It is the purpose of this document to identify the performance limitations of modern haulage equipment and to examine the impact of haulage road design on vehicular controllability. Based on these evaluations, haulage road design criteria that will promote continuity and safety throughout the haulage cycle were established.

Time allocated for this project prohibited a detailed investigation of mechanical design for every type of haulage road user. However, safe road design criteria should be sufficiently comprehensive to allow application to all machine types.

This complication required that design criteria be based on the one type of surface mining equipment that exhibits the lowest safety potential. Research of engineering data for all major types of surface mine machinery revealed that large off-the-road haulage trucks had the smallest margin of safety due to their great size and weight, characteristic use, and control components. Thus, designing haulage roads to accommodate these vehicles leaves a wide margin of safety for all other surface mining equipment.

Extensive engineering data for all makes and models of large off-the-road haulage vehicles was solicited from manufacturers. Information was tabulated to identify specifications for width, height, weight, tire track, wheel base, type of braking system, steering ability, retarder performance, speed and range on grade, and numerous other factors for each truck model. Various models were then grouped into four weight-range categories, and minimum, mean, and average specifications were identified for each weight category.

Design guidelines for each weight category, including velocity-stopping distance curves, vertical curve controls, haulageway widths, curve widening, and spacing of runaway devices, are presented in this report.

The haulageway designer may utilize the Contents section of this report as a checklist to assure that all elements of design have been considered in planning the haulage road.

HAULAGE ROAD ALINEMENT

As far as is economically feasible, all geometric elements of haulage roads should be designed to provide safe, efficient travel at normal operating speeds. The ability of the vehicle operator to see ahead a distance equal to or greater than the stopping distance required is the primary consideration. This section of the study addresses the effect of speed, slope, and vehicle weight on stopping distance, as well as design criteria for vertical and horizontal alinement.

Stopping Distance--Grade and Brake Relationships

From a safety standpoint, haulage road grades must be designed to accommodate the braking capabilities of those vehicles having the least braking potential which will most frequently traverse the haul route. In the majority of cases, rear, bottom, and side dump trucks, by virtue of their function

within the mining operation, are the most frequent haulage road users. Due to their extreme weight and normally high operating speeds in relation to other equipment, their ability to decelerate by braking is lowest of the constant haulage road users. The design of routes that accommodate the braking systems of haulage trucks should leave a sufficient margin of safety for other equipment less frequently used, such as dozers, loaders, scrapers, graders, etc.

Most truck manufacturers' specifications for brake performance are limited to an illustration of the speed that can be maintained on a downgrade through use of dynamic or hydraulic retardation. Although retardation through the drive components is an efficient method of controlling descent speed, it does not replace effective service brakes. In the event of retardation system failure, wheel brakes become the deciding factor between a halted or runaway vehicle.

Unfortunately, very few, if any, truck manufacturers define the capabilities of their service and emergency braking systems in terms of performance. They are usually described by lining area, drum or disk size, method of actuation, and system pressure. Thus, an operator does not know whether the brakes of the vehicle will hold on a descent grade in the event of a retardation failure. Because of the possible need to utilize service brakes as the sole means of halting or slowing a truck, their performance must be defined and taken into consideration in the design of safe haulage road grades.

The Society of Automotive Engineers (SAE), realizing the need for effective brake performance standards, has developed test procedures and minimum stopping distance criteria for several weight categories of large, off-highway trucks. SAE-recommended practice J166 delineates the following values as maximum permissible service brake stopping distances from an initial velocity of 20 mph, on a dry, level, clean concrete surface:

Vehicle weight, pounds	Service brake maximum stopping distance at 20 mph, feet
<100,000 (category 1).....	60
100,000 to 200,000 (category 2).....	90
>200,000 to 400,000 (category 3)....	125
>400,000 (category 4).....	175

While the majority of haulage truck manufacturers equip their products with brake systems that meet or exceed these criteria, there is no indication of how brake performance may vary with changes in grade, road surface, or initial speed. However, the stopping-distance limitations set forth provide the basic data from which performance under different conditions may be mathematically deduced.

The stopping distance curves (figs. 1-4) depict stopping distances computed for various grades and speeds in each SAE test weight category. The points for each of the various curves have been derived using the formula

$$SD = [1/2\ gt^2 \cdot \sin\theta + V_o t] + \left[\frac{(gt \sin\theta + Vo)^2}{2g(u\ min - \sin\theta)}\right], \qquad (1)$$

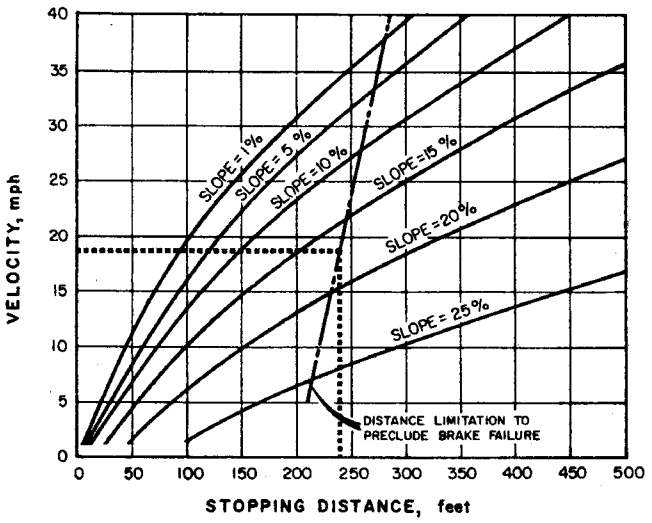

FIGURE 1. - Stopping distance characteristics of vehicles of less than 100,000 pounds GVW.

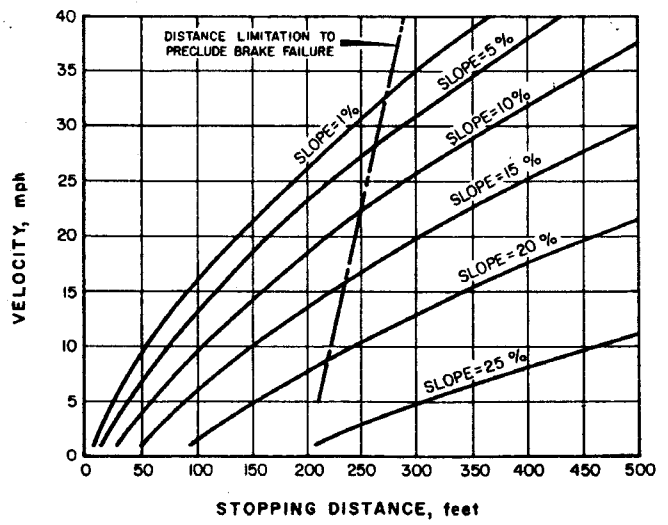

FIGURE 2. - Stopping distance characteristics of vehicles of 100,000 to 200,000 pounds GVW.

