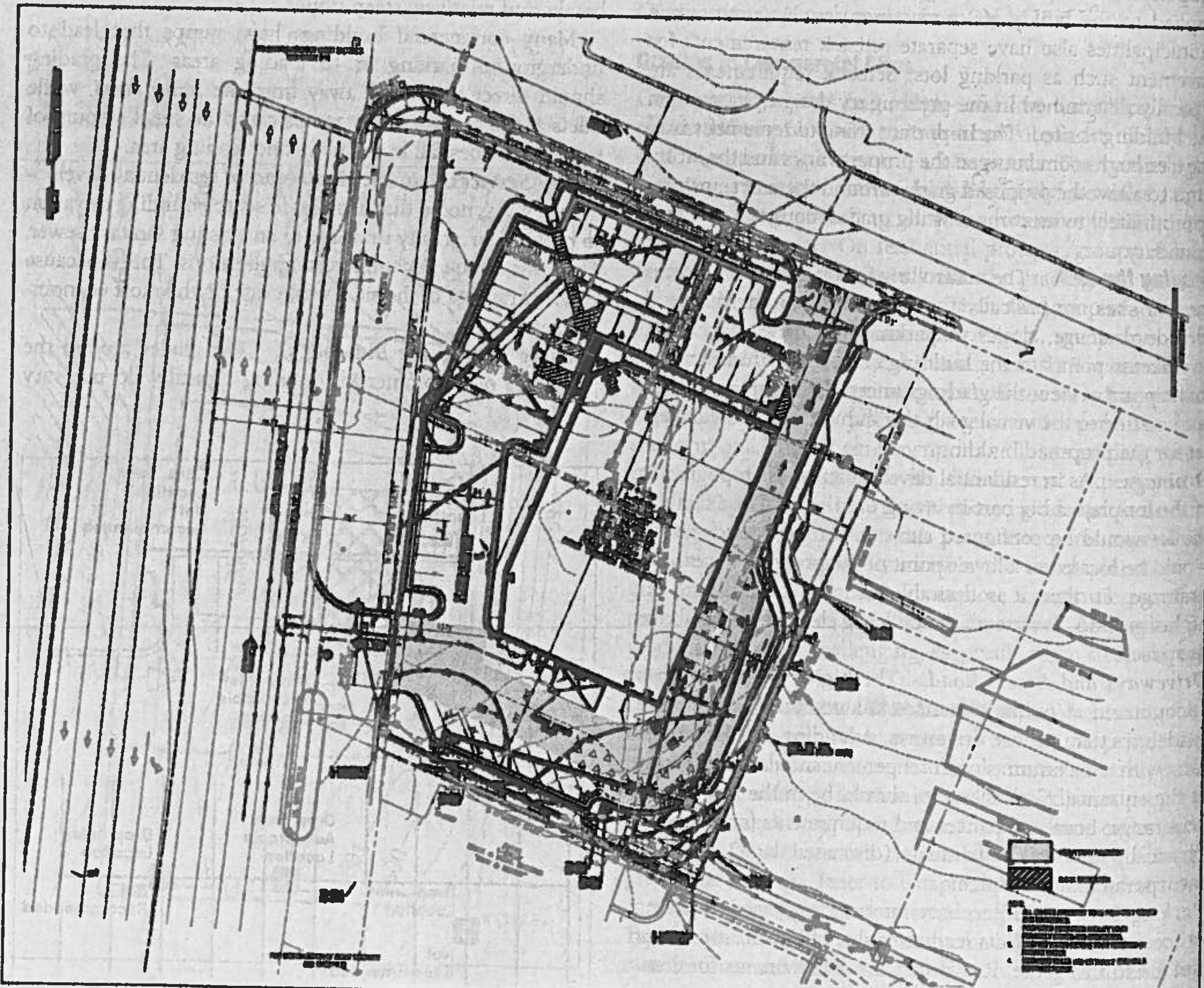


FIGURE 23.24 Commercial building grading plan.

Inc.—typically used for the drafting of maps and engineering or architectural drawings—can also create three-dimensional models (or designs). CAD files of this nature are referred to as *smart drawings*. The drawing is considered smart because it has more data information than a typical flat (two-dimensional) drawing. With traditional flat drawing, two or three drawings (or views) may be required to convey all the necessary dimensions. One smart drawing has within it all the dimensions.

Digital Terrain Models

Description. A digital terrain model (DTM) is a database of points that each have three spatial coordinates (x, y, and z). These points are connected to form a series of adjacent triangles representing an irregular surface. Figure 23.25 is an example of a DTM.

As discussed in Chapter 14, survey points are compiled to create a DTM of the existing ground surface. This DTM is then used to generate the existing contours using one of the surface modeling software packages. By creating a proposed DTM (proposed surface), proposed contours can be similarly generated. This eliminates the tedious task of hand-drawing contours after interpolating their configurations based on spot elevation locations and intended drainage patterns.

Creating the Proposed Surfaces

Land development design software such as Land Desktop by Autodesk, Inc., and Inroads by Bentley Systems, Inc., has automated most of the more mundane tasks associated with grading. Further, as the software becomes more sophisticated, it is becoming more capable of actually designing the entire proposed surface (grading plan). However, the

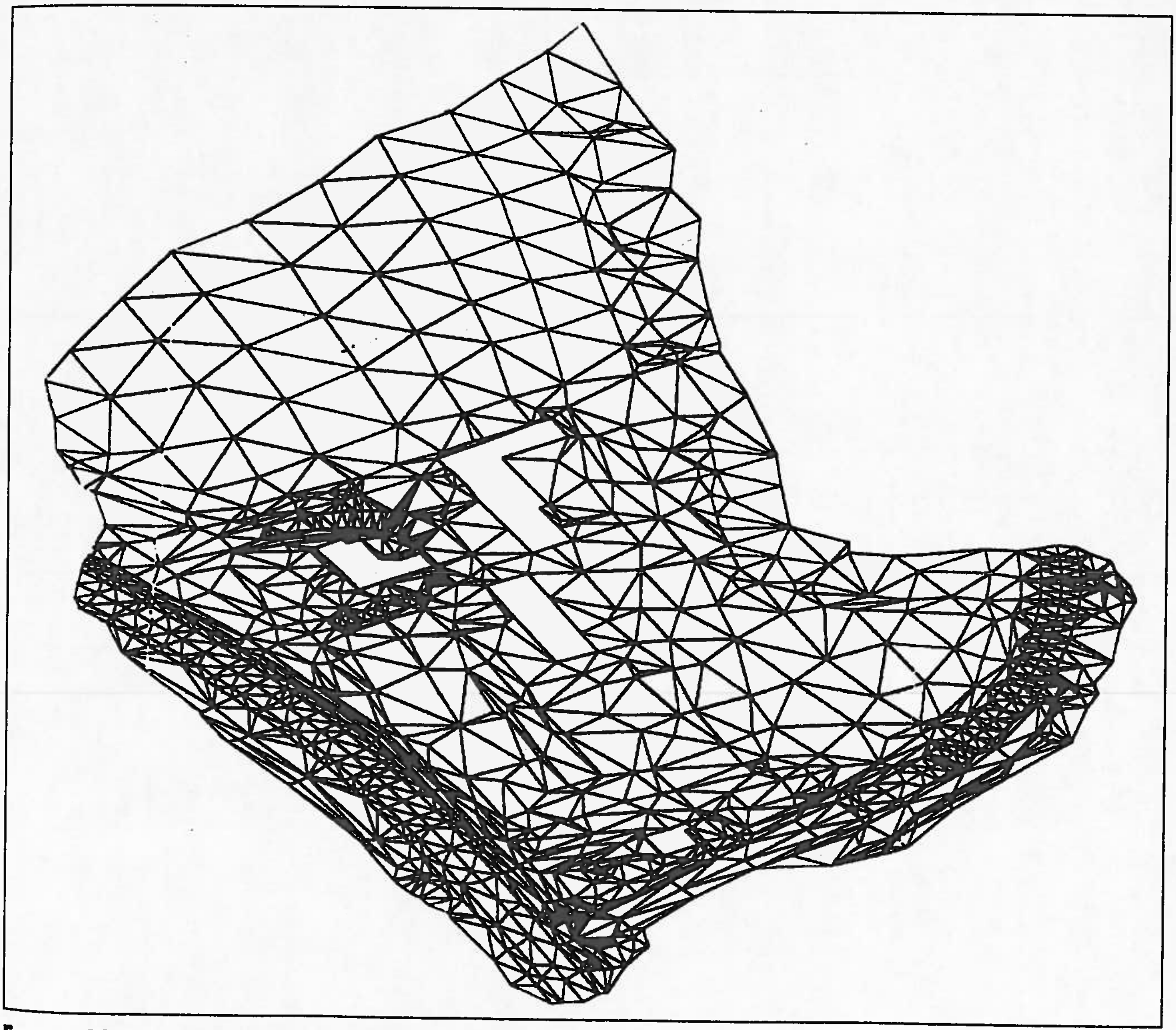


FIGURE 23.25 Digital terrain model (DTM).

designer should be knowledgeable of the principles presented in this chapter. As a rule of thumb for using any design software, the designer needs to understand and know what information to give the computer and be knowledgeable enough about the subject to validate and use the information the computer returns.

There is an array of specific grading tools being developed within the different surface-modeling software packages to model roadways, ponds, berms, parking areas, and so on. However, there are basically only three types of information contained in a smart drawing that is input into a DTM to define the proposed surface:

1. *Random points:* A single point would be input directly into the DTM to define such things as the high point of a hill, the low point of a pond, or the top of a drainage inlet.

2. *Breaklines:* Breaklines are lines that reside in three-dimensional space. They represent continuous, defined edges such as top of ridge, bottom of swale, crest of road, face of building (at ground surface), or walls. Grading tools used to model roadways and parking areas typically generate a set of breaklines, commonly centerline or profile grade line (PGL) as well as top of curb and flow line, that define the features.

3. *Contours:* Contours are three-dimensional lines; the *z*-coordinate (elevation) is equal for all combinations of *x* and *y*. Contours are input into the DTM to define such things as berms and ponds or to define any area that cannot be adequately defined by random points and break lines.

Using Smart Drawings and DTMs for Construction

Smart Drawings and DTMs in the Field. As technology has advanced, contractors have acquired the ability to input digital information into their equipment to facilitate the construction of a site. Considering this, two questions come to mind: What information is needed for machine-controlled grading and who will be responsible for supplying this information?

For the most part, the proposed grading plan itself does not provide a contractor sufficient information to grade a site. This is mainly because it typically reflects only finished grades. The contractor, however, is interested in the mass grade configuration as well as finished grades. The designer must remember that the contractor first mass grades the site in order to install roads, utilities, foundations, and so on. Therefore, information about road boxes, trench configuration, basement depth, subbases, and so on, are the main concern for initial construction of the site. The contractor must use profiles and details included in the plan set in addition to the grading plan. This situation would remain the same if a smart drawing of the grading plan were sent to the contractor. Following this same logic, the proposed surface (DTM) would also be insufficient.

