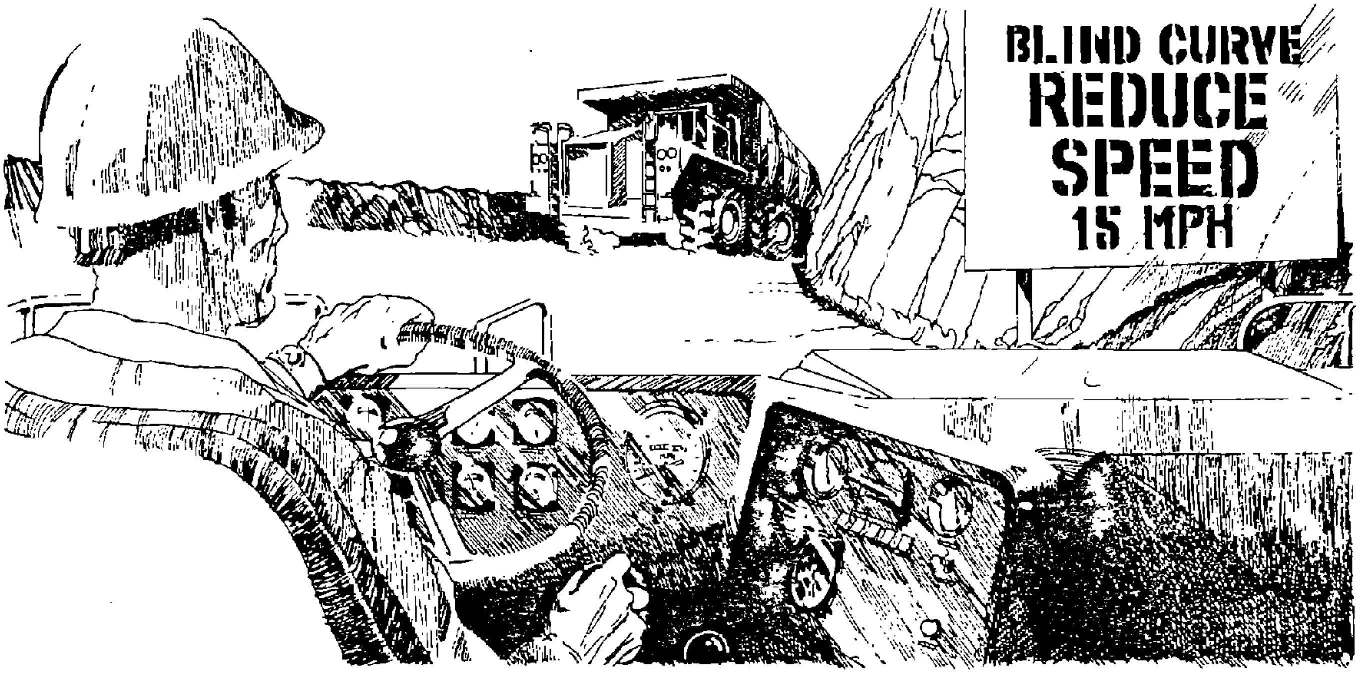
BuMines OFR 114-76

PB 259 634

SURFACE MINE HAULAGE ROAD DESIGN STUDY



USBM CONTRACT NO. J0255037

JUNE, 1976

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BIBLIOGRAPHIC DATA SHEET	1. Report No. BuMines OFR 114-76	2.	3. Recipient's Accession No. PB-259 634
4. Title and Subtitle Surface Mine Haulage Road Design Study			5. Report Date June 1976
			6. Performing Organization Code
7. Author(s) Bruce E. Stauffer and Patrick M. McClain			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Skelly and Loy 2601 North Front Street Harrisburg, PA 17110			10. Project/Task/Work Unit No.
			11. Contract/Grant No. J0255037
12. Sponsoring Agency Name and Address Office of Assistant Director--Mining Bureau of Mines U.S. Department of the Interior Washington, DC 20241			13. Type of Report & Period Covered Contract research, FY 1976
			14. Sponsoring Agency Code

15. Supplementary Notes

Approved for release by Director, Bureau of Mines, November 2, 1976.

16. Abstracts The report recommends criteria for the design of safe surface mine haulage roads. Information relevant to road design at surface mine sites delineates vertical and horizontal alignment; subbase and surface materials; drainage; cross-slope, superelevation; runaway vehicle protection; and road and vehicle maintenance criteria. An appendix is included which details the study methods used in compiling the final report information. A bibliography following the main text lists literature referenced for the report data and which is available as a valuable tool for use by individuals involved in haul road design.

17. Key Words and Document Analysis. 17a. Descriptors

Surface mines and mining
- Haulage roads
- Road design
- Safety recommendations
- Haul road construction

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 08I, 17C

18. Distribution Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited by NTIS.	UNCLASSIFIED	
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35 (10-70) USCOMM-DC 40329-P71

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BuMines OFR 114-76

SURFACE MINE HAULAGE ROAD

DESIGN STUDY

PHASE V

FINAL REPORT

Prepared for:

United States Department of the Interior
Bureau of Mines
Eastern Administrative Office
Pittsburgh, Pennsylvania 15213

CONTRACT NO. J0255037

Submitted by:

SKELLY and LOY
Engineers - Consultants
2601 North Front Street
Harrisburg, Pennsylvania 17110

BuMines Open File Report 114-76

June, 1976

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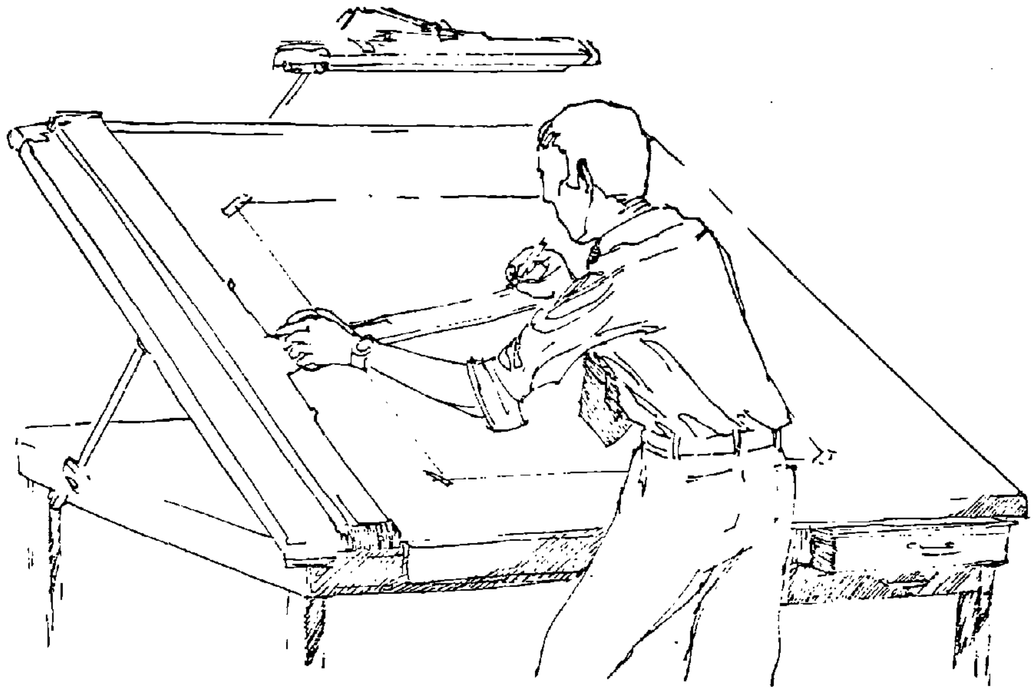

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS AND RECOMMENDATIONS

One of the most important factors in the design of a safe haul road is the braking capabilities of trucks which will use the road. Braking performance should be determined by on-site testing, if feasible, or from manufacturers' information, if available. Because an operator cannot always depend on his vehicle's retardation system, it is recommended that equipment manufacturers provide a sticker or data plate on each machine which would delineate maximum braking capabilities in terms of vehicle speed and percent of grade negotiable with service brakes only.

Operational velocities, road downgrades, road adhesion characteristics and sight distance restrictions are among the parameters which must be considered in designing roads which will accommodate vehicle braking system limitations. For the purposes of this study, the Society of Automotive Engineers' minimum braking standards were mathematically expanded to apply to haulage road characteristics. Velocity-stopping distance curves were developed and presented in this report to indicate the most conservative stopping distances required to safely stop a haulage vehicle. The braking performance of the vast majority of trucks manufactured for use in surface mining operations will exceed these theoretical limitations. Therefore, use of these curves in haulage road design will provide maximum safety for any make, model, or type of haul road user.

Coefficient of road adhesion, a numerical representation of the friction between tire and road surface, is a factor affecting stopping distance of a vehicle. When the frictional force between a rolling tire and road surface is less than that at the interface of brake components during application, wheel sliding will occur. Thus, uniform deceleration is denied by sliding, resulting in a far greater stopping distance.

Many of the newer haul units are equipped with road condition switches which can be engaged to reduce brake pressure when traveling on poor surfaces. However, the effectiveness of these devices is limited on downgrade surfaces which are covered with mud, ice or snow, or composed of dry sandy material. Every effort should be made to ensure that the road surface coefficient of road adhesion is maximized and kept free of any material which will reduce its frictional characteristics. Table II-2 shows the coefficients of road adhesion for various surface materials and may be used to identify those with the best tire/surface adhesion potential.

On safe haul roads, the sight distance from the driver's eye to the hazard ahead must equal or exceed the vehicle's shortest stopping distance. Sight distance may be limited by horizontal and/or vertical obstructions or by climatological conditions such as fog, rain, and snow. Sight distance limitations will be better defined when results of research being funded by the Bureau of Mines into Improved Visibility Systems become available. Peripheral vision improvement and "blind spot" elimination are two major areas where visibility improvements are needed.

Tables included in this report show recommended widths for one, two, three and four lane roads within all vehicle categories. These tables apply to both tangent and curved roadways. Vertical curve control graphs delineate minimum vertical curve lengths taking into consideration algebraic difference in grades, height of driver's eye, height of object above road surface, and required stopping sight distance.

The need for more stability in road bed was documented by observations during the site investigation phase of the project. Mining engineers, haul road designers, and maintenance personnel confirmed this to be the case. Section II of this report deals with all aspects of a haulage road cross section, including traffic and warning signs, drainage considerations, cross slope, haulway width and conventional parallel berms. Materials for use as subbase and surface courses, recommended depths and methods of placement are suggested.

During the data gathering stage of the study, it became increasingly apparent that most berm research is related to highway vehicles. The enormous weight differential between off highway and highway vehicles (sometimes greater by a factor of 100) suggests a berm proportionately larger would provide similar impact characteristics. However, the high center of gravity combined with a disproportionately narrow wheel track width make haulage vehicles more susceptible to overturn. The tire size, steering mechanism, and suspension characteristics indicate a significantly different response pattern from that of a car. Also, not only would a berm 100 times the size of a highway berm be monstrously large, but the area of land it would occupy would likely create a severe economic penalty.

Conventional parallel berms do not appear to offer much protection to a runaway or out of control haulage vehicle. In fact they can be more of a hazard than a controlling device as they could act as a launch ramp, projecting the truck out into space, or serve to overturn a vehicle whose wheels, on one side, continued to climb the berm.

A median berm design, currently utilized in Australia, was found to offer considerable improvement over conventional parallel berms. This type of medial control acts as a vehicle arresting device and has been very effective in controlling runaway vehicles at Australian mining companies. More research, especially experimental field testing, is needed to find a way to effectively utilize berms as a safety device on haulage roads.

An additional runaway vehicle control device which has been found to be very effective on long, sustained grades is the escape lane. Where applicable, and when properly constructed and maintained, escape lanes have good potential for controlling runaways with little or no vehicle damage or driver injury. This type of safety device is encouraged whenever space is available.

Many road design parameters, such as horizontal and vertical alignment, rate and runout for superelevation, curve widening and vertical curves are well defined in this report and in many road construction manuals. Other important parameters, however, such as maximum and sustained grades, and the length of those grades that vehicles may safely traverse, is information not readily available. This data can be supplied by manufacturers who can also make recommendations for equipment modifications which fit the truck to the job.

Appropriate haul road design, construction, maintenance, and drainage can make for a safer, more efficient operation while greatly reducing environmental problems related to stream sedimentation. Careful consideration of subbase, surface materials and road width, and proper application of cross slopes, berms, drainage provisions and culverts are just as important to reduction of required road and vehicle maintenance as they are to road design.

Regularly scheduled road maintenance is a necessity for safe haulage operations. Reduction in vehicle damage and in required maintenance and repair more than compensates for its added costs.

Damage to tires, filter clogging due to excessive dust, stuck vehicles, reduced traction, and other problems necessitating operational delays are reduced or eliminated by a regularly scheduled, and correctly applied, road maintenance program. In addition, vehicular control is greatly improved when roads are kept in good condition.

Periodic vehicle maintenance and inspection are basic considerations for safe and profitable mine haulage. Inspection checklists, to be completed daily by the operator and periodically by the maintenance crew, are required at many mine operations. Maintenance schedules are often computer controlled and require signing of a filed checklist by the responsible mechanic and maintenance foreman after maintenance is performed. These procedures should be considered at all surface mine sites.

The majority of parameters necessary for safe haul road design are discussed and defined by specific criteria in this report. However, certain design elements cannot be adequately defined without additional research and field testing. Braking capabilities should be delineated through empirical rather than theoretical data. Additional consideration must be given to relating safe haul road development to its effect on mining economics.

A separate study is currently being conducted to satisfy these two research needs. It is anticipated that by January 1, 1977, a supplement to this report will be available which evaluates the economic impact of incorporating safe design criteria and delineates haulage vehicle braking limitations derived through field tests.

Identifying these parameters, however, does not alleviate the need for comprehensive evaluations of other factors which offset safe haul road design. Throughout research efforts for this report, the need for additional studies became increasingly apparent. The following areas should receive primary consideration as additional research requirements:

1. The effects of various berm sizes, materials, configurations, and angles of incidence on the redirection and/or deceleration of large surface mining equipment.

2. Heat dissipation capabilities of surface mine haulage equipment braking systems as a function of brake application frequency and duration due to speed and grade.

3. Impact of vehicle or extraneous artificial haul road illumination on driver's sight distance during night operations.

4. Frequency and magnitude of haulage equipment component failures resulting from vibration induced fatigue on poorly constructed haul road surfaces.

SURFACE MINING

HAULAGE ROAD DESIGN

MANUAL

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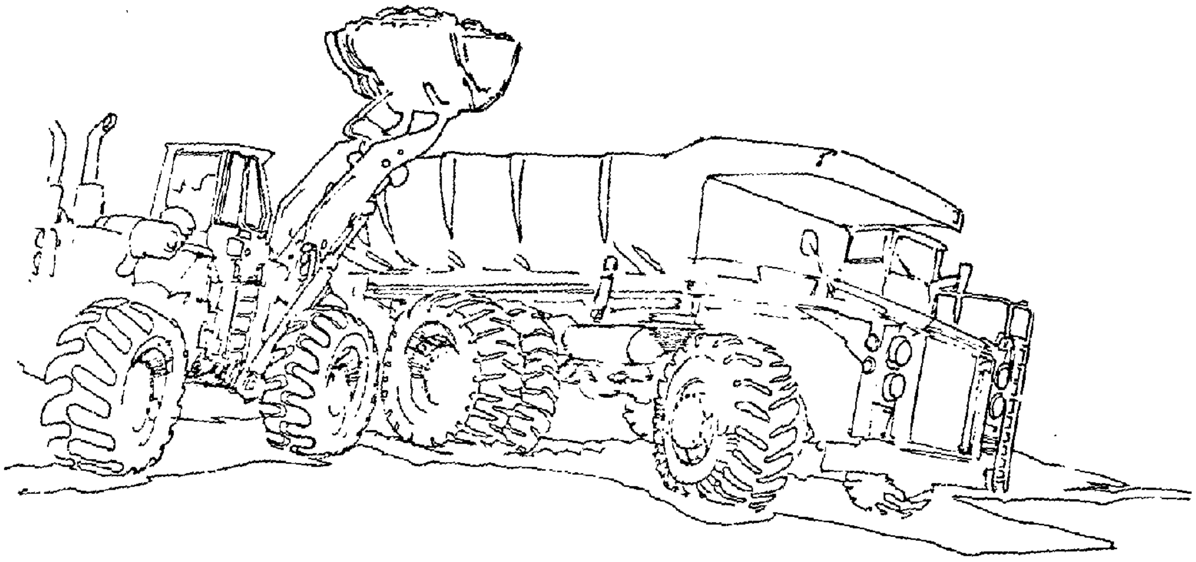


INTRODUCTION

INTRODUCTION

Over the past thirty years, surface mine haulage equipment has developed from trucks capable of moving twenty tons of material to vehicles which transport as much as 350 tons. Unfortunately, the design of roads this equipment must traverse has not advanced at the same rate. In many areas road building technology appropriate to vehicles of three decades past is still being practiced today. As a result, numerous unnecessary haulage road accidents have occurred every year. A number of these mishaps can be attributed to operator error. However, far too many are caused by road conditions which are beyond the vehicle's ability to negotiate safely.

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

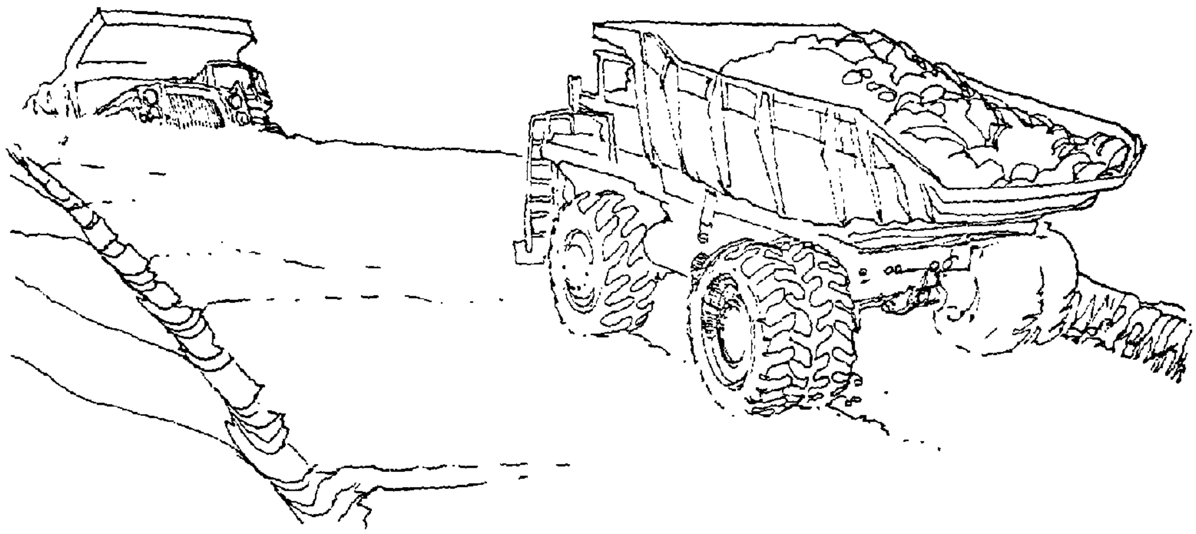
Time allocated for this project prohibited a detailed investigation of mechanical design for every type of haul road user. However, safe haul road design criteria should be sufficiently comprehensive to allow application to all machine types.

This complication required that design criteria be based on the one type of surface mining equipment which exhibits the lowest safety potential. Research of engineering data for all major types of surface mine machinery revealed that large off-road haulage trucks had the smallest margin of safety due to their great size and weight, characteristic use, and control components. Thus, designing haul 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-highway haulage vehicles was solicited from manufacturers. Information was tabulated to identify specifications for width, height, weight, tire track, wheel base, braking system type, 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. 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, haulway widths, curve widening, and spacing of runaway devices, are presented in this report.

The haulway designer may utilize the Contents section of this document as a check list to assure that all elements of design have been considered in haul road planning.



I-HAULAGE ROAD ALIGNMENT

HAULAGE ROAD ALIGNMENT

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 alignment.

STOPPING DISTANCE - GRADE/BRAKE RELATIONSHIPS

From a safety standpoint, haul 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 haul trucks, by virtue of their function within the mining operation, are the most frequent haul 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 haul road users. Designing routes to 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 which can be maintained on a downgrade through use of dynamic or hydraulic retardation. While 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 disc size, method of actuation, and system pressure. Thus, an operator does not know whether his vehicle's brakes 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 haul 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 J-166 delineates the following values as maximum permissible service brake stopping distances from an initial velocity of 20 miles per hour, on a dry, level and clean concrete surface:

Vehicle Weight (lbs.)	Service Brake Maximum Stopping Distance (ft. from 20 mph)
Up to 100,000	60
Over 100,000 to 200,000	90
Over 200,000 to 400,000	125
Over 400,000	175

While the majority of haulage truck manufacturers equip their products with brake systems which 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 expanded.

The stopping distance curves, Figures I-1 through I-4, depict stopping distances computed for various grades and speeds in each SAE test weight category. Plot points for each of the various curves have been arrived at through the formula:

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

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 (sec)

Θ = angle of descent (degrees)

V_o = speed (fps) at time of perception

u min = coefficient of friction at the wheel brake 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: first, the time necessary for pressure to build and actuate brake components after the pedal is depressed in the cab. For ease of discussion, this value is designated t_1. Information supplied by a member of SAE subcommittee 10, the authors of J-166, gives the following as values for t_1. These numbers have been verified by various subcommittee members and their companies.

Vehicle Weight (lbs.)	Brake Reaction Time t_1 (seconds)
Less than 100,000	0.5
Over 100,000 to 200,000	1.5
Over 200,000 to 400,000	2.75
Over 400,000	4.5

A second component of t, designated as 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 was assigned for t_2 in all cases. This value is documented by the American Association of State Highway Officials' 1965 Handbook entitled "A Policy on Geometric Design of Rural Highways".

A value for u min, the coefficient of friction achievable at the lining and drum or disc interface, is arrived at through the formula:

$$u \min = \frac{V^2}{2g\ S} \qquad (2)$$

where: V = SAE Test Velocity of 29.33 fps
g = gravitational pull of 32.2 fps^2
S = SAE Actual Braked Distance*

*Actual Brake Distance is 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 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 work 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 a brake system's ability 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 endure before ill effects are noticed. The obvious need to limit stopping distances for prevention of excessive brake heat, combined with the inability to realistically simulate thermal characteristics, presented a problem.

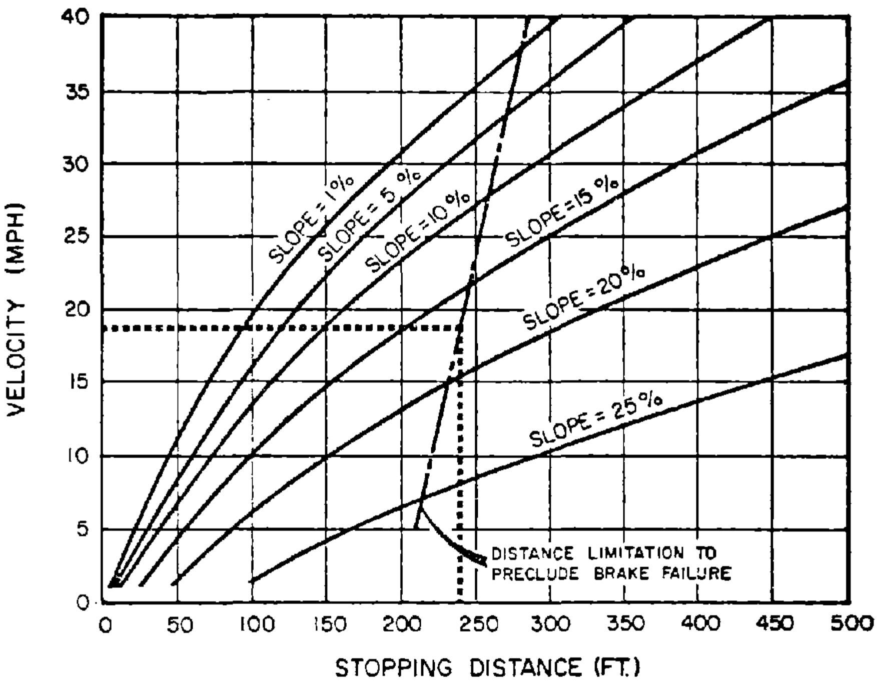
Resolution of this difficulty was achieved through the acceptance of empirical test data from the British Columbia Department of Mines and Petroleum Resources[1]. This organization has conducted over one thousand haul truck stopping distance tests at active mine sites in British Columbia. The variety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

(1) Dawson, V.E., "Observations Concerning On-Site Brake Testing of Large Mining Trucks", Society of Automotive Engineers, Warrendale, Pa., 1975.