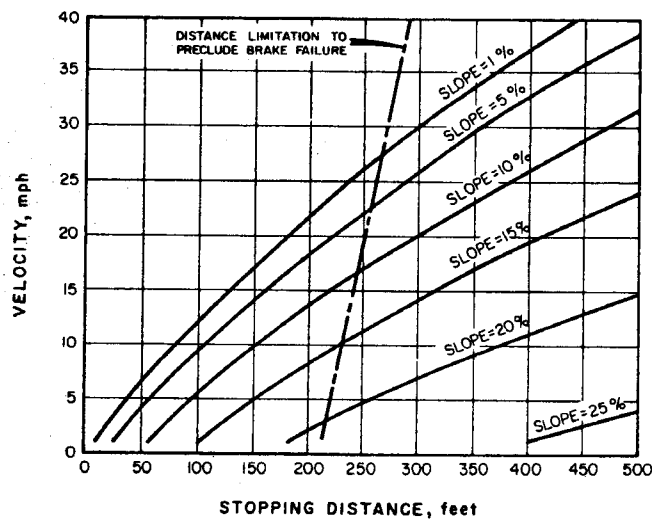

FIGURE 3. - Stopping distance characteristics of vehicles of 200,000 to 400,000 pounds GVW.

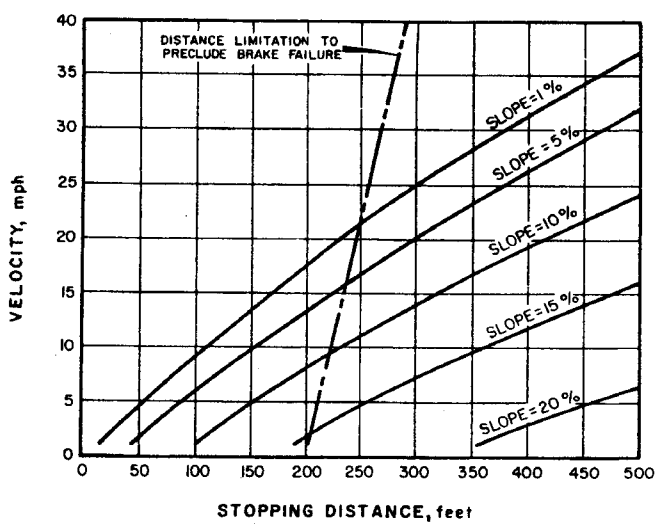

FIGURE 4. - Stopping distance characteristics of vehicles of greater than 400,000 pounds GVW.

where SD = stopping distance, feet,

g = gravitational pull (32.2 fps^2),

t = time expended between driver's perception of the need to stop and the actual occurrence of frictional contact at the wheel brakes, seconds,

θ = angle of descent, degrees,

V_o = speed at time of perception, feet per second,

and u min = coefficient of friction at the tire-road contact area, dimensionless.

Although the significance of SAE stopping distances is not readily apparent in equation 1, it was the means of arriving at u min and t values.

The t value is actually composed of two separate time intervals, t_1 and t_2.

The time necessary for pressure to build and actuate brake components after the pedal is depressed in the cab is designated t_1. Information supplied by a member of SAE subcommittee 10 (the authors of J166) gives the following as values for t_1. These numbers have been verified by various subcommittee members and their companies.

Vehicle weight, pounds	Brake reaction time (t_1), seconds
<100,000	0.5
100,000 to 200,000	1.5
>200,000 to 400,000	2.75
>400,000	4.5

A second component of t, designated t_2, is the lag attributed to driver perception and reaction, or the time lost from the instant an operator sees a hazard until his foot actually begins depressing the brake pedal. A time of 1.5 seconds[3] was assigned for t_2 in all cases.

A value for u min, the coefficient of friction achievable at the tire and ground interface, is found using the formula

$$u\ min = \frac{V^2}{2gS}, \qquad (2)$$

[3]American Association of Highway Officials. A Policy on Geometric Design of Rural Highways. Association General Offices, Washington, D.C., 1965, 311 pp.

where V = SAE test velocity of 29.33 fps,

g = gravitational pull of 32.2 fps^2,

and S = SAE actual braked distance (computed by subtracting $t_1 \times 29.33$ from the SAE recommended stopping distance for each weight classification).

In all cases, the equation computes to a coefficient of friction (u min) averaging 0.30 and a vehicular deceleration of approximately 9.66 fps^2.

With the t and u min values identified, it is possible to use equation 1 and arrive at values illustrated in the stopping-distance curves for different grade-speed operating conditions. This formula, however, does not allow a determination of the distance at which constant brake application will result in excessive heat buildup and, consequently, cause fade or complete brake failure.

Since it is unrealistic to assume that brakes can remain applied without fade for excessive periods of time, heat buildup must be considered. Unfortunately, factors influencing the ability of a brake system to dissipate heat vary to such an extent that accurate mathematic simulation is virtually impossible. In fact, there appears to be no definite conclusion as to the maximum temperature a brake system can withstand before negative effects are noticed. The obvious need to limit stopping distances to prevent excessive brake heat, combined with the inability to realistically simulate thermal characteristics, presented a problem.

Resolution of this difficulty was achieved through the acceptance of empirical test data from the British Columbia Department of Mines and Petroleum Resources.[4] This organization has conducted more than 1,000 haulage truck stopping-distance tests at active mine sites in British Columbia. The variety of truck makes and models included in the testing program present a representative brake performance cross section for many of the vehicles currently marketed.

Information supplied by V. E. Dawson, who coordinated this testing, indicated that to preclude fade, a 200-foot braking distance should be considered the maximum allowable. Although some tested vehicles were able to exceed this limitation and still execute a safe, controlled stop, statistics indicate that a 200-foot restriction permits a reasonable margin of safety. Each stopping-distance graph illustrates this 200-foot maximum braking distance as a vertical line increasing with velocity. Increases of distance for speed reflect footage consumed by driver perception and reaction time, factors not considered during actual tests.

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[4]Dawson, V. E. Observations Concerning On-Site Brake Testing of Large Mining Trucks. Pres. at Earthmoving Industry Conf., Central Illinois Sec., SAE, Warrendale, Pa. Apr. 15-16, 1975, 33 pp.

Inclusion of this stopping-distance restriction completes the stopping-distance graphs. Maximum operating speed and descent grade can be found for a known truck weight by reading vertically along the maximum permissible stopping-distance limitation line. At grade curve intersections, read left to find velocity. An example is given on the graph for less than 100,000-pound trucks (fig. 1).

