Combination of Horizontal and Vertical Alinement

In the design of haulage roads, it is important that horizontal and vertical alinements complement each other. Poorly designed combinations can accent deficiencies and produce unexpected hazards.

Although the alternatives available to a haulage road designer are limited, it would be prudent to consider the following potential problem conditions.

1. Avoid introducing sharp horizontal curvature at or near the crest of a hill. The driver has difficulty perceiving the curve, especially at night when the lights of his vehicle shine ahead into space. If a curve is absolutely necessary, start it in advance of the vertical curve.

2. Avoid sharp horizontal curves near the bottom of hills or after a long sustained downgrade. Trucks are normally at their highest speed at these locations.

3. If passing is expected, design sections of haulage road with long tangents and constant grades. This is especially important in two-lane operations.

4. Avoid intersections near crest verticals and sharp horizontal curvatures. Intersections should be made as flat as possible. Consider the sight distance in all four quadrants.

HAULAGE ROAD CROSS SECTION

Subbase

A stable road base is one of the most important fundamentals of road design. Placement of a road surface over any material that cannot adequately support the weight of traversing traffic will severely hamper vehicular mobility and controllability. Moreover, lack of a sufficiently rigid bearing material beneath the road surface will permit excessive rutting, sinking, and overall deterioration of the traveled way. Thus, a great deal of maintenance will be necessary to keep the road passable.

Surface mine operators often elect to forego the use of subbase materials and accept infringements on mobility in the interest of economics. In other words, it may be less expensive to permit the existence of some segments of the road that hamper, but do not prohibit, vehicular movement, rather than incur the cost of constructing a good road base. Although this appears economical at the onset of road construction, the eventual results will nearly always be undesirable.

If the road surface is not constantly maintained, rutting will occur and create haulage intervals where vehicles must slow their pace to negotiate the adverse conditions. Over a period of time this will represent a considerable time loss to the production cycle. More importantly, these adverse conditions

pose a serious threat to vehicular controllability and create unsafe haulage road segments. Therefore, it is important that stability of the haulageway be guaranteed throughout its length.

In many surface mine operations, the road surface is underlain by natural strata capable of supporting the weight of any haulage vehicle. For example, in the case of bedded stone formations, it is sufficient to place only the desired road surface material directly on the bedded stone. However, the bearing capacity of other subsurface materials must be defined to determine if they can adequately support the weight of vehicles intended for use.

Defining the bearing capacity of soils is a detailed procedure that should be accomplished by a qualified soils engineer. Only in this manner can the capacity of a particular soil be determined. However, general information is available on the bearing capabilities of various soil groups.

The information in table 5, when compared with vehicle tire loads in pounds per square foot, identifies soil types that are inherently stable as road base and those that must be supplemented with additional material. The tire loading for most haulage vehicles filled to design capacity, with tires inflated to recommended pressure, will rarely exceed 16,000 psf. Although the tire loading may be somewhat less, depending on the number of tires, their size, ply rating, and inflation pressure, and overall vehicle weight, this figure can be utilized when determining subbase requirements. Any subgrade that is less consolidated than soft rock will require additional material in order to establish a stable base; therefore, the designer must determine the amount of additional material that should be placed over the subgrade to adequately support the road surface.

TABLE 5. - Presumptive bearing capacity of soils

Material	1,000 psf
Hard, sound rock	120
Medium hard rock	80
Hard pan overlying rock	24
Compact gravel and boulder-gravel formations; very compact sandy gravel	20
Soft rock	16
Loose gravel and sandy gravel; compact sand and gravelly sand; very compact sand--inorganic silt soils	12
Hard dry consolidated clay	10
Loose coarse to medium sand; medium compact fine sand	8
Compact sand-clay soils	6
Loose fine sand; medium compact sand--inorganic silt soils	4
Firm or stiff clay	3
Loose saturated sand clay soils, medium soft clay	2

One of the most widely used methods of making this determination is through the use of curves commonly referred to as CBR (California Bearing Ratio) curves. This system, originally developed in 1942, continues to be used by highway designers for evaluating subbase thickness requirements in

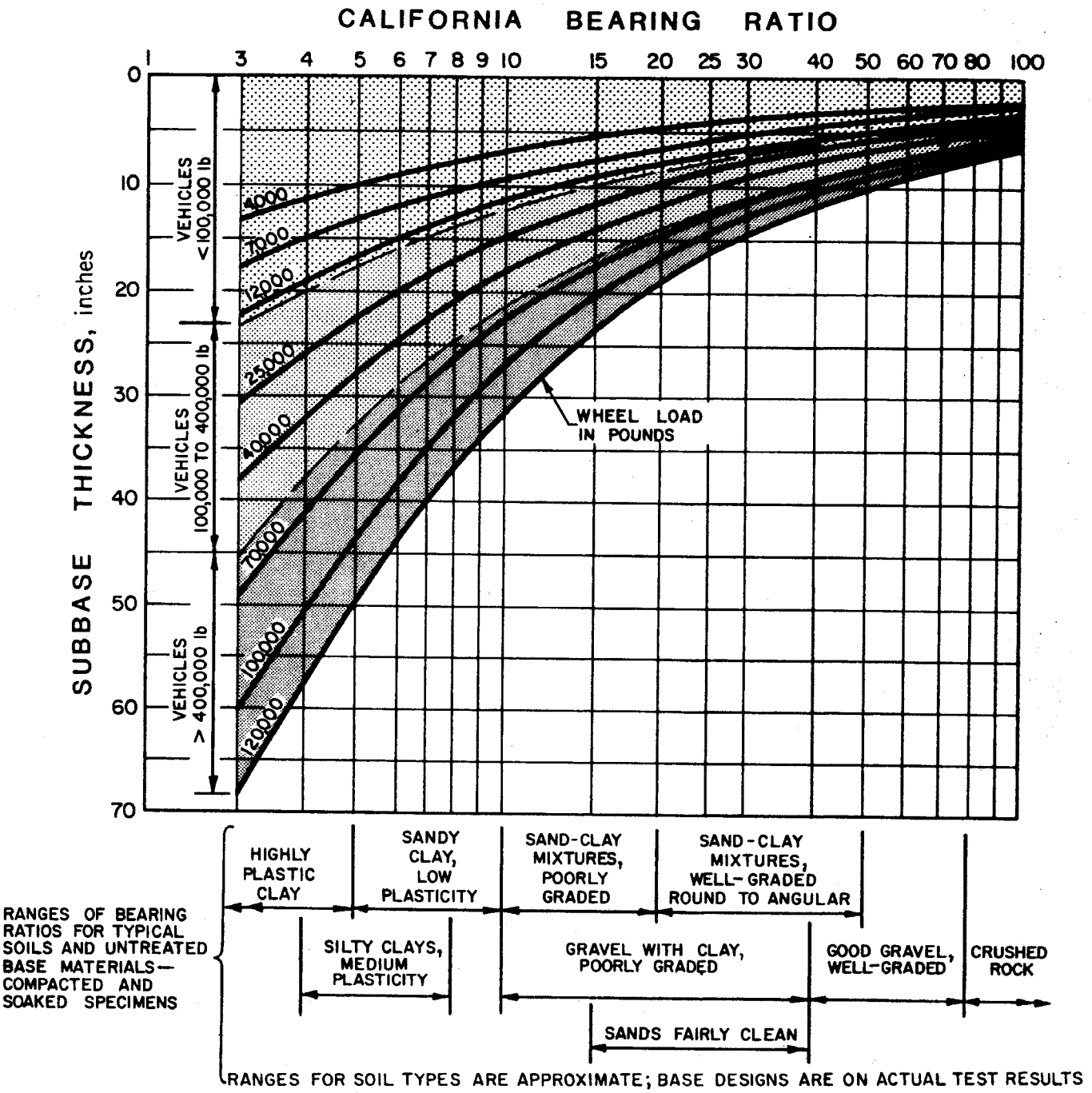

FIGURE 18. - CBR curves.

relation to subgrade characteristics. To be completely accurate, it necessitates CBR tests to precisely determine the bearing capabilities of both subgrade and subbase materials. These tests can be conducted by a soil-testing laboratory at relatively minimal cost simply by submitting samples of the subgrade and subbase materials.

The curves of figure 18 depict subbase thickness requirements for a wide range of CBR test values. To serve as a general indication of the subbase thicknesses required for various subgrade soil types, ranges of bearing ratios

for typical soils and untreated subbase materials are included at the bottom of the graph. It must be emphasized that these ranges are extremely vague. Actual test results may prove the bearing ratios for a specific soil group to be considerably better then the low value depicted on the chart. Although it is not a recommended practice, the CBR ranges reflected by the graph may be utilized in lieu of actual test results if only general information is desired. In this approach, the lowest possible CBR value presented for a given soil type should be used.

As shown by the curves, final subbase thicknesses are determined by vehicle wheel loads as well as soil type. Wheel loadings for any haulage vehicle can be readily computed from manufacturers' specifications. By dividing the loaded vehicle weight over each axle by the number of tires on that axle, the maximum loading for any wheel of the vehicle can be established. In every case, the highest wheel loading should be used for the determinations. When a wheel is mounted on a tandem axle, the value should be increased 20%.

To provide a readily available indication of the wheel-loading characteristics of currently manufactured vehicles, the chart is divided into three categories. Each category represents the range of wheel loadings, under fully loaded conditions, that may be anticipated for vehicles in a given weight class. Classifications do not represent the higher wheel loads that will be incurred by tandem axles in each weight range.

After wheel-loading and CBR values have been established, the chart may be employed to compute subbase requirements, as illustrated by the following example. It must be noted that the graphic plot for any wheel load never reaches zero. This "open" dimension is the depth allocated for the placement of final surface material. When the recommended thicknesses for various surfaces (as prescribed in the Road Surfacing section) fail to consume the open dimension, remaining space must always be filled with a subbase having a CBR of 80 or greater. Crushed rock is preferred.

Example: A haulage road is to be constructed over a silty clay of medium plasticity with a CBR of 5. The maximum wheel load for any vehicle using the road is 40,000 pounds. Fairly clean sand is available with a CBR of 15 to serve as subbase material. Road surface is to be constructed of good gravel which has a CBR of 80.

Step A. The 40,000-pound wheel-load curve intersects the vertical line for a CBR of 5 at 28 inches. This means that the final road surface must be at least this distance above the subgrade.

Step B. A clean sand CBR of 15 intersects the 40,000-pound curve at 14 inches, indicating that the top of this material must be kept 14 inches below road surface.

Step C. An intersection of the 80 CBR for gravel and the 40,000-pound wheel load occurs at 6 inches. Since this will constitute the final surface material, it should be placed for the remaining 6 inches. Completed subbase construction for the foregoing conditions is described in figure 19.