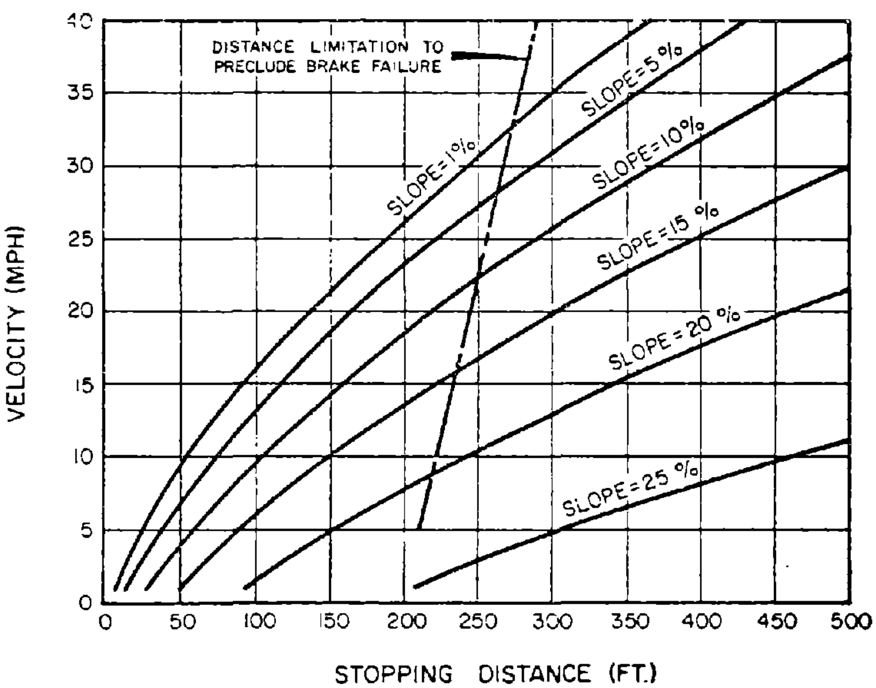
Information supplied by Mr. V. E. Dawson, who coordinated this testing, indicated that to preclude fade, a two hundred foot braking distance should be considered the maximum allowable. Although some tested vehicles were able to exceed this limitation and still execute a safe, controlled stop, statistics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

Inclusion of the 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 (Figure I-1).

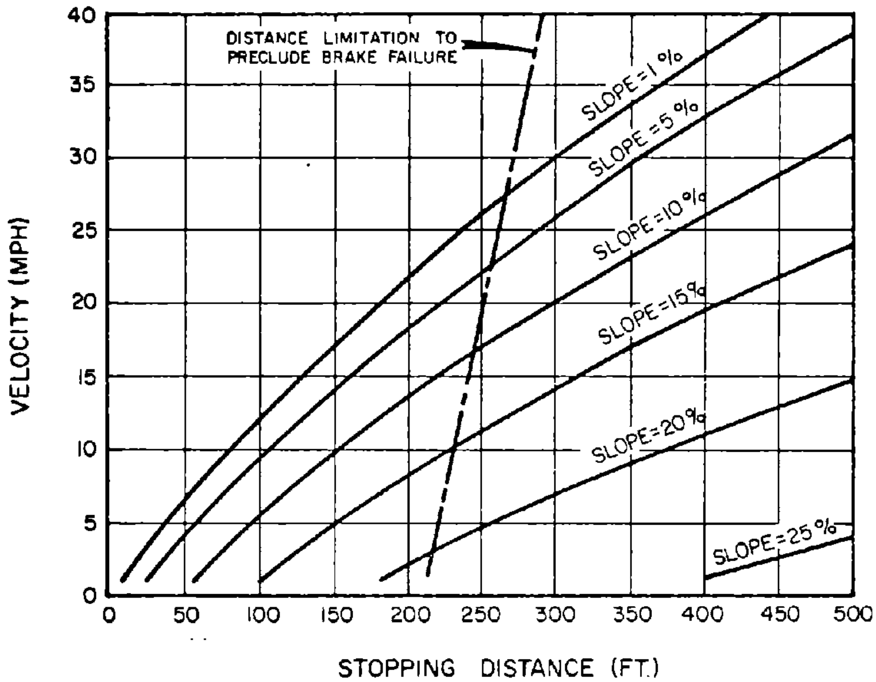
Figures I-1 to I-4 have been based primarily on mathematic derivations. They do not depict results of actual field tests, but are presented simply to offer an indication of the speed and grade limitations which must be considered in designing a haul road for a general truck size. Actual field testing has proven that many haulage vehicles can and do exceed theoretical capabilities. The quantity of this



VELOCITY VS STOPPING DISTANCES
ON VARIOUS SLOPES
VEHICLES WITH <100,000 LBS. GVW
FIGURE I-1



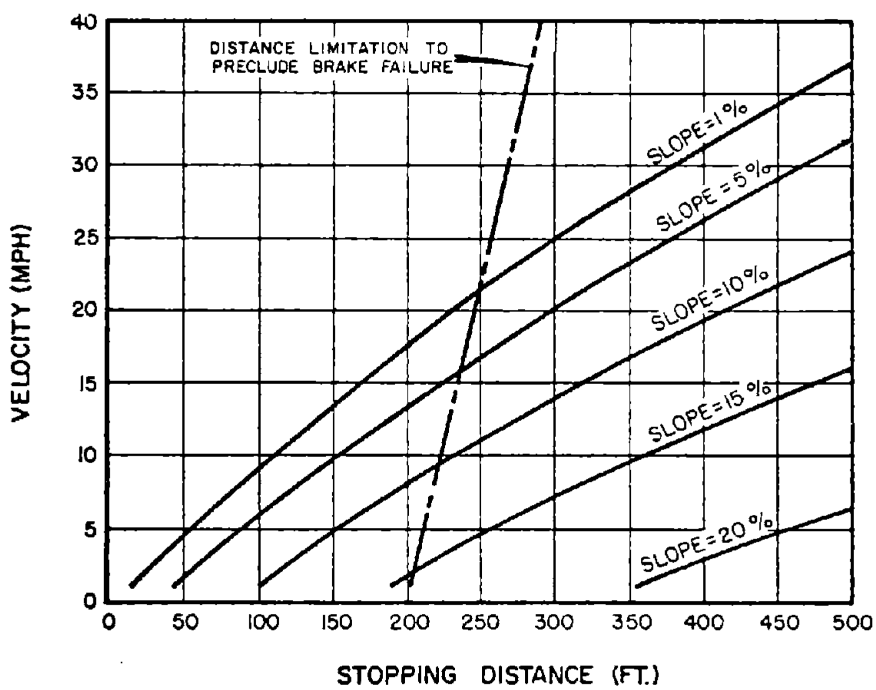
VELOCITY VS STOPPING DISTANCES
ON VARIOUS SLOPES
VEHICLES WITH 100,000 TO 200,000 LBS. GVW
FIGURE I-2



VELOCITY VS STOPPING DISTANCES ON VARIOUS SLOPES

VEHICLES WITH 200,000 TO 400,000 LBS. GVW

FIGURE I-3



VELOCITY VS STOPPING DISTANCES ON VARIOUS SLOPES

VEHICLES WITH >400,000 LBS. GVW

FIGURE I-4

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 figures be used to make general determinations in the preliminary planning stage of design. Before actual road layout begins, manufacturers of the vehicles which will ultimately utilize 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's and possibly a few manufacturers' efforts, 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

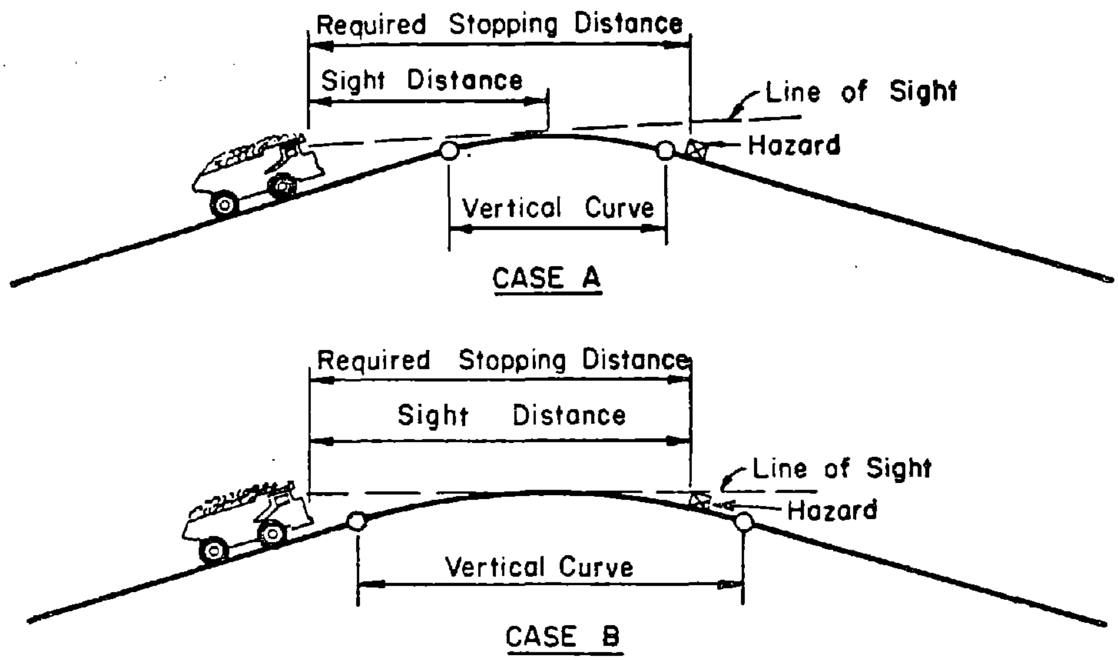
Sight distance is defined as the extent of peripheral area visible to the vehicle operator. It is imperative that sight distance be sufficient to enable a vehicle traveling at a given speed to stop before reaching a hazard. The distance measured from the driver's eye to the hazard ahead must always equal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

On vertical curve crests, the sight distance is limited by the road surface. Figure I-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.

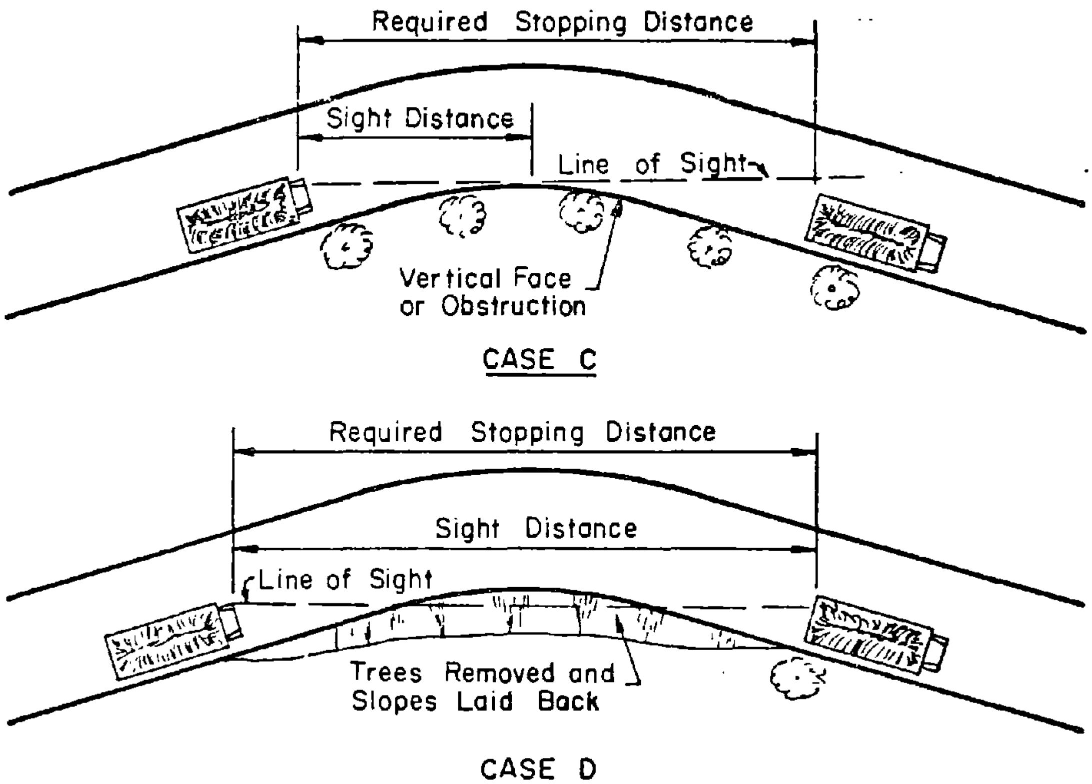
On horizontal curves, the sight distance is limited by adjacent berm dikes, steep rock cuts, trees, structures, etc. Figure I-5, Case C illustrates a horizontal curve with sight distance restricted by trees and steep side cut. Case D shows that by removing the trees and laying back the slope, the sight distance can be lengthened to equal the required stopping distance.

VERTICAL ALIGNMENT

Vertical alignment 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



SIGHT DISTANCE ON VERTICAL CURVES



SIGHT DISTANCE ON HORIZONTAL CURVES

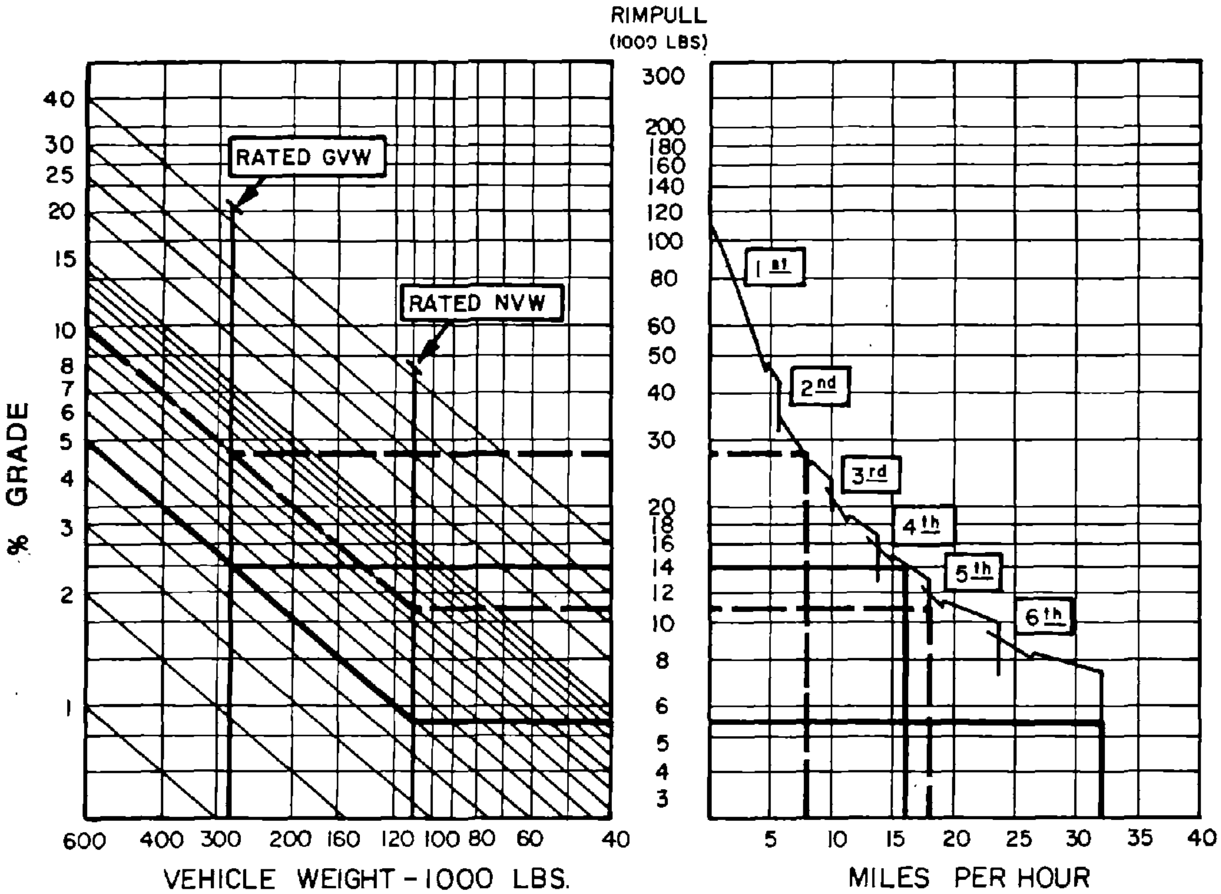
FIGURE I-5

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 above 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, Figures I-1 through I-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 in the 100,000 - 200,000 pound category 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.

The following illustration is a haul truck performance chart similar in composition to those supplied by a majority of equipment manufacturers.



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.

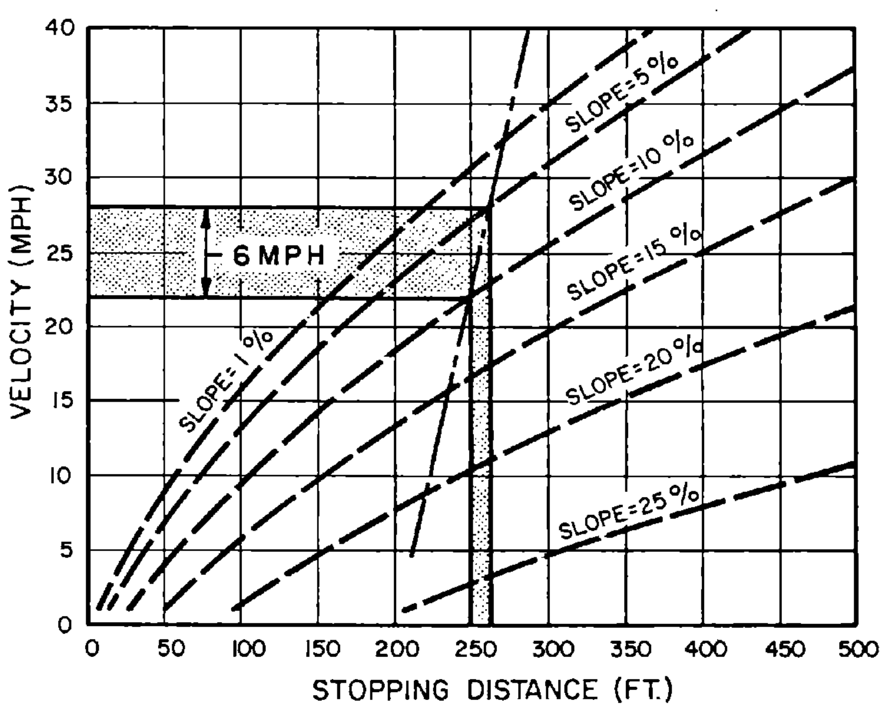
VEHICLE PERFORMANCE CHART

FIGURE I-6

Although the graph reflects performance characteristics for a specific make and model, 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 of 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 - 200,000 pound category is presented below for reference. As indicated by superimposed lines on the graph, a 5% grade reduction translates to a descent speed increase of six miles per hour without exceeding safe stopping distance limitations.

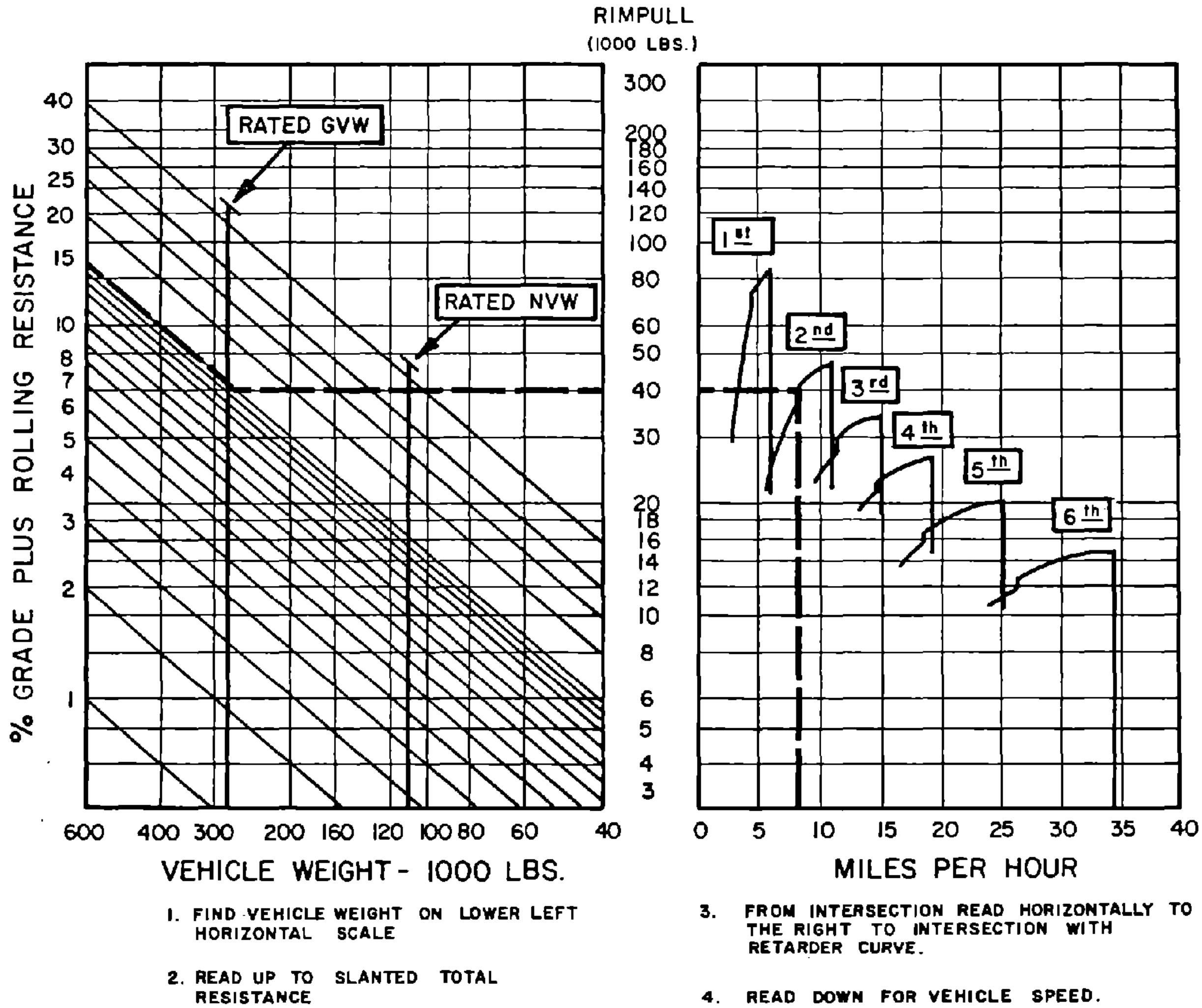


The above described benefits to production neglect consideration of construction economics. In the majority of cases, earthmoving to construct flatter gradients will incur greater costs. Moreover, design flexibility at many operations is curtailed by limited property ownership and physical constraints 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 haul road segments are yet another factor which must be considered in vertical alignment. 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. This does not mean, however, 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 the following example are available for most modern haulage equipment to illustrate its 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.



