highway corridor alignment and aid in developing alternative alignments. It is a planning tool that can serve as an excellent aid to engineers by presenting a project's strengths and weaknesses in a wide variety of formats to suit any audience.

14.3 HIGHWAY EARTHWORK AND FINAL PLANS

The final element in the location process is to establish the horizontal and vertical alignments of the highway project and to prepare highway plans and specifications for estimating project costs and preparation of bids by contractors. The following sections explain how the terrain influences the cost to transport earthen materials that will be used to construct the roadbed and how to estimate payment. The final result of the location process is a highway plan used in estimating quantities and computing the overall project cost.

14.3.1 Highway Grades and Terrain

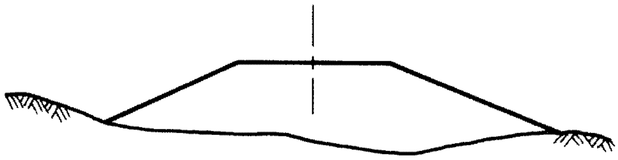
One factor that significantly influences the selection of a highway location is the terrain of the land, which in turn affects the laying of the grade line. The primary factor that the designer considers on laying the grade line is the amount of earthwork that will be necessary for the selected grade line. One method to reduce the amount of earthwork is to set the grade line as closely as possible to the natural ground level. This is not always possible, especially in undulating or hilly terrain. The least overall cost also may be obtained if the grade line is set such that there is a balance between the excavated volume and the volume of embankment. Another factor that should be considered in laying the grade line is the existence of fixed points, such as railway crossings, intersections with other highways, and in some cases existing bridges, which require that the grade be set to meet them. When the route traverses flat or swampy areas, the grade line must be set high enough above the water level to facilitate proper drainage and to provide adequate cover to the natural soil.

The height of the grade line is usually dictated by the expected floodwater level. Grade lines should also be set such that the minimum sight distance requirements (as discussed in Chapter 3) are obtained. The criteria for selecting maximum and minimum grade lines are presented in Chapter 15. In addition to these guidelines, the amount of earthwork associated with any grade line influences the decision on whether the grade line should be accepted or rejected. The following sections describe how a highway grade is established that minimizes earth moving and maximizes the use of native soil.

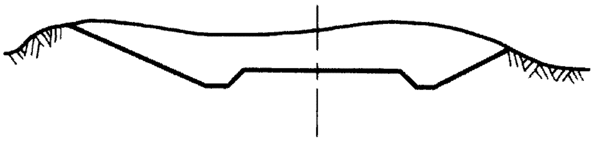
Computing Earthwork Volumes

One of the major objectives in selecting a particular location for a highway is to minimize the amount of earthwork required for the project. Therefore, the estimation of the amount of earthwork involved for each alternative location is required at both the preliminary and final stages.

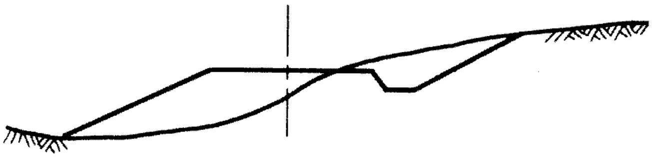
To determine the amount of earthwork involved for a given grade line, cross sections are taken at regular intervals along the grade line. The cross sections are usually spaced 50 ft apart, although this distance is sometimes increased for preliminary



(a) Fill



(b) Cut



(c) Fill and cut

Figure 14.16 Types of Cross Sections

engineering. These cross sections are obtained by plotting the natural ground levels and proposed grade profile of the highway along a line perpendicular to the grade line to indicate areas of excavation and areas of fill. Figure 14.16 shows three types of cross sections. When the computation is done manually, the cross sections are plotted on standard cross-section paper, usually to a scale of 1 in. to 10 ft for both the horizontal and vertical directions. The areas of cuts and fills at each cross section are then determined by the use of a planimeter or by any other suitable method. Surveying books document the different methods for area computation. The volume of earthwork is then computed from the cross-sectional areas and the distances between the cross sections.