Figures 1 through 4 have been based primarily on mathematic derivations. They do not depict results of actual field tests, but are presented simply to offer an indication of the speed and grade limitations that must be considered in designing a haulage road for a general truck size. Actual field testing has proven that many haulage vehicles can and do exceed theoretical capabilities. This empirical data, however, does not encompass a wide range of speed and grade situations. Therefore, use of this information would not permit sufficient design flexibility.

It is recommended that the operational limitations depicted in these illustrations be used to make general determinations in the preliminary planning stage of design. Before actual road layout begins, manufacturers of the vehicles that will ultimately use the road should be contacted to verify the service brake performance capabilities of their products. In all cases, verification should reflect the capabilities of wheel brake components without the assist of dynamic or hydraulic retardation.

The discontinuity between theoretical and empirical results substantiates the need for intensive and comprehensive brake evaluation programs. With the exception of British Columbia and possibly a few manufacturers, testing has been restricted to the somewhat idealistic SAE procedures. It is anticipated that continuing demands for larger equipment and the increasing safety consciousness of mine operators and employees will eventually make intensive testing programs a reality.

Sight Distance

Sight distance is defined as "the extent of peripheral area visible to the vehicle operator." It is imperative that sight distance be sufficient to enable a vehicle traveling at a given speed to stop before reaching a hazard. The distance measured from the driver's eye to the hazard ahead must always equal or exceed the required stopping distance.

On vertical curve crests, the sight distance is limited by the road surface. Figure 5, case A, illustrates an unsafe condition. The sight distance is restricted by the short vertical curve and the vehicle cannot be stopped in time to avoid the hazard. Case B shows a remedy to the dangerous condition. The vertical curve has been lengthened, thus creating a sight distance equal to the required stopping distance.

On horizontal curves, the sight distance is limited by adjacent berm dikes, steep rock cuts, trees, structures, etc. Case C illustrates a horizontal curve with sight distance restricted by trees and steep side cut.

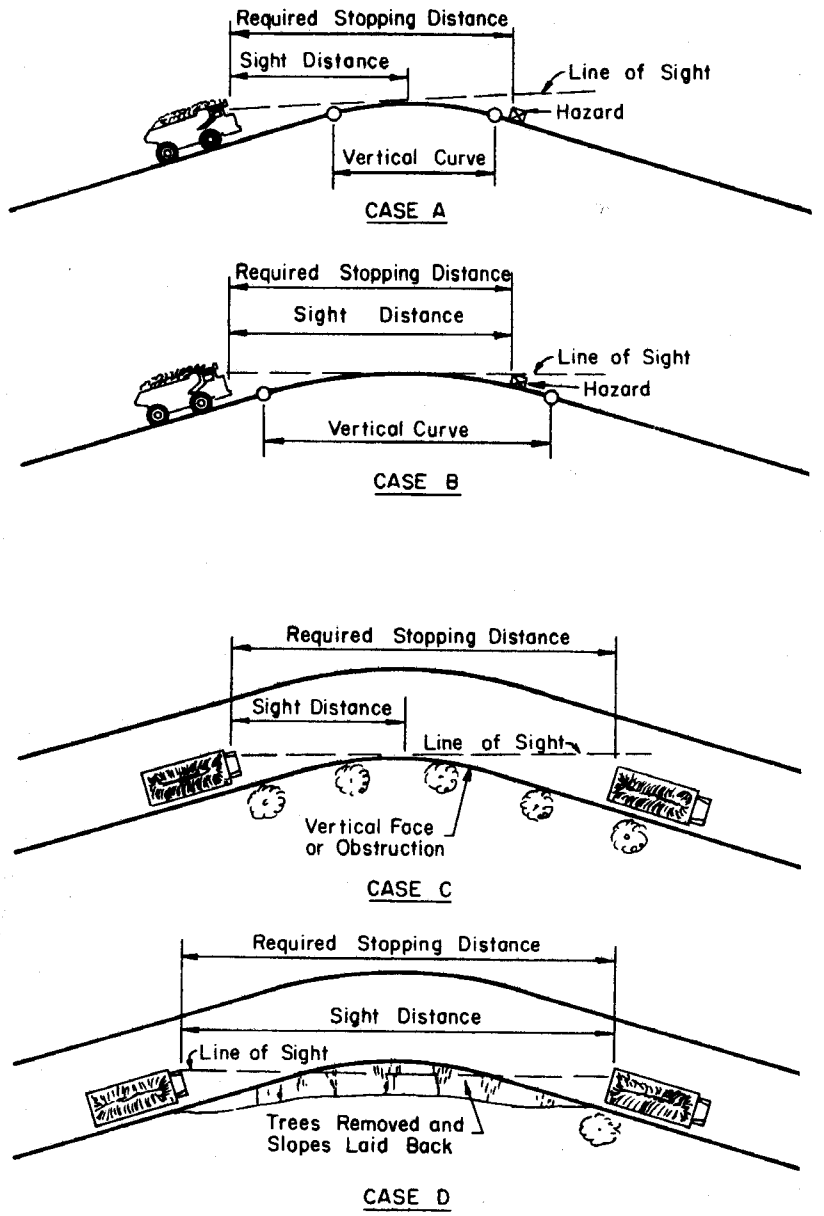


FIGURE 5. - Sight distance diagrams for horizontal and vertical curves.

Case D shows that by removing the trees and laying back the slope, the sight distance can be lengthened to equal the required stopping distance.

Vertical Alinement

Vertical alinement is the establishment of grades and vertical curves that allow adequate stopping and sight distances on all segments of the haulage road. A safe haulage environment cannot be created if grades are designed without consideration for the braking limitations of equipment in use. The same is true for situations where hill crests in the road impede driver visibility to the point that vehicle stopping distance exceeds the length of roadway visible ahead. Design practices relevant to the foregoing parameters are presented in the following subsection.