VEHICLE RETARDER CHART

FIGURE I-7

Thus, the vehicle can be kept to a speed within safe emergency braking limitations. The chart does not, however, specify the retardation limits in terms of time or length of sustained grade.

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 factors discussed above, it is reasonable to accept 10 percent as a maximum safe sustained grade limitation.

Vertical Curves

Vertical curves are used to provide smooth transitions from one grade to another. Their length 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 which discourages good drainage and frequently leads to "soft spots" and potholes. Curve lengths necessary to provide adequate sight distance were computed as follows:

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

or

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

where,
A = algebraic difference in grades
S = attainable stopping distance on grade
h_1 = driver's eye height
h_2 = height of object above haul road surface

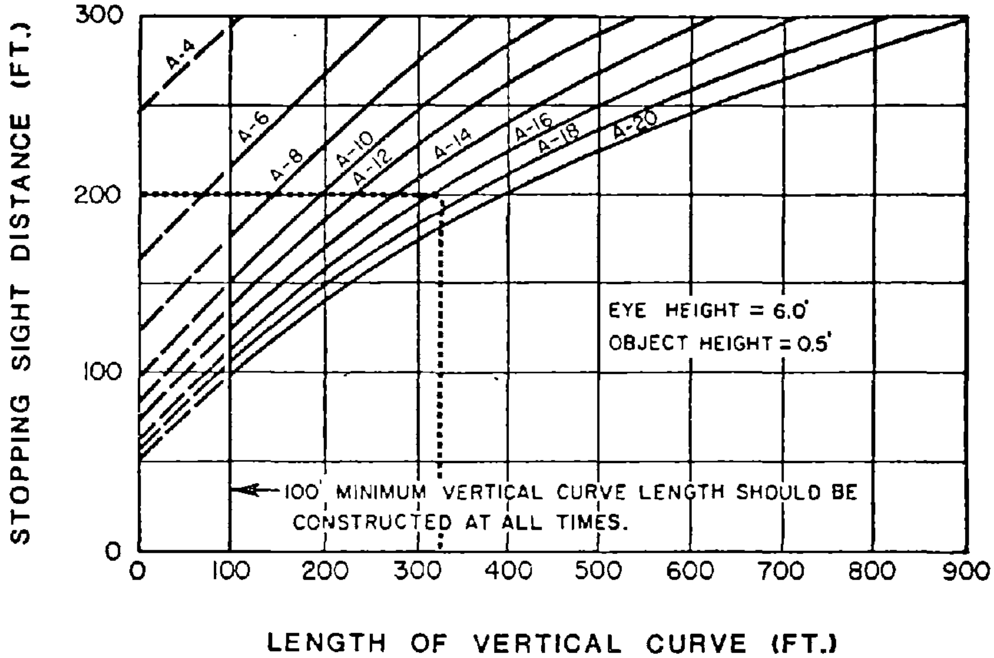
Figures I-8 through I-15 show recommended minimum lengths of vertical curves versus stopping distances for various algebraic differences in grade. Each figure represents a different driver's eye height, ranging from six to twenty feet.

The object height used in computing crest vertical curves was six inches. Although there is some support for an object height equal to the vehicle tail light 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.

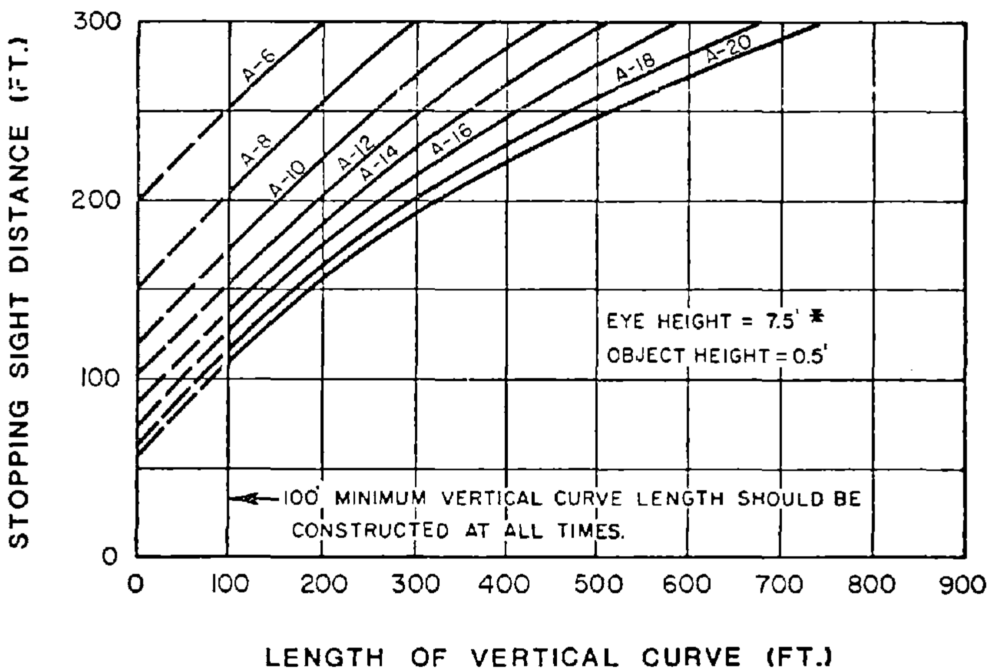
To illustrate use of the vertical curve charts, first select the graph which indicates the lowest driver's eye height for vehicles in the haulage fleet. Then, from the stopping distance charts (Figures I-1 through I-4), find the required stopping distance for the appropriate operating speed, vehicle 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 I-8 for a stopping distance of two hundred feet and an algebraic difference of sixteen to give a required curve length of 325 feet.

HORIZONTAL ALIGNMENT

Horizontal alignment during haul 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 alignment is essential to both safety and efficiency throughout a haulage cycle. The following subsections discuss the parameters prerequisite to correct horizontal alignment and how they affect road design. It must be emphasized that recommendations set forth 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 trade-offs and any alterations to design criteria should be accompanied by a compensatory reduction in operating speed.

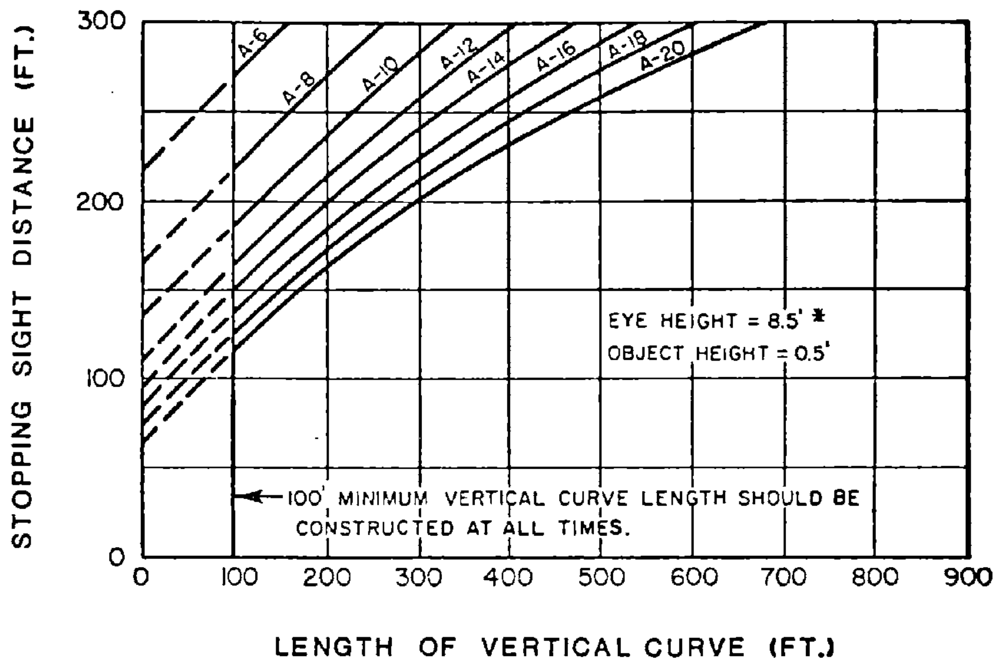


VERTICAL CURVE CONTROLS
FIGURE I-8



* (REPRESENTS MIN. EYE HEIGHT FOR SINGLE UNIT HAUL TRUCKS IN THE <100,000 LB. G.V.W. CATEGORY)

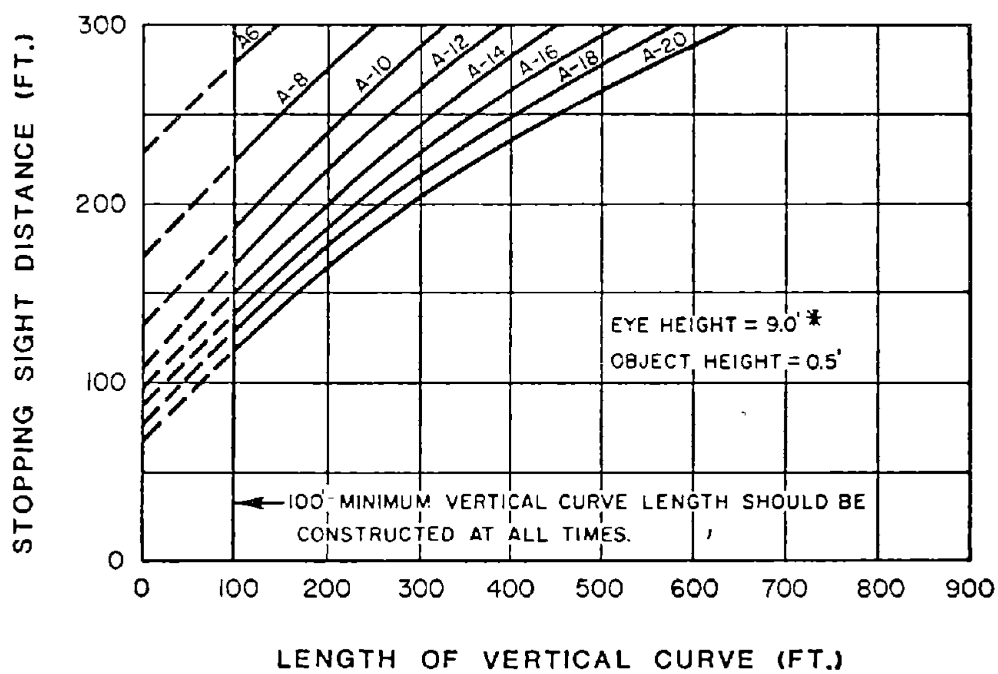
VERTICAL CURVE CONTROLS
FIGURE I-9



* (REPRESENTS MIN. EYE HEIGHT FOR SINGLE UNIT / ARTICULATED HAUL TRUCKS IN THE 100,000 TO 200,000 LBS. G.V.W. CATEGORY)

VERTICAL CURVE CONTROLS

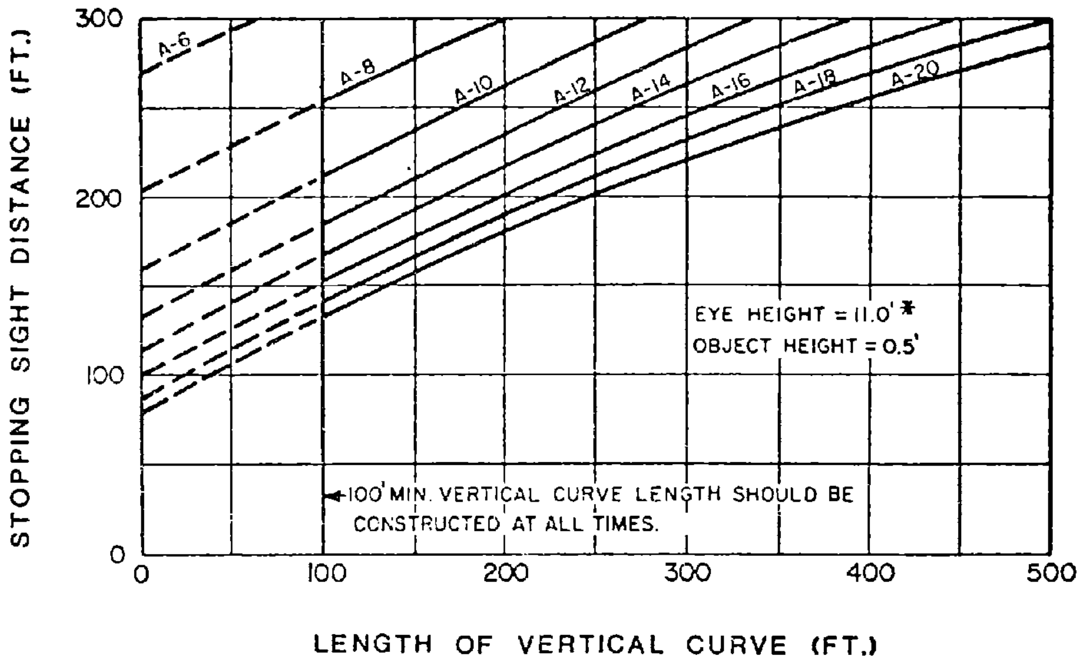
FIGURE I-10



* (REPRESENTS MIN. EYE HEIGHT FOR ARTICULATED HAUL TRUCKS IN THE 200,000 TO 400,000 LBS. G.V.W. CATEGORY)

VERTICAL CURVE CONTROLS

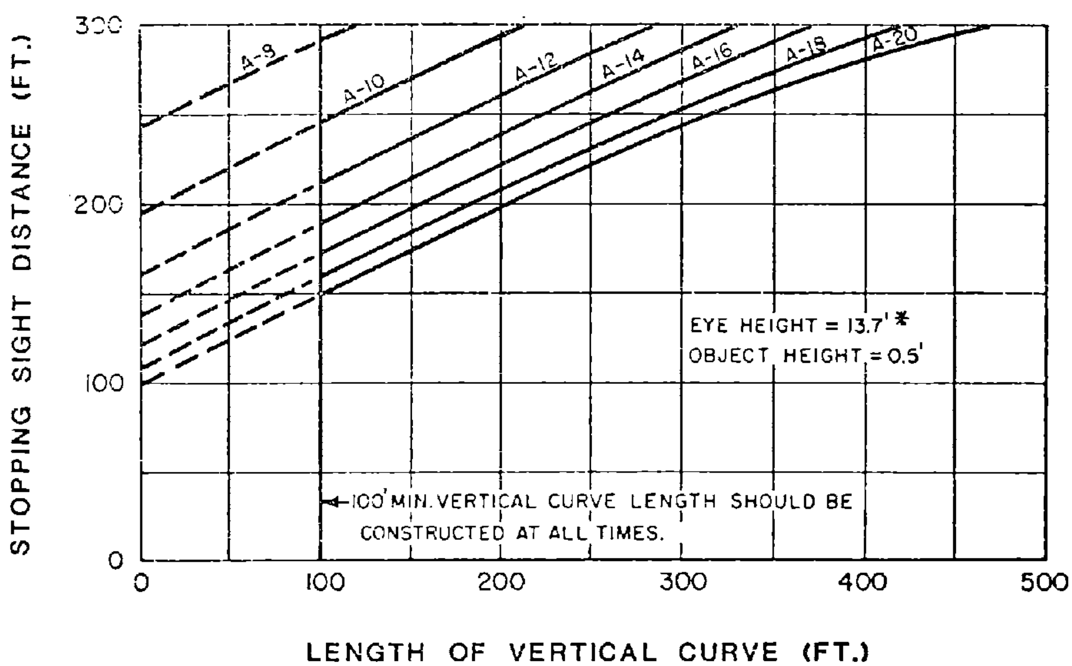
FIGURE I-11



* (REPRESENTS MIN. EYE HEIGHT FOR SINGLE UNIT HAUL TRUCKS IN THE 200,000 TO 400,000 LBS. G.V.W. CATEGORY AND ARTICULATED HAUL TRUCKS IN THE >400,000LBS. G.V.W. CATEGORY)

VERTICAL CURVE CONTROLS

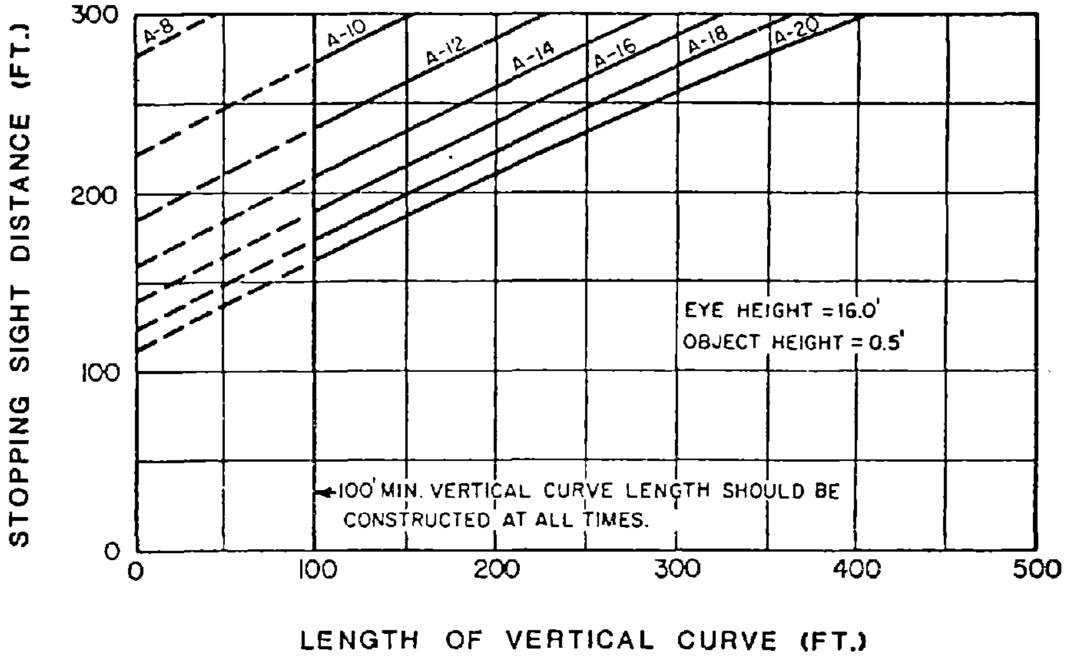
FIGURE I-12



* (REPRESENTS MIN. EYE HEIGHT FOR SINGLE UNIT HAUL TRUCKS IN THE >400,000 LBS. G.V.W. CATEGORY)

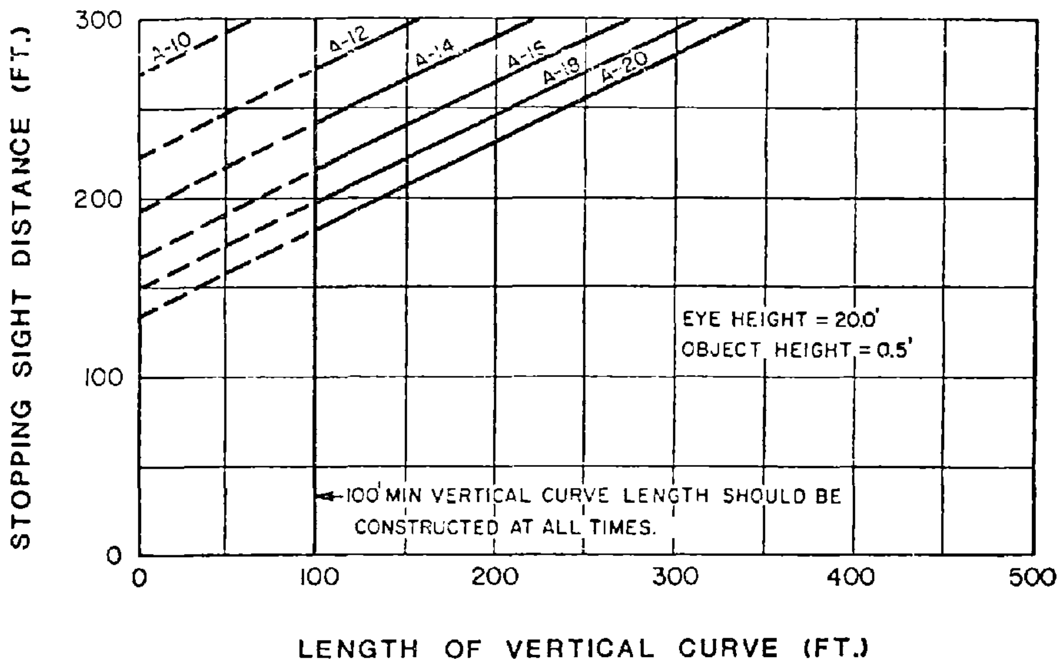
VERTICAL CURVE CONTROLS

FIGURE I-13



VERTICAL CURVE CONTROLS

FIGURE I-14



VERTICAL CURVE CONTROLS

FIGURE I-15

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:

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

where,
- e = superelevation rate, ft./ft.
- f = side friction factor
- V = vehicle speed, mph
- R = curve radius, feet

Theoretically, due 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 somewhat 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 above formula, there are two factors counteracting the centrifugal force: the superelevation rate and the side friction factor. Much experimental work has been done to determine side friction factors. Several authorities[1)] 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' radius curve, and a 0.32 factor at 15 mph on a 50' radius curve. Neither demonstrate 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 the following table.

This table serves two purposes. It not only suggests superelevation rates, but also recommends proper curve/speed relationships. For

1) A Policy on Geometric Design of Rural Highways, AASHO; 1965 and Route Surveying - Carl F. Meyer; 1949.

Table I-1

RECOMMENDED SUPERELEVATION RATES (ft. per ft.)

Vehicle Speed (mph)	10	15	20	25	30	35 & above
Radius (ft.)						
50	.04	.04				
100			.04			
150				.05		
250				.04	.06	
300					.05	.06
600					.04	.05
1000	.04	.04	.04	.04	.04	.04

example, a vehicle traveling 30 mph approaching a 150' radius curve superelevated .04 ft. per ft. should slow to at least 20 mph.

Superelevation Runout

The portion of haulway used to transition from a normal cross slope section to 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 haulway 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 the following table.

Table I-2

RECOMMENDED RATE OF CROSS SLOPE CHANGE

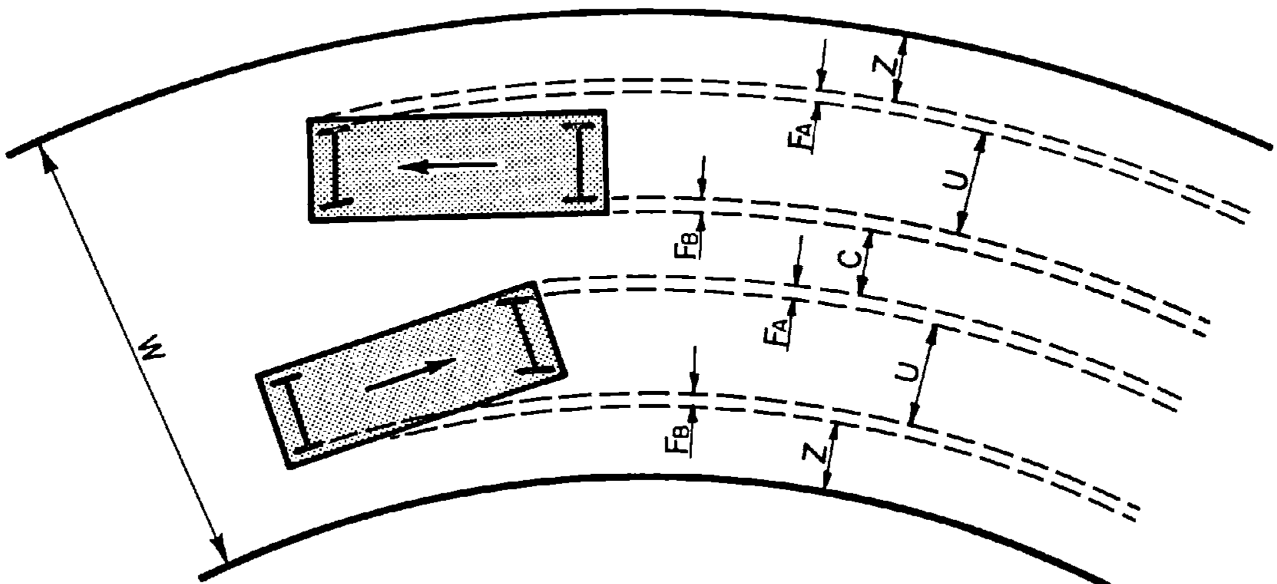
Vehicle Speed (mph)	10	15	20	25	30	35 and above
Cross Slope Change in 100' Length of Haulway (ft. per ft.)	.08	.08	.08	.07	.06	.05

To illustrate the use of this table, assume a vehicle is traveling 35 mph on tangent with normal cross slope .04 ft. per ft. to the right. It encounters a curve to the left necessitating a superelevation rate of .06 ft. per ft. to the left. The total cross slope change required is 0.10 ft. per ft. (0.04 + 0.06). The table above recommends a 0.05 cross slope change in 100 feet. Total runout length is computed as 200 feet. $(0.10 \div 0.05) \times 100 = 200$. 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 haulways requiring sharp curves must be designed to take into consideration the minimum turning path capability of the vehicles. Figure I-16 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 I-16 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 I-3 and I-4 recommend haulway widths for curving roadways up to four lanes.