A common method of determining the volume is that of average end areas. This procedure is based on the assumption that the volume between two consecutive cross sections is the average of their areas multiplied by the distance between them, computed as follows.

$$V = \frac{L}{54}(A_1 + A_2) \tag{14.7}$$

where

V = volume (yd^3)
A_1 and A_2 = end areas (ft^2)
L = distance between cross sections (ft)

The average end-area method has been found to be sufficiently accurate for most earthwork computations, since cross sections are taken 50 to 100 ft apart, and minor irregularities tend to cancel each other. When greater accuracy is required, such as in situations where the grade line moves from a cut to a fill section, the volume may be considered as a pyramid or other geometric shape.

It is common practice in earthwork construction to move suitable materials from cut sections to fill sections to reduce to a minimum the amount of material borrowed from borrow pits. When the materials excavated from cut sections are compacted at the fill sections, they fill less volume than was originally occupied. This phenomenon is referred to as *shrinkage* and should be accounted for when excavated material is to be reused as fill material. The amount of shrinkage depends on the type of material. Shrinkages of up to 50 percent have been observed for some soils. However, shrinkage factors used are generally between 1.10 and 1.25 for high fills and between 1.20 and 1.25 for low fills. These factors are applied to the fill volume in order to determine the required quantity of fill material.

Example 14.4 Computing Fill and Cut Volumes Using the Average End-Area Method

A roadway section is 2000 ft long (20 stations). The cut and fill volumes are to be computed between each station. Table 14.1 on page 726 lists the station numbers (column 1) and lists the end area values (ft^2) between each station that are in cut (column 2) and that are in fill (column 3). Material in a fill section will consolidate (known as shrinkage), and for this road section, is 10 percent. (For example, if 100 yd^3 of net fill is required, the total amount of fill material that is supplied by a cut section is $100 + (0.10 \times 100) = 100 + 10 = 110$ ft^3.)

Determine the net volume of cut and fill that is required between station 0 and station 1.

Solution:

$$V_{\text{cut}} = \frac{100(A_{0C} + A_{1C})}{54} = \frac{100(3 + 2)}{54} = 9.25 \text{ yd}^3$$

$$V_{\text{fill}} = \frac{100(A_{0F} + A_{1F})}{54} = \frac{100(18 + 50)}{54} = 125.9 \text{ yd}^3$$

$$\text{Shrinkage} = 125.9\ (0.10) = 13 \text{ yd}^3$$

$$\text{Total fill volume} = 126 + 13 = 139 \text{ yd}^3$$

The cut and fill volume between station 0 + 00 and 1 + 00 is shown in columns 4 and 7.

Cut: 9 yd^3 (column 4)
Fill: 126 yd^3 (column 5)
Shrinkage: 13 yd^3 (column 6)
Total fill required: 139 yd^3 (column 7)

Table 14.1 Computation of Fill and Cut Volumes and Mass Diagram Ordinate

End Area (ft^2)			*Volume (yd^3)*				*Net Volume (4 to 7)*		
1 Station	*2 Cut*	*3 Fill*	*4 Total Cut*	*5 Fill*	*6 Shrinkage 10 percent*	*7 Total Fill (5 + 6)*	*8 Fill (−)*	*9 Cut (+)*	*10 Mass Diagram Ordinate*
0	3	18	9	126	13	139	130	—	0
1	2	50	7	272	27	299	292	—	−130
2	2	97	11	420	42	462	451	—	−422
3	4	130	22	335	34	369	347	—	−873
4	8	51	89	178	18	196	107	—	−1220
5	40	45	157	120	12	132	—	25	−1327
6	45	20	231	46	5	51	—	180	−1302
7	80	5	374	13	1	14	—	360	−1122
8	122	2	467	4	0	4	—	463	−762
9	130	0	500	0	0	0	—	500	−299
10	140	0	444	6	1	7	—	437	201
11	100	3	333	61	6	67	—	266	638
12	80	30	287	93	9	102	—	185	904
13	75	20	231	130	13	143	—	88	1089
14	50	50	130	241	24	265	135	—	1177
15	20	80	56	333	33	366	310	—	1042
16	10	100	19	407	41	448	429	—	732
17	0	120	6	444	44	488	482	—	303
18	3	120	80	315	31	346	266	—	−179
19	40	50	130	148	15	163	33	—	−445
20	30	30	—	—	—	—	—	—	−478

$$\begin{aligned}\text{Net volume between stations 0-1} &= \text{total cut} - \text{total fill} = 9 - 139\\ &= -130\ \text{yd}^3\ \text{(column 8)}\end{aligned}$$

Note: Net fill volumes are negative (−) (column 8) and net cut volumes are positive (+) (column 9).