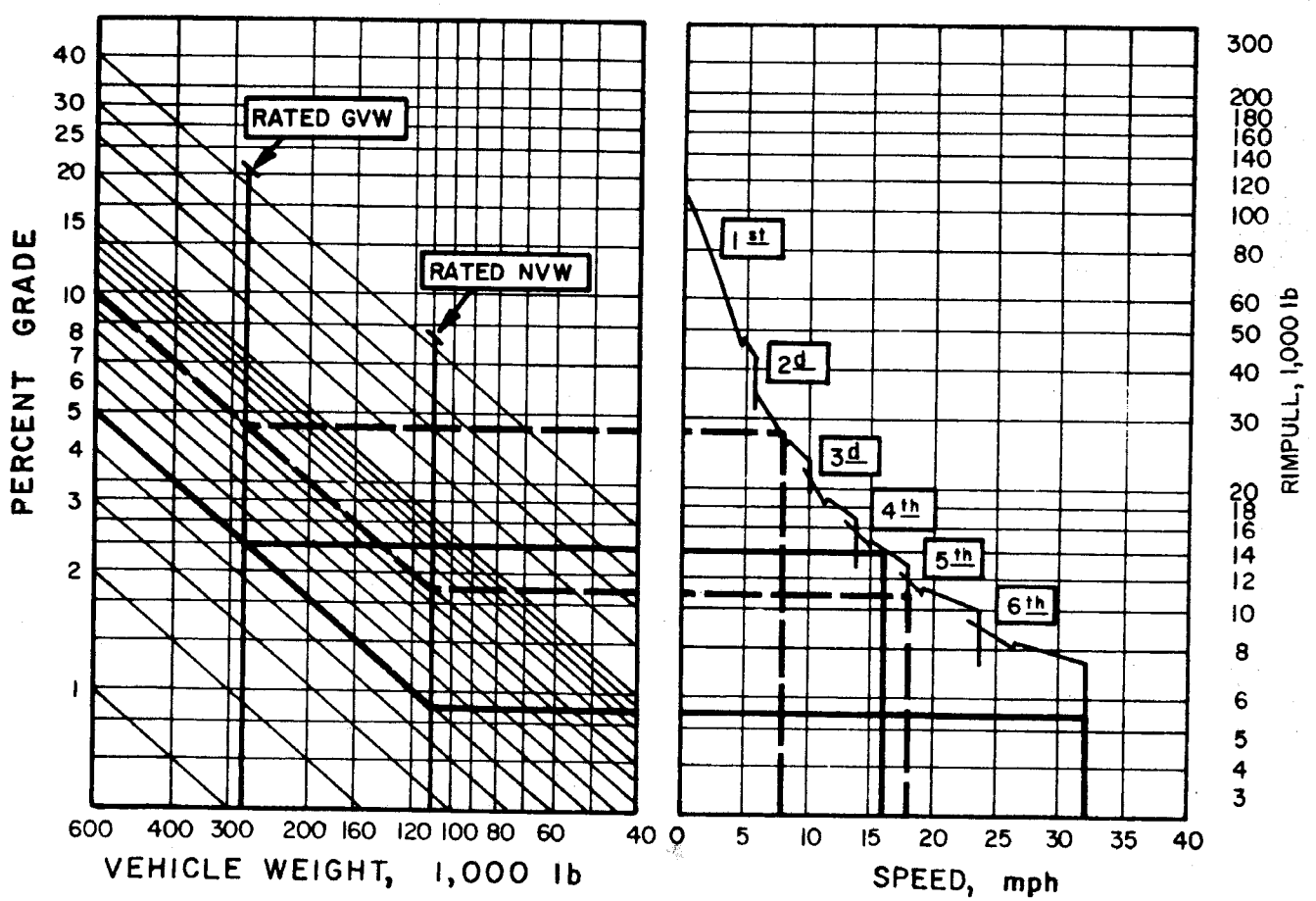
Maximum and Sustained Grades

Theoretical maximum allowable grades for various truck weight ranges in terms of emergency stopping situations have been defined in the stopping-distance curves (fig. 1-4). Defining maximum permissible grades in terms of stopping capabilities alone, however, is somewhat misleading in that no consideration is given to production economics. If, for example, a road were designed to include the maximum grade a truck weighing between 100,000 and 200,000 pounds (category 2) can safely descend, speed at the beginning of that grade must be reduced and sustained for the duration of descent. By the same token, ascending equipment would require frequent gear reductions and similar speed losses. This changing velocity means lost production time, additional fuel consumption, component wear, and eventually, maintenance.

Figure 6 is a performance chart similar in composition to those supplied by a majority of equipment manufacturers. Although the graph reflects performance characteristics for a specific make and model of haulage vehicle, it shows a representative impact of grade on performance. Two different symbols have been superimposed to delineate attainable speed as it is influenced by a vehicle operating on a 5% and 10% grade under loaded and unloaded conditions.

It is apparent from the chart that a reduction in grade significantly increases a vehicle's attainable uphill speed. Thus, haulage cycle times, fuel consumption, and stress on mechanical components, which results in increased maintenance, can be minimized to some extent by limiting the severity grades.

By relating the 10% to 5% grade reduction to the stopping-distance charts in the previous section, it can be seen that safety and performance are complementary rather than opposing factors. To demonstrate this fact, a reproduction of the stopping-distance chart for vehicles in the 100,000-to-200,000-pound



1. FIND VEHICLE WEIGHT ON LOWER LEFT HORIZONTAL SCALE.
2. READ UP TO SLANTED TOTAL RESISTANCE.
3. FROM INTERSECTION READ HORIZONTALLY TO THE RIGHT TO INTERSECTION WITH PERFORMANCE CURVE.
4. READ DOWN FOR VEHICLE SPEED.

FIGURE 6. - Vehicle performance chart.

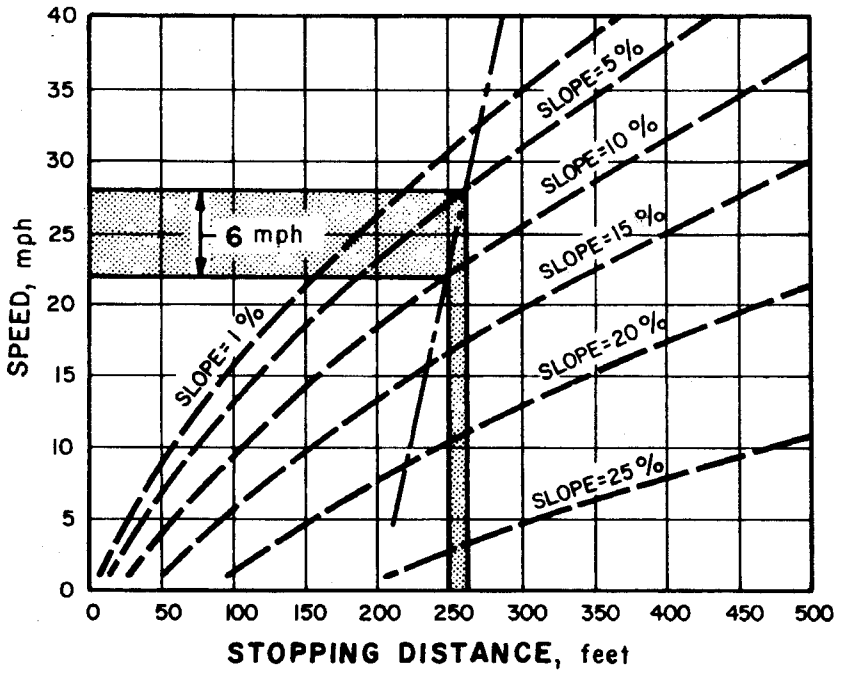


FIGURE 7. - Effect of grade reduction on stopping distances.

category is presented in figure 7 for reference. As indicated by superimposed lines on the graph, a 5% grade reduction translates to a descent speed increase of 6 mph without exceeding safe stopping-distance limitations.