Now a mass grade surface could be prepared. A mass grade surface DTM would not only provide a contractor with all the required mass grading information in one place but could also be used by the designer to better estimate earthwork quantities. So should the designer make it a practice to prepare full mass grade DTMs? To answer this, the designer must decide whether the additional work justifies slightly more accurate earthwork calculations. Further, consideration should be given to whether the designer prefers to reduce (or eliminate) the responsibility of the contractor to compile the needed mass grade information from the plans, profiles, and details by providing this information in a mass grade DTM. This in itself might justify the extra work. However, a good contractor will most likely still take the time to check the DTM against the plans, profiles, and details.

Long before the age of machine control, contractors used the designer's drawings to construct a site. Machine control is a valuable tool for the contractor. However, it does not change the design and/or construction concepts presented in this book. A set of site drawings provides all the information required to construct the site. The process of the contractor—extracting the information from the plans—has always acted as a check of the information. So it may make the most sense to leave machine control considerations to the contractor.

Feasibility and Liability. One of the most common and dangerous mistakes is to believe that computers are infallible. It is very easy to believe that all the information contained in a smart drawing is accurate. It is important to remember that much of the information in the smart drawing for the proposed conditions was created by the designer and not by the computer. It is very possible that what is printed is different from what is found by inspection of the three-dimensional model. A proposed DTM is an approximate representation of the surface that is to be constructed. It is defined by the amount of information it contains. The more information (points) provided, the closer the approximation is. Consideration must be given to whether or not a DTM contains adequate information to be used for construction before providing it to a contractor.

However, on cooperative project construction where the engineer and contractor work together, commonly referred to as design-build delivery, the need for the engineer to provide higher-quality information is certain. Although this design-build is more common for transportation and large-scale infrastructure projects, it is becoming increasingly common in the land development field as well, especially for public-sector clients. Client cost savings have been shown on projects where the contractor is included in the design process to check and validate construction techniques for earthwork balancing that account for bulking and shrinkage of materials typical for the area to be constructed. The contractor's knowledge, if leveraged in the design process, can significantly improve the cost savings to the client and the speed to complete the project.

GRADING SUMMARY

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 this requires a combination of art and science rarely equaled in any other aspect of the site development process.

EARTHWORK INTRODUCTION

The term *earthwork* refers to the manual movement of soil. Earth is taken from one location and moved to another in order to form the land as desired. In general, moving earth from one location on a site to another can be expensive. It is even more costly to a project when earth must be removed from or brought onto a site. Therefore, it is very important to have a balanced site, where there is not a large amount of excess soil or, conversely, soil demand.

CUT/FILL MAPS

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 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 evidenced by 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 23.26 shows a grading plan of a building with cut and fill areas. As an example of determining 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-foot 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 feet, the zero line follows the existing 99.0 foot 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 this chapter.

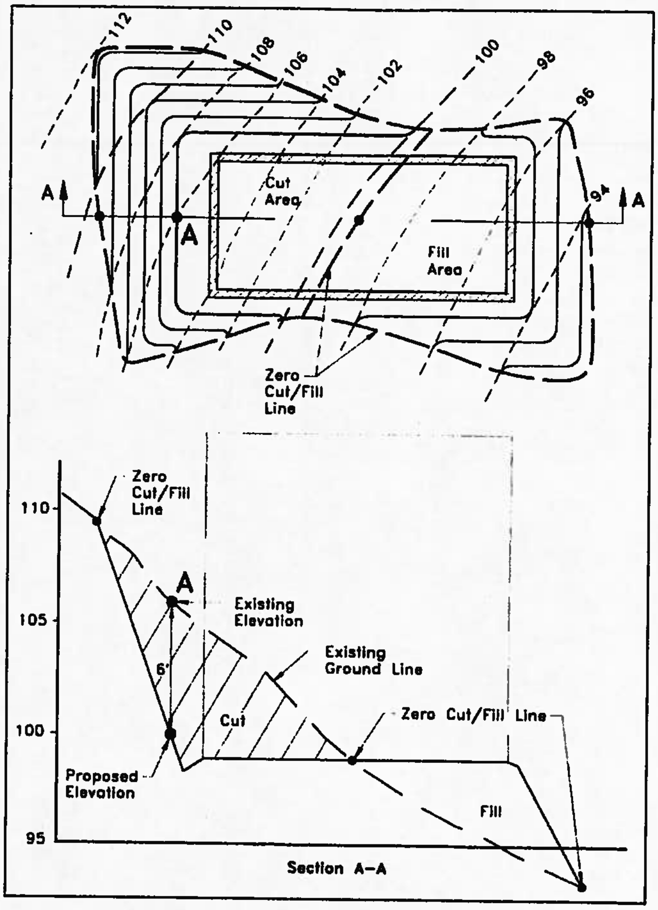


FIGURE 23.26 Plan and section view showing cut and fill areas.

Consideration of cut and fill quantities is very important when developing a grading plan. For many reasons, a balance of cut and 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 soil as fill on the lower portion of the site. This concept is illustrated in Figure 23.26.

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 assume they may be used as fill material. (See Appendix C for further discussion.)

- Soils generally shrink when used as fill, and the shrinkage factor can vary greatly between different soils. A grading plan that appears 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 intentionally produce 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).

EARTHWORK

Calculating the amount of displaced material is referred to as an *earth takeoff* (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 during preliminary engineering. This rough grading plan shows the buildings, streets, and parking areas with spot elevations at critical points and contour lines with 2-foot or 5-foot 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 either more effective or required because it is too early in the design process for electronic files to have been created. 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.

ETO METHODS

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 easily produce street cross sections.

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 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, which 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 location 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 last way is tedious and has inherent errors (e.g., estimating partial segments of the squares), but can be effective for very rough estimates. 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:

$$SF_{act} = A \cdot H_{scale} \cdot V_{scale} \qquad (23.8)$$

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.

$$V_{inc} = \frac{A_i + A_{i+1}}{2} \cdot L \qquad (23.9)$$

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 Equation 23.9, 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 volumes for the site.

The volume from the average end area (Equation 23.9) significantly overestimates the volume at the two end sections. As shown in Figure 23.27, the solid segment L is wedge shaped. The volume for a wedge (pyramid) is:

$$V_W = \frac{A}{3} \cdot L \qquad (23.10)$$

where A is the area of the first cross section, in this case station A_i. A comparison of the volumes for the wedge segment as computed by the average end area and the wedge equation shows that the average end area volume is 50 percent greater. The volume resulting from 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.

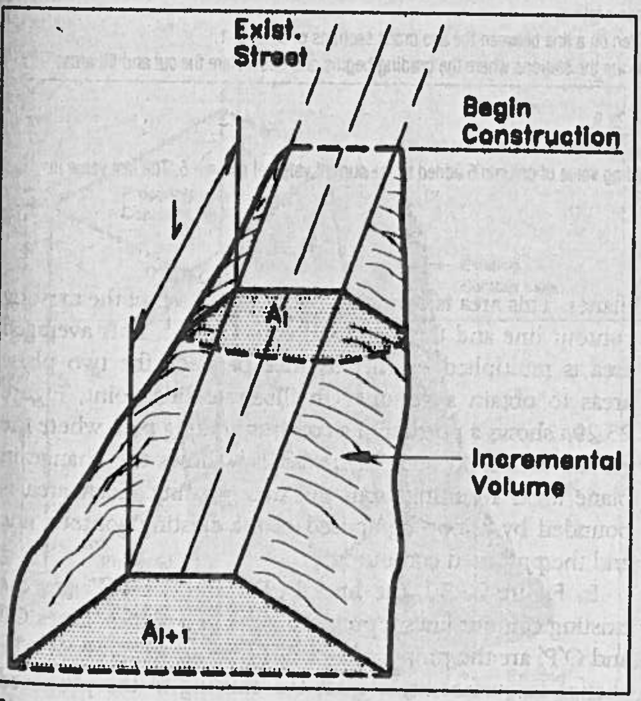


FIGURE 23.27 Wedge-shaped volume.

EXAMPLE 1

Figure 23.28 shows three cross sections of a roadway where C and F designate the cut or fill area on the cross section. Table 23.3 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, 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 for cut and fill. An extremely high cost associated with the cut or fill operations necessitates that the computed earthwork quantity be considerably more accurate. Consideration for additional cross sections through a curve is necessary

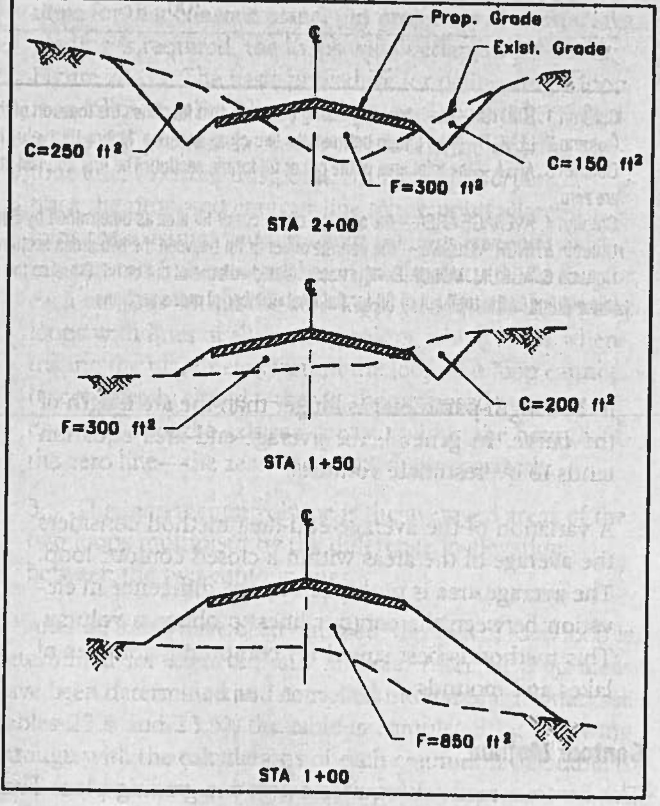


FIGURE 23.28 Earthwork example: Cross-section method.

TABLE 23.3 ETO by Cross-Section Method

(1) Station	(2) Length (ft)	(3) Area (ft²)	(4) Average Area (ft²)	(5) Incr. Volume (ft³)	(6) Accum. Volume (ft³)
			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	7500	
2 + 50		0			72,500
			CUT		
0 + 50		0			0
	50		0	0	
1 + 00		0			0
	50		100	5000	
1 + 50		200			5000
	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 28.9.
Column 5: INCR. VOLUME—the volume of cut or fill between the two cross sections. This is equal to column 2 × 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.

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 of 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.

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 plane areas to obtain a volume. To illustrate this point, Figure 23.29*a* shows a portion of a contour grading plan where the graded area is in cut. Figure 23.29*b* shows the change in plane areas resulting from the new grading. Each area is bounded by a loop composed of the existing contour line and the proposed contour line.