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

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

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

Vehicle Weight Classification	Turning Radius
1	19.00'
2	24.43'
3	N/A
4	38.88'

HAULWAY WIDTHS ON CURVES

FIGURE I-16

Table I-3
DESIGN WIDTHS FOR CURVING HAULWAYS
SINGLE UNIT VEHICLES

R Radius On Inner Edge Of Pavement	One-Lane				Two-Lane				Three-Lane				Four-Lane			
	Pavement Width In Feet For Design Vehicle:															
	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

*Category 1 – Vehicles <100,000 lbs. (G.V.W.)
Category 2 – Vehicles 100,000 lbs. to 200,000 lbs. (G.V.W.)
Category 3 – Vehicles 200,000 lbs. to 400,000 lbs. (G.V.W.)
Category 4 – Vehicles >400,000 lbs. (G.V.W.)

Table I-4
DESIGN WIDTHS FOR CURVING HAULWAYS
ARTICULATED VEHICLES

R Radius On Inner Edge Of Pavement	One-Lane			Two-Lane			Three-Lane			Four-Lane		
	Pavement Width In Feet For Design Vehicle:											
	21*	31	41	21	31	41	21	31	41	21	31	41
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

*Category 21 - Vehicles 100,000 lbs. to 200,000 lbs. (G.V.W.)
Category 31 - Vehicles 200,000 lbs. to 400,000 lbs. (G.V.W.)
Category 41 - Vehicles >400,000 lbs. (G.V.W.)

COMBINATION OF HORIZONTAL AND VERTICAL

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

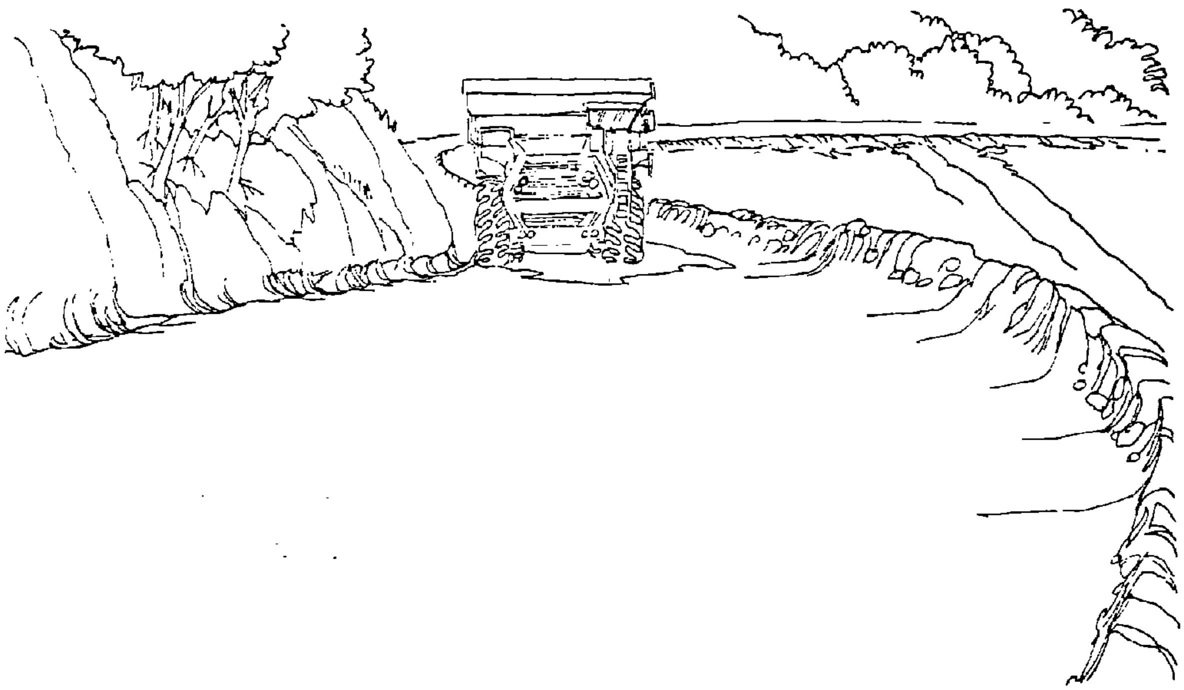
Certainly the alternatives available to a haul road designer are limited, but it would be prudent to consider the following potential problem conditions.

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 his lights 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 haul 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.



II-HAULAGE ROAD CROSS SECTION

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 which cannot adequately support the weight of traversing traffic will severely hamper vehicular mobility and controlability. 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 placement 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 haul segments which 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 haul 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 haul road segments. Therefore, it is important that haulway stability 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 haul use.

Defining the bearing capacity of soils is a detailed procedure which 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 following table illustrates this in pounds per square foot for a number of soil types.

The information in Table II-1, when compared with vehicle tire loads in pounds per square foot, identifies soil types which are inherently stable as road base and those which must be supplemented with additional material. The tire loading for most haulage vehicles filled to design

Table II-1

PRESUMPTIVE BEARING CAPACITY OF SOILS

Material	in 1000 lbs. per sq. ft.
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

capacity, with tires inflated to recommended pressure, will rarely exceed 16,000 lbs. per square foot. Although the tire loading may be somewhat less depending on the number of tires, their size, ply rating and inflation pressure, and on the overall vehicle weight, this figure can be utilized when determining subbase requirements.

Comparing the loading of 16,000 lbs. per sq. ft. with Table II-1 illustrates that any subgrade which is less consolidated than soft rock will require additional material in order to establish a stable base.

The designer must determine the amount of additional material that should be placed over the subgrade to adequately support the road surface.

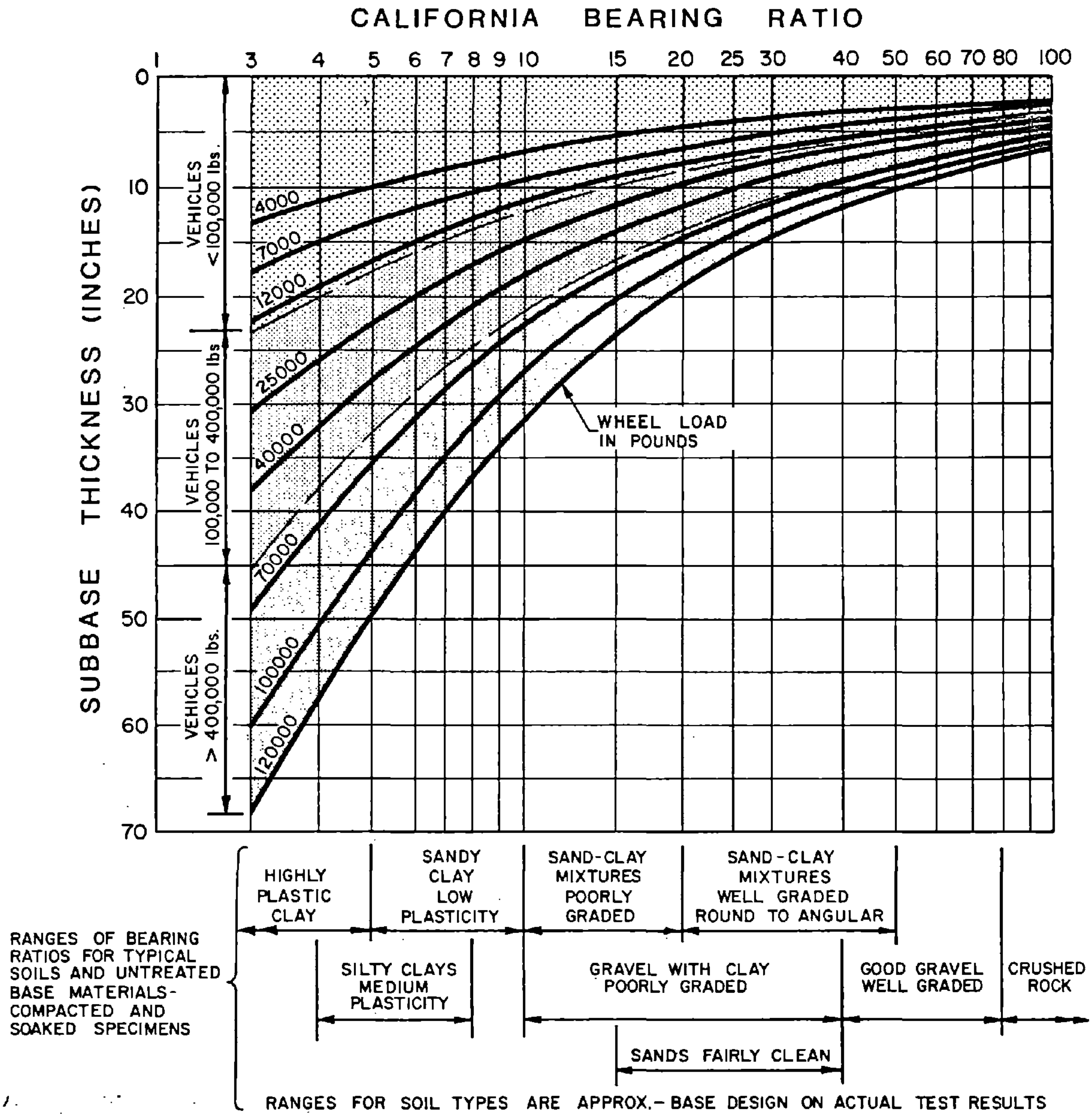
One of the most widely used methods of making this determination is through the use of curves commonly referred to as C.B.R. (California Bearing Ratio) Curves. This system, originally developed in 1942, continues to be used by highway designers for evaluating subbase thickness requirements in relation to subgrade characteristics. To be completely accurate, it necessitates C.B.R. tests to precisely determine the bearing capabilities of both subgrade and subbase materials. These tests can be conducted by a soils testing laboratory at relatively minimal cost simply by submitting samples of the subgrade and subbase materials.

The curves of Figure II-1 depict subbase thickness requirements for a wide range of C.B.R. 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 than the low value depicted on the chart. Although it is not a recommended practice, the C.B.R. 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 C.B.R. 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 subbase thickness determinations. When a wheel is mounted on a tandem axle, the value should be increased by twenty percent.

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 C.B.R. values have been established, the chart may be employed to compute subbase requirements, as illustrated



CBR CURVES

FIGURE II-1

by the following example. It must be noted that the graphic plot for any wheel load never reaches 0. 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 C.B.R. of 80 or greater. Crushed rock is preferred.

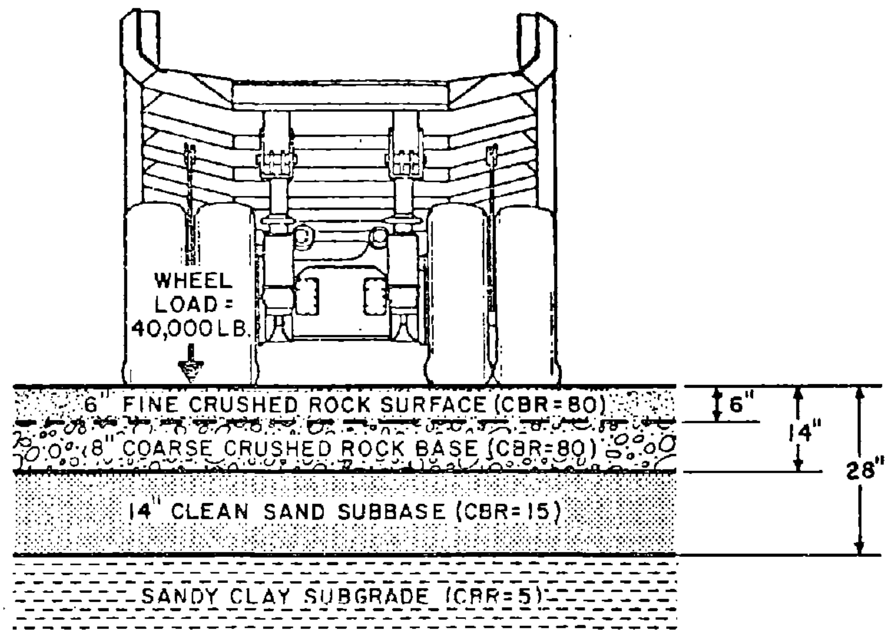
Example 1: A haul road is to be constructed over a silty clay of medium plasticity with a C.B.R. of 5. The maximum wheel load for any vehicle using the road is 40,000 pounds. Fairly clean sand is available with a C.B.R. of 15 to serve as subbase material. Road surface is to be constructed of good gravel which has a C.B.R. of 80.

Step A. The 40,000 pound wheel load curve intersects the vertical line for a C.B.R. 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 C.B.R. of 15 intersects the 40,000 pound curve at 14" indicating that the top of this material must be kept 14" below road surface.

Step C. An intersection of the 80 C.B.R. for gravel and the 40,000 pound wheel load occurs at 6". Since this will constitute the final surface material, it should be placed for the remaining six inches.

Completed subbase construction for the conditions outlined above is described in the following schematic drawing.



EXAMPLE OF SUBBASE CONSTRUCTION

FIGURE II-2

Following the determination of subbase depth requirements, proper placement procedures must be implemented. Regardless of material utilized, or depth, subbase should be compacted in layers never exceeding eight inches. To ensure stability of the final surface, subbase materials should exceed the final desired surface width by a minimum of two 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 eight inch layer must be subjected to repeated passes of the compacting equipment until it fails to compress under the vehicle's weight.

SURFACE MATERIALS

The authors of this report have visited over three hundred 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 haul way 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 haul 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, 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 controlability 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 haul road design.

Many road surfacing materials are available which 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 haul road construction.

TABLE II-2

ROAD ADHESION COEFFICIENTS AS DESCRIBED BY VARIOUS TECHNICAL REFERENCES

ROAD SURFACE	ROAD ADHESION COEFFICIENTS			
	Reference #1 & #4*		Reference #2*	Reference #3*
	Rubber Tire	Track	Rubber Tire	Rubber Tire
Concrete				
New	0.90	0.45	0.80 to 1.00	0.8 to 0.9
Travelled			0.60 to 0.80	
Polished			0.55 to 0.75	
Wet			0.45 to 0.80	0.8
Asphalt				
New			0.80 to 1.00	0.8 to 0.9
Travelled			0.60 to 0.80	
Polished			0.55 to 0.75	
Excess Tar			0.50 to 0.60	
Wet			0.30 to 0.80	0.5 to 0.7
Gravel				
Packed & Oiled			0.55 to 0.85	0.6
Loose	0.36	0.50	0.40 to 0.70	
Wet			0.40 to 0.80	
Rock				
Crushed			0.55 to 0.75	
Wet			0.55 to 0.75	
Cinders				
Packed			0.50 to 0.70	
Wet			0.65 to 0.75	
Earth				
Firm	0.55	0.90		0.68
Loose	0.45	0.60		
Wet				0.55
Clay Loam				
Dry	0.55	0.90		
Rutted	0.40	0.70		
Wet	0.45	0.70		
Sand				
Dry	0.20	0.30		
Wet	0.40	0.50		
Coal				
Stockpiled	0.45	0.60		
Snow				
Packed	0.20	0.25	0.30 to 0.55	0.2
Loose			0.10 to 0.25	
Wet			0.30 to 0.60	
Ice				
Smooth	0.12	0.12	0.10 to 0.25	0.1
Sleet				0.1
Wet			0.05 to 0.10	

*References

1) Motor Truck Engineering Handbook, James W. Fitch, page 217.
2) Caterpillar Performance Handbook, Edition I, Caterpillar Company, 1970, Section 19.
3) Taborek, Jaroslav, J., Mechanics of Vehicles, Penton Publishing Company, 1957, page 8.
4) Society of Mining Engineers, SME Mining Engineering Handbook, Volume II, The American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1973, Section 17, page 70.

This determination is based on the road adhesion and rolling resistance factors characteristic of different surface types, i.e., 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 haul road safety, primary emphasis should be placed on these characteristics. Table II-2 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 which 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 gear and 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 II-3 illustrates this point by presenting the rolling resistance values associated

Table II-3

ROLLING RESISTANCE FOR VARIOUS SURFACE TYPES

Surface Type	Road Adhesion Coefficient (Approx.)	Rolling Resistance lbs. per ton of gvw (Approx.)
Cement, Asphalt, Soil Cement	0.8	40
Hard Packed Gravel, Cinders or Crushed Rock	0.7	60
Moderately Packed Gravel, Cinders or Crushed Rock	0.6	100
Unmaintained Loose Earth	0.5	150
Loose Gravel and Muddy Rutted Material	0.4	200-400

with several road surface materials and their road adhesion characteristics. The data in Table II-3 indicates 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 haul road surface that will ensure maximum safety and operational efficiency. Because each of these materials has merits which are applicable to specific haulage situations, they are discussed separately in the following pages.

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 which reduces dust problems. In addition, the characteristic stability of this material creates a haul surface which is smooth and can be traveled with little fear of encountering deep ruts or potholes that would impede vehicular controlability. 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 haul 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 which must lie directly beneath asphaltic concrete. Although any material with a C.B.R. 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 Figure II-1 included in the Subbase Section. The example given in this figure illustrates that the final clean sand layer of subbase had to remain 14" below the final road surface. This is the dimension that must be filled by the combination of base course and asphaltic concrete. Thus 10" of base course and 4" 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 which constantly travel the haul road surface, a 4" layer may be accepted as the minimum required in most cases. The cost of constructing a 4" thick layer ranges between $4[1] and $5[2] a square yard for labor, equipment and material. Using the higher figure for a five 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 which is dependent upon many variables. Temperature of the mix, compaction procedures, wetting, joining, and density control are only some 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

(1) Building Construction Cost Data for 1975, Robert Snow Means Company, Inc., 1974.
(2) 1976 Dodge Manual, McGraw Hill Information Systems Company, 1975.

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 haul 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 haul roads. When constructed and maintained properly, both materials offer a stable roadway which 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 haul route is subject to relocation or must accommodate heavy tracked vehicles, it would be impractical to place 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 specified by Figure II-2, 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 four inches in size, the surface must be much more refined. The following specification presents an example of a stone wearing surface that has proven suitable on mine haul roads.

Table II-4
STONE SURFACE GRADATION

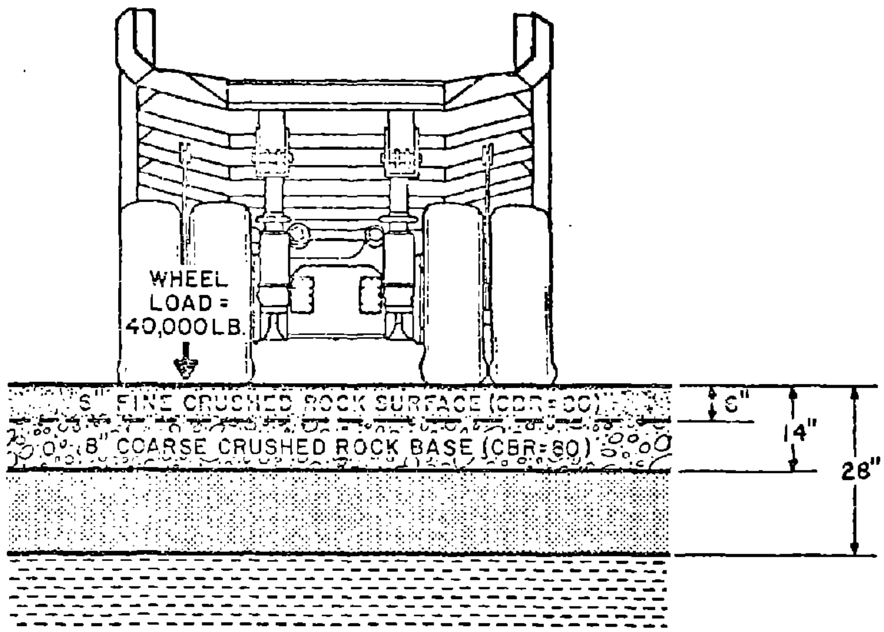
Screen Size	Material Passing
1½"	100%
1"	98%
3/4"	92%
3/8"	82%
#4	65%
#10	53%
#40	33%
#200	16%
Liquid Limit	25.2
Plasticity Limit	15.8
Plasticity Index	9.4
Optimum Moisture Content During Placing	12.2%

Any crushed stone or gravel which meets or exceeds the specifications presented in the illustration will qualify as an adequate surface composition.

Bank gravel, which is a mixture of pebbles and sand, frequently exists at many minesites 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, milltailings, 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 percent fines to prevent muddy, sloppy conditions when thawing. Those subject to hot, dry weather should not have less than 5 percent fines in order to prevent drying out and loosening up.

If proper subbase and base are established prior to placing top material, the depth of surface material need not exceed six 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 six inch depth. It is recommended that either rubber tired or steel rollers be used for compaction. Heavy rubber tired equipment can be employed when these machines 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 illustrates a haul road cross-section utilizing a crushed stone wearing surface for a wheel load of 40,000 lbs.



EXAMPLE OF CRUSHED STONE
SURFACE CONSTRUCTION
FIGURE II-3

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 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 asphaltic concrete.

Stabilized Earth

Stabilized Earth is defined herein as any soil which, 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 haul road surface, they can significantly reduce the quantity of base material required. In fact, many times 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 haul 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 haul 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 haul road will benefit from the use of these additives, they are most applicable for haul road segments that are subject to constant relocation.

If the operator wishes to use any of the materials previously described, there are a number of references which may be reviewed to determine the type and volume required for a particular situation. Two publications that will serve as excellent guides are:

> Soil Cement Construction, published by the Portland Cement Association, 33 West Grand Avenue, Chicago 10, Illinois,
>
> Asphalt Pavement Engineering, by Hugh A. Wallace and J. Rogers Martin, published by McGraw-Hill, Inc.

HAULWAY WIDTH

The haul road designer must be very concerned about the road width he specifies. Sufficient room for maneuvering must be allowed at all times to promote safety and maintain continuity in the haulage cycle. Surface mine machinery, unlike passenger and commercial vehicles which have somewhat "standardized" dimensions, 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 even more 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 with those of the lane to arrive at a total roadway width.

Tangent (Straight) Section Lane Width Requirements

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 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 haul 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. While this method is sufficient for smaller vehicles, it is not advisable for computing lane spans to accommodate larger machines. In order to compensate for the increase in perception distance created by greater vehicle width, the space allocated for side clearance should vary with vehicle size, rather than remain a constant.

A practical guideline for establishing the vehicle to lane width ratio is contained in the 1965 AASHO Manual for Rural Highway Design. 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 haul way spans on this criteria. By incorporating this guideline, both safety and efficiency will be enhanced.