The described benefits to production neglect consideration of construction economics. In the majority of cases, earthmoving to construct flatter gradients will incur greater costs. Moreover, design flexibility at many operations is curtailed by limited property ownership and physical constraints such as adverse geologic and topographic conditions. To recommend one optimum maximum grade to suit all operations, therefore, would be unfeasible. It must be the responsibility of each operator or road designer to assess the braking and performance capabilities of his particular haulage fleet and, based on this data, determine whether available capital permits construction of ideal grades or requires steeper grades at the sacrifice of haulage-cycle time.

The only guidelines that can definitely be set forth for maximum grade criteria are the laws and/or regulations currently mandated by most major mining States. Presently, a few States allow maximum grades of 20%. However, the majority of States have established 15% as the maximum grade.

Length of sustained gradients for haulage road segments are yet another factor that must be considered in vertical alinement. Many mine operators have found optimum operating conditions reflected on maximum sustained grades no greater than 7% to 9%. Also, many State laws and regulations establish 10% as a permissible maximum sustained grade. However, this does not mean that vehicles cannot be safely operated on more severe downgrades.

Significant improvements have been made in controlling downhill speed through hydraulic and dynamic retardation of drive components. Charts similar to figure 8 are available for most modern haulage equipment and illustrate their controllability on downgrades. As indicated by the example, this particular vehicle is advertised as being capable of descending a 15% grade at 8 mph if geared down to second range. Thus, the vehicle can be kept to a speed that is within the safe emergency braking limitations. The chart does not, however, specify the retardation limits in terms of time or length of sustained grade.

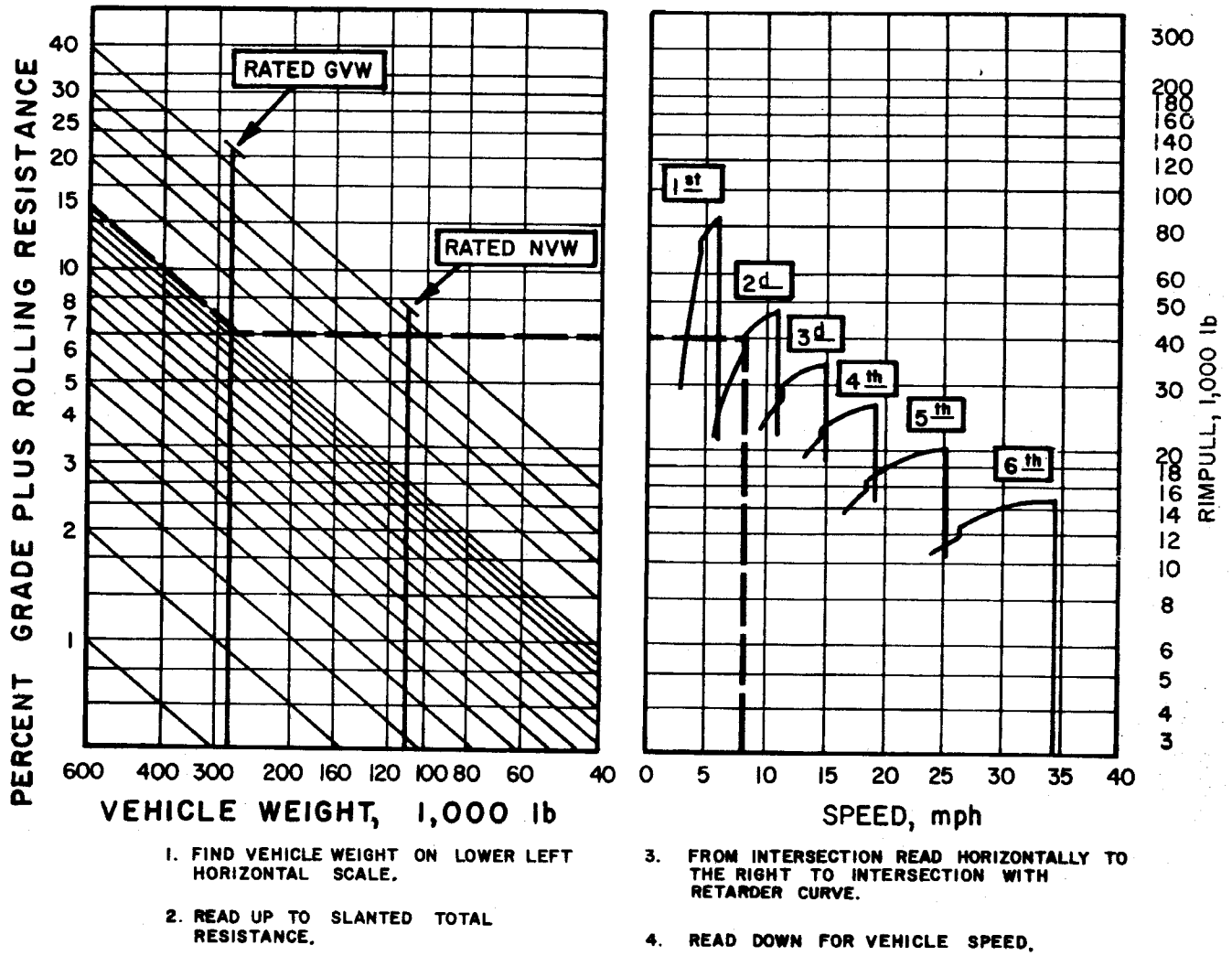


FIGURE 8. - Vehicle retarder chart.

All retardation systems function by dissipating the energy developed during descent in the form of heat. In hydraulic systems, this is accomplished through water-cooled radiators; the dynamic method generally relies on air-cooled resistance banks. It is possible to overheat either system if the combination of grade and length is excessive.

Considering the foregoing factors, it is reasonable to accept 10% as maximum safe sustained grade limitation.

Vertical Curves

Vertical curves are used to provide smooth transitions from one grade to another. Their lengths should be adequate to drive comfortably and provide ample sight distances at the design speed. Generally, vertical curve lengths greater than the minimum are desirable, and result in longer sight distances However, excessive lengths can result in long relatively flat sections, a feature that discourages good drainage and frequently leads to "soft spots" and potholes. Curve lengths necessary to provide adequate sight distance were computed as follows:

$$L = 2S - \frac{200\ (\sqrt{h_1} + \sqrt{h_2})^2}{A} \quad \text{(when S is greater than L)} \tag{3}$$

or,

$$L = \frac{AS^2}{100\ (\sqrt{2h_1} + \sqrt{2h_2})^2} \quad \text{(when S is less than L),} \tag{4}$$

where A = algebraic difference in grades,

S = attainable stopping distance on grade,

h_1 = driver's eye height,

and h_2 = height of object above haulage road surface.