In Figure 23.30, the 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 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

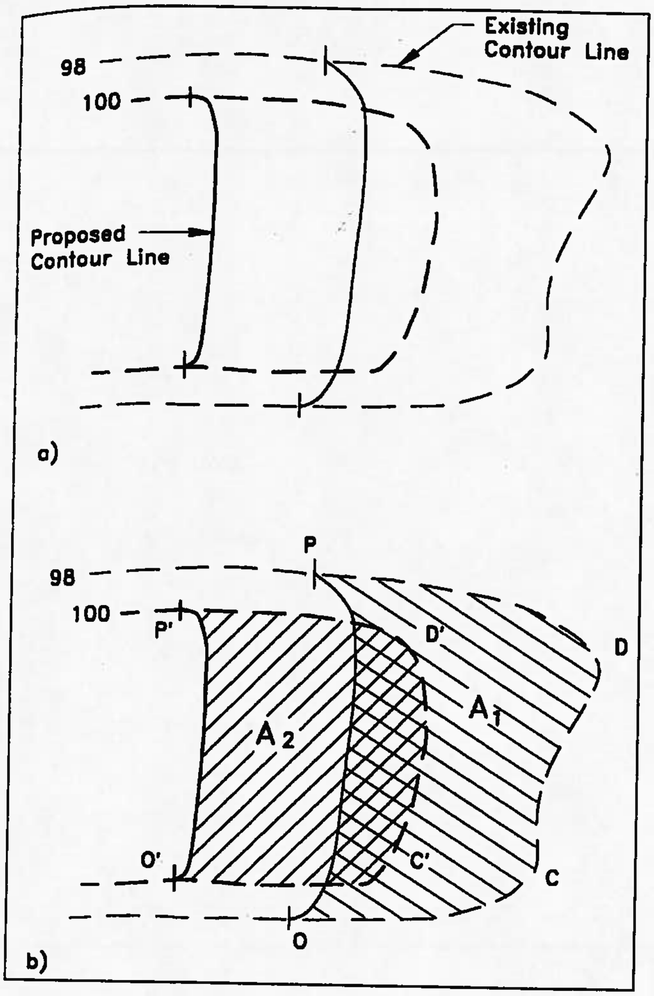


FIGURE 23.29 Contour grading plan illustrating change in areas.

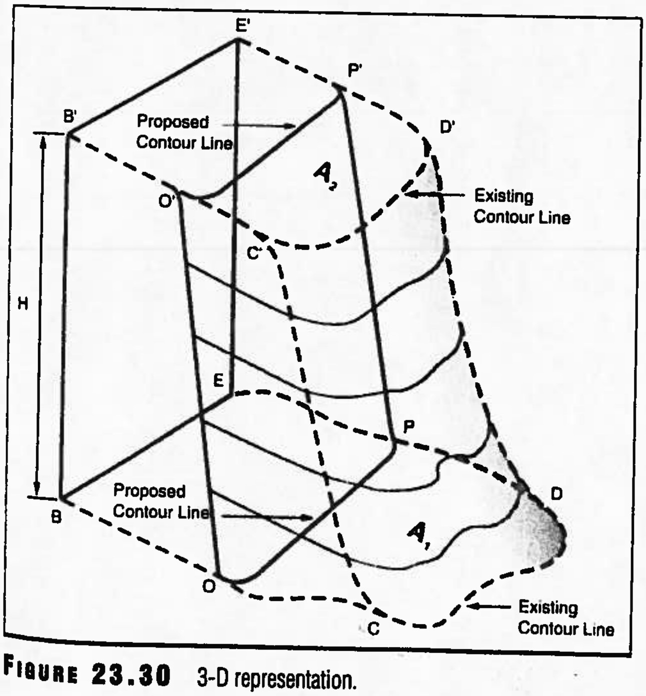


FIGURE 23.30 3-D representation.

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:

$$V = \frac{A_1 + A_2}{2} \cdot H \tag{23.11}$$

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 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 23.31, points A and C are where the proposed contour lines tie into 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 24.31.
2. For each contour line within a zero loop, there are other loops composed of part of an existing contour and a proposed contour. Each of these loops outlines 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 23.32. The basic procedure for delineating a loop is as follows: (a) on the grading plan (Figure 23.33) find where the proposed contour line meets the existing contour line; (b) from this point, using a colored pencil, trace the proposed contour line to the point where it joins the existing contour again; (c) then trace the existing contour line back to the original point; (d) do this for each contour within the zero loop; (e) identify individual loops with lines of alternating colors, which 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 23.4 and 23.5), 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 identifies areas of the site where adjustments can be made to balance the cut and fill.

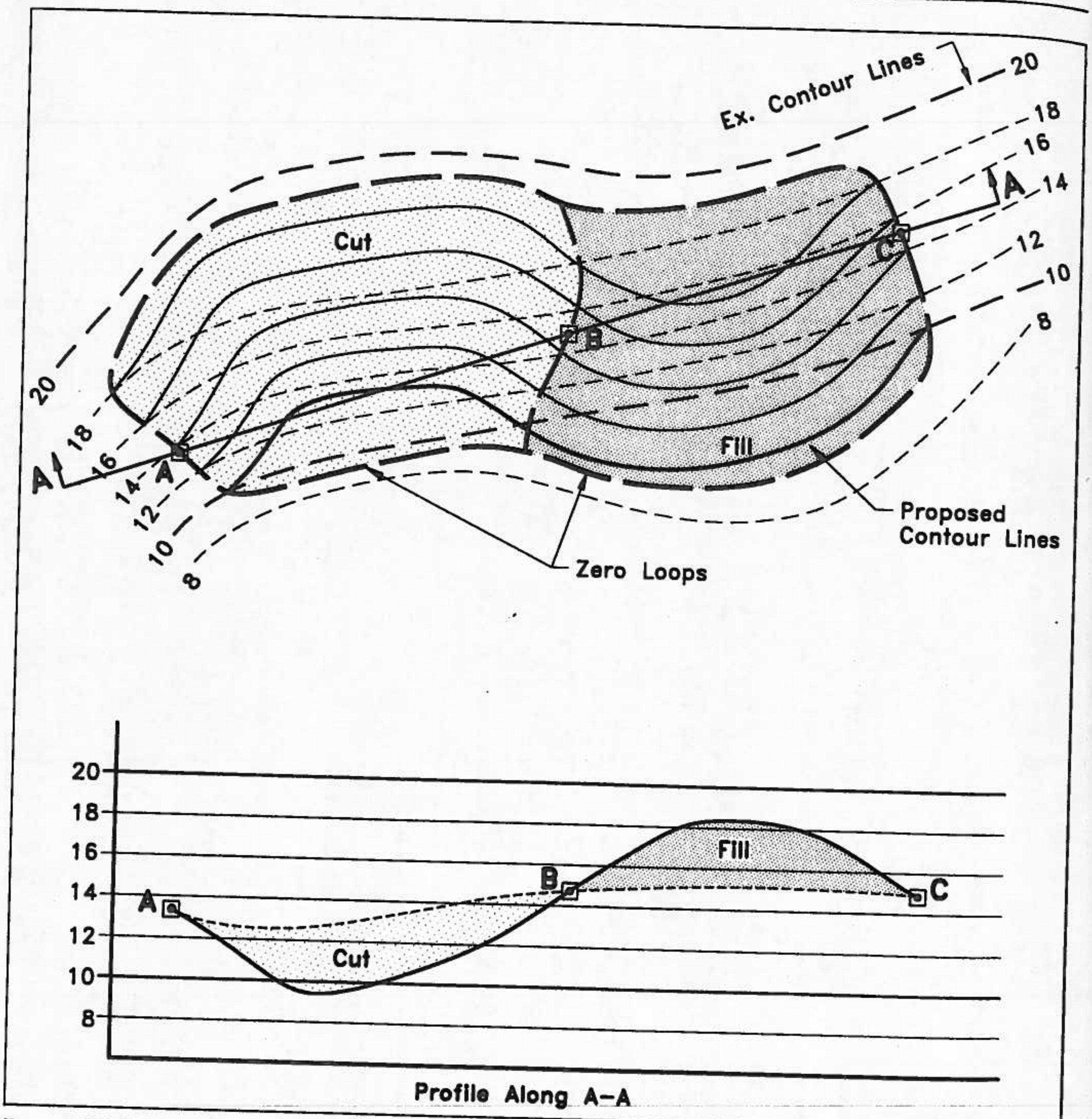


FIGURE 23.31 Schematic diagram showing zero lines.

EXAMPLE 2

Use the contour method to determine the amount of cut and fill for the grading plan of Figure 23.33.

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 23.32. The line C-G-H-D separates the fill area from the cut area. It is analogous to the line in Figure 23.31 that runs through the center of the graded area to divide the cut and fill areas.

Figure 23.34 shows the change in graded areas for the contour lines for elevations 414 feet, 416 feet, and 418 feet 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

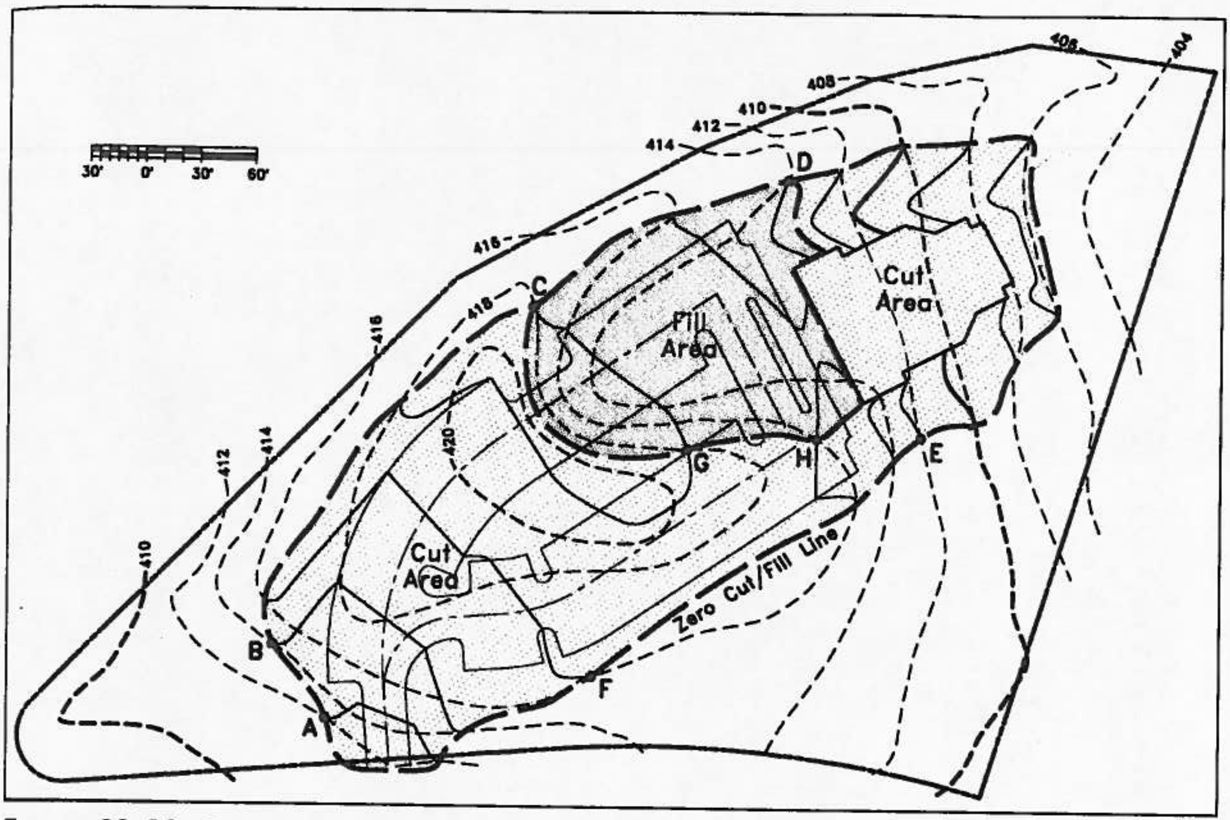


FIGURE 23.32 Grading plan showing cut/fill areas.

along the existing contour back to point J. Similarly, the areas for the loops MQM and NOPN are measured.