Similar calculations are performed between all other stations, from station 1 + 00 to 20 + 00, to obtain the remaining cut or fill values shown in columns 2 through 9.

Computing Ordinates of the Mass Diagram

The mass diagram is a series of connected lines that depicts the *net* accumulation of cut or fill between any two stations. The ordinate of the mass diagram is the net accumulation in cubic yards (yd^3) from an arbitrary starting point. Thus, the difference in ordinates between any two stations represents the net accumulation of cut or fill between these stations. If the first station of the roadway is considered to be the starting point, then the net accumulation at this station is zero.

Example 14.5 Computing Mass Diagram Ordinates

Use the data obtained in Example 14.4 to determine the net accumulation of cut or fill beginning with station 0 + 00. Plot the results.

Solution: Columns 8 and 9 show the net cut and fill between each station. To compute the mass diagram ordinate between station X and $X + 1$, add the *net* accumulation from Station X (the first station) to the net cut or fill volume (columns 8 or 9) between stations X and $X + 1$. Enter this value in column 10.

Station 0 + 00 mass diagram ordinate = 0

Station 1 + 00 mass diagram ordinate = $0 - 130 = -130 \text{ yd}^3$

Station 2 + 00 mass diagram ordinate = $-130 - 292 = -422 \text{ yd}^3$

Station 3 + 00 mass diagram ordinate = $-422 - 451 = -873 \text{ yd}^3$

Station 4 + 00 mass diagram ordinate = $-873 - 347 = -1220 \text{ yd}^3$

Station 5 + 00 mass diagram ordinate = $-1220 - 107 = -1327 \text{ yd}^3$

Station 6 + 00 mass diagram ordinate = $-1327 + 25 = -1302 \text{ yd}^3$

Station 7 + 00 mass diagram ordinate = $-1302 + 180 = -1122 \text{ yd}^3$

Continue the calculation process for the remaining 13 stations to obtain the values shown in column 10 of Table 14.1. A plot of the results is shown in Figure 14.17 on page 728.

Interpretation of the Mass Diagram

Inspection of Figure 14.17 and Table 14.1 reveals the following characteristics.

1. When the mass diagram slopes downward (negative), the preceding section is in fill, and when the slope is upward (positive), the preceding section is in cut.
2. The difference in mass diagram ordinates between any two stations represents the *net accumulation* between the two stations (cut or fill). For example, the net accumulation between station 6 + 00 and 12 + 00 is $1302 + 904 = 2206 \text{ yd}^3$.
3. A horizontal line on the mass diagram defines the locations where the net accumulation between these two points is zero. These are referred to as "balance points," because there is a balance in cut and fill volumes between these points. In Figure 14.15, the "x" axis represents a balance between points A' and D' and a balance between points D' and E'. Beyond point E', the mass diagram indicates a fill condition for which there is no compensating cut. The maximum value is the

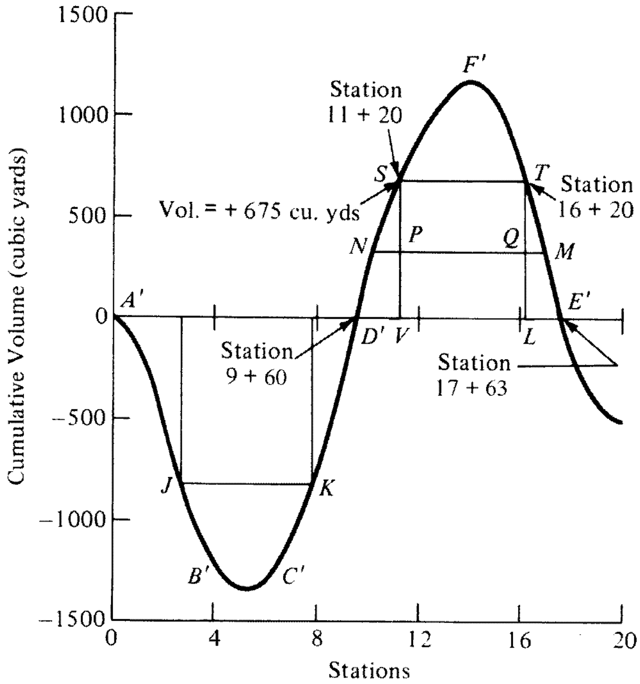


Figure 14.17 Mass Diagram for Computation Shown in Table 14.1

ordinate at station 20 + 00 of −478 yd^3. For this section, imported material (called borrow) will have to be purchased and transported from an off-site location.