Figures 9 through 16 show recommended minimum lengths of vertical curves versus stopping distances for various algebraic differences in grade. Each figure represents a different driver's eye height, ranging from 6 to 20 feet.

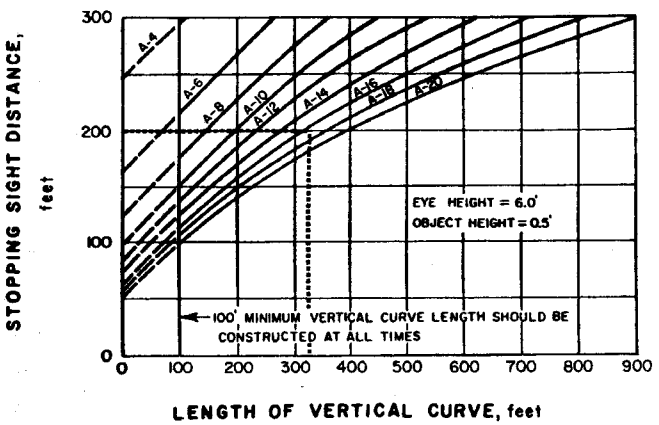


FIGURE 9. - Vertical-curve controls—6-foot eye height.

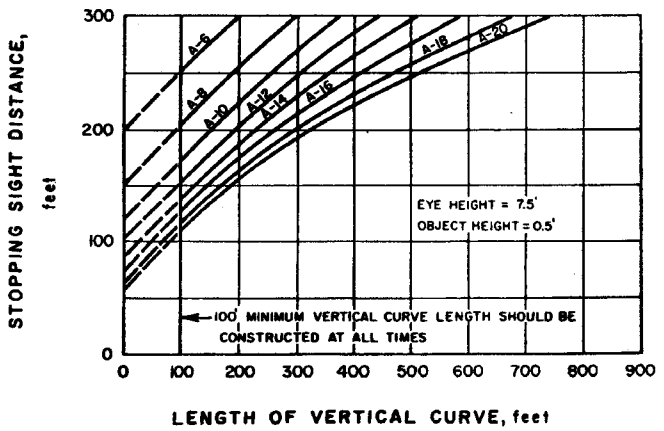


FIGURE 10. - Vertical-curve controls—7-1/2-foot eye height. This is the minimum eye height for single-unit haulage trucks of <100,000 pounds GVW.

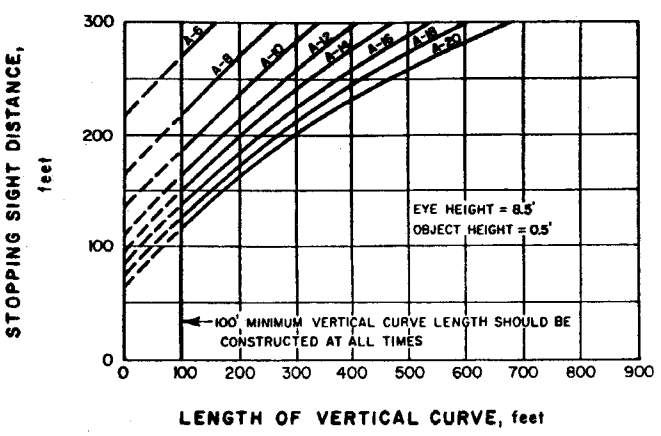


FIGURE 11. - Vertical-curve controls—8-1/2-foot eye height. This is the minimum eye height for single-unit and articulated haulage trucks of 100,000 to 200,000 pounds GVW.

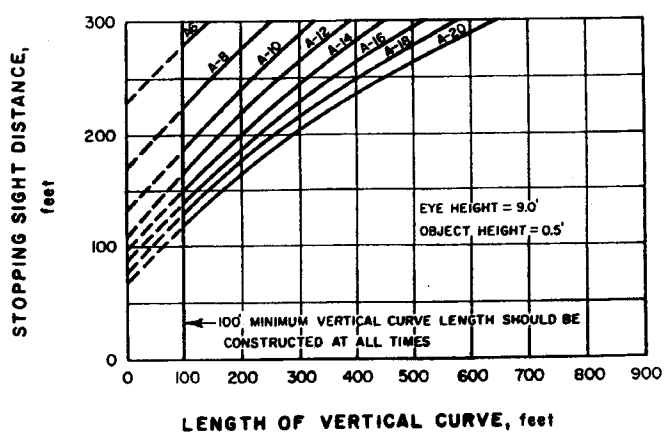


FIGURE 12. - Vertical-curve controls—9-foot eye height. This is the minimum eye height for articulated haulage trucks of >200,000 to 400,000 pounds GVW.

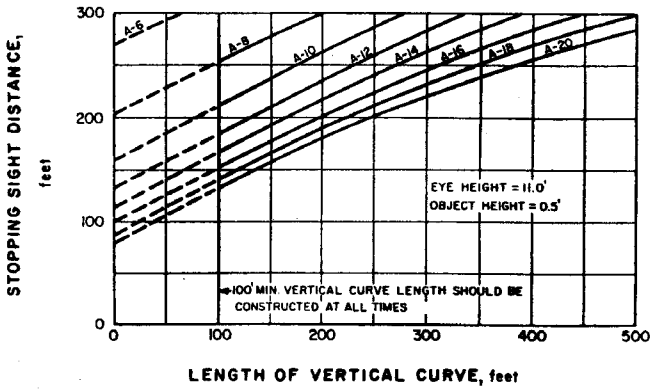


FIGURE 13. - Vertical-curve controls—11-foot eye height. This is the minimum eye height for single-unit haulage trucks of >200,000 to 400,000 pounds GVW and articulated haulage trucks of >400,000 pounds GVW.

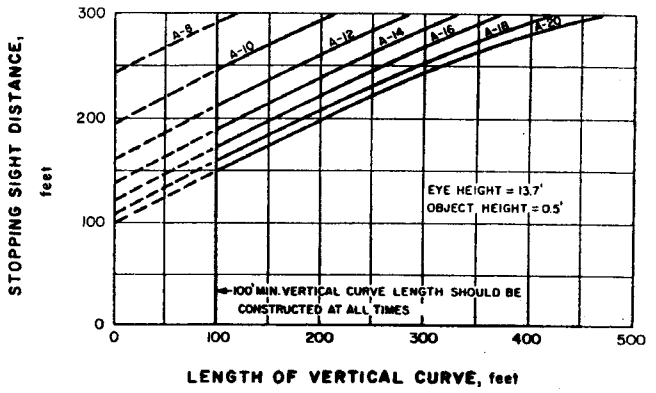


FIGURE 14. - Vertical-curve controls—13-foot 7-inch eye height. This is the minimum for single-unit haulage trucks of >400,000 pounds GVW.