The loop areas for each contour line in the fill areas are measured and entered into a computation table (Column 2), as shown in Table 23.4. The following calculations complete the table.

Column 3: The average area for the first two consecutive contour lines—that is, for the 413-foot and 414-foot contour lines—is:

TABLE 23.4 Contour Method: ETO for Fill Area

(1) Elev. (ft)	(2) Loop Area (ft²)	(3) Avg. Area (ft²)	(4) Diff. in Elev. (ft²)	(5) Incr. Vol. (ft³)	(6) Accum. Vol. (ft³)
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

TABLE 23.5 Contour Method: ETO Quantities for Cut Area

(1) Elev. (ft)	(2) Loop Area (ft²)	(3) Avg. Area (ft²)	(4) Diff. in Elev. (ft²)	(5) Incr. Vol. (ft³)	(6) Accum. Vol. (ft³)
			PARKING AREA		
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
			BUILDING AREA		
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

$$\frac{8823 + 11453}{2} = 10138 \text{ ft}^2 \qquad (23.12)$$

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

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

$$2 \cdot (416 - 414) \cdot 10138 \text{ ft}^2 = 20276 \text{ ft}^3 \qquad (23.13)$$

Similar loop areas are obtained for the contour lines within the zero loop of the two cut areas, as shown in

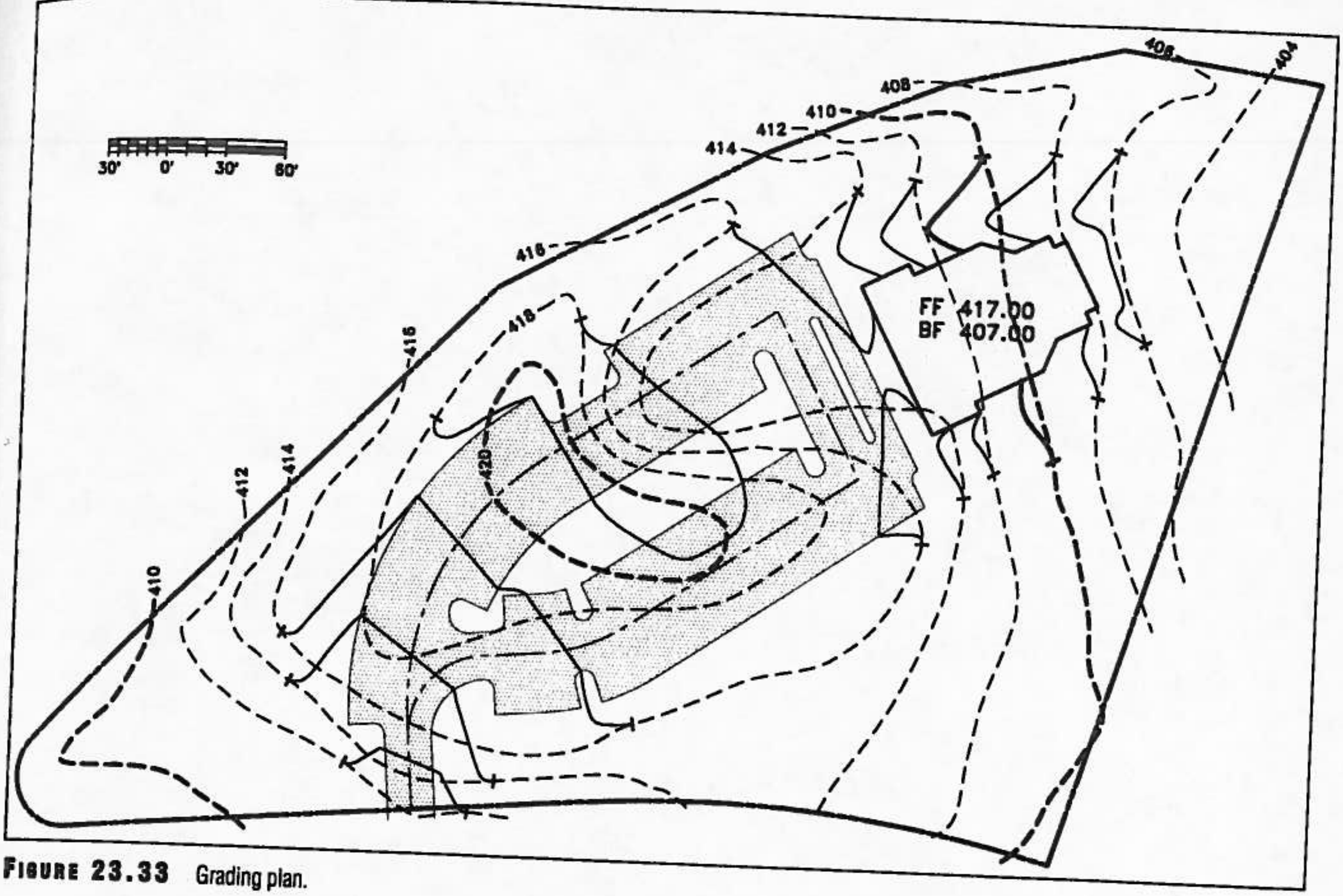


FIGURE 23.33 Grading plan.

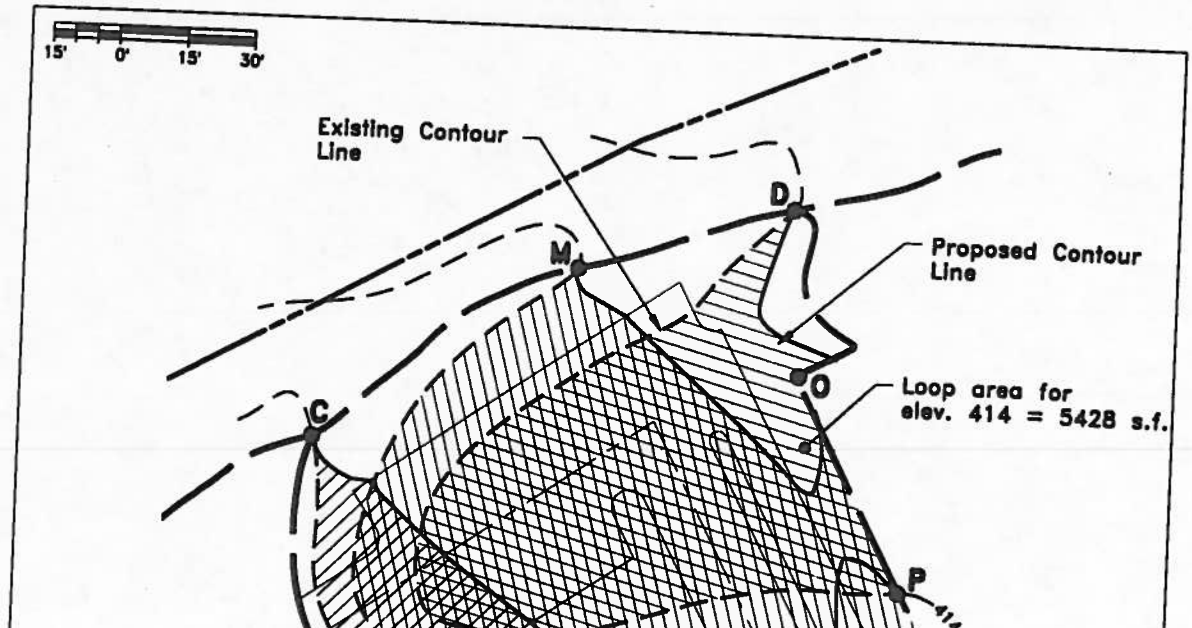


FIGURE 23.34 Contour method: loops for fill area.

Figure 23.32. 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 previous discussion on contour patterns for buildings and retaining walls in this chapter). The other loop areas around the building have not been shown for clarity. See Figure 23.35.

The total volume of material of cut and fill is:

$$\text{Total volume of cut} = \frac{(62556 + 38439)\ \text{ft}^3}{27\ \text{ft}^3\ \text{per yd}^3} \approx 3740\ \text{yd}^3$$

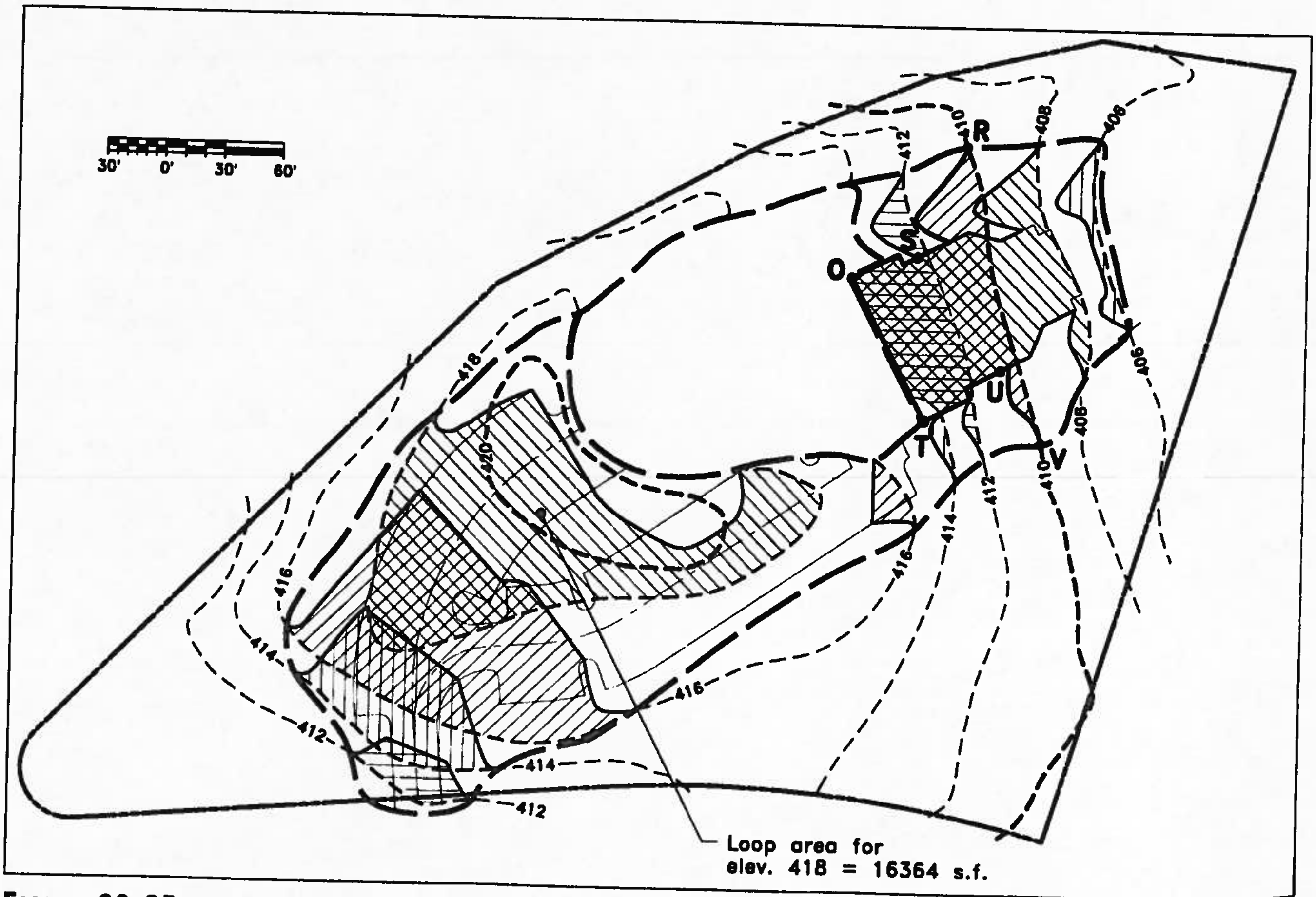
$$\text{Total volume of fill} = \frac{35662\ \text{ft}^3}{27\ \text{ft}^3\ \text{per yd}^3} \approx 1321\ \text{yd}^3 \qquad (23.14)$$