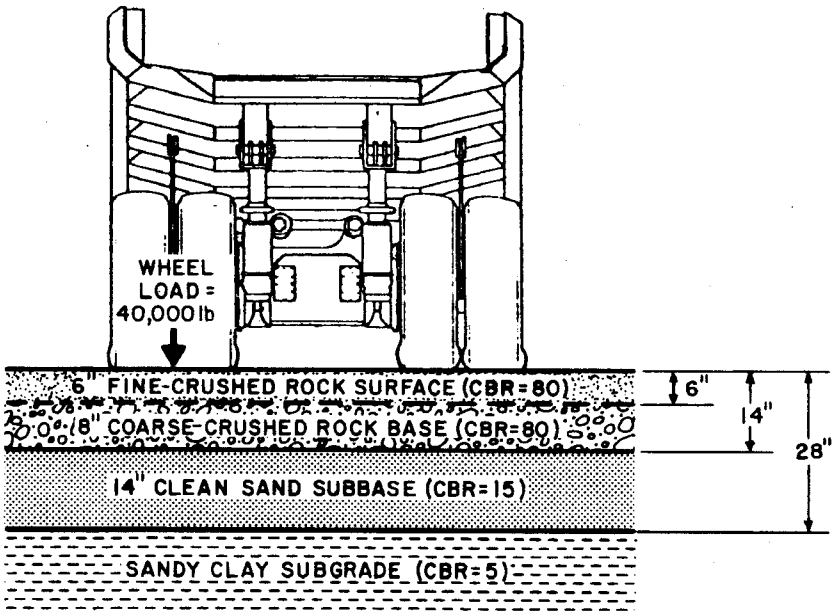

FIGURE 19. - Example of subbase construction.

Following the determination of subbase depth requirements, proper placement procedures must be implemented. Regardless of material used, or depth, the subbase should be compacted in layers never exceeding 8 inches. To insure stability of the final surface, subbase materials should exceed the final desired surface width by a minimum of 2 feet and must always be compacted while moist. Proper compaction equipment usually consists of heavy rollers. However, few surface mine operators include rollers in their vehicle fleet. When rolling equipment is not available, an alternative such as heavy-tracked equipment may be employed. Each 8-inch layer must be subjected to repeated passes of the compacting equipment until it fails to compress under the weight of the vehicle.

Surface Materials

The authors of this report have visited over 300 mining operations throughout the United States. At many of these mine sites, especially small coal mining and quarry operations, little consideration appeared to be given to the construction of a good haulage road surface. In fact, development of the haulageway is frequently accomplished by simply clearing a path over existing terrain.

While this practice is undoubtedly the most economical means of road construction in terms of initial cost, the benefit is seldom long-lived. Failure to establish a good haulage road surface will result in increased vehicle and road maintenance costs and will severely retard the ability of a vehicle to safely negotiate the route. These difficulties are usually greatest on earth and bedded rock surfaces. Greater vehicle maintenance is required on rock surfaces as a result of excessive tire wear. It is virtually impossible to construct a bedded rock surface free of jagged edges. Thus, the tires of traversing vehicles are continually cut by scuffing.

Earth roads, unless thoroughly compacted and stabilized, may cause both vehicular and road maintenance difficulties. Dust problems are frequent during dry seasons and, if not controlled, the dust can contaminate air filtration components, brakes, and other moving parts, making frequent replacement of these items necessary. Moreover, dust represents a major safety hazard to the vehicle operator in that it can become so dense that visibility is severely reduced. Eliminating the dust problem requires continual wetting of the

surface, which represents yet another maintenance expenditure. When subjected to heavy wetting, nonstabilized earthen roads become extremely slick and severely defaced by erosion. Thus, reduced vehicular controllability from a slippery surface creates a safety hazard, and maintenance must be increased to eliminate erosion gullies. Jagged rock and unconsolidated earth surfaces should always be avoided in a safe haulage road design.

Many of the available road-surfacing materials may be used to maximize safety and reduce road maintenance requirements. However, the field can be narrowed considerably by determining those which are most appropriate for use in haulage road construction. This determination is based on the road adhesion and rolling resistance factors characteristic of different surface types; that is, the resistance factors acting between the road and tire. Road adhesion coefficients play an important role in determining a vehicle's potential to slide. Since the principal concern is haulage road safety, primary emphasis should be placed on these characteristics. Table 6 shows coefficients of road adhesion, determined through years of research, for various surfaces. It must be noted that as the values decrease, the potential for a vehicle tire to begin sliding increases.

A beneficial side effect of selecting a road surface that has a high coefficient of road adhesion for safety is that operational efficiency will increase as well. Rolling resistance has a direct effect on vehicular performance. It is commonly defined as "the combination of forces a vehicle must overcome to move on a specified surface." This factor is usually expressed in pounds of resistance per ton of gross vehicle weight caused by the bearing friction losses resulting from tires sinking in loose material. For the majority of road surface materials, an increase in coefficient of road adhesion can be directly related to a reduction in rolling resistance. Table 7 illustrates this point by presenting the rolling resistance values associated with several road surface materials and their road adhesion characteristics. The data in table 7 indicate that a good road surface will, in many cases, decrease operational costs by reducing resistance to travel. Thus, safety and economics, again, work together.

Asphaltic concrete, crushed stone or gravel, and stabilized earth are the most practical construction materials for developing a haulage road surface that will insure maximum safety and operational efficiency. Because each of these materials has merits that are applicable to specific haulage situations, they are discussed separately in the following pages.

TABLE 6. - Road adhesion coefficients as described by various technical references

Road surface	Road adhesion coefficients			
	Rubber tire[1]	Track[1]	Rubber tire[2]	Rubber tire[3]
Concrete:				
New	0.90	0.45	0.80-1.00	0.8-0.90
Traveled			.60- .80	
Polished			.55- .75	
Wet			.45- .80	.80
Asphalt:				
New			.80-1.00	.8- .90
Traveled			.60- .80	
Polished			.55- .75	
Excess tar			.50- .60	
Wet			.30- .80	.5- .70
Gravel:				
Packed and oiled			.55- .85	.60
Loose	.36	.50	.40- .70	
Wet			.40- .80	
Rock:				
Crushed			.55- .75	
Wet			.55- .75	
Cinders:				
Packed			.50- .70	
Wet			.65- .75	
Earth:				
Firm	.55	.90		.68
Loose	.45	.60		
Wet				.55
Clay loam:				
Dry	.55	.90		
Rutted	.40	.70		
Wet	.45	.70		
Sand:				
Dry	.20	.30		
Wet	.40	.53		
Coal: Stockpiled	.45	.60		
Snow:				
Packed	.20	.25	.30- .55	.20
Loose			.10- .25	
Wet			.30- .60	
Ice:				
Smooth	.12	.12	.10- .25	.10
Sleet				.10
Wet			.05- .10	

[1]Society of Mining Engineers. SME Mining Engineering Handbook. Volume II. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, sec. 17, 1973, p. 70.

[2]Caterpillar Co. Caterpillar Performance Handbook, Peoria, Ill., 1st ed., sec. 19, 1970, p. 42.

[3]Taborek, J. J. Mechanics of Vehicles. Machine Design, Cleveland, Ohio, 1957, p. 8.

TABLE 7. - Rolling resistance for various surface types

Surface type	Road adhesion coefficient (approx.)	Rolling resistance, pounds per ton gross vehicle weight (approx.)
Cement, asphalt, soil cement.....	0.8	40
Hard-packed gravel, cinders, or crushed rock.....	.7	60
Moderately packed gravel, cinders, or crushed rock.....	.6	100
Unmaintained loose earth.....	.5	150
Loose gravel and muddy rutted material.....	.4	200-400

Asphaltic Concrete

From a safety standpoint, asphaltic concrete appears the most desirable road surface material. It offers a high coefficient of road adhesion and creates a surface that reduces dust problems. In addition, the characteristic stability of this material creates a smooth haulage surface that can be traveled with little fear of encountering deep ruts of potholes that would impede vehicular controllability. If potholes or ruts do appear, they can be readily corrected by patching.

These surfaces are equally attractive from a production standpoint. While an increasing number of operators are beginning to utilize asphaltic concrete because of lower road maintenance costs, the smooth surface also allows haulage vehicles to travel safely at greater speeds. This speeds up the production cycle.

A seasonal disadvantage to using this composition, however, is revealed during the first snow or freezing rain. The characteristically smooth surface of asphalt offers little resistance to development of an ice or snow glaze. Thus, the roadway can become extremely slick and remain so until corrective measures are employed. This could constitute a serious threat to operational safety in mining areas where rapid and frequent freeze conditions prevail.

If asphaltic concrete is the chosen surface material, it must be applied within the constraints of good engineering practice. In order to be stable, it must be composed of asphalt binder, aggregate, and asphalt cement. The exact mixture for available material in a given locality may be obtained from State Highway Departments or local general paving contractors.

Prior to placing the asphalt, a sufficient subbase must be established, followed by an additional layer of base course. Base course is a term designating the layer of stable material that must lie directly beneath asphaltic concrete. Although any material with a CBR of 80 or greater may be used for this purpose, crushed stone is recommended. Depth of base required will be entirely dependent on subgrade conditions and may be determined with some degree of accuracy by using the curves shown previously in figure 18. The

example given in the figure illustrates that the final clean sand layer of subbase had to remain 14 inches below the final road surface. This is the dimension that must be filled by the combination of base course and asphaltic concrete. Thus, 10 inches of base course and 4 inches of asphalt are required.

Unfortunately, the high cost of asphaltic road surface severely restricts its feasibility on roads of short life. Due to the extreme weight on the wheels of vehicles that constantly travel the haulage road surface, a 4-inch layer may be accepted as the minimum required in most cases. The cost of constructing a 4-inch-thick layer ranges from $4[6] to $5[7] per square yard for labor, equipment, and material. Using the higher figure for a 5-mile road 30 feet wide would necessitate an expenditure of $440,000 for paving alone.

The placement of asphaltic concrete surface is an extremely detailed process that is dependent upon many variables. Temperature of the mix, compaction procedures, wetting, joining, and density control are only a few of the critical elements that must be considered during construction. Unless the mine operator is thoroughly familiar with all elements of asphalt placement or wishes to follow procedures outlined in State Highway Construction Manuals, a reputable paving contractor should be retained to do the work. Before construction of the road, asphaltic concrete should be tested on a small plot to note its adaptability to normal environmental and travel conditions in the area of intended application.

The required base course is also an expense to be considered in the total construction cost. Many operators are capable of performing this operation with their own labor, materials, and equipment, thus minimizing its cost.