4. Other horizontal lines can be drawn connecting portions of the mass diagram. For example lines *J*-*K* and *S*-*T*, which are each five stations long, depict a balance of cut and fill between stations at points *J* and *K* and *S* and *T*.

Example 14.6 Computing Balance Point Stations

Compute the value of balance point stations for the mass diagram in Figure 14.17 for the following situations:

(a) The x-axis
(b) The horizontal distance *S*-*T*, which measures 500 ft

Solution:

(a) Balance points are computed by interpolation using the even stations where the ordinates change from cut to fill (or vice versa).

Balance point D' occurs between Station 9 + 00 and 10 + 00 (since ordinate values are −299 and +201).

Assuming that the mass diagram ordinate changes linearly between stations, by similar triangles, we can write

$$\text{Station of the Balance Point } D' = (9 + 00) + [299/(299 + 201)](100) = 9 + 60$$

Similarly,

$$\text{Station of the Balance Point } E' = (17 + 00) + [303/(303 + 179)](100) = 17 + 63$$

(b) To determine the balance point stations for line *ST*, it is necessary to draw the mass diagram to a larger scale than depicted in the textbook, and to read the station for one of the points directly from the diagram. Using this technique, station 11 + 20 was measured for point *S* and from this value the station for point *T* is computed as

$$(11 + 20) + (5 + 00) = \text{Station } 16 + 20$$

Computing Overhaul Payments

Contractors are compensated for the cost of earthmoving in the following manner. Typically, the contract price will include a stipulated maximum distance that earth will be moved without the client incurring additional charges. If this distance is exceeded, then the contract stipulates a unit price add-on quoted in additional station-yd^3 of material moved. The maximum distance for which there is no charge is called free haul. The extra distance is called overhaul.

Example 14.7 Computing Overhaul Payment

The free-haul distance in a highway construction contract is 500 ft and the overhaul price is \$11/yd^3 station. For the mass diagram shown in Figure 14.17, determine the extra compensation that must be paid to a contractor to balance the cut and fill between station 9 + 60 (*D*) and station 17 + 63 (*E*).

Solution:

Step 1. Determine the number of cubic yards of overhaul.

The overhaul volume will occur between stations 9 + 60 and 11 + 20, and between stations 16 + 20 and 17 + 63. The overhaul value is obtained by interpolation between stations 11 + 00 and 12 + 00 or by reading the value from the mass diagram.

By interpolation, the value is

$$\begin{aligned}\text{Overhaul} &= \text{Ordinate at station } 11 + (\text{difference in ordinates at 12 and 11})\,(20/100)\\ &= 638 + (904 - 638)(0.2) = 638 + 53 = 691 \text{ yd}^3\end{aligned}$$

This overhaul value should equal the value at station 16 + 20. By interpolation, the value is

$$732 - (732 - 303)(0.2) = 646 \text{ yd}^3$$

Since the values are not equal, use the average (669 yd^3) or measure the overhaul from a larger scale diagram to obtain a value of 675 yd^3. This value is selected for the calculation of contractor compensation.

Step 2. Determine the overhaul distance.

The method of moments is used to compute the weighted average of the overhaul distances from the balance line to the station where free haul begins.

Beginning with stations 9 + 60 to 10 + 00, the volume moved is 201 yd^3, and the average distance to the free-haul station (11 + 20) is $(10 + 00 - 9 + 60)/2 + 100 + 20 = 140$ ft.

From stations 10 + 00 to 11 + 00, the volume moved is $(638 - 201) = 437$ yd^3, and the distance moved to the free-haul line is $(11 + 00 - 10 + 00)/2 + 20 = 70$ ft.

From station 11 + 00 to station 11 + 20, the volume moved is $675 - 638 = 37$ yd^3, and the average distance is 10 ft.