However, these volumes must be adjusted for topsoil, allowance for concrete and pavement thickness, 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 configuration 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-foot-high mound built up from level ground. Imagine that the 8-foot elevation is represented by a ring of a specific radius, r8, as shown in Figure 23.36. The outer edge of the ring is formed by the 8-foot contour line. The volume of earth in this initial ring is that of a right circular cylinder = 8(pr82)/4. Next consider a ring formed by the 6-foot contour line with radius r6, (r6 > r8), concentric with the 8-foot-high cylinder. The incremental volume in this ring is 6p(d62 – d82)/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 23.36 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 V′U′V′ on the left side of Figure 23.36.



Loop area for elev. 418 = 16364 s.f.

FIGURE 23.35 Contour method: loops for cut area.

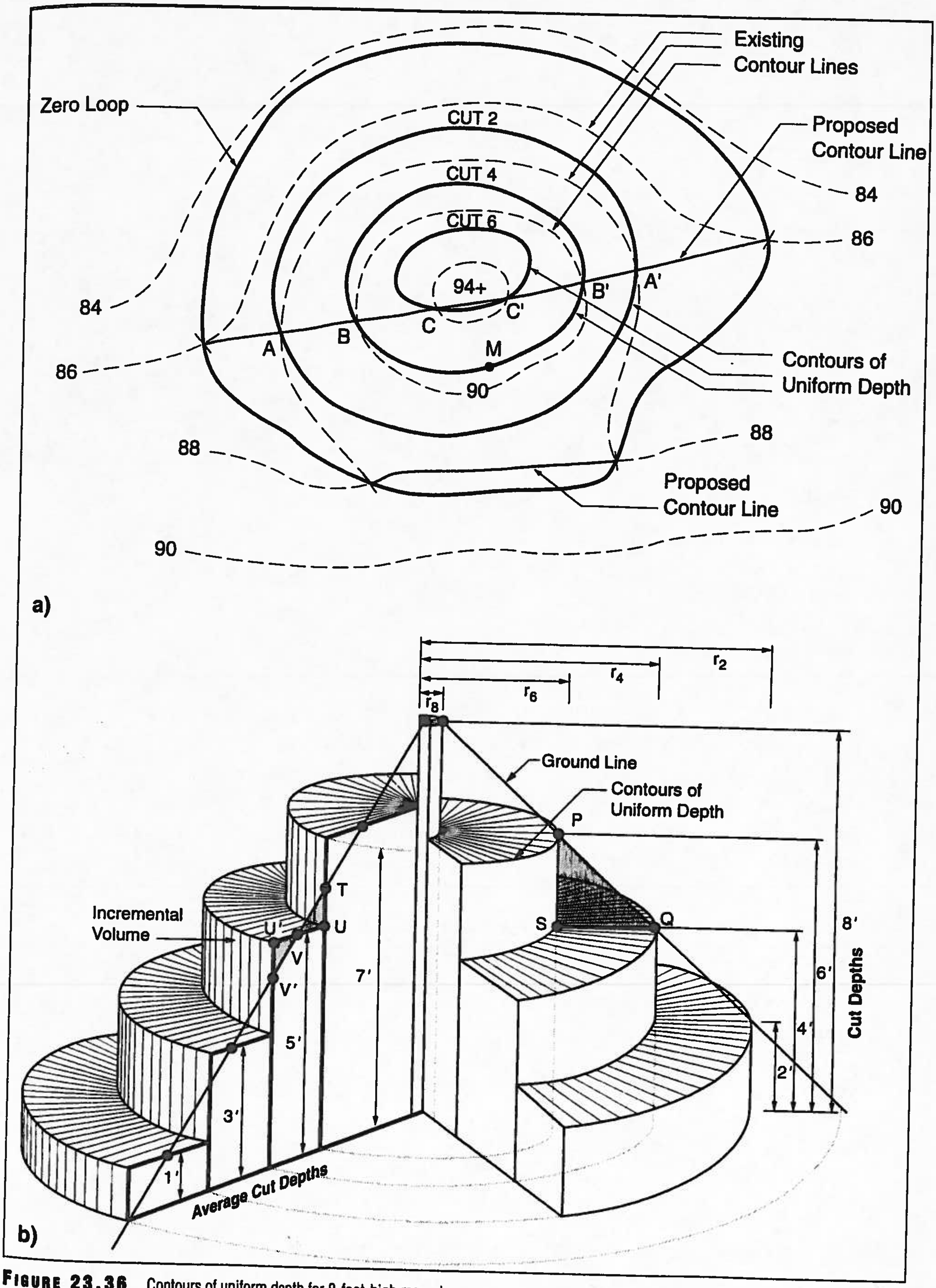


FIGURE 23.36 Contours of uniform depth for 8-foot-high mound.

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 23.37), the projection of these surfaces onto the plan view assumes these surfaces to be parallel to a horizontal plane, as shown in Figure 23.37.

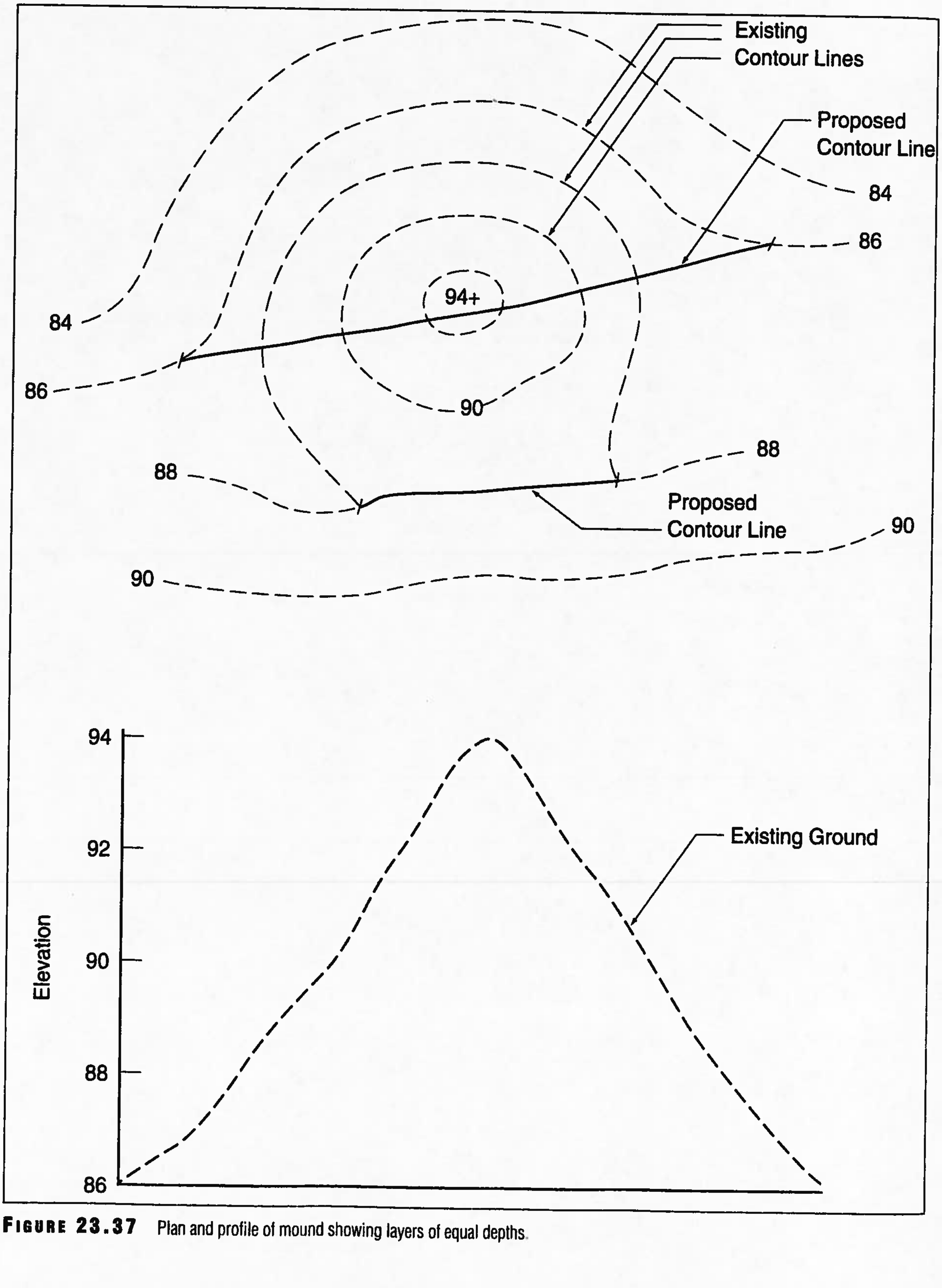


FIGURE 23.37 Plan and profile of mound showing layers of equal depths.

Figure 23.37 shows a profile view of the mound and the corresponding contours in plan view. The profile shows the underlying surfaces in increments of 2 feet. The first layer under the original ground represents a cut depth equal to 2 feet. In plan view this layer appears as a loop where the difference in elevation between the existing grade and proposed grade is 2 feet. 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, . . . feet, 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 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 as follows:

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 is 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. It is easiest to keep the planes at the same increment as the contour interval. If the contour interval is 2 feet, the next plane would be at a depth/height of 2 feet. 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 feet, as indicated by points A and A′ in Figure 23.36. A loop that connects these points and all points where the proposed elevation is 2 feet higher/lower than the existing elevation outlines a plane that is 2 feet higher/lower than the zero plane. A loop crosses 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 feet, the next plane is at a depth/height of 4 feet. Draw a loop that connects all points 4 feet higher/lower than the existing elevation (points B and B′ in Figure 23.36). 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, shown in Table 23.6. 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 product of Column 3 and Column 4. Column 6 is the accumulated earthwork of Column 5.