Because of the relatively high cost of asphaltic concrete surfaces, each operator must determine if the benefits of increased speed and reduced road maintenance will offset the investment. In most cases, the determining factors will be the length of haul and required life of roadway. If roadway life is relatively short, an asphalt surface may be difficult to justify. If, on the other hand, the haulage road is to be considerably long and in service for a number of years, the placement of asphaltic concrete may be quite feasible.

Compacted Gravel and Crushed Stone

A great number of surface mining operations throughout the country are presently utilizing gravel and crushed stone surface haulage roads. When constructed and maintained properly, both materials offer a stable roadway that resists deformation and provides a relatively high coefficient of road adhesion with low rolling resistance. The greatest advantage of gravel and stone surfaces is that safe and efficient roadways can be constructed rapidly at a relatively low cost. In areas where the haulage route is subject to

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[6] Robert Snow Means Co., Inc. Building Construction Cost Data for 1975. 1974, 280 pp.

[7] McGraw-Hill Information Systems Co. 1976 Dodge Manual. New York, 1975, 238 pp.

relocation or must accommodate heavy tracked vehicles, it would be impractical to use a permanent surface such as asphaltic concrete.

Determination of the depth of material to be placed follows the same procedure outlined for asphaltic concrete. The depth from surface required for the final subbase material used, as shown in figure 19, determines the thickness of gravel or crushed stone necessary for base and surface.

In some cases, the base and wearing surface may consist of the same type of materials. For example, a crushed stone wearing surface may often overlay a crushed stone base. However, while base materials may consist of particles as great as 4 inches in size, the surface must be much more refined. The following specifications in table 8 present an example of a stone wearing surface that has proven suitable on mine haulage roads. Any crushed stone or gravel that meets or exceeds the specifications presented in the illustration will qualify as an adequate surface composition.

TABLE 8. - Stone surface gradation

Screen size	Material passing, percent
1-1/2 inches	100
1 inch	98
3/4 inch	92
3/8 inch	82
No. 4 mesh	65
No. 10 mesh	53
No. 40 mesh	33
No. 200 mesh	16
Liquid limit	25.2
Plasticity limit	15.8
Plasticity index	9.4
Optimum moisture content during placing	12.2

Bank gravel, which is a mixture of pebbles and sand, frequently exists at many mine sites and thus is usually a low-cost surfacing material. Care should be taken, however, to remove boulders, cobblestones, vegetation, and other undesirable material before the gravel is spread. Other similar materials suitable for surfacing are fine blasted rocks, scoria, disintegrated granite and shale, cinders, volcanic ash, mill tailings, and slag.

The percentage of fines in the gravel will affect surface stability in freezing or hot, dry weather. Therefore, roads that are subject to freezing should not have more than 10% fines to prevent muddy, sloppy conditions when thawing. Those subject to hot, dry weather should not have less than 5% fines in order to prevent drying and loosening.

If proper subbase and base are established prior to placing top material, the depth of surface material need not exceed 6 inches. To achieve a uniform layer, placement should be accomplished with a motor grader or an equivalent piece of equipment. Following placement, the material must be thoroughly compacted to a 6-inch depth. It is recommended that either rubber-tired or steel

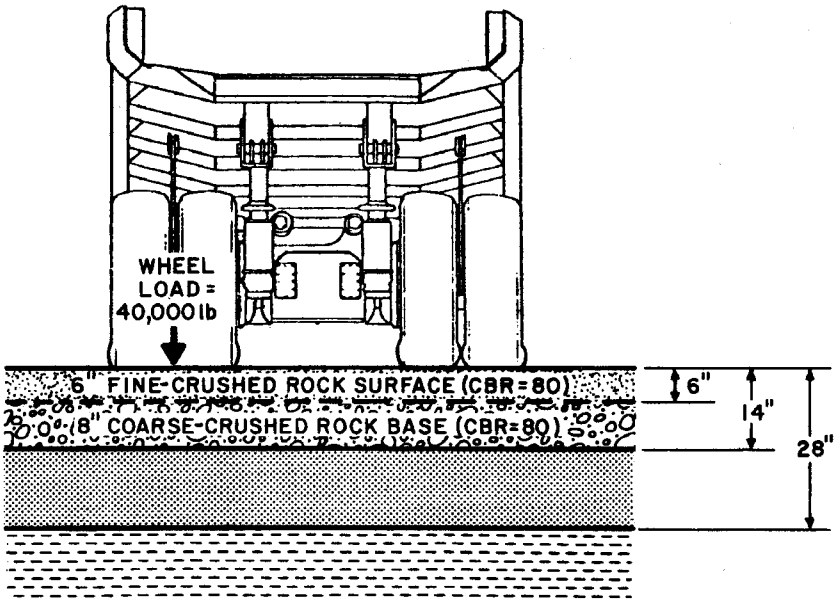

FIGURE 20. - Example of crushed-stone surface construction.

rollers be used for compaction. Heavy rubber-tired vehicles can be employed when rollers are not available. However, rubber-tired vehicles must be run repetitively to cover the entire road width, and compaction will not be quite as good. The following typical section (fig. 20) illustrates a haulage road cross section utilizing a crushed stone wearing surface for a wheel load of 40,000 pounds.

After a haulage surface is constructed with materials of this type, frequent road maintenance is required. Most of this maintenance will consist of periodic grading to remove small ruts and potholes that will inevitably be created by passing traffic. The exact maintenance schedule required will depend greatly on traffic, and it must be developed to accommodate conditions at each individual location. In some cases, traffic may be heavy enough to realize benefits from a continuous maintenance schedule.

In most stone quarry operations, both gravel and crushed stone are readily available from the stockpiles of finished products. At other surface mining operations, crushed stone is often available from the blasting and excavation of rock overburdens. As a result, it is difficult to derive an exact construction cost. However, the expense of constructing gravel or crushed stone roadways is always considerably less than that of asphaltic concrete.

Stabilized Earth

Stabilized earth is defined herein as any soil that, through special procedures or additives, has been transformed from a naturally unconsolidated state to a degree of stability that will accommodate the weight of haulage vehicles. Achieving this level of stabilization involves incorporating soil binders such as cement, asphalt, calcium chloride, lignosulfates, or hydrated lime.

Although these materials will not create a sufficient haulage road surface, they can significantly reduce the quantity of base material required. In fact, often the various soil binders can be mixed directly with subgrade soils to create a platform for the road surface, making the construction of a subbase unnecessary. At other times soil binders will reduce the amount of subbase or base material required. The potential of a specific binder to reduce or make unnecessary subbase or base material depends on the inherent

strength of the material with which it is to be incorporated and the weight of vehicles that will use the haulage road. Final determinations of feasibility must be made by a qualified soils engineer who has evaluated the effects a binder will have on the subgrade or base material at a particular haulage road location. The application of various additives can be discussed in general terms, however.

Asphalt impregnation and soil cementing, by virtue of their somewhat higher costs, should be utilized primarily for permanent haulage roads. On occasion, they may prove beneficial in areas where the subgrade is extremely weak and would require large quantities of offsite subbase for stabilization. In these instances, the addition of asphalt and portland cement to small quantities of fill material can create a stable base.

Calcium chloride, lignosulfates, and hydrated lime are more economical than asphalt impregnation and soil cement, but are not nearly as effective. These substances are best employed to supplement crushed stone or gravel bases to increase their mechanical stability. Although the construction of any haulage road will benefit from the use of these additives, they are most applicable for road segments that are subject to constant relocation.

If the operator wishes to use any of the materials previously described, two publications[8] may be consulted to determine the type and volume required for a particular situation.

Haulageway Width

The haulage road designer must be very concerned about the road width. Sufficient room for maneuvering must be allowed at all times to promote safety and maintain continuity in the haulage cycle. Unlike passenger and commercial vehicles which have somewhat "standardized" dimensions, surface mine machinery varies drastically in size from one production capacity rating to another. Thus, requirements have to be defined for particular sizes rather than for general types. Complicating the problem is the need to specify additional widening for straight road to curve transitions.

Because of the large number of influencing variables, the following guidelines for determining width are separated into individual categories. Recommendations presented are values for the size of traveled lane to be provided and do not take into consideration the additional dimensions necessary for subbase outslopes, drainage facilities, berms, etc. These items are discussed separately, and their dimensions must be added to those of the lane to determine the total roadway width.

Width criteria for the traveled lane of a straight haul segment should be based on the widest vehicle in use. Designing for anything less than this

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[8]Portland Cement Association. Soil Cement Construction. Chicago, Ill., 1956, 99 pp.
Wallace, H. A., and J. R. Martin. Asphalt Pavement Engineering. McGraw-Hill Book Co., Inc., New York, 1967, 340 pp.

dimension will create a safety hazard due to lack of proper clearance. In addition, narrow lanes often create an uncomfortable driving environment, resulting in slower traffic, and thereby impeding production.

Rules of thumb for determining haulage road lane dimensions vary considerably from one reference source to another. Many of the guidelines specify a constant width to be added to the width of the haulage vehicle. This method is sufficient for smaller vehicles, but it is not advisable for computing lane spans to accommodate larger machines. To compensate for the increase in perception distance created by greater vehicle width, the space allocated for side clearance should vary with vehicle size.

A practical guideline for establishing the vehicle-to-lane width ratio is contained in the 1965 AASHO Manual for Rural Highway Design.[9] The AASHO Manual recommends that each lane of travel should provide clearance, left and right of the widest vehicle in use, that is equivalent to one-half the vehicle width. Adding credence to this recommendation is the fact that a number of the larger surface mines base their haulageway spans on this criterion. By incorporating this guideline, both safety and efficiency will be enhanced.

Table 9 and figure 21 illustrate the recommended widths that should be provided for various lane configurations based on the design vehicle dimension, along with a typical section depicting how multiple lane dimensions accrue.

TABLE 9. - Recommended lane widths--tangent sections

Vehicle width, feet	1 lane	2 lanes	3 lanes	4 lanes
8	16	28.0	40	52.0
9	18	31.5	45	58.5
10	20	35.0	50	65.0
11	22	38.5	55	71.5
12	24	42.0	60	78.0
13	26	45.5	65	84.5
14	28	49.0	70	91.0
15	30	52.5	75	97.5
16	32	56.0	80	104.0
17	34	59.5	85	110.5
18	36	63.0	90	117.0
19	38	66.5	95	123.5
20	40	70.0	100	130.0
21	42	73.5	105	136.5
22	44	77.0	110	143.0
23	46	80.5	115	149.5
24	48	84.0	120	156.0
25	50	87.5	125	162.5
26	52	91.0	130	169.0
27	54	94.5	135	175.5
28	56	98.0	140	182.0

[9]Work cited in footnote 4.