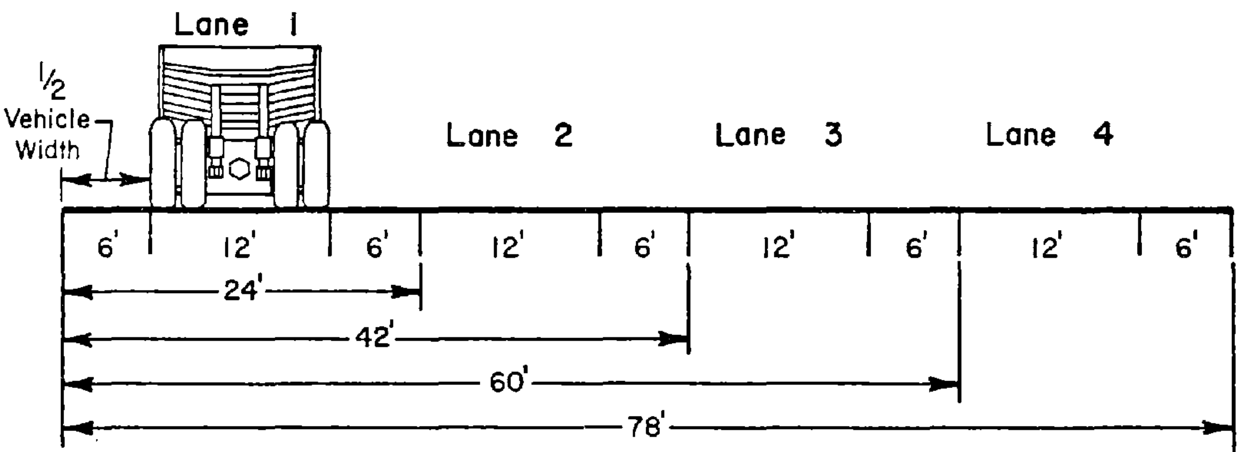
The following chart illustrates the recommended widths that should be provided for various lane configurations based on the design vehicle dimension, along with a typical section depicting how multiple lane dimensions accrue.

Data presented in this chart is intended to serve as guiding criteria for primary haul road users. Special consideration must be given to road segments which 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

Table II-5

RECOMMENDED LANE WIDTHS - TANGENT SECTIONS

Vehicle Width	1 Lane	2 Lanes	3 Lanes	4 Lanes
8	16	28	40	52
9	18	31.5	45	58.5
10	20	35	50	65
11	22	38.5	55	71.5
12	24	42	60	78
13	26	45.5	65	84.5
14	28	49	70	91
15	30	52.5	75	97.5
16	32	56	80	104
17	34	59.5	85	110.5
18	36	63	90	117
19	38	66.5	95	123.5
20	40	70	100	130
21	42	73.5	105	136.5
22	44	77	110	143
23	46	80.5	115	149.5
24	48	84	120	156
25	50	87.5	125	162.5
26	52	91	130	169
27	54	94.5	135	175.5
28	56	98	140	182



TYPICAL SECTION FOR 12 FT. VEHICLE WIDTH these equipment types. Prior to selecting a final design width make the following assessments, and establish a dimension sufficient for all possible users.

- Define the width of all equipment which may have to travel the haulage road.
- Solicit dimensional data for any anticipated new machines.
- Determine the overall width of any equipment combinations that may be involved in a passing situation.
- 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 the preceding chart will serve as an excellent guide for the road designer, there are exceptions for single lane construction which must be acknowledged.

The lane widths illustrated in the chart for one lane construction apply only when stopping distance of the haul vehicle is exceeded by sight distance. On haul segments where the opposite is true, a single lane span equivalent to 2 1/2 X 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. Haul 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 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 haul road design and construction. From the standpoint of reducing a driver's steering effort, a level haul 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.(1), (2), & (3) 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 pub-

(1) Mudd, Seely W., Surface Mining, The American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., New York, 1968, p. 681.
(2) American Association of Highway Officials, A Policy on Geometric Design of Rural Highways, Association General Offices, Washington D.C., 1965, page 224.
(3) Seelye, Elwin E., Design, Volume 1, Edition 3, John Wiley and Sons, New York, 1968, pages 12-16.

lished reference, the recommended rate of cross slope for surfaces normally constructed on mine haulage roads is 1/4" to 1/2" drop for each foot of width.

Mine operators should consider 1/4" to 1/2" 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 1/4" 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" per foot 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 over 5%. Therefore, where an ice or mud problem cannot be feasibly eliminated, cross slopes should be limited to the minimum value. Road maintenance should ensure 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, 1/2" per foot 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" per foot 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 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 haul 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 haul roads must ensure a continuous drop across two lanes in one direction and the same slope across the other in the opposite direction. The two 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 haul road operation.

During an exhaustive literature search into similar investigations conducted in the interest of highway safety, many variables were found to govern a vehicle's response 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. The following table illustrates the typical relationships between an intermediate size passenger car and large haulage vehicle.

Table II-6

TYPICAL VEHICLE RELATIONSHIPS

	Passenger Car	Haulage Vehicle	Factor
Weight	4,000 lbs.	400,000 lbs.	100.0 times greater
Wheel Base	9.9 ft.	19.7 ft.	2.0 times greater
Height of Vehicle	4.5 ft.	19.0 ft.	4.2 times greater
Wheel Track	5.0 ft.	17.0 ft.	3.4 times greater
Rolling Radius	1.1 ft.	4.7 ft.	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 wheel track width 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 to the well documented passenger car responses.

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 the above tabulation. 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 haul 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 dynamic characteristics and a subsequent computerized simulation model analysis. This approach would allow the predictive analysis of a variety of vehicle/berm interactions and require only sufficient testing to verify the modeling procedure.

Since the level of endeavor necessary to adequately define a haulage vehicle's response 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 the field investigations phase of this analysis 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 as well as 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 haul 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 haul road with an earthen backing material. This style of berm presents the impacting vehicle with a near-vertical face which 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: substantial damage to the vehicle can result from its use; the vehicle would tend to impact the berm at sharp angles of incidence (possibly injuring the driver); and the local geologic and topographic characteristics of the mining area must accommodate the berm's construction.

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 haulage vehicle's tire. 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 payed for itself in relation to the costs of haulage equipment replacement as well as in lost production time.

In summary, a berm's contribution 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 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 haul 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 haul roads. Unlike conventional roads, however, haul routes experience traffic from vehicles which 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 which should be considered for use along surface mine haul ways are discussed below.

Speed Limit Signs

Speed limits should be posted on segments of the haulage route which 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 preceding:

- Changes in descending haul road grades.
- Entrances to congested areas such as: pit, crusher, maintenance areas, overburden dumping points, vehicle crossings, etc.
- Unusual road alignments such as severe vertical and horizontal curves, narrow lanes, and areas of restricted sight distance.
- Areas subject to material spills or other frequent obstructions.

Stop Signs

From a production view point, it is best to avoid interruptions in the haul cycle; however, this may not be compatible with road safety. Although vehicle stopping points along the haul 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:

Any secondary access road at the point it intersects with the main haulway.

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

Haul 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 haulway 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 haul road at minimum intervals of 250'.

The brief preceding discussion of signs is intended to serve as an illustration of those which should receive first consideration. Each surface mine haul road exhibits its own peculiarities and may require more or less signal definition. In any case, proper care must be taken to ensure 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 haul roads. Erosive action on haul roads can cause ruts and washouts, and can saturate the soil, causing a lack of stability. The proper use of drainage facilities can alleviate this problem, resulting in safer, more efficient haul 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, due to the relative ease of design, construction, and maintenance.

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

- 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.

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

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

- In total cut section, carry drainage on both sides.

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

See typical roadway sections following.

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 which 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 % grade, "V" configuration (4:1, 2:1,etc.), and depth of flow. In V-ditch, as well as other configurations, depth of flow depends on % grade and the texture of material lining the ditch. Loose and porous linings and low percentage grades reduce flow rates and increase depths, while smooth, impervious linings and steeper grades create the opposite effect. To alleviate excessive erosion which may result from high flow velocities, certain ditch lining materials must be incorporated as the grade increases, except when the ditch is in non-erodable material. Some general rules to be followed for various grades in erodable soils are designated below. Please note these are "general rules" and are by no means recommended to supersede state or local regulations.

- At a 0%-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.
- At a 3%-5% grade, the ditch should be seeded and protected with jute matting until a substantial grass lining can be established.
- At grades over 5%, the lining should consist of dumped rock placed evenly on both sides to a height no less than 0.5' above the computed maximum depth.

Following this section are simplified charts which depict the depth of water that may be anticipated in various ditch configurations depending on the contributing flow in cubic feet per second (cfs), 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 II of the Engineer Field Manual for Conservation Practices, published by the United States Department of Agriculture, Soil Conservation Service. 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 ten year, twenty-four hour storm charts should govern. The rainfall intensity generated by a ten 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 which are 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 the following tables, the appropriate ditch depth needed to accommodate a specific volume of water may be derived. After determining the slope and finding the water flow (cfs), consult the corresponding ditch configuration table where the cfs is found. At the extreme left of this line will be the depth necessary to accommodate the flow for that ditch configuration.

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 sub-base 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'. Where placement of a ditch lining material is recommended, it shall also be increased 0.5' on each side.

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

Culverts

Culvert sections are the most efficient and effective means of conveying free flowing drainage away from the haul road, and must be incorporated to alleviate the potential of water overflows onto haul road segments. Any accumulation of water on the haul 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.

TABLE II-7

DITCH CAPACITY FOR VARIOUS V-DITCH CONFIGURATIONS

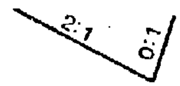
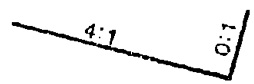
DEPTH OF WATER (FT.)	SLOPE (%)																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	GRASS COVER			JUTE MATTING					DUMPED ROCK											
	WATER VOLUME (CFS)																			
																				
0.2	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
0.4	.4	.5	.6	.6	.7	.5	.5	.5	.6	.6	.6	.7	.7	.7	.8	.8	.8	.8	.8	.9
0.6	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
0.8	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
																				
0.2	.1	.2	.2	.2	.2	.1	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.3	.3	.3	.3
0.4	.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
0.6	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
0.8	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	35.4	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

TABLE II-7 (CONTINUED)

DITCH CAPACITY FOR VARIOUS V-DITCH CONFIGURATIONS

DEPTH OF WATER (FT.)	SLOPE (%)																			
	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											
	WATER VOLUME (CFS)																			



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	165.5	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												

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																			

Numerous factors affect each of these design considerations. Therefore, each parameter is discussed as a separate category on the following pages.

Culvert Location

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

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

Whenever a haul 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.

Culverts should be placed in natural water courses intersected by the haul road.

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 ditch required by breaking runoff areas into small segments which 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. This agency requires the spacing of culverts for ditch relief at various road grades as noted below:

Road Grade in Percent	Spacing of Culverts in Feet
2–5	300–800
6–10	200–300
11–15	100–200

The above illustration exemplifies the need to research all state or local standards prior to any design decisions. In the event that there are no regulations regarding culvert spacing, it is recommended that:

Table II–8

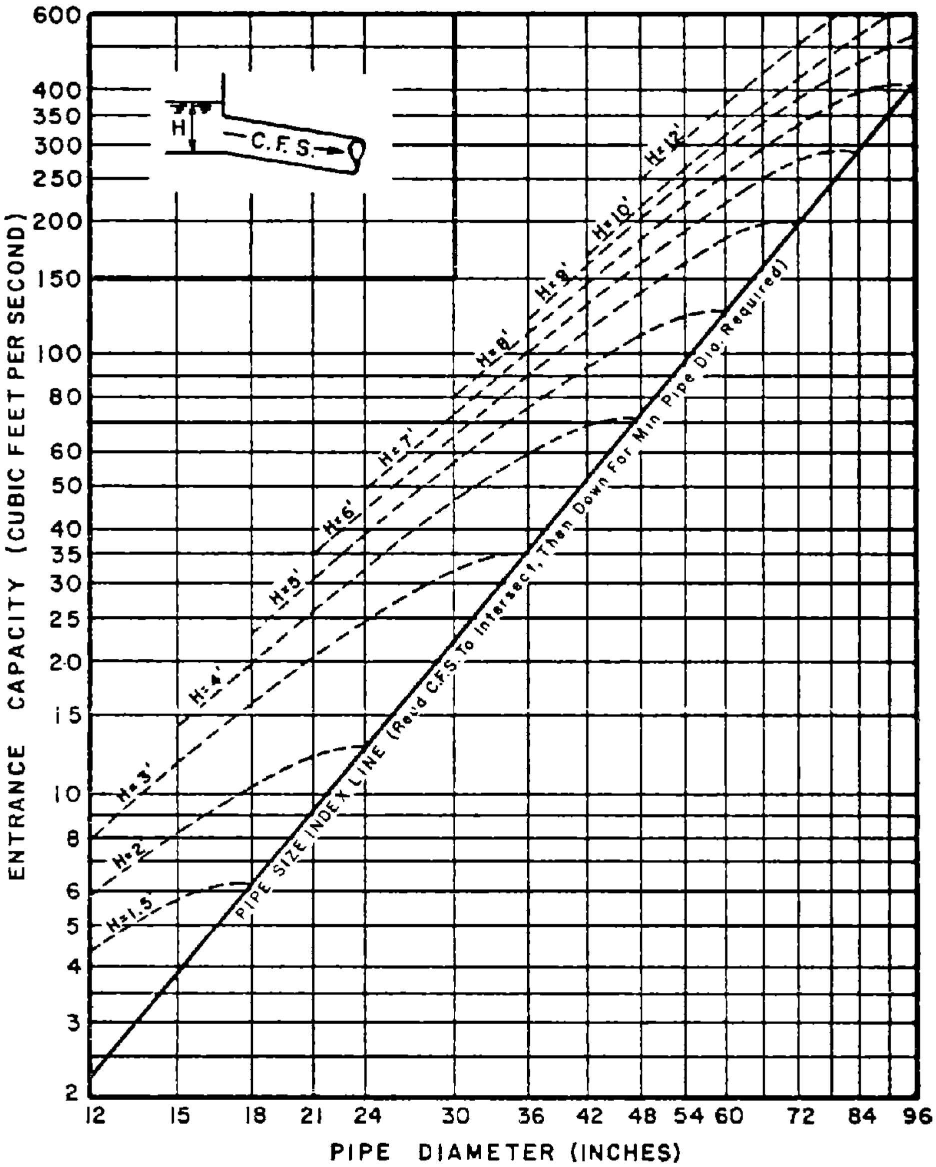
CULVERT SPACING

Spacing not exceed 1000' on grades from 0–3%
Spacing not exceed 800' on grades from 3–6%
Spacing not exceed 500' on grades from 6–9%
Spacing not exceed 300' on grades from 10% or greater

Culvert Type and Size

For the majority of haul 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, the pipe diameter must be large enough to accept maximum flow without creating a backup at its inlet. The graph presented below may be utilized to determine pipe sizes for various flows. Flows in cfs 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 back-up 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 cfs, read from the cfs column until the dashed line is intersected, then down. For example, a flow of 8 cfs intersects 2' of head at the 15" pipe diameter, thus 8 cfs of water at the inlet side of a 15" pipe will pond 9" above the top of the pipe (2' - 15" = 9"). 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 8 cfs were to be followed without creating a backup, the intersection of the diagonal will show that a pipe diameter of approximately 21" is required.



PIPE CULVERT CAPACITY GRAPH

FIGURE II-4

Culvert 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 lbs., a minimum cover of 2' over the pipe be used. For support of vehicle weights over 100,000 lbs. minimum cover should be 3'.

In all cases, the fill should be hand-tamped in 4" 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 non-erodable material should be provided.

Regulations specifying erosion and sediment control devices to be utilized at storm drain outlets have been developed by the United States 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 his region, the operator can determine the requirements that apply specifically to his operation. However, there are two rules of thumb to follow:

a) 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 non-erodable material.

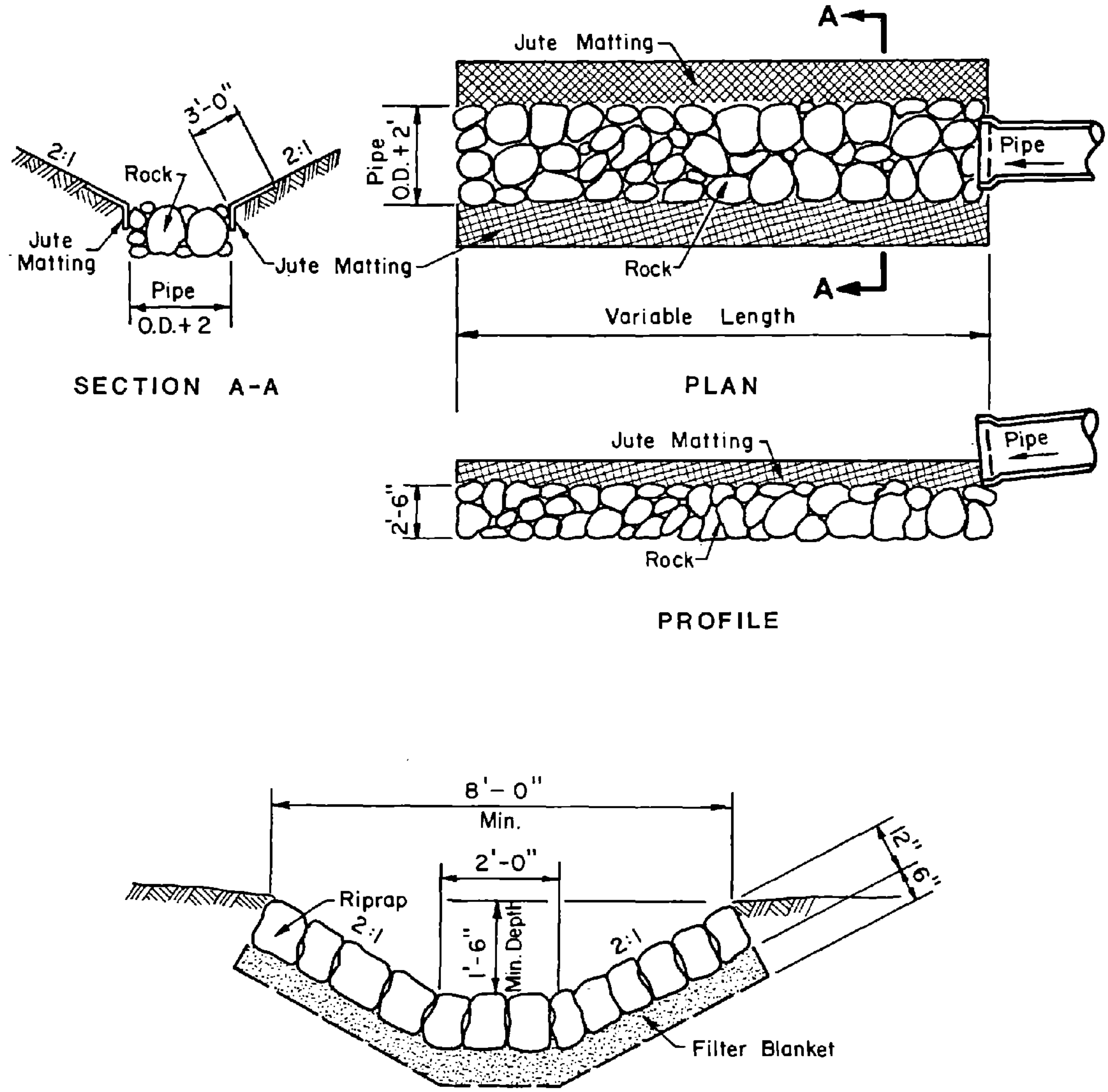
b) At any discharge point, where flow velocity exceeds the USDA, SCS recommended maximum for various soil types, erosion protection must be provided.

The following chart depicts the various treatments that may be anticipated for erosion control depending on discharge velocity. Details are presented for the rip-rap 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 II-9

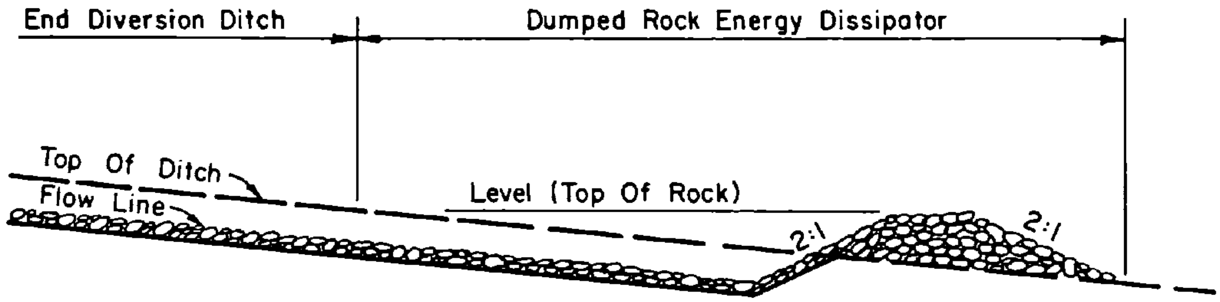
SLOPE PROTECTION AT CULVERT OUTLETS

Outlet Velocity fps	Slope of Embankment %	Treatment Recommended
0-2	Under 10%	Establish Vegetation
2-5	Over 10%	Riprap
5-15	All Slopes	Riprap
Over 15	All Slopes	Energy Dissipator

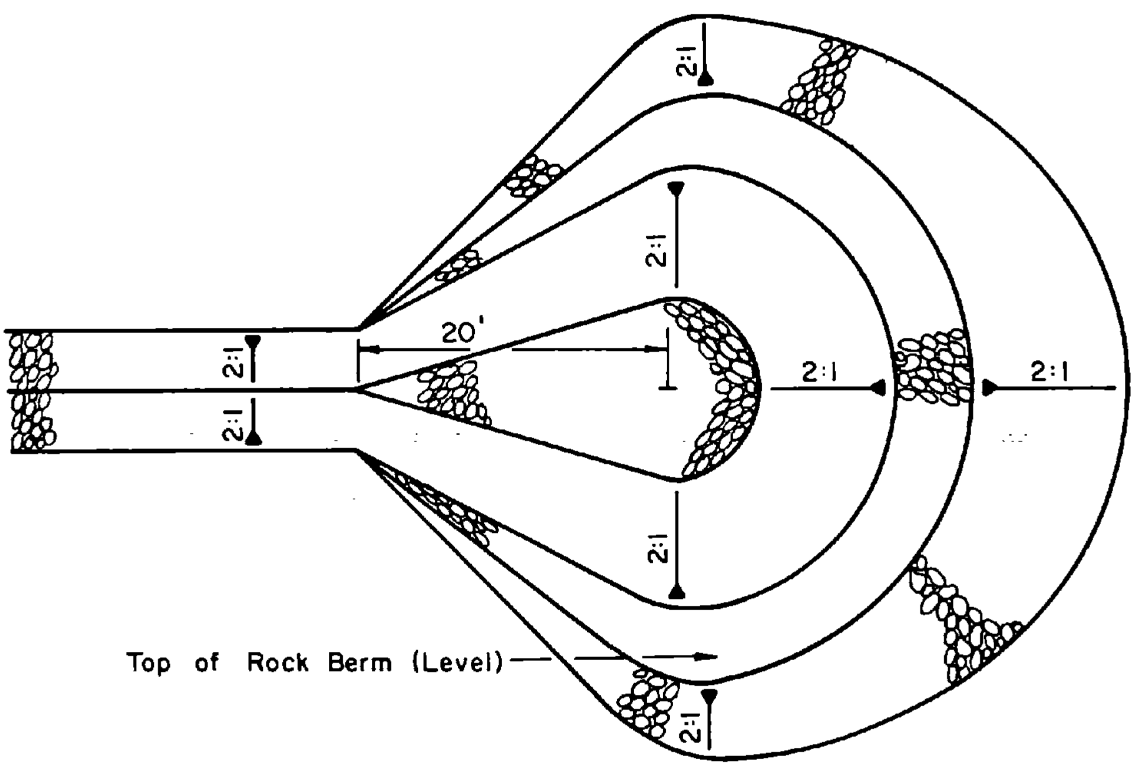


EROSION CONTROLS

FIGURE II-5



PROFILE



PLAN

DUMPED ROCK ENERGY DISSIPATOR

FIGURE II-6

LEGEND FOR TYPICAL HAULWAY SECTIONS

(1) - Lane Edge to Center Line of Ditch: dimension varies with center line 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" per foot 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 Center Line 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.