EXAMPLE 3

Using the same grading plan as in the previous example, perform an ETO using the equal planes method. Figure 23.38 shows the grading plan with the zero lines, and the 2-foot, 4-foot, and 6-foot depths of cut loops as well as the 2-foot, 4-foot, and 6-foot depths of fill loops.

The area of each loop is determined and entered into Column 2 of Table 23.6. 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 = Column 3 × Column 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 incremental volume of cut or fill. A summation of all incremental fill volumes and cut volumes gives the total for the site.

Figure 23.39 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 23.40, 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, decreasing unit area size decreases the precision. For each unit area, an interpolation between contours is necessary to determine the elevations at each

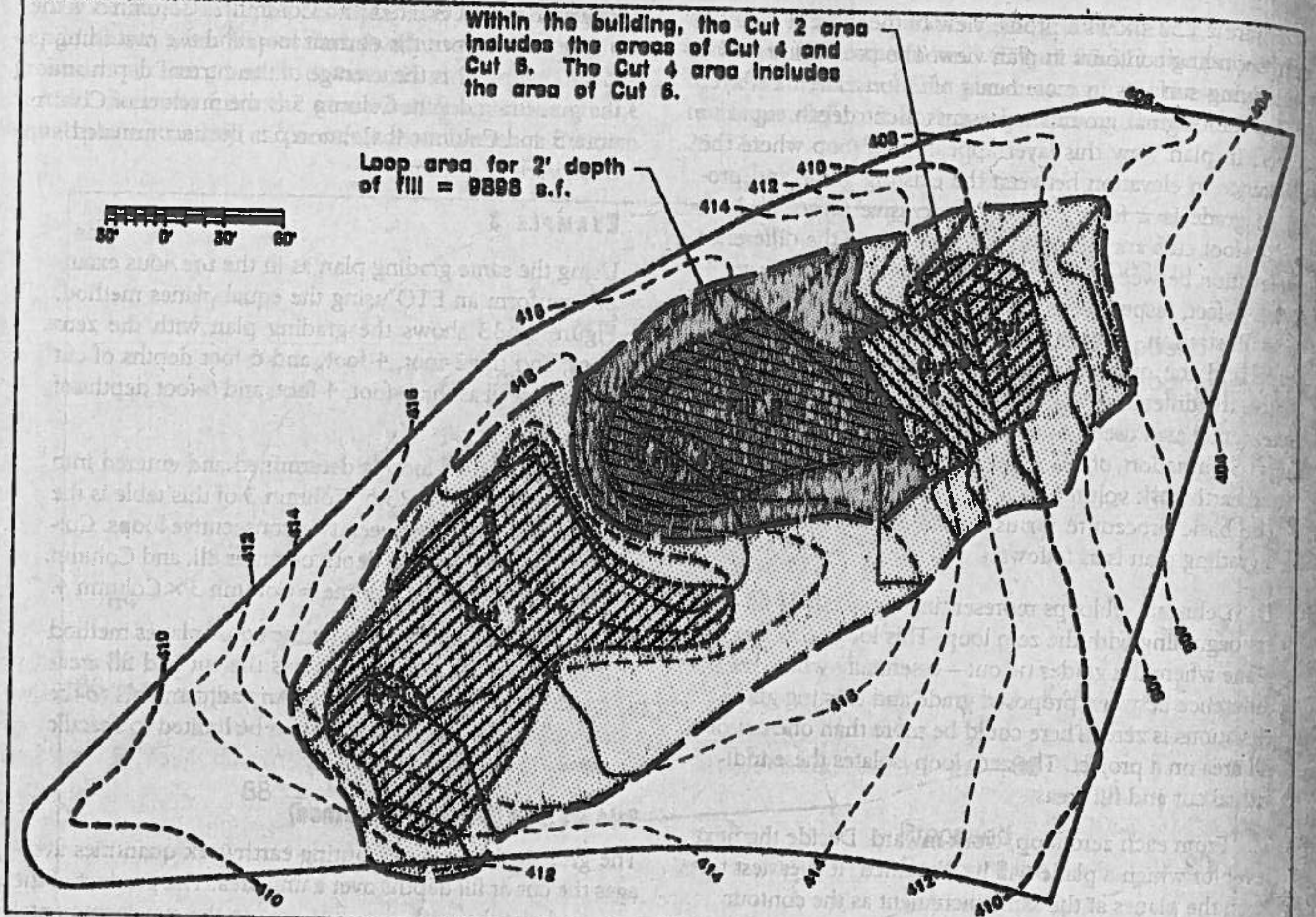


FIGURE 23.38 Cut and fill loops for equal planes method.

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 as follows:

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-inch squares for plans with scales of 1 inch = 100 feet 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 incremental 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/deficiency dirt. Summing all positive and negative numbers separately is the amount of cut and fill, respectively.

Figure 23.41 shows the grid method for the same grading plan with 1-inch 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, that is, 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 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

TABLE 23.6 ETO Computations for the Equal-Planes Method

(1) CUT DEPTH	(2) LOOP AREA (FT²)	(3) DIFF. IN AREA (FT²)	(4) AVG. DEPTH (FT)	(5) INCR. VOLUME (FT³)
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 ft³
				= 4,096 yd³
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 ft³
				= 1423 yd³

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 23.41 has four rows and eight columns. The incremental volume for each grid is given in Table 23.7.

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:

$$\frac{38.3\ \text{ft} \times (60\ \text{ft} \times 60\ \text{ft})}{27\ \text{ft}^3\ \text{per yd}^3} = 5100\ \text{yd}^3\ \text{of cut} \qquad (23.15)$$

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

The unusual low value for the fill volume (430 cubic yards) is due to the large grid size relative to the small fill area of the plan.

Comparing DTMs

When grading software is used to develop the grading plan, typically a proposed and an existing DTM exist. Rough earthwork quantities can be obtained by simply comparing the two DTMs. In general, the existing is considered the first (or bottom) surface and the proposed is the second (or top) surface. Thus, if the second surface is above the first, the volume that is contained in between is output as a fill volume, and if the second surface is below the first, the volume that is contained in between is output as a cut volume. The precise way

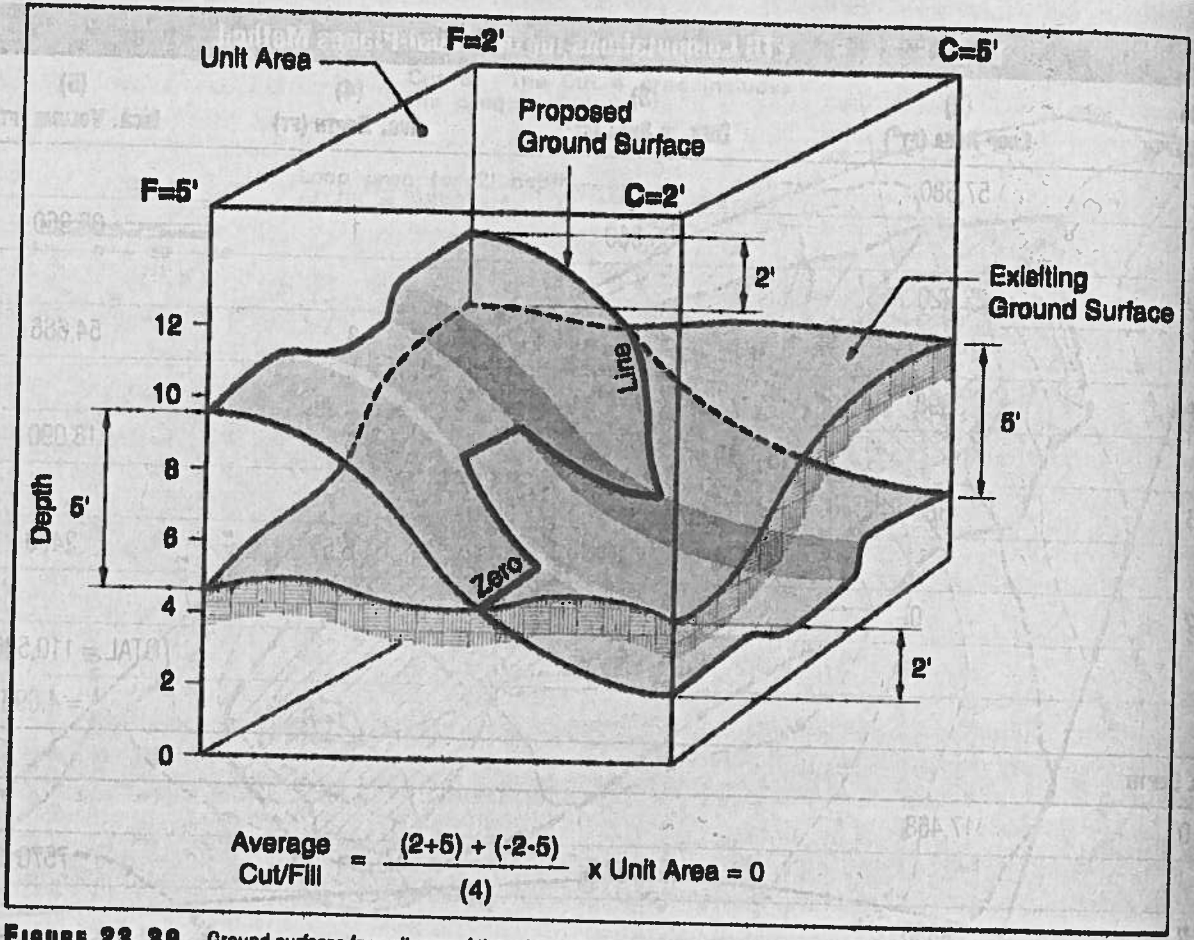


FIGURE 23.39 Ground surfaces for unit area of the grid method.

these volumes are computed may vary depending on the particular software that is being used, and each software package may offer more than one method for computing the volumes. One possible method is illustrated in Figure 23.42. In this example, the triangles of the proposed (upper) surface are projected onto the existing (lower) surface, forming a series of three-dimensional columns. The volumes of these columns are then calculated and summed by the computer.

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, subbase 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 they may affect the computed gross quantity by 10 to 30 percent. 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.