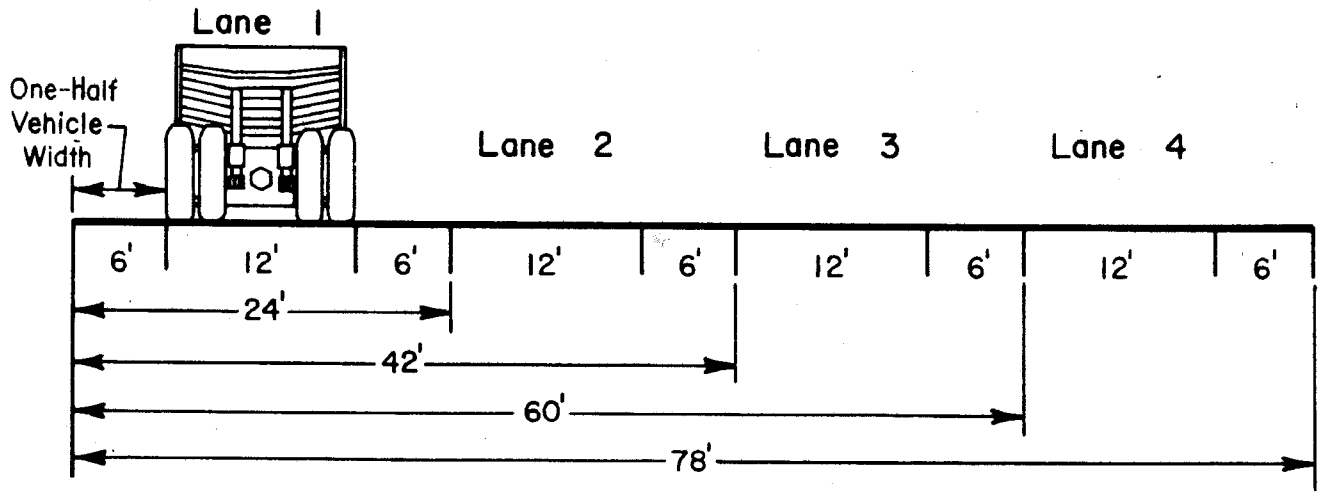

FIGURE 21. - Typical haulageway sections for 12-foot-wide vehicle.

Data presented in this chart is intended to serve as guiding criteria for primary haulage road users. Special consideration must be given to road segments that may have to accommodate larger equipment such as shovels, draglines, drills, etc. A safety hazard will exist if the design road width is less than that necessary for the movement of such equipment. Prior to selecting a final design width, make the following assessments, and establish a dimension sufficient for all possible users:

1. Define the width of all equipment that may have to travel the haulage road.

2. Solicit dimensional data for any anticipated new machines.

3. Determine the overall width of any equipment combinations that may be involved in a passing situation.

4. Delineate the location of road segments requiring a greater than normal width.

In cases where the passage of unusually wide machinery is occasional, there is no reason to establish additional lane width equal to half that of the vehicle. Although in most instances table 9 will serve as an excellent guide for the road designer, there are exceptions for single-lane construction that must be acknowledged.

The lane widths illustrated in the table for one-lane construction apply only when the stopping distance of the haulage vehicle is exceeded by sight distance. On haulage segments where the opposite is true, a single-lane span equivalent to 2-1/2 times the vehicle width is advisable. This will allow sufficient space for moving vehicles to avoid collision with others that might be stalled or otherwise incapacitated on the haulage route. Haulage road planners must also consider the fact that the minimum width recommendations for single-lane roads, even when sight distance is adequate, do not allow sufficient room to pass. If a vehicle should become inoperable on the road, it would restrict the movement of any vehicle equal in size. To prevent this

occurrence, it is recommended that a minimum of 4 feet of additional lane width be provided over the entire haulage route.

Cross Slope

Cross slope, the difference in elevation between the road edges, must be given consideration during haulage road design and construction. From the standpoint of reducing a driver's steering effort, a level surface would be most beneficial. Adequate drainage, however, requires that a cross slope be created. To accommodate both drainage and steerability, balance must be established between a level and sloped configuration. The rate of cross slope that will allow a rapid removal of surface water without adversely affecting vehicular control must be determined.

Both the theoretical and practical aspects of initiating a constant drop across the breadth of roadways have been studied and documented for years.[10] Although the majority of this work has been conducted in relation to urban and rural highway design, the criteria developed are equally applicable to surface mine haulage roads. In nearly every published reference, the recommended rate of cross slope for surfaces normally constructed on mine haulage roads is a 1/4-inch to 1/2-inch drop for each foot of width.

Mine operators should consider one-quarter to one-half inch per foot as the limiting criteria for design. Special consideration must be given to determining when to use the maximum and minimum rates since the applicability of each depends on surface texture.

Cross slopes of one-quarter inch per foot are applicable to relatively smooth road surfaces that can rapidly dissipate surface water. In most cases, minimum slope is best suited to surfaces such as asphaltic concrete. However, there are conditions which warrant the use of 1/4-ipf criteria for surfaces of lesser quality. When ice or mud are constant problems, excessive cross sloping can cause vehicles to slide. This possibility is especially pronounced at slow operating speeds on grades of more than 5%. Therefore, where an ice or mud problem cannot be feasibly eliminated, cross slopes should be limited to the minimum value. Road maintenance should insure that the road surface is kept smooth and drains properly.

In situations where the surface is relatively rough or where ice or mud is not a problem, a 1/2-ipf cross slope is advisable. The greater inclination permits rapid drainage and reduces the occurrence of puddles and saturated subbase, which can weaken road stability. On well constructed gravel and crushed rock roads, the 1/2-ipf criteria is preferable.

Of equal importance to the degree of slope is the direction it should take in relation to various road configurations. Since the placement of high

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[10] Mudd, S. W. Surface Mining. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, 1968, p. 681.
Word cited in footnote 4.
Seelye, E. E. Design. John Wiley & Sons, New York, 1968, pp. 12-16.

and low lane edges determine slope direction, it is necessary to define the circumstances under which the left edge should be higher than the right or vice versa. In the case of multiple-lane construction, both sides of the final pavement may be equal, with a high point or "crown" at one of the intermediate lane edges.

The cross slope direction for single-lane construction is governed by adjacent land features. In cases where the haulage road is cut into existing ground, the high lane edge may be placed on either side. However, on fill sections, the highest lane edge should be nearest the most severe outslope.

For two-, three-, and four-lane surfaces, a crown is appropriate. On dual- and four-lane roads, the cross slope should be constructed to provide a constant drop at the recommended rate from the center point of the roadway. The location of crown on three-lane haulage roads must insure a continuous drop across two lanes in one direction and the same slope across the other in the opposite direction. The two lanes sloping toward the same edge of road should be lanes for vehicles traveling in the same direction.

Conventional Parallel Berms

The use of berms has long been accepted as a standard safety feature in areas where a haulage vehicle could accidentally run over the outslope of a haulage road. The applicability and effectiveness of berms were analyzed to establish governing criteria for their design and placement in a typical haulage road operation.

During an exhaustive literature search into similar investigations conducted in the interest of highway safety, many variables were found to govern the response of a vehicle to encountering a berm. Studies have shown the interaction of vehicular dynamics and berm characteristics determine whether a vehicle will impact a berm, deflect off it, or mount and climb over it. All relevant areas of primary research dealt with passenger cars encountering conventional berms at highway speeds. No information was available on vehicles with the characteristics of those normally found in surface mine operations. It is this lack of information in the area of large vehicles that restricted the development of this phase of the project.

The adaptability of available berm information is doubtful in view of the basic differences in vehicle design. Table 10 illustrates the typical relationships between an intermediate size passenger car and large haulage vehicle.

TABLE 10. - Typical vehicle relationships

	Passenger car	Haulage vehicle	Factor
Weight.....pounds..	4,000	400,000	100.0 times greater
Wheel base.....feet..	9.9	19.7	2.0 times greater
Height of vehicle....do...	4.5	19.0	4.2 times greater
Wheel track.....do...	5.0	17.0	3.4 times greater
Rolling radius.....do...	1.1	4.7	4.3 times greater

Using this and other accepted data as a basis for rationalization, various conjectures can be made concerning a haulage vehicle's response to a berm. The enormous weight of a typical haulage vehicle is a major consideration.

The weight would have significant deformational effect upon the berm resulting in a reaction pattern that would be an atypical response to the normal berm cross section. The high center of gravity in combination with a disproportionately narrow width of the wheel track make haulage vehicles more susceptible to overturn than passenger cars. The differences in tire size and steering mechanism reduce the tendency of haulage vehicles to redirect themselves when encountering a berm. Other factors such as inertial characteristics, sprung mass ratio differences, and suspension characteristics indicate significantly different response patterns for haulage vehicles when compared with those of passenger cars.

Assuming that a haulage vehicle would respond in a similar manner to a passenger car in a microscale situation, a proportionally sized berm would be approximately 20 feet high for the average haulage vehicle shown in table 10. It is not possible for such a berm to be economically constructed and efficiently maintained. For a normal berm sideslope of 1.5:1, the additional bench alone necessary to accommodate a berm of this size would be 60 feet.

It was determined from the literature review and analysis that a simplified approach to sizing haulage road berms that does not take into consideration vehicular dynamics would require substantial field testing. An alternative approach would involve an in-depth investigation of haulage vehicle dynamics and a subsequent computerized simulation model analysis. This approach would allow the predictive analysis of a variety of vehicle-and-berm interactions and require only sufficient testing to verify the modeling procedure.

Since the level of endeavor necessary to adequately define the response of a haulage vehicle to a berm is far beyond that originally conceived in the scope of this project, current berm sizing and placement were investigated and documented. This approach allows the standardization of practices that are currently in use, and also permits qualitative discussion of the supporting logic and experience upon which berm rationale has been, and is being, based.

Information gathered during pertinent field investigation provided substantial insight into berm configurations and applications that have met with a degree of success in present haulage operations. In addition, data regarding berms was gathered from Canadian and other international sources.

There are two principal berm designs that are in common use. One is the typical triangular or trapezoidal berm formed typically from unconsolidated, relatively homogeneous material obtained during overburden removal or from material obtained as a result of the haulage road construction itself. The effectiveness of this type of berm in redirecting a vehicle is dependent primarily on the natural angle the berm construction material assumes after being deposited. The steeper the side slope of berm, the more effective the berm is at redirecting the vehicle, all other factors remaining equal. The

inherent tendency of these berms to redirect rather than impact and deflect is a definite advantage in terms of potential vehicle damage in the event of an encounter. It should be emphasized, however, that the redirectional effectiveness of berms is reduced as the angle of incidence is increased, and that this type of berm would tend to overturn the trucks if the wheels continued to climb the berm. Also, maintenance of these berms can be troublesome if the berm material is subject to erosion.