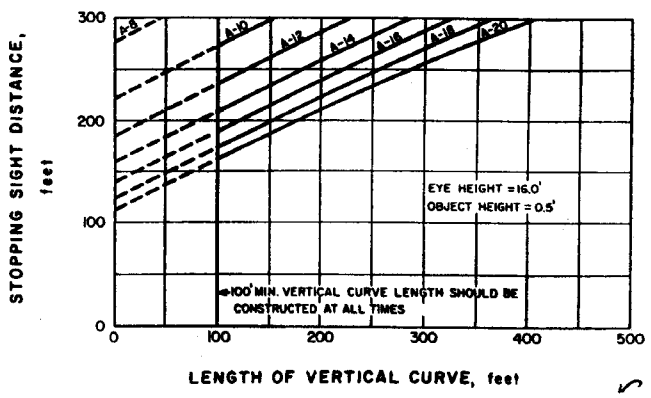


FIGURE 15. - Vertical-curve controls—16-foot eye height.

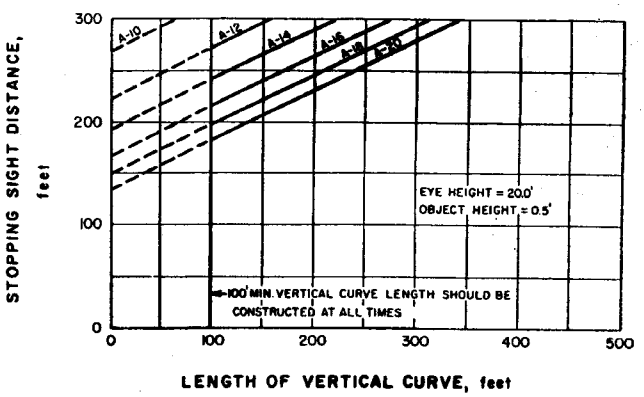


FIGURE 16. - Vertical-curve controls—20-foot eye height.

The object height used in computing crest vertical curves was 6 inches. Although there is some support for an object height equal to the vehicle taillight height, we believe the relatively small increase in vertical curve length is warranted to cover such possibilities as a prostrate figure, an animal, or dropped gear on the road surface.

To illustrate use of the vertical curve charts, first select the graph that indicates the lowest driver's eye height for vehicles in the haulage fleet. Then, from the stopping-distance charts (fig. 1-4), find the required stopping distance for the appropriate operating speed, vehicle weight, and grade. Use the steeper of the two grades to take into consideration the most critical situation. Read right to intersect the appropriate algebraic difference and down to find vertical curve length. An example is given in figure 9 for a stopping distance of 200 feet and an algebraic difference of 16 (A-16) to give a required curve length of 325 feet.

Horizontal Alinement

Horizontal alinement during haulage road design and construction deals primarily with the elements necessary for safe vehicle operation around curves. Far too often turns are created without considering proper width, superelevation, turning radius, or sight distance. Correct horizontal alinement is essential to both safety and efficiency throughout a haulage cycle. The following subsections discuss the parameters prerequisite to correct horizontal alinement and how they affect road design. It must be emphasized that recommendations are based on the premise of providing maximum safety without taking construction economics into account. Due to the physical constraints particular to many mining sites, the cost of construction may increase significantly. Safety, however, should allow no tradeoffs, and any alterations to design criteria should be accompanied by a compensatory reduction in operating speed.

Superelevation Rate

Vehicles negotiating short-radius curves are forced radially outward by centrifugal force. Counteracting forces are the friction between the tires and the road surface, and the vehicle weight component due to the superelevation. The basic formula is

$$e + f = \frac{V^2}{15R}, \tag{5}$$

where e = superelevation rate, feet per foot;

f = side friction factor;

V = vehicle speed, miles per hour;

and R = curve radius, feet.

Theoretically, owing to superelevation, the side friction factor would be zero when the centrifugal force is balanced by the vehicle weight component. Steering would be effortless under these conditions.

There is a practical limit to the rate of superelevation. In regions subject to snow and ice, slow-traveling vehicles could slide down the cross slope. Regions not subject to adverse weather conditions can generally have slightly higher superelevation rates. However, even in these regions, the driver of a vehicle negotiating a curve at a speed lower than the design speed would encounter some difficulty holding the proper path. He would experience an unnatural maneuver, steering up the slope, against the direction of curve.

Another consideration in establishing the cross slope rate is the high percentage of load carried by the inner wheels of a truck stopped or moving slowly on the curve.

As shown by the formula, there are two factors counteracting the centrifugal force: The superelevation rate and the side friction factor. Much

experimentation has been done to determine side friction factors. Several authorities[5] recommend a factor of 0.21 for speeds of 20 mph and less. The American Association of State Highway Officials (AASHO) has plotted the results of several studies on vehicle speeds at short-radius curve intersections. Logically, the average running speed decreased as the radius decreased. And, as the speed decreased, the side friction factor increased, producing a factor of 0.27 at 20 mph on a 90-foot-radius curve, and a 0.32 factor at 15 mph on a 50-foot-radius curve. Neither demonstrates a need for a superelevation rate in excess of the normal cross slope.

This data, plus the recognized fact that sharper curves are shorter in length and afford less opportunity for providing superelevation and runout, lead to the derivation of table 1.

TABLE 1. - Recommended superelevation rates, fpf

Radius of curve, ft	Speed of vehicle, mph					
	10	15	20	25	30	35 and above
50	0.04	0.04				
100	.04	.04	0.04			
150	.04	.04	.04	0.05		
250	.04	.04	.04	.04	0.06	
300	.04	.04	.04	.04	.05	0.06
600	.04	.04	.04	.04	.04	.05
1,000	.04	.04	.04	.04	.04	.04

This table serves two purposes. It not only suggests superelevation rate rates, but also recommends proper curve and speed relationships. For example, a vehicle traveling 30 mph approaching a 150-foot-radius curve superelevated 0.04 fpf (foot per foot) should slow to at least 20 mph.

Superelevation Runout

The portion of haulageway used to transform a normal cross-slope section into a superelevated section is considered the runout length. The generally slower speeds at mining sites make the positioning of the runout less critical, but the purpose remains the same--to assist the driver in maneuvering his vehicle through a curve. States vary in their methods of applying superelevation runout. Some apply it entirely on the tangent portion of the haulageway so that full superelevation is reached before entering the curve. Most States, however, apply part on the tangent and part in the curve. For design criteria herein, one-third shall be in the curve and two-thirds on the tangent.

Runout lengths vary with the design speed and the total cross slope change. Recommended rates of cross slope change are shown in table 2.

[5]Work cited in footnote 3.
Meyer, C. F. Route Surveying. International Textbook Co., Scranton, Pa., 1956, 311 pp.