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 inches. 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 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 cases, the earthwork quantity will not be adversely affected if the topsoil depth is assumed uniform over the entire graded area. Another, more time-consuming method is to actually draw the topsoil depth

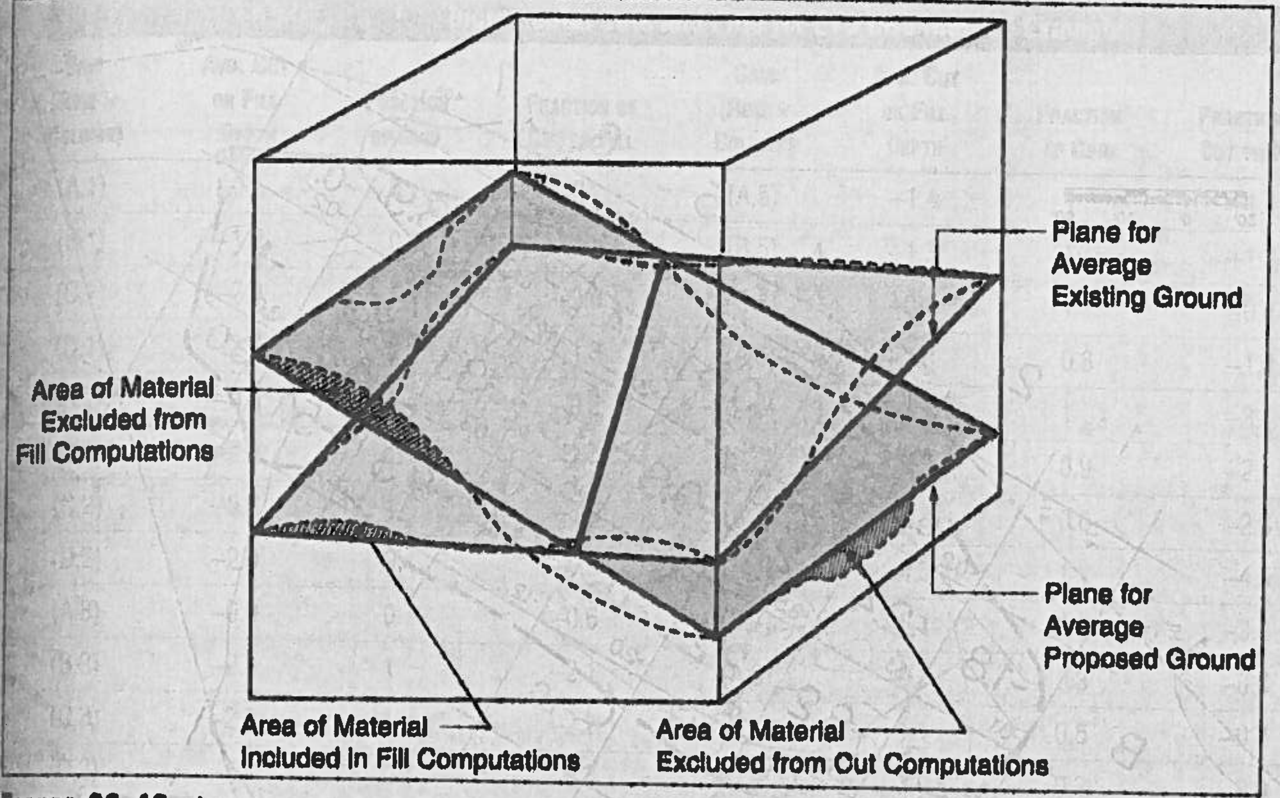


FIGURE 23.40 Average ground surface by linear approximation.

on the cross-section drawings and calculate the topsoil quantity using the average-end-area method. This procedure is followed 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 the fill areas. The 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 the 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 square feet. An assumed uniform topsoil depth of 6 inches equates to approximately 1100 cubic yards of topsoil. Likewise, within the fill area loop of 18,711 square feet, the approximate topsoil volume is 350 cubic yards. The vegetated area in the cut area is 26,200 square feet, and in the fill area it is 8000 square feet. Using a replacement topsoil depth of 14± inches results in using all of the stockpiled topsoil tabulated in Table 23.8.

When using computer modeling to determine earthwork quantities, the existing grade DTM is modified to represent the site after the required topsoil has been stripped. The modified DTM is the surface that will then be compared to the proposed surface. This eliminates the need to make manual adjustments to the cut and fill quantities.

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 8 inches to 2 feet in typical situations. In extreme cases, the thickness might be double these depths. Concrete pads and the subbase for resident houses has a thickness of 8 to 12 inches. Concrete pads and subbase for parking structures and high-rise commercial buildings typically are 18 to 24 inches thick. The pavement structure for roads may be 12 to 18 inches thick.

To account for subbase and concrete thickness, the earthwork quantity is based on the subgrade 10 elevation rather than the finished grade elevation. Therefore, in cut areas the base volume of the cut must be increased by the total volume of the subbase, pavement, and concrete. In fill areas, the

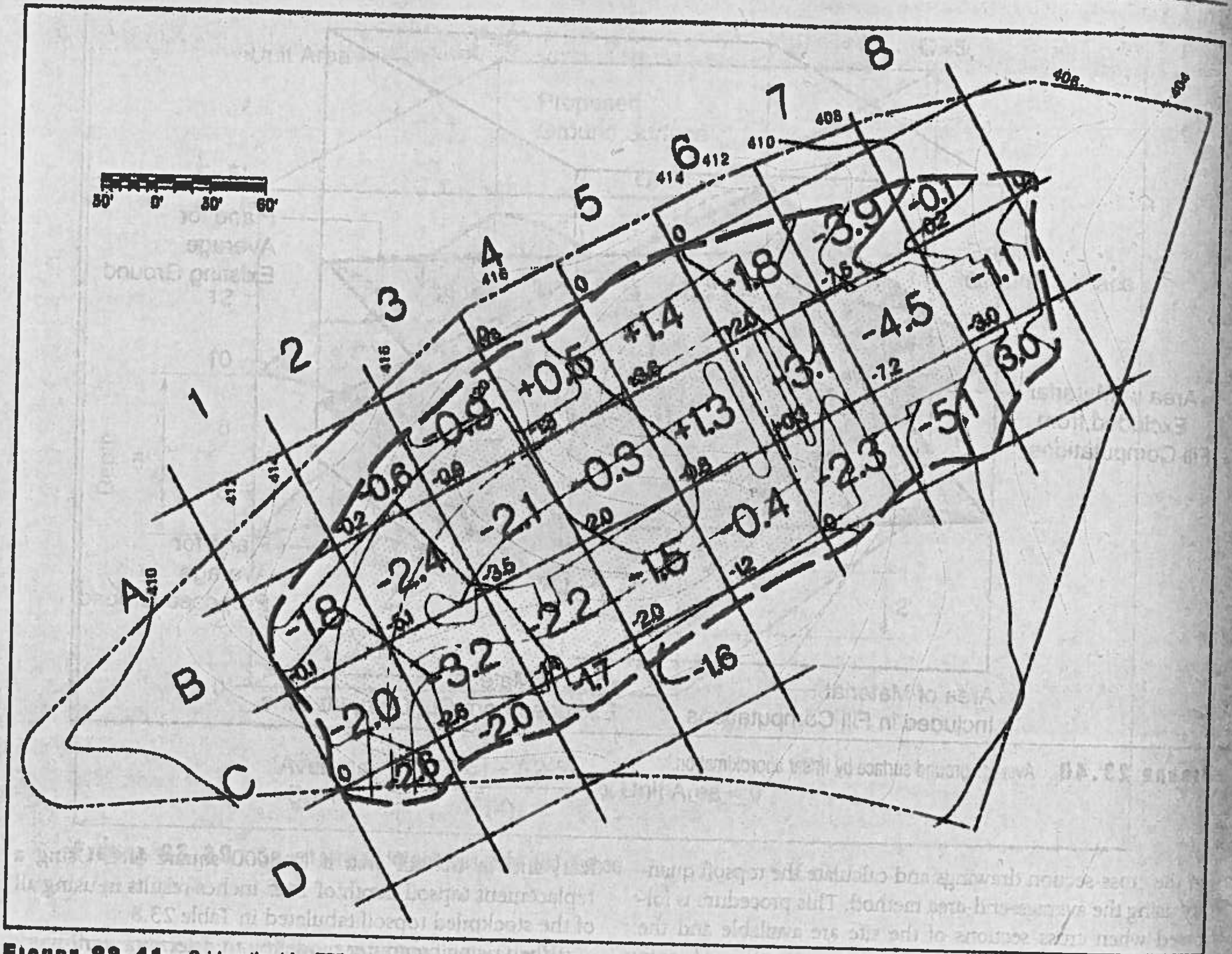


FIGURE 23.41 Grid method for ETO.

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 inches. The area of pavement in the cut area and the fill area is determined (by planimeter) to be 25,000 square feet and 10,000 square feet, respectively. The building pad has combined concrete and coarse aggregate layer thickness of 12 inches and a footprint area of 7000 square feet. The adjusted earthwork volumes for these items are shown in Table 23.9.

When using computer modeling to determine earthwork quantities, it makes sense to create a DTM that represents the surface that will result from mass grading of the site. For example, the elevations defining the roadway would be set at the bottom of the roadway box and not at finished grade. This would also hold true for concrete pads and building foundations. In the case of mass grading for residential subdivisions—where the lot is initially constructed lower than finished grade—the mass grade elevations would be incorporated into the surface.

This DTM would, for the purposes of earthwork calculations, be considered the proposed surface. This DTM would then be compared to the modified for topsoil stripping surface (as previously described) to determine the earthwork quantities. This eliminates the need to make manual adjustments to the cut and fill quantities.

Utilities

Accounting for soil volume for relatively narrow, shallow trenches is not typically done. As an example, the volume of a trench 6 feet deep and 3 feet wide is equal to 0.67 cubic yards per linear foot. The volume of a 15-inch conduit with 6 inches of bedding material is 0.10 cubic yards per linear foot. If a 15 percent 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 size of the trench becomes larger or deeper than the shallow example described here, 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.

TABLE 23.7 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
(A,1)	0	0	0
(B,1)	−1.8	0.8	−1.4
(C,1)	−2.0	1	−2.0
(D,1)	−2.6	0.5	−1.3
(A,2)	−0.6	0.4	−0.2
(B,2)	−2.4	1	−2.4
(C,2)	−3.2	1	−3.2
(D,2)	−2.0	0.4	−0.8
(A,3)	−0.9	0.7	−0.6
(B,3)	−2.1	1	−2.1
(C,3)	−2.2	1	−2.2
(D,3)	−1.7	0.4	−0.7
(A,4)	+0.5	0.9	+0.5
(B,4)	−0.3	1	−0.3
(C,4)	−1.5	1	−1.5
(D,4)	−1.6	0.2	−0.3
(A,5)	+1.4	1	+1.4
(B,5)	+1.3	1	+1.3
(C,5)	−0.4	1	−0.4
(A,6)	−1.8	0.8	−1.4
(B,6)	−3.1	1	−3.1
(C,6)	−2.3	0.9	−2.1
(A,7)	−3.9	0.6	−2.3
(B,7)	−4.5	1	−4.5
(C,7)	−5.1	0.7	−3.6
(A,8)	−0.1	0.3	−0.3
(B,8)	−1.1	0.6	−0.7
(C,8)	−3.0	0.3	−0.9
			Σ Cut = 38.3 ft
			Σ Fill = 3.2 ft