The other most common berm consists of large boulders lining the haulage road with an earthen backing material. This type of berm presents the impacting vehicle with a near-vertical face that deflects the vehicle for slight angles of incidence. Although more difficult to build, this type of berm offers distinct advantages in terms of berm maintenance. The basic limitations imposed by this configuration are (1) substantial damage to the vehicle can result from its use, (2) the vehicle would tend to impact the berm at sharp angles of incidence (possibly injuring the driver), and (3) the local geologic and topographic characteristics of the mining area must accommodate construction of the berm.

Height is the main factor to be considered in designing berms. For conventional berms, the rule of thumb regarding height is that for a berm to possess any measurable tendency to redirect a haulage vehicle, its height must be equal to or greater than the rolling radius of the vehicle's tire. At moderate vehicle speeds, this height allows sufficient time for the driver of the vehicle to apply corrective measures before the truck either overturns or mounts the berm. Additionally, for the natural angle of normal berm-building materials, this height of berm does not require a large amount of additional bench. As a result, it offers basic economic advantages. Berms lesser in height than the rolling radius of the vehicle tire do not allow the driver sufficient response time before the truck mounts and straddles the berm or overruns the berm entirely. Additionally, small berms do not have adequate lateral resistance to effectively assist in redirecting a haulage vehicle.

For boulder-faced berms, the height of the berm should be approximately equal to the height of the tire of the haulage vehicle. This allows an encountering vehicle to impact the berm at a point sufficiently high on the chassis to reduce the potential for overturning, while also improving the deflectional tendencies of the berm as a whole.

The placement of berms on a haulage road must be based on the topographical characteristics of the mining area as well as on common sense. Whenever the potential exists for an accident that could be avoided by the existence of a berm, the initial cost of constructing and extended cost of maintaining a berm is small in comparison to alternative safety features. If the berm is successful <u>once</u> in preventing a potentially serious accident, it has more than paid for itself in relation to the costs of haulage equipment replacement as well as in lost production time.

In summary, the contribution of a berm to the overall safety of a haulage operation depends upon a multitude of factors. A poorly designed or badly maintained berm could conceivably be worse than no berm at all. If a berm is

to be built, the mine operator must consider the purpose for which it would be used, the available materials and technology that can be economically applied to its construction, and its long-term advantages from both a safety and an economic standpoint.

As well as being a safety factor for haulage vehicles, berms serve many other useful purposes; for example, as marking devices for the edge of haulage roads; as drainage channeling devices preventing the uncontrolled erosion of outslopes, as fixed points of reference for haulage vehicle operators, and as effective safety devices for smaller maintenance vehicles that use the haulage road.

Traffic Signs

Every road in the United States that is publicly maintained uses signs to delineate stopping points, curves, speed limits, street names, intersections, etc. Through years of practical application, these devices have proven to be extremely effective in accident prevention.

The installation of warning and instructional signs can be equally as effective in promoting safety on surface mine haulage roads. However, unlike conventional roads, haulage routes experience traffic from vehicles that are controlled by the same operators day after day. Thus, the drivers are usually thoroughly familiar with all aspects of the roads they travel. As a result, designers can be much more selective in their placement of traffic signs. In the surface mining environment, these safety devices should be viewed as reminders rather than as first warning measures.

A number of signs that should be considered for use along surface mine haulageways are discussed in the following sections.

Speed Limit Signs

Speed limits should be posted on segments of the haulage route that require slower than normal rates of travel to safely negotiate a hazardous condition. Some of the more advantageous locations for posted speed limit reductions include road segments that precede

1. Changes in descending haulage road grades;

2. Entrances to congested areas, such as pit, crusher, maintenance areas, overburden dumping points, vehicle crossings, etc.;

3. Unusual road alinements, such as severe vertical and horizontal curves, narrow lanes, and areas of restricted sight distance; and

4. Areas subject to material spills or other frequent obstructions.

Stop Signs

From a production viewpoint, it is best to avoid interruptions in the haulage cycle; however, this may not be compatible with road safety. Although vehicle stopping points along the haulage route should be kept to a minimum, they must be considered necessary for safety in some cases. Areas where the placement of stop signs should definitely be considered are as follows:

1. Any secondary access road at the point it intersects with the main haulageway;

2. Intersections where sight distance does not exceed vehicle stopping distance for the recommended travel rate; and

3. Haulage road intersections with public roads.

Curve and Intersection Warning Signs

These signs can provide the driver with a warning of upcoming situations where he should exercise caution. These devices are best restricted to positions in advance of the most critical curves and heavily traveled intersections.

Culvert Crossing Markers

Whenever a culvert headwall or outlet is encountered beside the road, it should be marked with a standing reflector.

Traffic Control Signs

A sign must be provided at all points in the haulage cycle where the driver is required to perform a special maneuver (Keep Right, One Way, No Left Turn, Do Not Pass, Sound Horn, Blasting--Turn Off 2-Way Radios, etc.).

Limited Access Designators

Private Property, Keep Out, or other signs of this nature are required at all haulageway and public road intersections to keep passing motorists from inadvertently wandering into the operation. The small size of passenger vehicles combined with the limited sight distance of many large haulage trucks constitutes a safety hazard.

Safety Access Indicators

The location of all safety features such as escape lanes and median barriers should be signally depicted well in advance of their position. In addition to indicating the immediate entrance to these facilities, distances should be marked along the haulage road at minimum intervals of 250 feet.

The preceding brief discussion of signs is intended to illustrate the traffic signs that should receive primary consideration. Each surface mine

haulage road exhibits its own peculiarities and may require more or less signal definition. In any case, proper care must be taken to insure that all signs installed are at a height and location that is within the eyesight of drivers operating vehicles with the most restricted visibility.

Drainage Provisions

Soil erosion by water is a common problem that can plague the operation of safe and workable haulage roads. Erosive action on haulage roads can cause ruts and washouts, and can saturate the soil, causing instability. The proper use of drainage facilities can alleviate this problem, resulting in safer, more efficient haulage roads.

Ditch Configuration and Location

Many factors influence final ditch configuration, including soil type, depth of road base, storm design frequency, local restrictions, percent of grade, and predicted runoff from contributing land areas. However, general recommendations may be made to provide the operator with basic design concepts. V-ditches are recommended for nearly all applications, owing to the relative ease of design, construction, and maintenance.

1. The ditch cross slope adjacent to the haulageway should be 4:1 or flatter except in extreme restrictive conditions. In no case should it exceed a 2:1 slope.

2. The outside ditch slope will vary with the material encountered. In rock it may approach a vertical slope; in less consolidated material, a 2:1 slope or flatter.

3. The ditch should be located in undisturbed earth or rock; avoid placing ditches through fill areas.

4. In a cut-fill section, slope the haulageway toward the highwall. Carry drainage in a single ditch.

5. In a total cut section, carry drainage on both sides.

6. In fill sections, protect the toe of slopes with parallel interceptor ditches.

Ditch Capacity and Protection

Ditches must be designed to adequately handle expected runoff flows under various slope conditions. The primary consideration is the amount of water that will be intercepted by the ditch during a rainstorm. Various methods to determine runoff flows are described in a separate section.

After runoff flows are calculated, ditch design becomes a function of percent of grade, V-configuration (4:1, 2:1, etc.), and depth of flow. In the V-ditch, as well as other configurations, depth of flow depends on percent of grade and the texture of material lining the ditch. Loose and porous linings

and low percentage grades reduce flow rates and increase depths; smooth, impervious linings and steeper grades create the opposite effect. To alleviate excessive erosion that may result from high flow velocities, certain ditch-lining materials must be incorporated as the grade increases, except when the ditch is in nonerodable material. Some general rules to be followed for various grades in erodable soils are designated below. Please note that these are "general rules" and are by no means recommended to supersede State or local regulations.

1. At a 0% to 3% grade, the ditch may be constructed without benefit of a liner except in extremely erodable material such as sand, or easily weathered shales and silts.

2. At a 3% to 5% grade, the ditch should be seeded and protected with jute matting until a substantial grass lining can be established.

3. At grades over 5%, the lining should consist of dumped rock placed evenly on both sides to a height no less than 0.5 foot above the computed maximum depth.

Following this section are simplified charts that depict the depth of water that may be anticipated in various ditch configurations depending on the contributing flow in cubic feet per second, the percent of grade, and the type of material utilized as a liner. To determine the runoff flow that may be anticipated for a given ditch segment, the operator should first consult his State or local agencies for preferred methodologies to be used in estimating runoff. If no specific guidelines are given by these sources, the necessary information may be obtained from chapter 2 of the Engineering Field Manual for Conservation Practices.[11] This manual outlines the procedures for estimating runoff and contains all the data necessary to compute runoff volumes for all regions of the country.

When utilizing the Soil Conservation Service Engineering Field Manual to develop peak flow rates, the 10-year, 24-hour storm charts should govern. The rainfall intensity generated by a 10-year storm is recognized as the applicable standard for road drainage design by the American Association of State Highway Officials. Moreover, the volumes of water associated with this type of storm are well in excess of normal runoff conditions and necessitate the design of drainage facilities capable of handling extreme, rather than mean, rainfalls.

In the event that a ditch grade must be altered to accommodate changes in topography, the depth of the ditch must be changed accordingly. Whether an increase or decrease in grade occurs, new volumes should be computed based on the flow in the preceding ditch segment and the volume of water generated by the contributing area contiguous to the new grade.

By consulting table 11, the appropriate ditch depth needed to accommodate a specific volume of water may be derived. After determining the slope and finding the waterflow (in cubic feet per second), consult the corresponding ditch configuration table where the cubic feet per second is found. At the extreme left of this line will be the depth necessary to accommodate the flow for that ditch configuration.

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[11] U.S. Department of Agriculture, Soil Conservation Service. Engineering Field Manual for Conservation Practices. 1969, pp. 2-1 to 2-76.