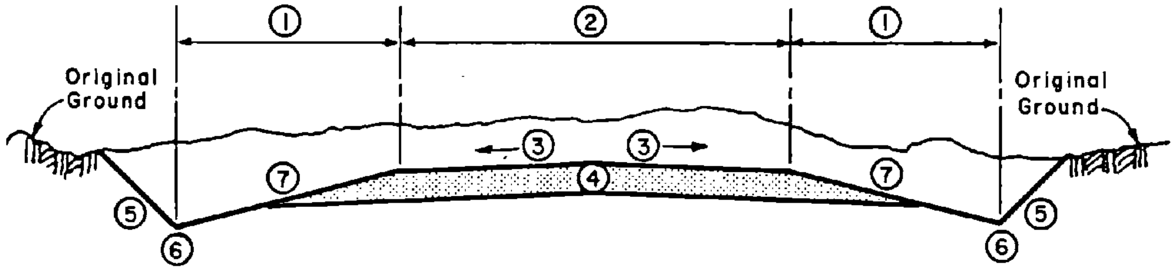
(8) - Road Widening to Accommodate Safety Berm: dimension varies with berm size required.

(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 haul road.

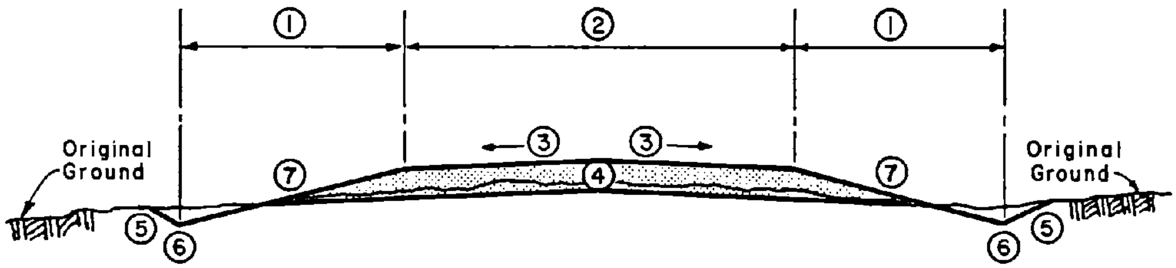
(10) - Berm Support: constructed to subbase material only, surface material ends at berm face.

(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.

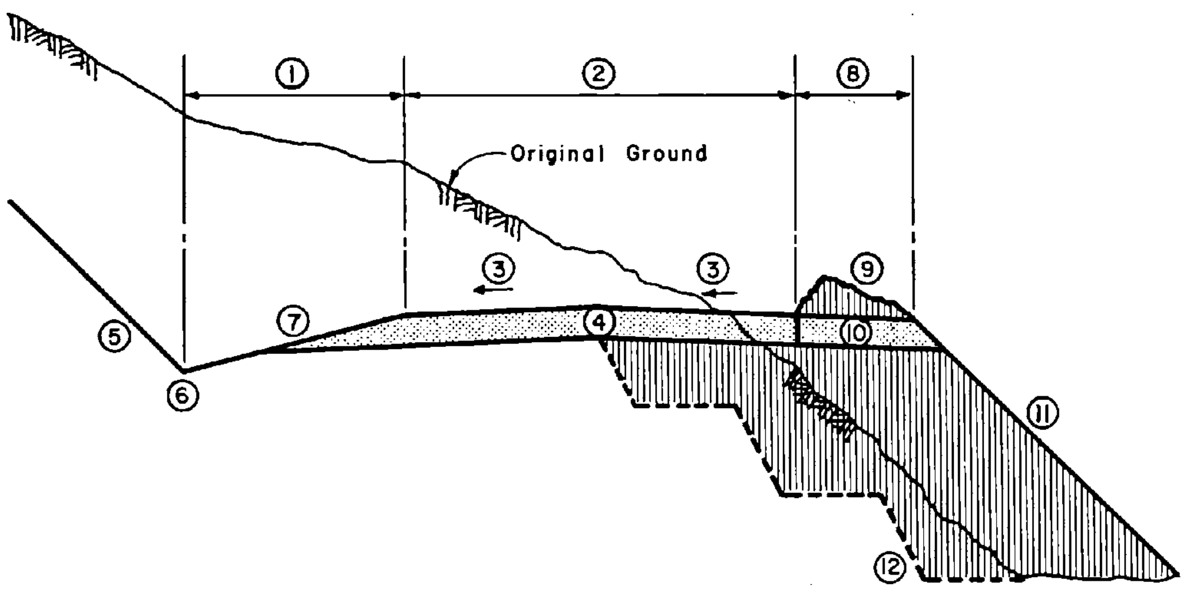
(12) - Fill Bench: required when original ground slope is 1:1 or greater, benches should be cut 8' - 10' horizontal with 8' - 10' vertical lift at 1/2:1, begin at toe of original ground slope and continue benching until road subgrade is reached.



TYPICAL CUT SECTION



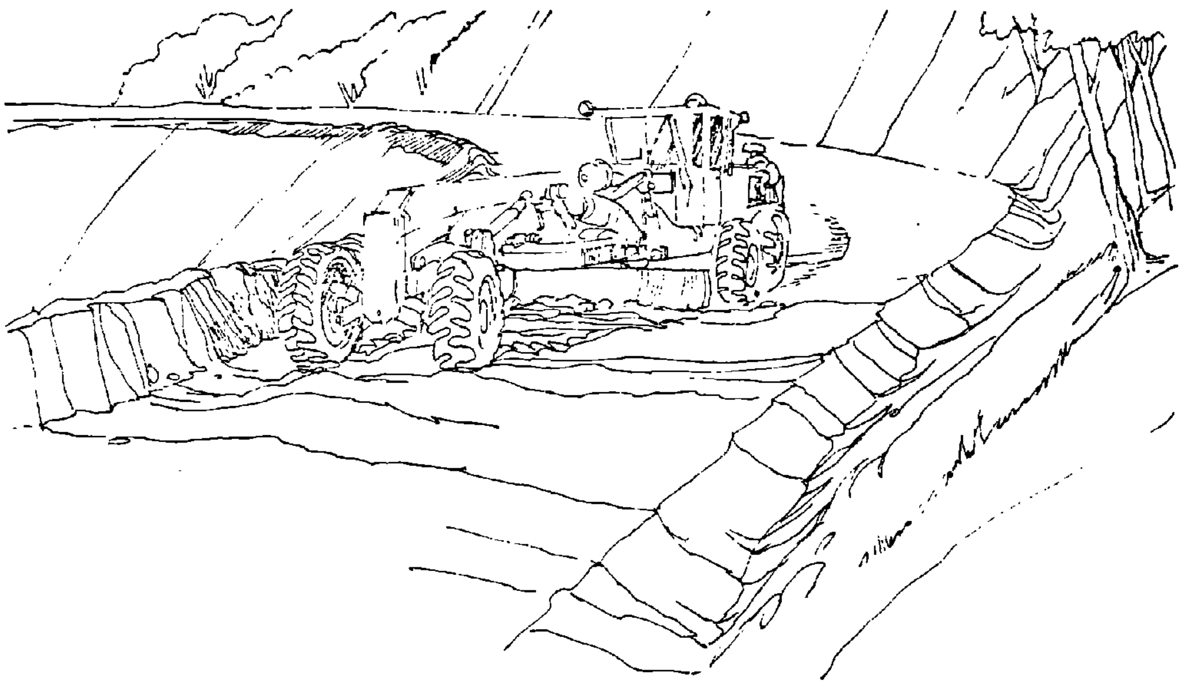
TYPICAL FILL SECTION



TYPICAL CUT - FILL SECTION

TYPICAL HAULWAY SECTIONS

FIGURE II-7



III-ROAD MAINTENANCE CRITERIA

ROAD MAINTENANCE CRITERIA

Regardless of how meticulously a haul road is planned and constructed, its surface is bound to be deformed by the constant pounding of haulage vehicles. Although deterioration may be controlled to a great extent by the type of surface material employed, the mine operator must still regard a road maintenance schedule as necessary to safety and economics.

Dust, potholes, ruts, depressions, bumps, and other poor surface conditions can and will occur on any road surface. If left unabated, they may impede vehicular control and damage haulage machinery.

When a rolling tire encounters a surface scar, there is a tendency to deflect from its normal direction of travel. Thus, the driver is forced to compensate for the abnormality by increasing his steering effort. If surface deformation is too great or if the driver is not aware of it before impact, complete loss of control may result. Often, even though the driver is able to negotiate a surface irregularity by steering, the tendency to over-compensate immediately after the danger has passed, could again result in loss of control.

In addition to degrading safety, road deterioration can be costly from a maintenance standpoint. Although surface mining equipment is designed to accept considerable abuse, its life can be increased if rough handling is kept to a minimum. The wear on virtually every component is increased significantly when a vehicle travels rapidly over a rough surface. If the vehicle must constantly brake to negotiate poor areas, unnecessary lining wear occurs as well.

When machinery must operate in dusty areas, the maintenance problems are compounded. Dust may infiltrate brakes, air filters, hydraulic lifts and other critical components. The abrasive effect of this fine material will likely result in frequent and costly cleaning or replacement of these items.

Essentially, the items related to deterioration of road surfaces are weather, haulage vehicles consistently following a similar path in the haul lane, and spillage. Because these factors are definable, road maintenance should begin with an all out effort to incorporate preventive rather than corrective procedures.

Roadside ditches and culverts should be periodically inspected and cleaned to ensure that no obstructions are present. If not cleared, the drainage facilities may overflow in wet weather and cause erosion of the road surface or saturation of sub-base materials. Maintenance crews equipped with hand tools or machinery such as dozers, loaders, and scrapers should be deployed at predetermined intervals to see that all ditch flow lines are free of debris.

If heavy haulage vehicles continue to utilize the same path in their respective haul lane, the concentration of load will eventually create ruts or furrows. To prevent this condition, mine operators should encourage drivers to use different areas of the haul lane.

Spillage of material from overloaded haulage vehicles is a significant problem at many mines. If not prevented and allowed to remain on the haul route, unnecessary bumps or mounds will exist. Therefore, every effort must be made at the loading point to prevent equipment from being heaped beyond the limit that can be held within the containing vessel.

During dry weather periods, or in consistently dry environments, dust problems may become severe; especially on gravel or crushed stone surfaces. In order to alleviate as much dust as possible from this type of material, the operator should consider applying chemical additives. The incorporation of chloride salts with gravel or crushed stone surfaces will enhance moisture retention and make road wetting necessary less frequently.

Adherence to the preventive measures discussed above can significantly reduce haul road maintenance problems. However, they are not a complete solution. Abnormal surface conditions will occur periodically that require additional road maintenance procedures.

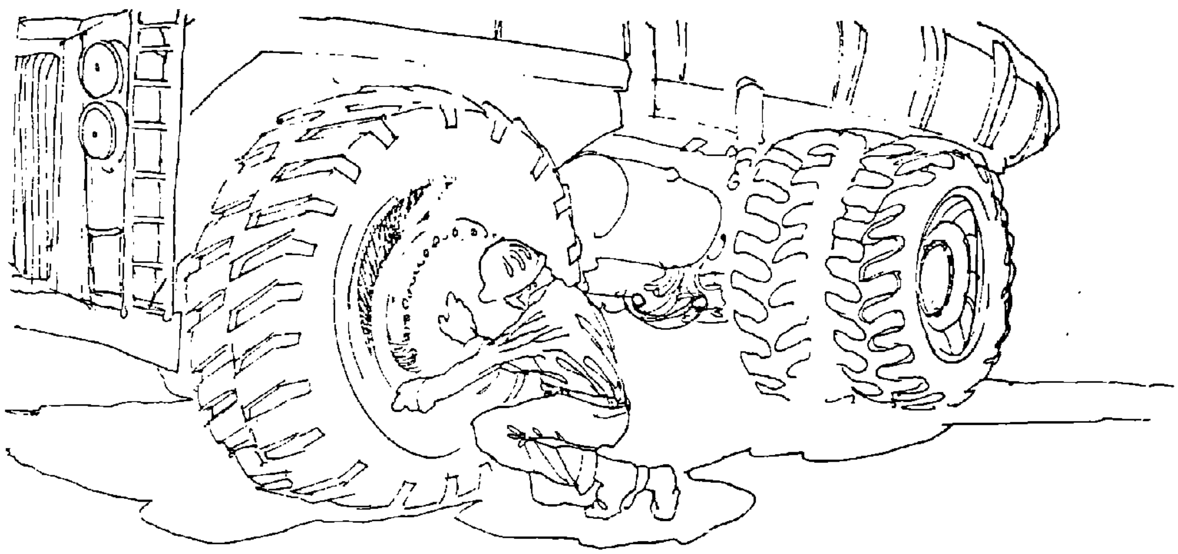
On more permanent surfaces such as asphaltic concrete, surface depressions should be corrected with asphaltic patches and either hand tamped or rolled into place. When severe depressions occur on well packed gravel surfaces the surrounding area should be scarified, filled, and recompacted to an even consistency.

A motor grader should be used continually to maintain cross slopes, remove spills, and to fill and smooth surface depressions as they occur. Whenever the motor grader is used, care must be taken to avoid pushing waste into drainage facilities and the protective faces of safety berms. Accumulated material from motor grader blading should either be placed in specially designated areas or cleaned up and removed.

Water trucks fitted with special sprinkler systems should be employed for road wetting in areas where dust is a problem.

Ice and snow, whenever they occur, must be completely removed from the haulage way with a motor grader or other appropriate equipment. Special attention to the removal of snow and ice is required on asphaltic concrete and other smooth surfaces. The close knit texture of these materials make them susceptible to rapid glazing in freezing weather. Consequently, they become slick and a definite hazard to vehicle controlability. Measures such as salting or cindering must be implemented immediately under these conditions.

All areas where loose material is employed to increase rolling resistance and vehicle retardation (escape lanes, median berms) should be periodically checked for loose consistency. If these areas become compacted, a bulldozer equipped with scarifying equipment should be used to break the surface.



IV–VEHICLE MAINTENANCE CRITERIA

VEHICLE MAINTENANCE CRITERIA

Mine haulage costs often represent up to 50 percent of total mining costs and sometimes as much as 25 percent of the overall operating, overhead, and other costs of the entire mining operation.[1] An item of this magnitude deserves, and generally gets, the major share of maintenance attention.

Most mining companies generally provide for regular, extensive maintenance inspections of their haulage vehicles. Some require daily inspection of such things as system pressures and integrity, tire pressure, fluid levels, electrical system continuity, belt tension, etc. Periodic maintenance (daily, weekly, or by hours of operation) is done to replace filters, change oil, grease fittings, clean air filters and breathers, clean and fill batteries, etc. Periodic inspection is required for such things as brake systems pressure, brake linings, wheel bearings, cab controls and accessories, etc. Repair and replacement of components such as engine, transmission, rear-end, axle, etc., is performed as required. Many companies require the truck drivers to file daily reports on vehicle condition. An example of a maintenance checklist is shown in Table IV-1.

1) Alan K. Burton, Bechtel Corporation. "Off-Highway Trucks in the Mining Industry - Part I." Mining Engineering, August 1975, pp. 28-34.

TABLE IV-1

EXAMPLE OF 500 OPERATING HOUR MAINTENANCE CHECK LIST

24 HOUR MECHANICAL PM

Unit No.	Date	Shift	Hourmeter	Performed By	Supervisor

Check all items listed below – repairs to be made during inspection. Major repairs not able to be completed within the 24 hour mechanical pm to be written on a shop work order.

1. ENGINE	OK	Repairs Made
A. FUEL SYSTEM		
Check: Fuel pressure at manifold – 65 lbs. minimum at 1900 RPM	☐	☐
Fittings & Lines	☐	☐
For Leaks	☐	☐
B. COOLING SYSTEM		
Check: Radiator & Mounting Bolts	☐	☐
Water Pump	☐	☐
Fan & Belts	☐	☐
Fan hub, mounting bolts & brackets	☐	☐
All Hoses and Leaks	☐	☐
Fan Shroud for cracks	☐	☐
C. ELECTRICAL SYSTEM		
Check: Alt. Charging	☐	☐
Batteries	☐	☐
All Lights	☐	☐
Rev. Alarm	☐	☐
For loose connections	☐	☐
D. EXHAUST SYSTEM		
Check: Manifolds	☐	☐
Stacks	☐	☐
Turbos	☐	☐
E. AIR SYSTEM		
Check: Air tubs, clamp to turbos Filters – 20" max at full stall	☐	☐
Air tanks, front & rear	☐	☐
Air Box drain tubes	☐	☐
Compressor	☐	☐
All connections & lines	☐	☐
Condition of air cleaner boxes	☐	☐
F. OIL PRESSURE		
Check: Guage – full RPM no load 40	☐	☐
60 lbs. Idle 4 to 10 lbs.	☐	☐
Engine Oil Level	☐	☐
For Leaks	☐	☐
G. MISCELLANEOUS		
Check: All leaks	☐	☐
Oil, Fuel, Water	☐	☐
Engine mountings front and rear for tightness & cracks	☐	☐

2. STEERING	OK	Repairs Made
Check: – Main steering pressure 2400 PSI	☐	☐
– Oil level slace system tank	☐	☐
– Slave steering pressure 500 PSI	☐	☐
– Steering valve hold down bolts	☐	☐
– Steering stops, adjust if necessary 2 3/4"	☐	☐
– Steering valve washers	☐	☐
– Orbitrol valve	☐	☐
– All Controls, linkage, cylinders and bushings	☐	☐
– For leaks main steering & slave steering system	☐	☐
– Emergency steering system	☐	☐
– Main hoist pressure 2200	☐	☐
3. BRAKES		
Check: – Brake fluid reservoir & breathers	☐	☐
– Lining thickness each wheel – 1/4" minimum: RF	☐	☐
LF	☐	☐
RR	☐	☐
LR	☐	☐
– Brake convertor pressures 1300 to 1500 PSI Min.	☐	☐
RF	☐	☐
LF	☐	☐
RR	☐	☐
LR	☐	☐
– Adjust all wheel brakes and parking brake	☐	☐
– All Lines & fittings	☐	☐
– Wheel seals for leaks	☐	☐
4. TRANSMISSION		
Check: Oil level at 800 RPM	☐	☐
Mounting bolts front & rear	☐	☐
Pressures at 1000 RPM in each gear	☐	☐
R	☐	☐
N	☐	☐
1st	☐	☐
2nd	☐	☐
3rd	☐	☐
4th	☐	☐
For Noises	☐	☐

TABLE IV-1 (CONTINUED)

EXAMPLE OF 500 OPERATING HOUR MAINTENANCE CHECK LIST

24 HOUR MECHANICAL PM

5. FINAL DRIVE COMPONENTS	OK	Repairs Made
Check: Differential pinion seals, front & rear for leaks ________	☐	☐
Differential pinion bearings front & rear for slack ________	☐	☐
Differential mounting bolts ________	☐	☐
Planetary carrier bolts ________	☐	☐
Planetary for leaks ________	☐	☐

6. FRAME & CHASSIS	OK	Repairs Made
Check: Articulating hinge pins for slack and lubrication ________	☐	☐
Frame For Cracks ________	☐	☐
Ride Struts - replace if 1" from bottoming out		
1. Bearings top and bottom of each ride struts ________	☐	☐
Rock Knockers ________	☐	☐
Damaged Components ________	☐	☐
Box hinge pins for wear and lubrication ________	☐	☐
Wishbones and bearings and for lubrication ________	☐	☐
Mud Flaps ________	☐	☐
Dump Box condition ________ good ☐ fair ☐ poor ☐		

7. CAB	OK	Repairs Made
Check: All Instruments ________	☐	☐
Seat ________	☐	☐
Heater ________	☐	☐
Glass & Mirrors ________	☐	☐
Window and door components ________	☐	☐
W/S Wipers and Washers ________	☐	☐
Lock-out bolt 5th and 6th gear ________	☐	☐

8. MISCELLANEOUS ITEMS	OK	Repairs Made
Check: Wheel Luggs ________	☐	☐
Auto, Lub., lines, fittings ________	☐	☐
Engine output bearing and center driveline bearing ________	☐	☐
Top driveline bolts ________	☐	☐
Rear driveline bolts ________	☐	☐
Front driveline bolts ________	☐	☐
Inter axle lock up ________	☐	☐
Torque conv. lock up ________	☐	☐
Body Kick out ________	☐	☐
Bed Pads ________	☐	☐
Condition of hyd tank ________	☐	☐
Condition of fuel tank ________	☐	☐
Bumper footstep, hand rail catwalk ________	☐	☐
Tow cable ________	☐	☐
Hood Condition ________	☐	☐
Check interlock timer ________	☐	☐

REMARKS: ____

____

____

____

Special attention should be given during maintenance checks to all brake system components to see that they are properly adjusted to manufacturer's specifications. A vehicle with improperly maintained service brakes, or pressure leakage in the brake components which causes activation of the emergency brake system, could result in unequal brake application and excessive heating of one drum. Ignition of brake system components and flame propagation to other truck areas is not uncommon and is one reason why fire extinguishers have become standard equipment. In addition, improper adjustment of one or more linings places total dependence on the others. If uncorrected, the brakes which are functioning properly will experience excessive and unnecessary wear.

While this checklist adequately covers those maintenance items that are to be checked on a 500 hour operating cycle, a daily log should be kept for each piece of equipment. This log book serves to record any difficulties or equipment anomolies experienced by each driver. Items that require repair or adjustment should be noted in the log book for the review of the next driver. If the maintenance item is of sufficient magnitude to affect the operating integrity of the equipment, a notation in the log should indicate such, and a notification filed with the maintenance foreman. Through this procedure an operator starting his shift is made aware of the equipment's condition and can check to see that repairs have been performed. After repairing any equipment malfunctions, the mechanic or electrician performing the work should be required to initial the log entry, and file an independent report to his foreman with a copy to the production foremen, if applicable. At the end of a specified period (one or two weeks), the maintenance foreman should be required to review equipment log books to familiarize himself with minor problems being experienced by the operators. Log pages should be signed, dated, and filed within a master log kept for each piece of equipment.

Any equipment maintenance program must be governed by the individual operation. The above example indicates how the responsibility for equipment maintenance can be distributed to guarantee that adequate checks are conducted and responsive actions are taken. However, the ultimate responsibility for safe day to day operation of haulage equipment depends on the equipment operator. Since any deficiencies will affect his safety, the driver should personally ensure that his machinery functions properly before beginning work.

Every mining company should initiate a program to educate drivers in the performance of pre-operational equipment checks. For most types of haulage equipment, a pre-op check will require no more than fifteen or twenty minutes prior to each work shift. The pre-op check of machine components for the driver will be limited to only those items which are critical to safe operation and the minimal time expenditure will be compensated by safer vehicle operation.

A general indication of the manner in which driver's maintenance can be conducted is delineated by SAE recommended practice J153. However, the procedures set forth therein do not encompass the numerous component differences inherent to various types of large haulage vehicles. The precise manner in which pre-op checks should be conducted for each equipment type can be established through the manufacturers and maintenance foreman.

Following is a list of items which should be considered essential to an effective pre-operational safety check. This list may or may not apply to specific equipment types and is not entirely comprehensive. However, it does illustrate a majority of the primary steps required.