Overhaul distance moved between station 9 + 60 and 11 + 20 is

$$\{(201)(140) + (437)(70) + (37)(10)\} \div 675 = 59{,}100 \div 675 = 87.6 \text{ ft}$$

Similarly, compute the overhaul distance between the balance point at station 17 + 63 and the beginning of free haul at station 16 + 20. Beginning with stations 17 + 63 to 17 + 00, the volume moved is 303 yd^3, and the average distance to the free-haul station (16 + 20) is $(17 + 63 - 17 + 00) \div 2 + (17 + 00 - 16 + 20) = 111.5$ ft.

From stations 17 + 00 to 16 + 20, the volume moved is $(675 - 303) = 372$ yd^3, and the distance moved to the free-haul line is $(17 + 00 - 16 + 20) \div 2 = 40$ ft.

Overhaul average distance moved between station 16 + 20 and 17 + 63 is

$$\{(303)(111.5) + (372)(40)\} \div 675 = 48{,}664.5 \div 675 = 72.1 \text{ ft}$$

Total overhaul distance = 87.6 + 72.1 = 159.7 ft

Step 3. Compute overhaul cost due to the contractor.

$$\begin{aligned}\text{Overhaul cost} &= \text{contract price } (\$/\text{yd}^3 \text{ station}) \times \text{overhaul } (\text{yd}^3) \times \text{stations}\\ &= 11 \times 675 \times (0.876 + 0.721) = \$11{,}858\end{aligned}$$

Computer programs are now available that can be used to compute cross-sectional areas and volumes directly from the elevations given at cross sections. Some programs will also compute the ordinate values for a mass diagram and determine the overhaul, if necessary.

14.3.2 Preparation of Highway Plans

An example of a highway plan and the proposed vertical alignment are illustrated in Figure 14.18. The solid line is the vertical projection of the centerline of the road profile. The dotted lines represent points along the terrain a distance of 55 ft from the centerline. The circles and triangles are points along the terrain that are 85 ft from the centerline of the road. This information can be used to plot cross sections that depict the shape of the roadway when completed. The final grade line is adjusted until the amount of excess cut or fill has been minimized. If there is an excess of cut material, then it must be removed and stored at another location. If there is an excess of fill, then material must be purchased and delivered to the site. Thus, an ideal situation occurs when there is a balance between the amount of cut and fill.

Once the final location of the highway system is determined, it is then necessary to provide the plans and specifications for the facility. The plans and specifications of a highway are the instructions under which the highway is constructed. They are also used for the preparation of engineers' estimates and contractors' bids. When a contract is let out for the construction of a highway, the plans and specifications are part of the contract documents and are therefore considered legal documents. The plans are drawings that contain all details necessary for proper construction, whereas the specifications give written instructions on quality and type of materials. Figure 14.18a on page 732 shows an example of a highway plan and the horizontal alignment. Figure 14.18b shows the highway plan and the vertical alignment. The latter view is, sometimes referred to as the *profile,* indicating the natural ground surface and the center line of the road with details of vertical curves. The horizontal alignment is usually drawn to a scale of 1 in. to 100 ft, although in some cases the scale of 1 in. to 50 ft is used to provide greater detail. In drawing the vertical alignment, the horizontal scale used is the same as that of the horizontal alignment, but the vertical scale is exaggerated 5 to 10 times. The vertical alignment may also give estimated earthwork quantities at regular intervals, usually at 100 ft stations.

Most state agencies require consultants to prepare final design drawings on standard sheets 36 × 22". These drawings are then usually reduced to facilitate easy handling in the field during construction. Other drawings showing typical cross sections and specific features such as pipe culverts and concrete box culverts are also provided. Standard drawings of some of these features that occur frequently in highway construction have been provided by some states and can be obtained directly from the highway agencies. Consultants may not have to produce them as part of their scope of work.

14.4 SUMMARY

The selection of a suitable location for a new highway requires information obtained from highway surveys. These surveys can be carried out by either conventional ground methods or use of electronic equipment and computers. A brief description of some of the more commonly used methods of surveys has been presented to introduce the reader to these techniques.

A detailed discussion of the four phases of the highway location process has been presented to provide the reader with the information required and the tasks involved in selecting the location of a highway. The computation of earthwork volumes is also presented, since the amount of earthwork required for any particular location may significantly influence the decision to either reject or select that location. Note,