TABLE 11. - Water-volume capacity for various V-ditch configurations, cubic feet per second

Depth of water (feet)	Slope, percent																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Grass cover			Jute matting					Dumped Rock											
									2:1	0:1										
0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
.4	.4	.5	.6	.6	.7	.5	.5	.5	.6	.6	.6	.7	.7	.7	.8	.8	.8	.8	.8	.9
.6	1.1	1.6	1.7	1.9	2.1	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.1	2.2	2.3	2.4	2.4	2.5	2.6
.8	2.5	3.5	3.6	4.1	4.6	3.0	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.6	4.8	4.9	5.1	5.2	5.4	5.5
1.0	4.5	6.3	6.5	7.5	8.3	5.5	5.9	6.3	6.7	7.1	7.4	7.8	8.1	8.4	8.7	9.0	9.2	9.5	9.8	10.0
1.2	7.3	10.3	10.5	12.1	13.6	8.9	9.6	10.3	10.9	11.5	12.1	12.6	13.1	13.6	14.1	14.5	15.0	15.4	15.9	16.3
1.4	11.0	15.5	15.8	18.3	20.4	13.4	14.5	15.5	16.4	17.3	18.2	19.0	19.8	20.5	21.2	21.9	22.6	23.3	23.9	24.5
1.6	15.6	22.1	22.6	26.1	29.1	19.2	20.7	22.1	23.5	24.7	25.9	27.1	28.2	29.3	30.3	31.3	32.2	33.2	34.1	35.0
1.8	21.4	30.3	30.9	35.7	39.9	26.2	28.3	30.3	32.1	33.8	35.5	37.1	38.6	40.0	41.4	42.8	44.1	45.4	46.6	47.8
2.0	28.3	40.0	40.9	47.2	52.8	34.7	37.5	40.0	42.5	44.8	47.0	49.0	51.0	53.0	54.8	56.6	58.4	60.1	61.7	63.3
										2:1	2:1									
0.2	0.1	0.2	0.2	00.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
.4	.8	1.1	1.1	1.3	1.5	1.0	1.0	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.7
.6	2.3	3.3	3.3	3.8	4.3	2.8	3.0	3.3	3.4	3.6	3.8	4.0	4.1	4.3	4.5	4.6	4.7	4.9	5.0	5.1
.8	4.9	7.0	7.1	8.2	9.2	6.1	6.5	7.0	7.4	7.8	8.2	8.6	8.9	9.3	9.6	9.9	10.2	10.5	10.8	11.1
1.0	9.0	12.7	12.9	14.9	16.7	11.0	11.8	12.7	13.4	14.2	14.9	15.5	16.1	16.8	17.3	17.9	18.5	19.0	19.5	20.0
1.2	14.5	20.6	21.0	24.2	27.1	17.8	19.2	20.6	21.8	23.0	24.1	25.2	26.2	27.2	28.2	29.1	30.0	31.7	31.7	32.5
1.4	21.9	31.0	31.6	36.5	40.9	26.9	29.0	31.0	32.9	34.7	36.4	38.0	39.5	41.0	42.5	43.9	45.2	46.5	47.8	49.0
1.6	31.3	44.2	45.1	52.1	58.3	38.3	41.4	44.2	46.9	49.5	51.9	54.2	56.4	58.5	60.6	62.6	64.5	66.3	68.2	69.9
1.8	42.8	60.5	61.8	71.3	79.7	52.4	56.6	60.5	64.2	67.7	71.0	74.1	77.1	80.0	82.9	85.6	88.2	90.8	93.3	95.7
2.0	56.6	80.1	81.7	94.4	105.5	69.4	74.9	80.1	84.9	89.5	93.9	98.1	102.1	105.9	109.7	113.3	116.7	120.1	123.4	126.6
									4:1	0:1										
2.2	73.0	103.2	105.3	121.6	136.0	89.4	96.5	103.2	109.5	115.4	121.0	126.4	131.5	136.5	141.3	145.9	150.4	154.8	159.0	163.2
2.4	92.0	130.1	132.7	153.3	171.4	112.6	121.7	130.1	138.0	145.4	152.5	159.3	165.8	172.1	178.1	183.9	189.6	195.1	200.4	205.7
2.6	113.8	160.9	164.2	189.7	212.0	139.4	150.5	160.9	170.7	179.9	188.7	197.1	205.1	212.9	220.4	227.6	234.6	241.4	248.0	254.5
2.8	138.6	196.0	200.0	231.0	258.3	169.7	183.3	196.0	207.9	219.1	229.8	240.0	249.9	259.3	268.4	277.2	285.7	294.0	302.1	309.9
3.0	166.5	235.5	240.3	277.5	310.3	203.9	220.3	235.5	249.8	263.3	276.1	288.4	300.2	311.5	322.4	333.0	343.3	353.2	262.9	372.3
3.2	197.7	279.6	285.4	329.5	368.4	242.1	261.5	279.6	296.5	312.6	327.8	342.4	356.4	369.9	382.8	395.4	407.6	419.4	430.9	442.1
3.4	232.3	328.5	335.3	387.2	432.9	284.5	307.3	328.5	348.4	367.3	385.2	402.3	418.8	434.6	449.9	464.6	478.9	492.8	506.3	-
3.6	270.4	382.5	390.3	450.7	503.9	331.2	357.7	382.5	405.7	427.6	448.5	468.4	487.5	505.9	-	-	-	-	-	-
3.8	312.3	441.6	450.7	520.4	581.9	382.4	413.1	441.6	468.4	493.7	517.8	-	-	-	-	-	-	-	-	-
4.0	357.9	506.2	516.6	596.5	666.9	438.4	473.5	506.2	-	-	-	-	-	-	-	-	-	-	-	-
									4:1		2:1									
2.2	109.5	154.8	158.0	182.4	204.0	134.1	144.1	154.8	164.2	173.1	181.5	189.6	197.3	204.8	212.0	218.9	225.6	232.2	238.6	244.7
2.4	138.0	195.1	199.1	229.9	257.1	169.0	182.5	195.1	206.9	218.1	228.8	239.0	248.7	258.1	267.2	275.9	284.4	292.7	300.7	308.5
2.6	170.7	241.4	246.4	284.5	318.1	209.1	225.8	241.4	256.0	269.9	283.1	295.7	307.7	319.3	330.6	341.4	351.9	362.1	372.0	381.7
2.8	207.9	294.0	300.1	346.5	387.4	254.6	275.0	294.0	311.8	328.7	344.7	360.1	374.8	388.9	402.6	415.8	428.6	441.0	453.1	464.9
3.0	249.8	353.2	360.5	416.3	465.4	305.9	330.4	353.2	374.7	394.9	414.2	432.6	450.3	467.3	483.7	499.5	-	-	-	-
3.2	296.5	419.4	428.0	494.2	552.6	363.2	392.3	419.4	444.8	468.9	491.8	513.6	-	-	-	-	-	-	-	-
3.4	348.4	492.8	502.9	580.7	649.3	426.8	460.9	492.8	522.7	-	-	-	-	-	-	-	-	-	-	-
3.6	405.7	573.7	585.5	676.1	755.9	496.8	536.6	-	-	-	-	-	-	-	-	-	-	-	-	-
3.8	468.4	622.4	676.1	780.7	872.8	573.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4.0	536.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

In some cases, additional depth may be required. In all cases where a subbase must be placed, the depth of the flow must not exceed the lower level of the subbase material. In cases where a freeboard is required, the depth of any ditch shall exceed the centerline depth of flow by a minimum of 0.5 foot. Where placement of a ditch lining material is recommended, it shall also be increased 0.5 foot on each side.

It is important to note that the ditch should be kept free at all times of debris or any material that would alter design capacity.

Culverts

Culvert sections are the most efficient and effective means of conveying free-flowing drainage away from the haulage road, and must be incorporated to alleviate the potential of water overflows onto haulage road segments. Any accumulation of water on the haulage road can seriously impede vehicular control and promote road degradation.

To achieve the most efficient drainage scheme, the designer must consider culvert location, sizing, placement, and inlet/outlet controls. Numerous factors affect each of these design considerations. Therefore, each parameter is discussed as a separate category on the following pages.

Location

1. Culverts should be located at all ditch low points unless natural water courses are present.

2. A culvert should be installed at all road intersections and prior to switchback curves on the upgrade beginning of curvature.

3. Whenever a haulage road segment requires a transition from a through-cut to a cut-fill, a culvert should be installed to intercept drainage prior to spilling over an outslope.

4. Culverts should be placed in natural watercourses intersected by the haulage road.

5. In cut-fill sections, culverts may be placed at various intervals along the ditch to intercept drainage and convey it to natural drainways below the fill slope. This procedure can significantly reduce the size of the ditch required by breaking runoff areas into small segments that contribute only to specific ditch segments.

In some instances, culvert intervals will be the designer's option. However, spacing requirements are often specifically delineated in State or local codes of construction practice. A typical example is the regulation imposed by the West Virginia Department of Natural Resources Division of Reclamation.[12]

[12] Department of Natural Resources. West Virginia Surface Mining Reclamation Regulations. Ch. 20-6, ser. VII, sec. 4, No. 5.06, 1971, p. 10.

This agency requires the spacing of culverts for ditch relief at various road grades as noted:

Road grade, percent	Spacing of culverts, feet
2- 5	300-800
6-10	200-300
11-15	100-200

The preceding illustration exemplifies the need to research all State or local standards prior to any design decisions. If there are no regulations regarding culvert spacing, the following is recommended:

1. Spacing should not exceed 1,000 feet on grades from zero to 3%.

2. Spacing should not exceed 800 feet on grades from 3% to 6%.

3. Spacing should not exceed 500 feet on grades from 6% to 9%.

4. Spacing should not exceed 300 feet on grades 10% or greater.

Type and Size

For the majority of haulage-road culvert installations, corrugated metal pipe is most appropriate. Since this type of pipe is relatively light, high in strength, and usually readily available, it can be easily adapted to a variety of situations. Although other materials can be utilized, corrugated metal is currently used extensively throughout the surface mining industry.

Regardless of material, the culvert must be able to accept the maximum runoff flow from the drainage ditch to be completely effective. Also, the pipe diameter must be large enough to accept maximum flow without creating a backup at its inlet. Figure 22 may be utilized to determine pipe sizes for various flows. Flows in cubic feet per second on the left side may be read to their intersection with the diagonal graph line and then down to the corresponding minimum pipe diameter necessary to accept the flow. This minimum is indicative of a full flowing pipe without any water backup at the inlet. In some cases, however, it may be desirable to place a smaller, less expensive pipe and allow a small backup of water. The dashed lines on the chart (labeled "H") are included to depict how much head will be created behind the pipe if its size is restrictive. To determine the amount of head created by a given pipe size and cubic feet per second, read from the cubic feet per second column until the dashed line is intersected, then down. For example, a flow of 8 cfs intersects 2 feet of head at the 15-inch pipe diameter, thus 8 cfs of water at the inlet side of a 15-inch pipe will pond 9 inches above the top of the pipe (2 feet minus 15 inches). However, it must be emphasized that the practice of creating an inlet head is discouraged. The most beneficial design requires that a pipe handle the entire volume of water without backup. If the example for cfs were to be followed without creating a backup, the intersection of the diagonal will show that a pipe diameter of approximately 21 inches is required.