I. Vehicle At Rest — Parking Brakes Engaged, Wheels Blocked

A. Inspect Visible Body and Chasis Components for Damage, Integrity, and Operation Where Applicable.

1. Windows
2. Mirrors
3. Wipers
4. Lights (brake, parking, service drive, back-up, and turn)
5. Doors (cab, compartment access)
6. Guards (component shrouds, electric cable insulation, etc.)
7. Wheels and tires (tread, rock ejectors, lock rings, mounting lugs, tire pressure)

8. Steering (control arms, stabilizer bars)
9. Suspension (shock and spring mounts)
10. Control lines (hydraulic, pneumatic, mechanical cables, electric cables)
11. Air tank moisture relief valves
12. Connections at dynamic brake grids
13. Face of engine radiator core
14. Seat and seat belt mounts

B. Check All Accessible Reservoirs for Proper Fluid Levels

1. Brake
2. Steering
3. Fuel
4. Radiator
5. Engine Lubricant
6. Hydraulic Retarder
7. Transmission
8. Batteries

C. Clean Cab of All Debris and Secure Tools, Fire Extinguisher, Roadside Flares, etc.

II. Engine Running, Transmission in Neutral, Parking Brake Engaged, Wheels Blocked

A. Inspect Visible Chasis Components for Leaks

1. Control lines (hydraulic, penumatic, electrical)
2. Air tanks
3. Hydraulic pumps
4. Air compressors
5. Exhaust transfer pipes
6. Coolant lines
7. Radiator(s)
8. Dynamic braking grid blower

B. Check Operation of In-Cab Guages and Controls

1. Temperature (oil and water)
2. Pressure (air and hydraulic)

3. Tachometer
4. Air flow restriction indicators
5. Ammeter
6. Hydraulic servo acutators
7. Accelerator
8. Retarder
9. Service brake
10. Road condition switch
11. All system engagement indicator lights
12. Steering
13. Horn
14. Back-up warning
15. Engine shutdown
16. Emergency engine shutdown
17. Ground fault breaker

III. Vehicle In Motion on Level Surface at Low Speed

A. Check for Proper Operation of Primary Controls

1. Steering

a. Under power
b. Engine off to ensure integrity of emergency assist

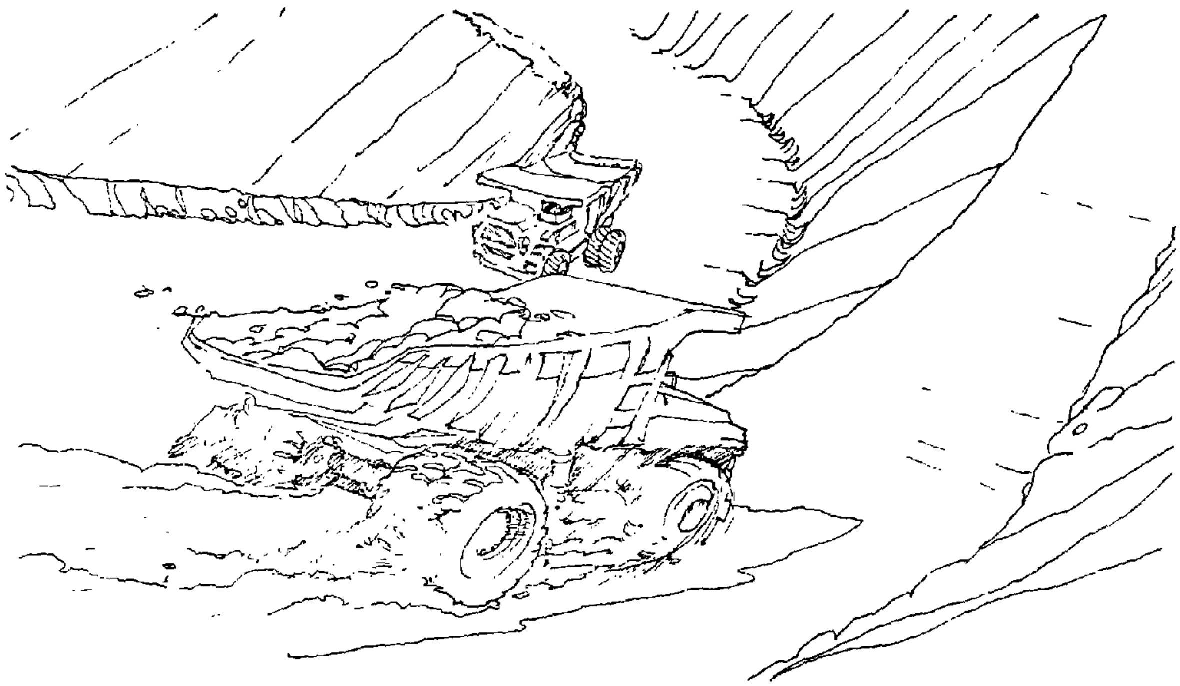
2. Braking

a. Retarder
b. Service brakes under power
c. Service brakes with engine shutdown

3. Transmission

B. Listen for Unusual Noises

Any component faults detected by the operator during this type of inspection should be noted and reported immediately to the maintenance supervisor. The final determination as to the severity of a detected fault, and whether or not the equipment is or is not safe to operate, can best be determined by maintenance personnel.



V-RUNAWAY VEHICLE SAFETY PROVISIONS

RUNAWAY VEHICLE SAFETY PROVISIONS

The large size of haulage vehicles precludes use of conventional vehicle arresting or impact attenuation devices to stop a runaway. In haulage operations with adverse grades, retarder failure has resulted in loss of life and substantial property damage. Some safety provisions should be incorporated into haul road design to guard against the consequences of runaway vehicles.

The primary design consideration for runaway vehicle protection is the required spacing between protective provisions. If a runaway situation should occur, the driver must encounter a safety provision before his truck is traveling too fast to maneuver. The top speed at which the driver can maintain control (steering) of a particular vehicle is designated "Maximum Permissible Vehicle Speed". A single velocity could have been identified as the recommended maximum for all safety provision entrances. However, the ultimate speed at which a driver can still maintain steerability and guidance of his vehicle varies according to manufacturer's design, road condition and operator's experience. The speed to accept as a guiding criteria for the spacing of runaway protective devices can best be determined through a cooperative effort between the operators and management at each mine site.

On Tables V-1 and V-2, distances between runaway truck safety provisions are given for various road grades, vehicle categories, and maximum permissible vehicle speeds. They apply to any type of runaway protection device, and delineate the distance in feet required between safety measure entrances for a truck to avoid exceeding the "Maximum Permissible Vehicle Speed".

The tables illustrate differences in spacing requirements as they are affected by initial downgrade speed at the time total brake system failure occurs. Initial truck speed at loss of braking and retardation was assumed to be 20 mph for Table V-1 and 10 mph for Table V-2. Although operating speeds may vary considerably depending on policies at each mine, ten and twenty mile per hour initial velocities constitute a sufficient range for the grades given.

Computation of values was accomplished through the formula:

$$S = \frac{\Delta V^2}{2g\,(\sin\Theta - \frac{b}{r})} \qquad (6)$$

where:

S = distance traveled until "Maximum Permissible Vehicle Speed" is reached (feet)

ΔV = difference in velocity between travel speed at loss of braking and retardation and the speed of travel at safety provision (value expressed as ft/sec)

g = 32.2 fps^2

Θ = angle of descent (expressed in degrees)
b = coefficient of rolling resistance (expressed as a mean value of .05 to encompass the majority of mine road/tire situations), dimensionless
r = rolling radius of tire (expressed as mean values for each vehicle category), dimensionless.

The following sections discuss two types of runaway vehicle safety provisions. Their spacing should be established in conformance with the recommendations set forth in the preceding discussion.

RUNAWAY VEHICLE COLLISION BERMS

As research into berms and runaway truck protection progressed within this project, an innovative design from Australia was investigated and found to have considerable merit. Utilizing an intermittent triangular-shaped berm constructed in the middle of a haulage road, Australian mining companies have been able to almost eliminate problems with runaway vehicles.

These runaway vehicle collision berms are constructed of non-consolidated screened fines and placed at crucial points within the haulage operation. If a vehicle's brakes and retarder fail during operation, the drivers are trained to align themselves so that they straddle the collision berms, and ride the vehicle to a stop. This type of median design is actually a simplified form of vehicle arresting device. The most critical design aspects of this type of berm are the spacing between the berm

TABLE V-1

DISTANCE BETWEEN RUNAWAY TRUCK SAFETY PROVISIONS (FT.)

HAULROAD GRADE	MAXIMUM PERMISSIBLE VEHICLE SPEED AT SAFETY PROVISIONS (INITIAL SPEED AT LOSS OF STOPPING CAPABILITY - 20 MPH)											
%	40 MPH				45 MPH				50 MPH			
-4	835	565	500	450	1,375	865	780	700	1,880	1,255	1,125	1,015
-6	370	305	285	265	580	475	445	415	835	685	645	600
-8	240	210	200	190	372	325	310	300	535	470	450	430
-10	175	160	155	150	275	250	240	230	395	360	345	335
-12	140	130	125	120	215	200	195	190	310	290	280	270
-14	115	108	106	103	180	168	165	161	259	243	237	232
-16	98	93	91	89	154	145	142	140	221	209	205	201
-18	86	82	80	79	134	127	125	123	193	183	180	177
-20	76	73	72	71	119	113	112	110	171	163	161	159
	55 MPH				60 MPH				65 MPH			
-4	2,560	1,700	1,530	1,380	3,335	2,215	1,995	1,780	4,230	2,810	2,530	2,255
-6	1,135	930	900	820	1,480	1,215	1,145	1,065	1,875	1,540	1,450	1,350
-8	730	640	612	585	955	835	800	765	1,210	1,055	1,015	970
-10	540	490	470	455	700	635	615	590	890	805	780	750
-12	425	390	380	370	555	510	500	480	700	650	630	615
-14	353	330	323	316	461	431	422	413	583	546	534	522
-16	301	284	279	274	393	371	364	357	498	470	461	452
-18	262	250	246	241	343	326	321	315	434	413	406	399
-20	233	222	219	216	304	291	286	282	384	368	362	357
	I	II	III	IV	I	II	III	IV	I	II	III	IV

I - Category 1 Vehicles - average rolling radius = 2.08'
II - Category 2 Vehicles - average rolling radius = 3.12'
III - Category 3 Vehicles - average rolling radius = 3.75'
IV - Category 4 Vehicles - average rolling radius - 4.8'

Note: Coefficient of rolling resistance - .05

TABLE V-2

DISTANCE BETWEEN RUNAWAY TRUCK SAFETY PROVISIONS (FT.)

HAULROAD GRADE	MAXIMUM PERMISSIBLE VEHICLE SPEED AT SAFETY PROVISIONS (INITIAL SPEED AT LOSS OF STOPPING CAPABILITY – 10 MPH)											
%	40 MPH				45 MPH				50 MPH			
-4	1,883	1,254	1,127	1,016	2,563	1,707	1,534	1,383	3,349	2,229	2,004	1,807
-6	836	684	644	606	1,138	930	877	825	1,486	1,215	1,145	1,078
-8	537	470	451	432	731	640	614	588	955	835	802	768
-10	396	358	347	336	539	487	472	457	704	637	617	597
-12	313	289	282	274	426	393	384	373	557	514	501	488
-14	259	242	237	232	353	330	323	316	461	431	422	412
-16	221	209	205	201	301	284	279	274	393	371	364	357
-18	193	183	180	177	262	250	245	241	343	326	321	315
-20	171	163	161	159	233	222	219	216	304	291	286	282
	55 MPH				60 MPH				65 MPH			
-4	4,238	2,821	2,537	2,286	5,231	3,483	3,131	2,823	6,331	4,215	3,789	3,416
-6	1,881	1,538	1,449	1,364	2,322	1,899	1,789	1,684	2,810	2,298	2,165	2,038
-8	1,209	1,057	1,015	972	1,492	1,305	1,253	1,200	1,806	1,580	1,516	1,452
-10	891	806	780	755	1,099	994	963	932	1,330	1,203	1,166	1,128
-12	705	651	634	617	870	803	783	762	1,053	972	947	922
-14	583	546	534	522	720	674	659	644	871	815	798	780
-16	498	470	461	452	614	580	569	558	743	702	689	676
-18	434	413	406	399	535	509	501	492	648	616	606	596
-20	384	368	362	357	475	454	447	440	574	549	541	533
	I	II	III	IV	I	II	III	IV	I	II	III	IV

I – Category 1 Vehicles – average rolling radius = 2.08'
II – Category 2 Vehicles – average rolling radius = 3.12'
III – Category 3 Vehicles – average rolling radius = 3.75'
IV – Category 4 Vehicles – average rolling radius – 4.8'

Note: Coefficient of rolling resistance – .05

sections and the height of the berm in relation to the vehicle's undercarriage. The spacing between berms must be sufficient to allow a runaway vehicle to align itself with the berm before impact. If properly aligned, the vehicle will shear off that portion of the berm above the undercarriage, expending energy through momentum transfer, rolling resistance, and frictional action until stopped. If improperly aligned, the vehicle could overturn. Accordingly, adequate space between berms must be maintained to allow the driver time to position his vehicle with respect to the berm.

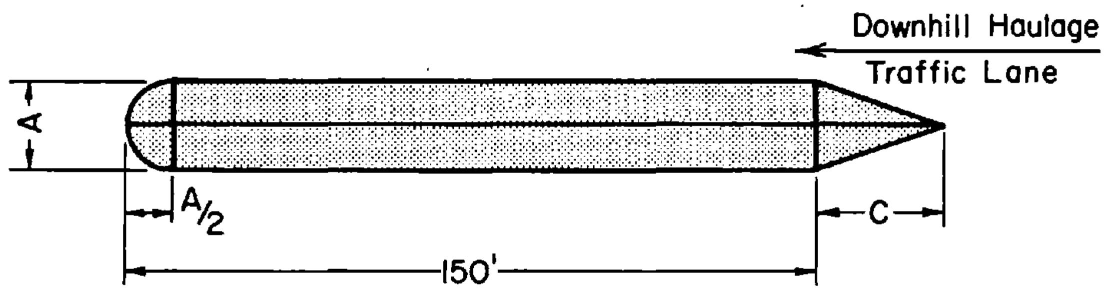
Typical sections of these berms with sizing and spacing criteria are shown in Figures V-1 and V-2.

A table is provided with Figure V-1 to show approximate sizing for various tonnage vehicles. Ranges are given rather than specific dimensions since each berm design must be governed by the height of undercarriage and wheel track of the vehicle for which the berm is designed. Where different sized vehicles are operating concurrently on a haulage road, the berm should be sized primarily according to the wheel track of the larger vehicle, since smaller vehicles will be stopped on the "entrance ramp" to the berm. The simplicity and economic attractiveness of this design lends itself well to practically any haulage operation. For haulage roads with less severe grades and associated fewer problems with runaway vehicles, collision berms may be located in critical areas only.

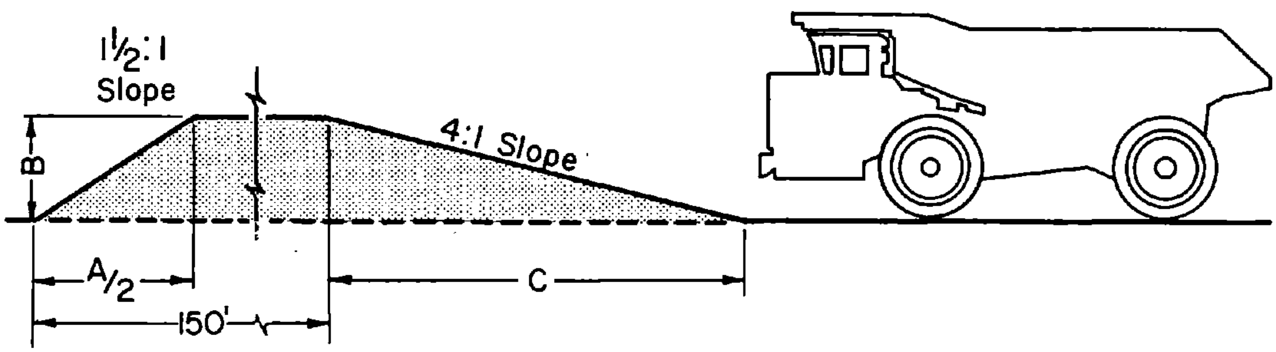
Median berms are most effective at reduced vehicle velocities. The drivers of haulage vehicles must be instructed in the proper use of the median berm and taught to rely upon it as a first line emergency maneuver, not as an action to be taken only after the vehicle has accelerated beyond a reasonable speed. A prerequisite to the use of berms is the ability to economically build a road of sufficient width to accommodate them. Another factor is the necessity of using screened fines in the construction. Depending upon the type of operation, a mobile crusher could be used to facilitate the construction and maintenance of the berm.

At one minesite in Australia with extremely severe grades (8% to 12%), these median collision berms have been in use for three years. Within that time, runaways have occurred on an average of once every two to three months. In all cases except one, the vehicles were safely stopped with usually only minor damage to the undercarriage. In the one incident where the vehicle was not stopped, the berm slowed the truck to the point where the driver could safely steer into the cut side of the bench.

Prior to incorporating this device in temperate climate areas, careful consideration must be given to required maintenance. The majority of surface mining states experience freeze conditions during winter months. If collision berms are not protected from solidification in these

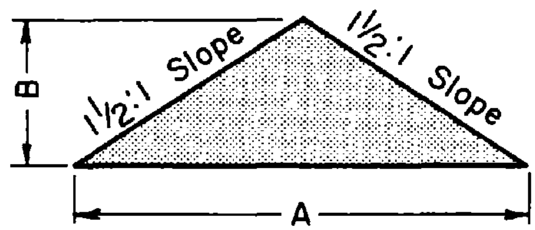


PLAN



PROFILE

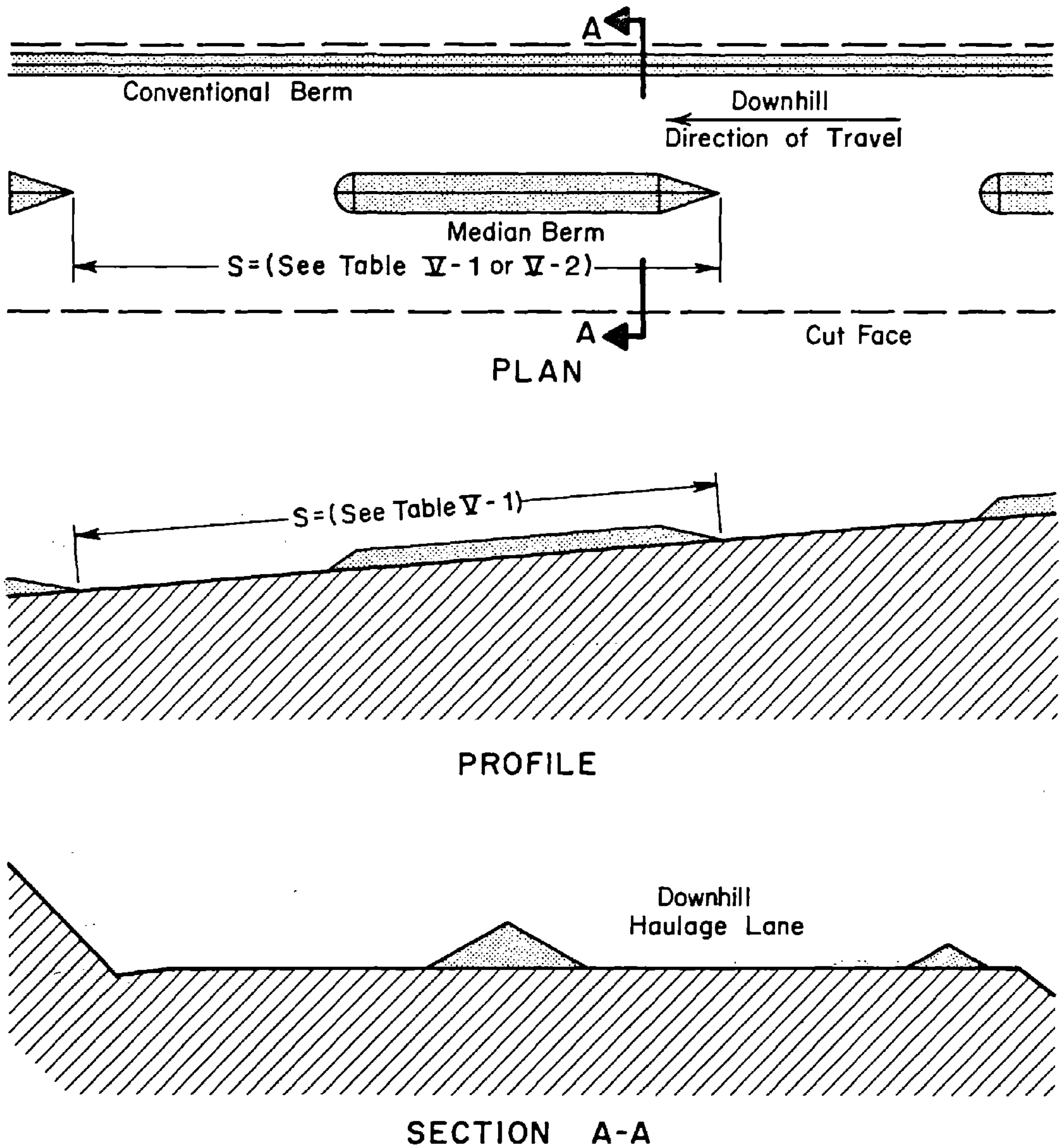
	A	B	C
CATEGORY 1 13 Ton to 25 Ton < 100,000 Lbs.	11'-12'	3.5'-4'	14'-16'
CATEGORY 2 28 Ton to 50 Ton 100,000-200,000 Lbs.	12'-15'	4'-5'	16'-20'
CATEGORY 3 55 Ton to 120 Ton 200,000-400,000 Lbs.	15'-18'	5'-6'	20'-24'
CATEGORY 4 120 Ton to 250 Ton > 400,000 Lbs.	18'-32'	6'-11'	24'-44'



SECTION

RUNAWAY VEHICLE COLLISION BERMS

FIGURE V-1



MEDIAN APPLICATION OF COLLISION BERMS

FIGURE V-2

periods, a vehicle could be severely damaged in an encounter. If climate at the mine site has this potential, collision berms must be constantly checked, and where freezing occurs, agitated to achieve their former unconsolidation. In cases where freezing and/or excessive rainfall is a constant problem, a protective covering of material such as polyethylene or an alternate safety provision is recommended.

ESCAPE LANES

Escape lanes for control of runaway vehicles have been used extensively on mountain highways in the United States. Relatively simple in design and successful in application, escape lanes are relied upon by highway designers for use on long, sustained grades.

Escape lanes have good potential for intercepting and stopping runaway haulage vehicles. However, they may be expensive to construct and maintain, depending on site conditions. Costs incurred in construction are primarily attributed to bench excavation and road bed preparation.

Emergency escape lanes have three basic areas of design and construction: entrance areas, deceleration areas, and stopping areas. Each of these will be discussed separately.

Entrance

The entrance from the main haulage way is perhaps the most important design and construction consideration of an escape lane. Entrance areas must be spaced according to maximum permissible vehicle speed and percent grade of the main haul road. Included within the entrance area are vertical curve transitions, horizontal curve development (including superelevations), and lane development. Care must be taken that any horizontal curve can be negotiated by the runaway vehicle. Table V-3 lists maximum horizontal curves as related to vehicle entrance speeds and superelevations. Superelevations less than .06' per foot or greater than .10' per foot are not recommended due to difficulties with curve development and drainage.

Table V-3

MAXIMUM PERMISSIBLE HORIZONTAL CURVES
FOR ESCAPE LANE ENTRANCE

Super-elevation	Vehicle Speed At Escape Lane Entrance					
	40	45	50	55	60	65
.06'/1'	12° or 477' rad.	10° or 596' rad.	8° or 716' rad.	6° or 930' rad.	5° or 1146' rad.	4° or 1432' rad.
.08'/1'	13° or 441' rad.	10° or 578' rad.	8° or 716' rad.	7° or 835' rad.	6° or 955' rad.	5° or 1146' rad.
.10'/1'	14° or 409' rad.	11° or 523' rad.	9° or 637' rad.	7° or 796' rad.	6° or 955' rad.	5° or 1146' rad.