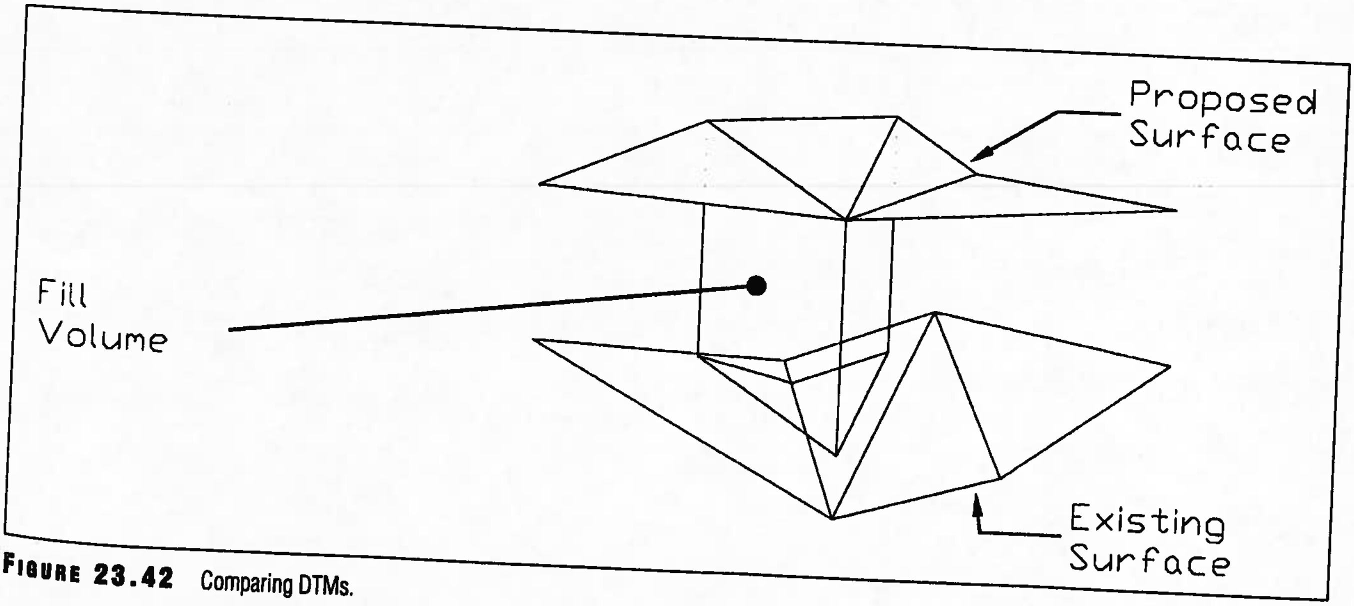


FIGURE 23.42 Comparing DTMs.

TABLE 23.8 ETO Values Adjusted for Topsoil Depth

Adjustment	Cut Volume (yd^3)	Fill Volume (yd^3)
Gross	4096	1423
Strip topsoil (6 inches)	–1100	+350
Replacement topsoil (14 inches)	+1130	–345
Adjusted volume =	4126	1428

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 about 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.

TABLE 33.9 ETO Values Adjusted for Subbase, Pavement, and Concrete Thickness

Adjustment	Cut Volume (yd^3)	Fill Volume (yd^3)
Gross	4096	1423
Strip topsoil (6 inches) replacement	–1100	+350
Topsoil (14 inches)	+1130	–345
Building pad (12 inches)	+260	–0
Pavement (10 inches)	+770	–310
Adjusted volume =	5156	1118

When using computer modeling to determine earthwork quantities, making adjustments to the earthwork quantities to account for undercut can sometimes be facilitated by using DTMs.

Take, for example, a site that has bedrock so close to the surface that rock needs to be removed to achieve finished grade. Further, assume that there is also rock exposed at existing grade. In this scenario, the amount of cut would need to be adjusted by the amount of rock removal and the topsoil stripping quantity would need to be adjusted per the surface rock. Figure 23.43 illustrates this concept.

If you consider the lines in Figure 23.43 to be surfaces, it is easy to see that Area A represents the amount of rock that would need to be removed. By comparing the proposed (mass) grade DTM to a DTM representing the surface of rock, the volume of rock removal would be determined (equal to the cut quantity generated by that comparison). The site earthwork cut quantity would be adjusted by subtracting the rock removal quantity.

If there are areas on the site where bedrock is so close to the surface that there is a thinner layer of topsoil or no topsoil at all, the topsoil stripping quantity would need to be adjusted per the amount of rock encroachment. In Figure 23.43, Area B represents the volume of rock encroachment and can be determined by comparing the rock surface DTM to the DTM that represents the existing surface after the topsoil has been stripped. The amount of rock encroachment would be the fill volume for this comparison and would be subtracted from the topsoil stripping quantity.

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 higher in-place density in most cases. If the same dirt excavated from a 1-cubic-foot hole is placed back into the hole without any compaction efforts, there will be excess dirt. Later, a depression appears in the hole area as the result of 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 is less than the amount of voids of the naturally consolidated soil, hence, 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 pounds per cubic foot, with 21.2 percent water content in its natural state. Laboratory test results show that this same soil has a maximum density of 110 pounds per cubic foot at optimum moisture content (OMC).

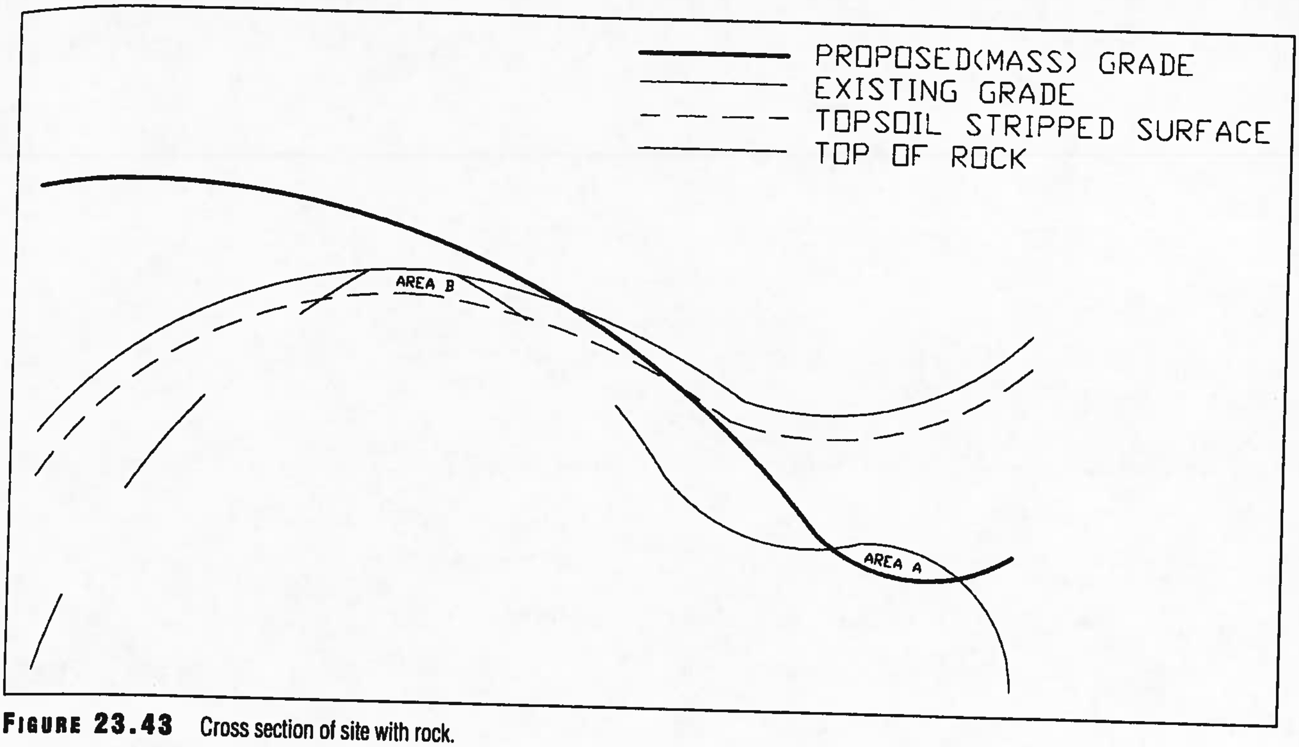


FIGURE 23.43 Cross section of site with rock.

(a) If a site requires 10,000 cubic yards 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. The relative ratios of the borrow and fill densities and volumes can be expressed as:

$$\frac{D_b}{D_f} = \frac{V_f}{V_b} \tag{23.16}$$

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

$$\frac{90\ \text{lb/ft}^3}{110\ \text{lb/ft}^3} = \frac{10{,}000\ \text{yd}^3}{V_b} \tag{23.17}$$

or $V_b \approx 12{,}200\ \text{yd}^3$

(b) How much volume will 10,000 cubic yards of borrow material occupy if placed at maximum density?

$$\frac{90\ \text{lb/ft}^3}{110\ \text{lb/ft}^3} = \frac{V_f}{10{,}000\ \text{yd}^3} \tag{23.18}$$

or $V_f \approx 8{,}200\ \text{yd}^3$

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

Part a:

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

Part b:

$$\frac{12{,}200\ \text{yd}^3 - 10{,}000\ \text{yd}^3}{12{,}200\ \text{yd}^3} = 18\% \tag{23.19}$$

Part c shows that relative to the required fill volume, 22 percent more borrow material is required, and relative to a given borrow volume the material reduces only 18 percent in volume when placed at maximum density. Notice that the borrow volume reduces by the same amount in both cases, that is, (12,200 – 10000)/12200 = 18 percent and (10,000 – 8200)/10000 = 18 percent. 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) 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 might range from 10 to 30 percent 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 percent. The measured fill volume is 1095 cubic yards. This requires 1.2(1095) = 1314 cubic yards. Assuming the cut volume is adequate for use as compacted fill, the resulting excess is 4560 – 1314 = 3246 cubic yards. This can be hauled away to be used as compacted fill elsewhere. The remaining 3246 cubic yards of excavated material converts to 0.8(3246) = 2600 cubic yards of fill material.

Table 23.10 shows the final tabulation to account for earthwork adjustments.

EARTHWORK SUMMARY

As noted at the beginning of the discussion on earthwork, it is very important to design a balanced site. This is because the movement of soil can be very expensive, often the single most costly construction item. Earthwork computations and/or digital modeling can be time consuming; however, the time spent is more than justified by the amount of money that can be saved by reducing the amount of material that must be wasted or hauled in a surplus cut situation or minimizing the amount of material that must be purchased and brought to the site in an excess fill situation. The designer should prepare ETOs throughout the design process in order to accurately quantify the required earthwork as well as develop a design that will optimize earthwork efforts.

TABLE 23.10 Tabulated ETO Values

ADJUSTMENT	CUT VOLUME (YD³)	FILL VOLUME (YD³)
Gross	4096	1423
Strip topsoil (6 inches) replacement	1100	+350
Topsoil (14 inches)	+1130	–345
Building pad (12 inches)	+260	–0
Pavement (10 inches)	+770	–310
Undercut	+0	+0
Large conduits and structures	+0	—
Subtotal =	5156	1118
Shrinkage (20%)		+224
Net fill volume =		1342
Net cut volume =	3814	

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ADDITIONAL INFORMATION

For additional information on computer-aided design software, smart drawings, land development software, and digital terrain models, go to the following sites on the World Wide Web:

www.autodesk.com

www.bentley.com