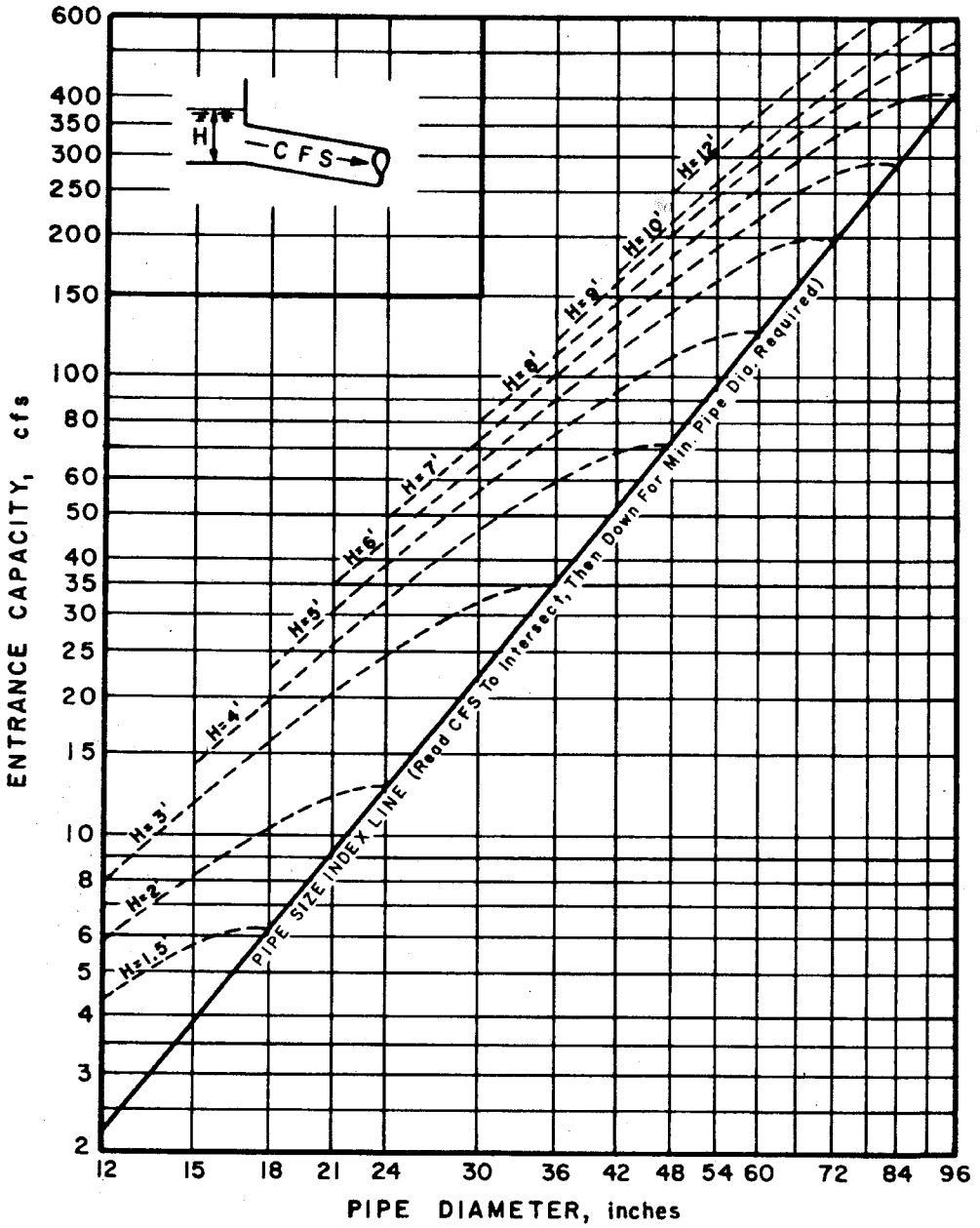


FIGURE 22. - Graph showing pipe culvert capacity.

Placement

After the location and pipe size have been selected and the pipe is ready for placement, consideration must be given to depth of cover over the pipe in relation to the vehicles that will use the road. It is suggested that for support of vehicle weight under 100,000 pounds, a minimum cover of 2 feet over the pipe be used. For support of vehicle weights over 100,000 pounds, minimum cover should be 3 feet.

In all cases, the fill should be hand-tamped in 4-inch layers from the bottom of trench to provide a stable, compacted base for the culvert.

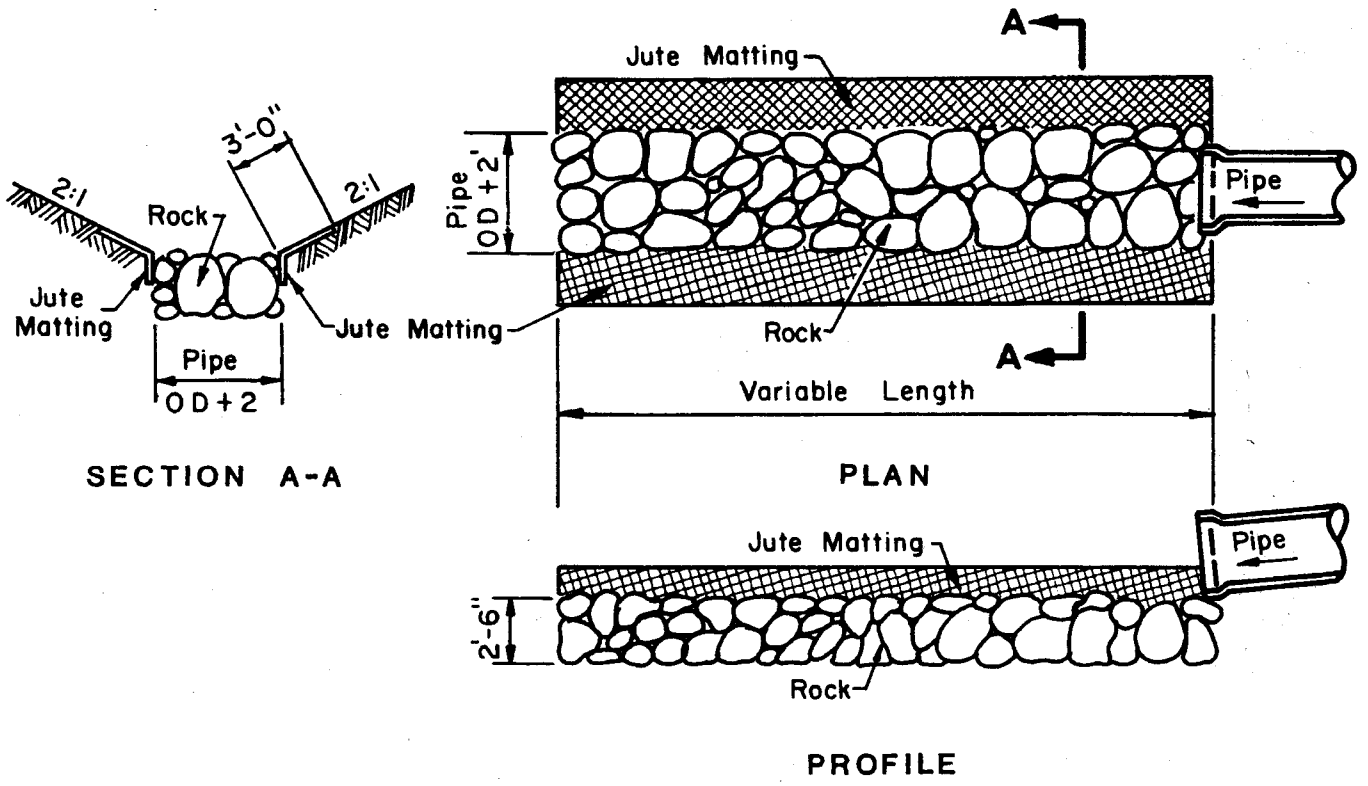
Inlet-Outlet Controls

At all culvert inlets, a protective encasement or "headwall" consisting of a stable noneroda-ble material should be provided.

Regulations specifying erosion- and sediment-control devices to be utilized at storm drain outlets have been developed by the U.S. Department of Agriculture, Soil Conservation Service. In addition, many States have adopted their own regulations for this purpose. By contacting one or both of these agencies in the region, the operator can determine the requirements that apply specifically to his operation. However, there are two rules of thumb to follow:

1. Flow from ditches or culverts shall never be discharged over a fill outslope. In fill situations, the discharges must be conveyed away by pipes, flumes or ditches lined with nonerodable material.

2. At any discharge point, where flow velocity exceeds the Soil Conservation Service's recommended maximum for various soil types, erosion protection must be provided. Examples are shown in figure 23.



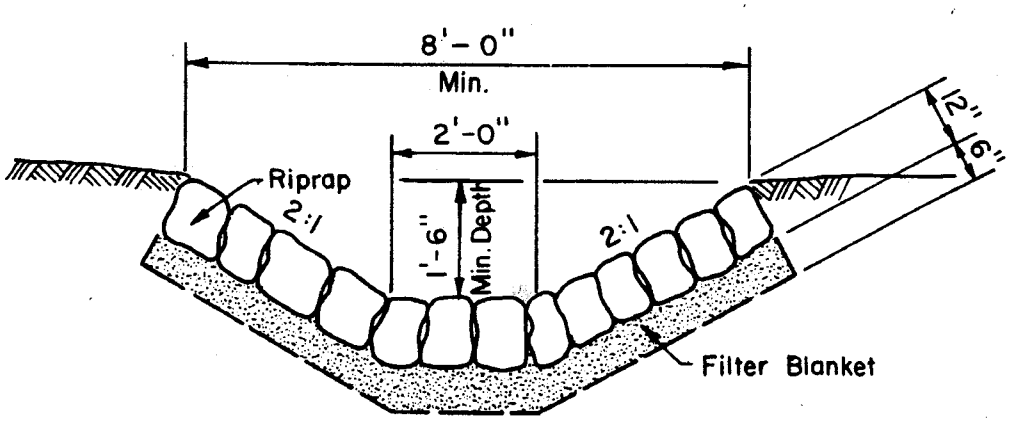


FIGURE 23. - Erosion controls.