TABLE 2. - Recommended rate of cross-slope change

Vehicle speed, mph.....	10	15	20	25	30	35 and above
Cross slope change in 100-ft length of haulageway (fpf).....	0.08	0.08	0.08	0.07	0.06	0.05

To illustrate the use of this table, assume a vehicle is traveling at 35 mph on tangent with normal cross slope 0.04 fpf to the right. It encounters a curve to the left necessitating a superelevation rate of 0.06 fpf to the left. The total cross-slope change required is 0.10 fpf (0.04 + 0.06). The table recommends a 0.05 cross-slope change in 100 feet. Total runout length is computed as 200 feet [(0.10 ÷ 0.05) x 100 = 200]. One-third of this length should be placed in the curve and two-thirds on the tangent.

Sharp Curve Design--Widening on Curves

Switchbacks or other areas of haulageways requiring sharp curves must be designed to take into consideration the minimum turning path capability of the vehicles. Figure 17 illustrates the turning radius of vehicles in each weight classification. The radii shown in the accompanying table are the minimum negotiable by all vehicles in each classification. Responsible design dictates that these minimums be exceeded in all except the most severe and restricting conditions. Figure 17 also illustrates the additional roadway width needed by a turning truck. Widths required by vehicles in each weight category vary with the degree of curve. Tables 3 and 4 recommend haulageway widths for curving roadways up to four lanes.

TABLE 3. - Design widths for curving haulageways--single-unit vehicles, feet

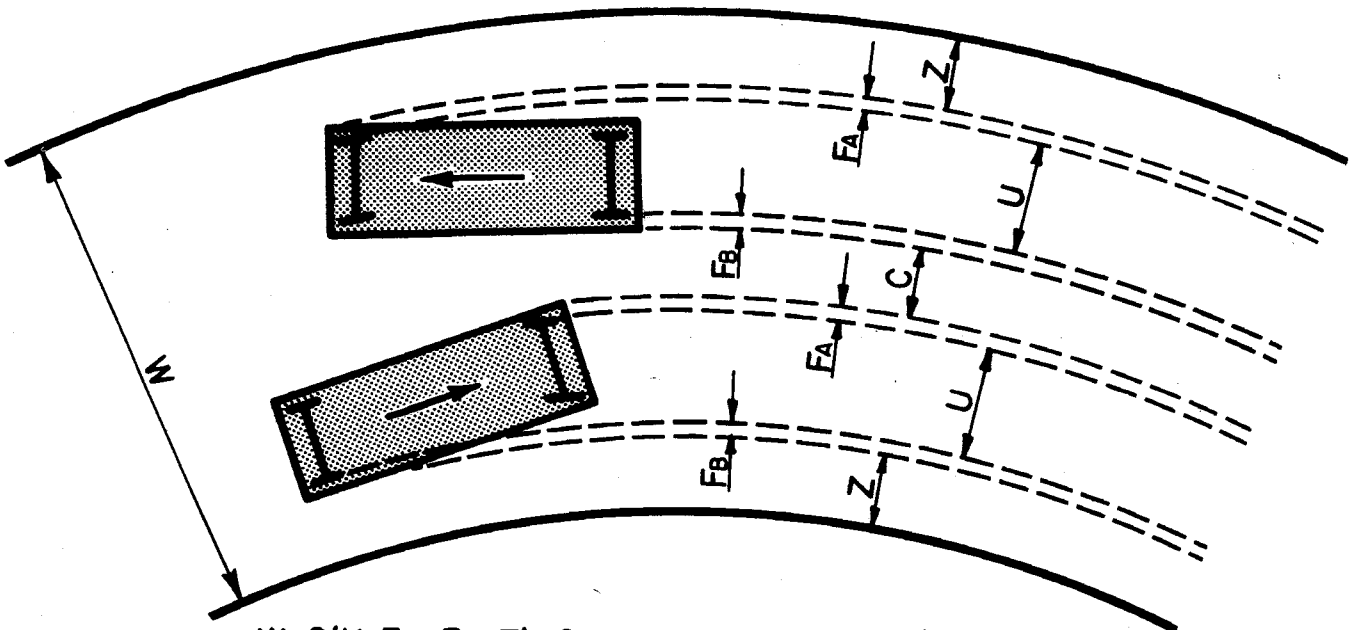
Curve radius on inner edge of pavement (R), feet	One-lane haulageway, vehicle category--				Two-lane haulageway, vehicle category--				Three-lane haulageway, vehicle category--				Four-lane haulageway, vehicle category--			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Minimum	29	34	45	70	51	60	79	123	73	86	113	176	95	112	147	229
25	27	34	44	68	48	60	76	119	68	86	109	170	89	111	142	221
50	25	31	41	63	44	54	72	110	63	77	103	158	82	100	134	205
100	24	29	39	59	42	51	69	103	60	73	99	147	78	95	128	192
150	24	29	39	58	41	50	68	101	59	72	97	145	77	94	126	188
200	23	29	38	57	41	50	67	101	59	71	96	144	76	93	125	187
Tangent	23	28	37	56	40	48	65	98	57	69	93	140	74	90	120	182

NOTE.--1 indicates category 1 vehicle: <100,000 pounds GVW.
2 indicates category 2 vehicles: 100,000 to 200,000 pounds GVW.
3 indicates category 3 vehicles: >200,000 to 400,000 pounds GVW.
4 indicates category 4 vehicles: >400,000 pounds GVW.

TABLE 4. - Design widths for curving haulageways--articulated vehicles, feet

Radius on inner edge of pavement (R), feet	One-lane haulageway, vehicle category--			Two-lane haulageway, vehicle category--			Three-lane haulageway, vehicle category--			Four-lane haulageway, vehicle category--		
	2	3	4	2	3	4	2	3	4	2	3	4
25	38	68	86	66	119	151	95	170	215	123	221	280
50	32	57	71	56	99	124	80	142	177	105	184	231
100	28	48	58	50	83	101	71	119	144	92	154	187
150	27	44	52	47	76	91	68	109	130	88	142	168
200	26	42	49	46	73	85	66	104	122	85	135	158
Tangent	25	41	41	44	71	72	63	102	103	81	133	133

NOTE.--2 indicates category 2 vehicles: 100,000 to 200,000 pounds GVW.
3 indicates category 3 vehicles: >200,000 to 400,000 pounds GVW.
4 indicates category 4 vehicles: >400,000 pounds GVW.



$W = 2(U + F_A + F_B + Z) + C$ $\qquad$ $C = Z = (U + F_A + F_B)/2$

U = Track width of vehicle (center-to-center tires), feet
F_A = Width of front overhang, feet
F_B = Width of rear overhang, feet
C = Total lateral clearance
Z = Extra width allowance due to difficulty of driving on curves, feet

Vehicle Weight Classification	Turning Radius, feet
1	19.00
2	24.43
3	N A
4	38.88

FIGURE 17. - Haulageway widths on curves.

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