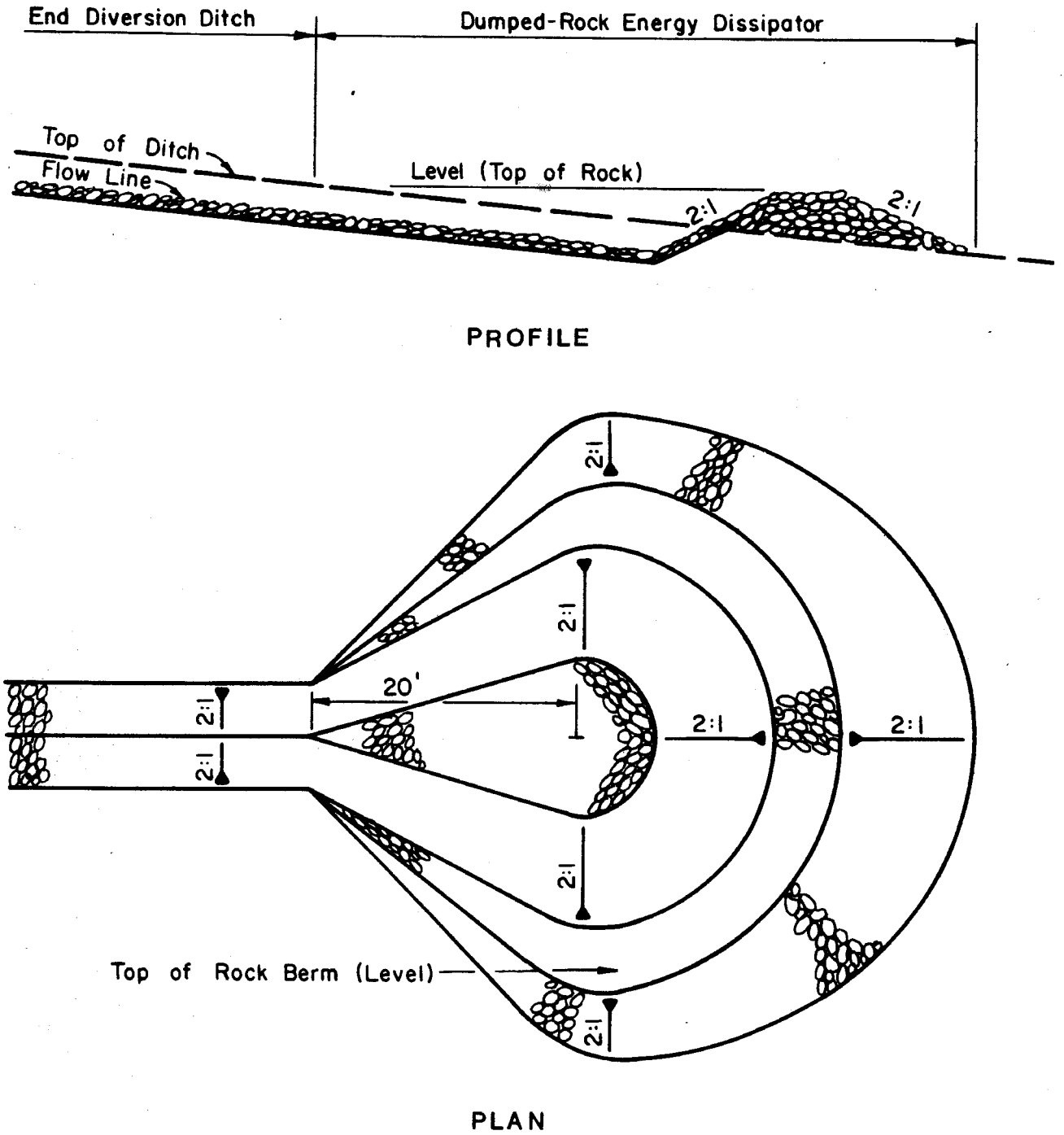


FIGURE 24. - Dumped-rock energy dissipator.

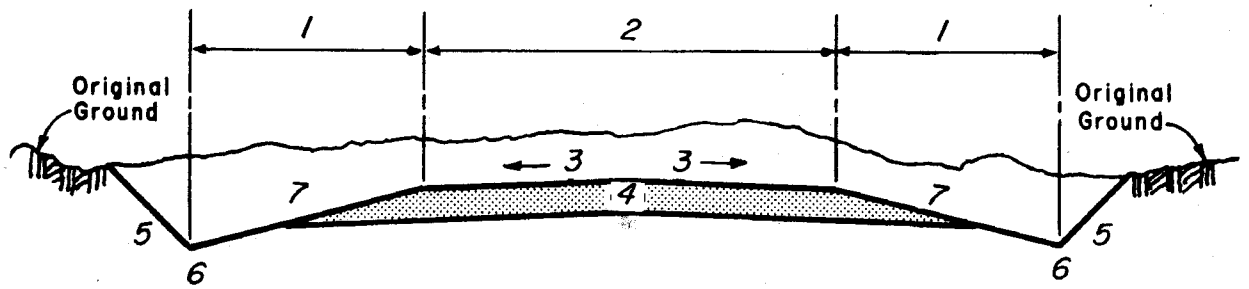
Table 12 depicts the various treatments that may be anticipated for erosion control dependent on discharge velocity. Details are presented in figure 24 for the riprap and energy dissipator treatment techniques as a guide for proper construction. The lengths of these devices will be entirely dependent on slope lengths and must be determined for each individual situation.

TABLE 12. - Slope protection at culvert outlets

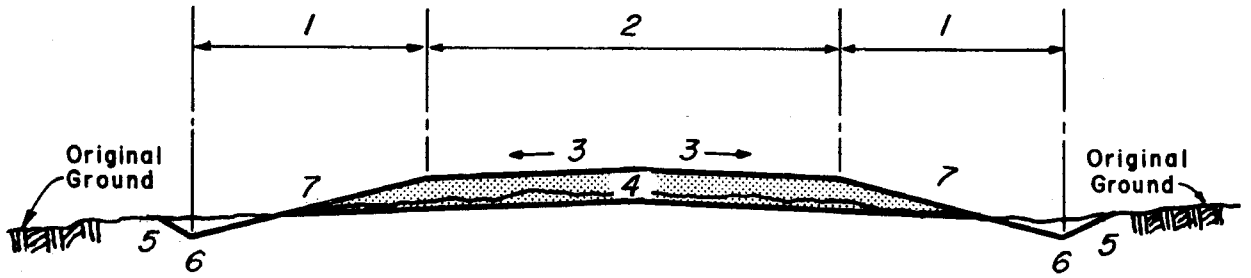
Outlet velocity, fps	Slope of embankment, percent	Treatment recommended
0-2.....	Under 10.....	Establish vegetation.
2-5.....	Over 10.....	Riprap.
5-15.....	All slopes.....	Do.
Over 15.....	.....do.....	Energy dissipator.

Typical Haulageway Sections

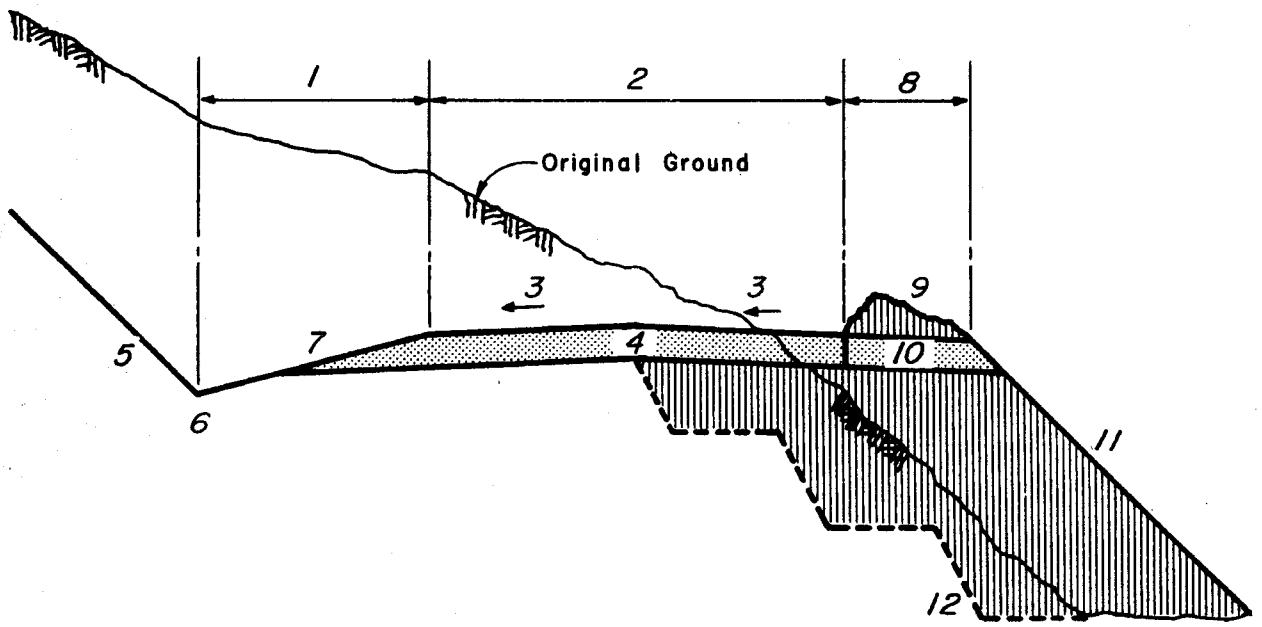
All of the criteria for proper haulage road cross-section design are depicted in figure 25: design considerations for a typical cut section, a typical fill section, and a typical cut-fill section. The type of section applicable to any particular haulage road is, of course, dependent upon the contour of the original ground surface. However, figure 25 and the recommendations provided throughout this section of the report as a guide, all of the most important parameters that must be considered during design of cross sections will be covered. Particular attention should be paid to road cross slopes and drainage ditches since these will contribute greatly to good drainage and, therefore, more effective erosion control.



TYPICAL CUT SECTION



TYPICAL FILL SECTION



TYPICAL CUT - FILL SECTION

FIGURE 25. - Typical haulageway sections.

Key

1 - Lane edge to centerline of ditch—Dimension varies with centerline depth *(6)* and required slope *(7)*.

2 - Lane width—Based on dimension of largest vehicle and numbers of lanes desired.

3 - Typical cross slope for excavated subgrade and final surface—Either 1/4 or 1/2 ipf, depending on surface material used.

4 - Combined surface and subbase—Depth varies with wheel load concentration.

5 - Ditch outslope—Natural angle of repose in rock, 2:1 in all soils.

6 - Depth at centerline of ditch—Required to be below subbase and deep enough to accept total volume of runoff from adjacent drainage area.

7 - Ditch slope adjacent to roadway—Varies from 4:1 to 2:1.

8 - Road widening to accommodate safety berm—Dimension varies with berm size required.

9 - Safety berm—Constructed with a near vertical slope adjacent to lane edge, final height and outslope of berm depends upon the rolling radius of the largest tires that will traverse the haulage road.

10 - Berm support—Constructed to subbase material only; surface material ends at berm face.

11 - Fill slope—Descending at natural angle of repose, fill consists of material cut from existing ground of other excavated material from the mining operation.

12 - Fill bench—Required when original ground slope is 1:1 or greater, benches should be cut 8 feet—10 feet horizontally with an 8- to 10-foot vertical lift at 1/2:1; begin at toe of original ground slope and continue benching until road subgrade is reached.