Another important element of proper entrance design is lane width. The lane must be wide enough to accommodate the vehicle but not so wide as to require excessive construction effort. Recommended minimum lane widths for escape lanes are presented in Table V-4 for various vehicle categories.

Table V-4

RECOMMENDED ESCAPE LANE WIDTHS

Category	Min. Width (ft.)
I	15
II	18
III	22
IV	29

Deceleration

The major contribution of an escape lane to deceleration of a runaway vehicle is that of reverse grade. The greater the reverse grade of an escapeway, the less length required. Table V-5 presents a tabulation of escapeway lengths as related to vehicle entrance velocities, percent grade of the escape lane, and vehicle characteristics. The formula used in computing escapeway length is:

$$S = \frac{V^2}{2g\left(\frac{b}{r} + \frac{\sin \Theta}{100}\right)} \qquad (7)$$

where:

S = required length for deceleration from entrance speed to 0 (feet)
V = entrance speed from Table V-1 and V-2
g = 32.2 fps^2
b = coefficient of rolling resistance
r = rolling radius of vehicle tire
Θ = angle of ascent (expressed in degrees).

It is important to note that a coefficient of rolling resistance of .2 was used to compute these distances. This value is the resistance offered by an unconsolidated surface material such as sand or loose earth. Escape lanes should not be a continuation of the main haul road and all normal road maintenance should cease at the end of the entrance area. Escape lanes are most functional when rolling resistance is high. Poorly compacted, deep, loose, granular type materials are best suited for road bed use in deceleration areas, since these materials tend to retard vehicle movement. It should also be noted that distances given in Table V-5 are to be applied from the end of the entrance area, i.e. at the end of the horizontal and vertical curves. Also, surface material characteristic of that used on the main haul road should be employed to the end of these curves.

In this manner, a safe transition from hard to loose surface can be achieved.

Table V-5

LENGTH OF ESCAPE LANE

% Grade of Escape Lane	Vehicle Speed At Entrance To Escape Lane						
	40	45	50	55	60	65	Category
20%	180'	230'	285'	335'	410'	475'	I
	205'	255'	315'	380'	455'	530'	II
	210'	270'	330'	395'	475'	555'	III
	225'	280'	345'	415'	500'	580'	IV
15%	220'	275'	340'	405'	490'	570'	I
	250'	320'	390'	465'	560'	655'	II
	265'	335'	410'	490'	590'	690'	III
	280'	355'	435'	520'	630'	730'	IV
10%	275'	345'	425'	510'	615'	715'	I
	325'	415'	505'	610'	735'	855'	II
	350'	445'	540'	650'	785'	915'	III
	375'	475'	585'	700'	850'	990'	IV

Note: Assuming Coefficient of Rolling Resistance = .2

Stopping

After a vehicle has been slowed through the deceleration grade and high rolling resistance road bed, it becomes necessary to stop the vehicle and prevent its coasting back down the escape lane.

Approximately three quarters of the way up the escape lane, provisions for stopping the vehicle should begin. Stopping or arresting techniques include the following:

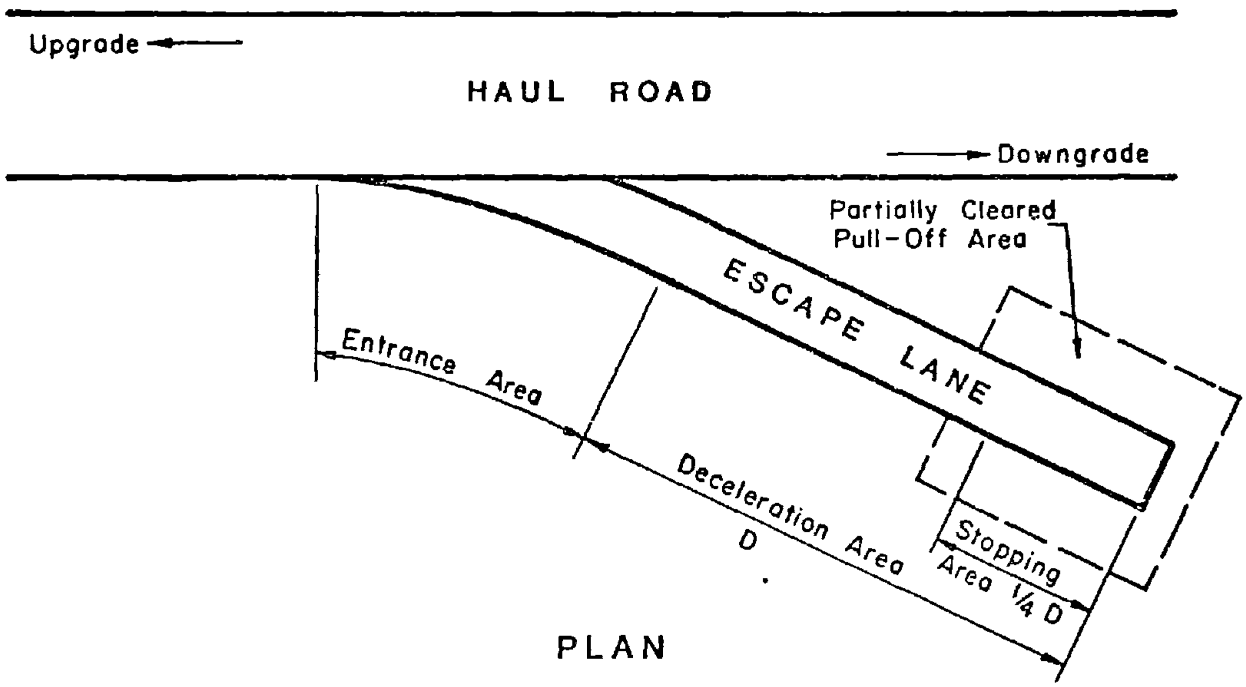
- Median Berm – A median berm, constructed on the escape lane, is one of the most efficient means for vehicle arrest. Using the same basis for design as that presented in the previous section, median berms are well suited for use in conjunction with escape lanes.

- Sand or Gravel or Mud Pits – After a vehicle has been slowed down on the escape lane, a deep sand, gravel or mud fitted pit will cause the wheels to become stuck, thus prohibiting further movement until assisted by another vehicle. This concept is very effective if properly maintained.

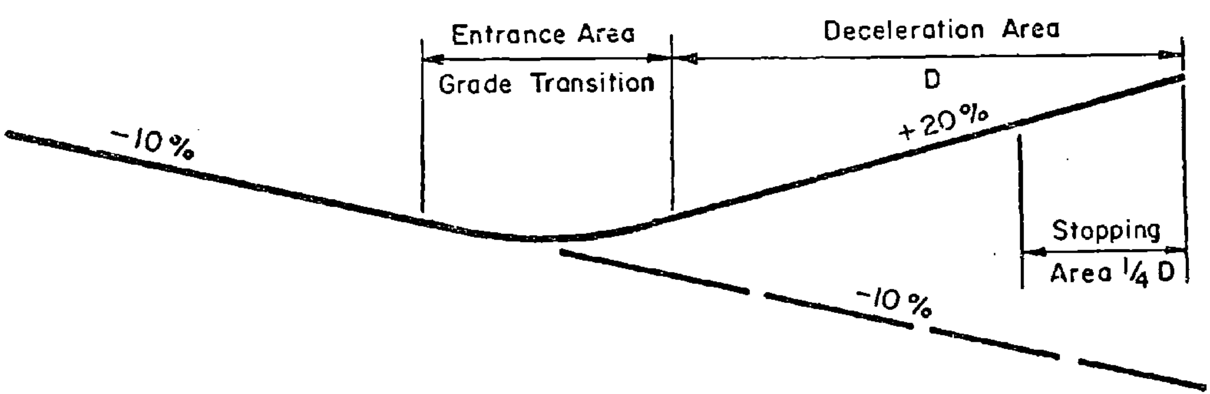
- Road Bumps – Road bumps, whether constructed by excavating trenches or establishing mounds across the lane, retard vehicle movement by trapping the wheels in "designed ruts". Mounds or bumps must be thoroughly compacted to ensure integrity under the weight of a truck.

- Manual Steering – If it is not practical or possible to do any of the above, or if the runaway does not reach the "stopping area", when the truck comes to rest the driver should be trained to either engage the transmission in a "park" position, or set an emergency brake (if usable), or engage the transmission in the lowest possible gear and turn the wheels away from the escape lane berm.

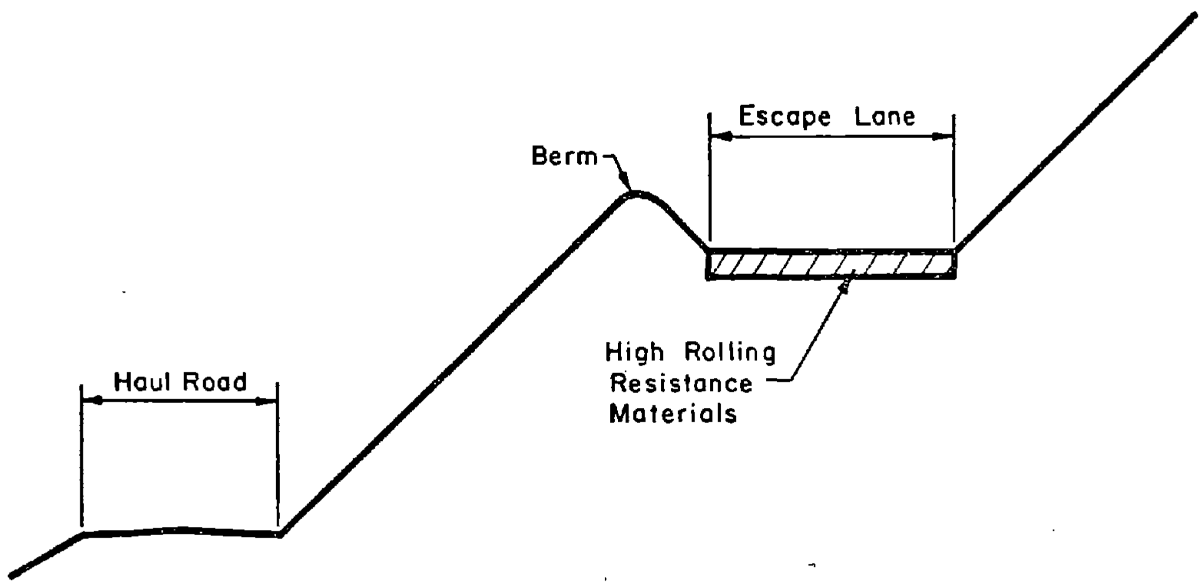
Figures V-3, V-4, V-5 depict typical Plan, Profile, and Section views of an emergency escape lane.



PLAN
HAUL ROAD ESCAPE LANE
FIGURE V-3



PROFILE
HAUL ROAD ESCAPE LANE
FIGURE V-4



CROSS SECTION
HAUL ROAD ESCAPE LANE
FIGURE V-5

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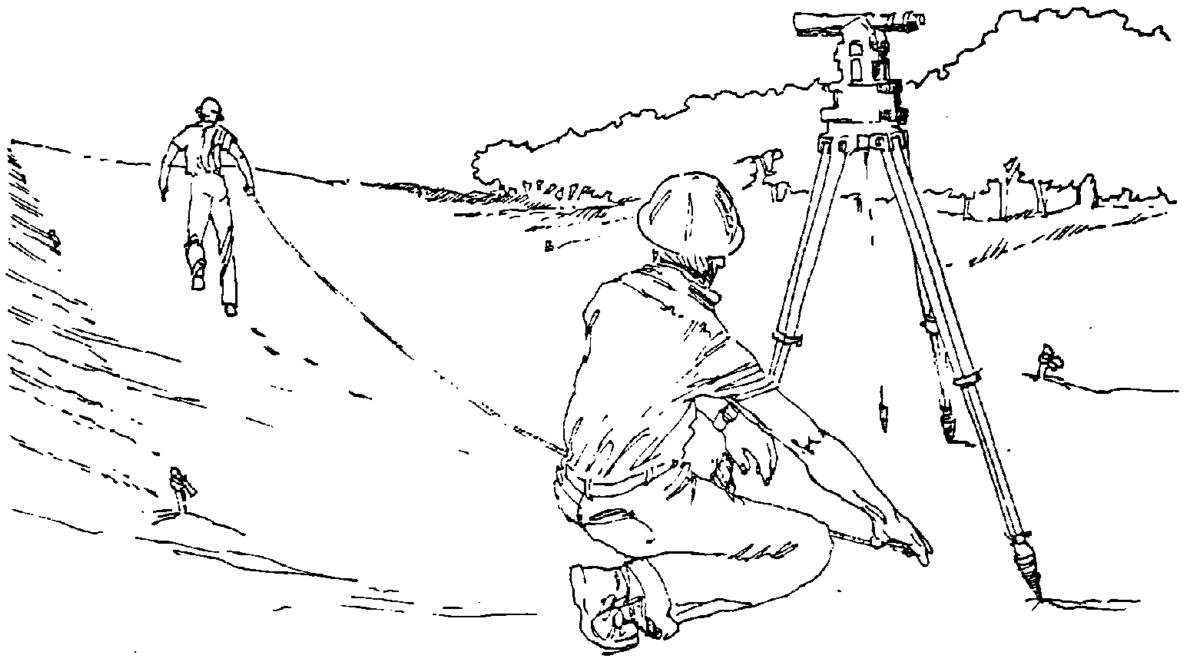


APPENDIX

APPENDIX

Unlike conventional highway design specifications which are documented in numerous textbooks and manuals, published standards for haul road construction are limited. For the most part, the design of these roads has been predicated on trial and error experience of individual mine operators. Far too often, however, the trial and error methodology results in development of haul roads which accommodate production but are not conducive to operational safety.

In July of 1975, Skelly and Loy was contracted by the United States Bureau of Mines to develop surface mine haulage road design criteria which would promote the safe operation of haulage vehicles. Due to lack of published information, it was necessary to approach the project on a step by step basis of progressive research. The following sections are presented to illustrate the manner in which the study was accomplished and to review the work performed during each project Phase and Task.

PHASE I - STUDY AND DETERMINATION

The first project phase consisted of a series of tasks and subtasks directed at defining the most predominant haul road users, and the manner in which their manufacture and component limitations would affect safe haul road design. Each of the tasks and subtasks included in this phase are described below.

Task 1 - Review SAE Braking Standards

At the beginning of this project, a review of surface mine haulage accident statistics revealed that a significant number of injuries have resulted from vehicle brake system failures. Thus, first consideration in the development of design criteria was given to establishing the effects of grade changes on braking limitations for haul road users. Due to the variety of brakes available, it was necessary to find a common basis for defining brake performance. The vehicle braking performance standards recommended by the Society of Automotive Engineers were selected for this purpose.

SAE brake performance standards applicable to this study were chosen for their adaptability to the following major surface mine haul road users:

Trucks
Wagons
Buses

Automobiles
Graders
Scrapers
Front-end Loaders, Backhoes
Dozers
Drill Rigs
Shovels
Rippers, Rooters, Scarifiers
Rollers

One suspects the SAE braking requirements for some of these vehicles, especially those used at high speeds such as automobiles, would be so stringent as to preclude them from consideration in design of haulage roads. However, to prevent prejudging, SAE braking standards pertaining to all the above vehicles were studied.

The RFP for this project contained a starter list of SAE standards to be considered. Other standards were added during a close scrutinization of the SAE Handbook indexes, especially the "subject index". The full text of each listed standard was studied and evaluated for relevance to this study. Most were considered to be inadequate.

A description of each listed standard and its purpose follows with a brief comment appraising its worth. The standards containing information of some value fell into two general categories: 1) those which establish maximum stopping distances for haul road vehicles, and 2) those which establish test procedures for evaluating the performance, structural integrity, and overall reliability of internal brake components. An asterisk identifies those standards in the following list which are within these two categories.

J880a* – Brake Rating System Test Code – Commercial Vehicles:

Purpose – To provide a method for determining a brake system rating for new commercial highway vehicles, based on the energy absorption and dissipation capacity of the brake system.

Comment – Provides the formula for calculation of the horsepower rating of the service brake system.

J971* – Brake Rating Test Code – Commercial Vehicle Inertia Dynamometer:

Purpose – To provide a method for determining a brake rating when tested on a dynamometer.

Comment – Provides the formula for calculation of the service brake rating horsepower.

J212 – Brake System Dynamometer Test Procedure – Passenger Car:

Purpose – To establish uniform laboratory dynamometer testing for passenger car brake systems.

Comment – Instructions for lab simulation of vehicle brake system performance. Not applicable.

J786a – Brake System Road Test Code – Truck, Bus, and Combination of Vehicles:

Purpose – To establish procedure for road test of brake systems.

Comment - May have some value in later phases of this project.

J225 - Brake System Torque Balance Test Code - Commerical Vehicles:

Purpose - To provide a method to determine the brake system torque balance.

Comment - Procedure and instructions for listing torque balance. Not applicable.

J667 - Brake Test Code - Inertia Dynamometer:

Purpose - To establish laboratory procedure for evaluating performance and wear of brakes by inertia dynamometer.

Comment - Lab simulation of test and operating conditions. Not applicable.

J1041 - Brake Test Procedure and Brake Performance Criteria for Agricultural Equipment:

Purpose - To establish test procedures for measurement of brake system performance for agricultural equipment.

Comment - For agricultural equipment that may be operated on the highway. Not applicable.

J181 - NONE THIS DESIGNATION
Tried J118 and J811 - Not appropriate.

J294 - Service Brake Structural Integrity Test Procedure - Vehicles Over 10,000 lbs:

Purpose - To establish a method of evaluating the structural integrity of the brake system of all new trucks, buses, and combinations of vehicle designed for roadway use.

Comment - Vehicles are those for highway use. Not applicable.

J992b* - Brake System Performance Requirements - Truck, Bus, and Combination of Vehicles:

Purpose - To present performance requirements for brake systems of new motor vehicles for roadway use.

Comment - This standard specifies maximum stopping distances for service and emergency systems. These are to be compared with off-highway maximum distances in a subsequent phase.

J319b* - Minimum Performance Criteria for Brake Systems for Off-Highway, Rubber-Tired, Self-Propelled Scrapers:

Purpose - To define minimum brake system performance.

Comment - This standard specifies maximum stopping distances for service and emergency brake systems.

J237a* - Minimum Performance Criteria for Braking Systems for Off-Highway, Rubber-Tired, Front-End Loaders and Dozers:

Purpose - To define minimum brake system performance.

Comment - This standard specifies maximum stopping distances for service and emergency brake systems.

J236a* - Minimum Performance Criteria for Braking Systems for Rubber-Tired, Self-Propelled Graders:

Purpose - To define minimum brake system performance.

Comment - This standard specifies maximum stopping distances for service and emergency brake systems.

J166* – Minimum Performance Criteria for Brake Systems for Off-Highway Trucks and Wagons:

Purpose – To define minimum brake system performance.

Comment – This standard specifies maximum stopping distances for service and emergency brake systems.

J263 – Emergency Air Brake Systems – Motor Vehicles and Vehicle Combinations:

Purpose – To establish design levels for air-operated emergency braking equipment.

Comment – Specifies emergency brake system application and release times.

J1026* – Minimum Performance Criteria for Braking Systems for Crawler Tractors and Crawler Loaders:

Purpose – To define minimum brake performance.

Comment – Braking systems shall have capability to make vehicle slide

J299* – Stopping Distance Test Procedure:

Purpose – To provide a method for determining stopping distances.

Comment – Provides definitions of all terms used in braking and stopping.

J293 – Vehicle Grade Parking Performance Requirements:

Purpose – To establish minimum performance requirements for on-grade parking.

Comment – Specifies the grade on which the vehicle shall be held and maximum acceptable application force.

J345a – Wet or Dry Pavement Passenger Car Tire Peak and Locked Wheel Braking Traction:

Purpose – To provide a general test procedure for measuring braking traction.

Comment – Deals exclusively with passenger cars. Not applicable.

J46 – Wheel Slip Brake Control System Road Test Code:

Purpose – To establish a procedure for the road test of wheel slip brake control systems.

Comment – Describes test procedure and test course, but no required test results. Not applicable.

J257* – Brake Rating Horsepower Requirements – Commercial Vehicles:

Purpose – To establish a minimum brake rating horsepower.

Comment – Standard provides formula for minimum horsepower: BRHP $\geq 12 + (1.4\ gvw/1000)$.

J360 – Motor Vehicle Grade Parking Performance Test Code:

Purpose – To establish a procedure for determining the parking performance on grade by the parking brake system.

Comment – Describes method of testing. Not applicable

J937b - Service Brake System Performance Requirements - Passenger Car:

Purpose - To establish minimum brake system performance requirements for new passenger cars in highway use.

Comment - Applies exclusively to vehicles for highway use. Not applicable.

J155 - Service Brake System Performance Requirements - Light Duty Truck:

Purpose - To establish minimum brake system performance requirements.

Comment - Gives maximum stopping distance with maximum pedal force - light trucks and multi-passenger vehicles. Much more restrictive than for off-roadway vehicles. Not applicable.

Finally, a tabulation of haulage road equipment was begun within the classifications of type and size (rating). The "Off-Highway Haul Units Comparative Data" catalog published by Equipment Guide-Book Company proved valuable, not only in this tabulation, but in the assembling of engineering data in later tasks.

Task 2 - Determine Adequacy of SAE Standards

Of the SAE standards studied in Task 1, the following provide information regarding stopping distance:

J319b provides maximum stopping distances for Scrapers

J237a provides maximum stopping distances for Front-End Loaders and Dozers

J236a provides maximum stopping distances for Graders

J166 provides maximum stopping distances for Trucks and Wagons

J992b provides maximum stopping distances for New Motor Vehicles for Roadway Use

J1026 defines the terms used in Brake Systems and Brake Testing

The standards which deal specifically with off-highway vehicles are J319b, J237a, J236a, and J166. Maximum stopping distances required herein are based on tests run on facilities and under conditions quite unlike those found at a typical surface mining site. For example, the test course consists of a clean swept, level, dry concrete surface of adequate length to conduct the test, with approach of sufficient length, smoothness, and uniformity of grade to assure stabilized travel speed of the vehicle. Required performance of vehicles on these standard test courses under controlled conditions allows comparative evaluation of vehicles and compliance of braking systems within weight classifications.

In order to utilize SAE data as a guideline for establishing grade criteria, it was necessary to employ the formulas and procedures described in the preceding report section entitled "Grade/Brake Relationships" in

Part I. As explained in that section, haul trucks exhibited the most restrictive brake performance capabilities of primary haul road users. Therefore, these vehicles were used to derive grade and stopping distance values in all computations.

Task 3 – Assemble and Categorize Engineering Data

Development of stopping capabilities on down grades during the first two tasks offered only a small portion of the information required to establish haul road design criteria. A complete delineation of design parameters necessitated gaining a total understanding of the physical dimensions and operating capabilities for each equipment type that would use the haulage road.

Initially, a limited amount of manufacturer's specifications for all equipment types were solicited or collected in-house. This limited assemblage of data was reviewed to determine which vehicles commonly employed at surface mines would impose the most stringent haul road design restrictions. Again, it was determined that designing the road to safely accommodate haul trucks would present a sufficient margin of safety for other vehicle types. After making this determination, extensive effort was devoted to attaining a comprehensive list of engineering data for all currently manufactured haul trucks.

Subtask A – Assemble Engineering Data

Many sources of off-highway truck design and operational statistics were contacted to obtain pertinent information. First, truck manufacturers were consulted for design and operational criteria applicable to brake and retarder systems. Next, transmission and brake system manufacturers were contacted for specific design and development data. Equipment distributors were helpful in establishing difficulties encountered by mine operators and supplied data which supplemented that obtained from Task 4 Field Investigations. "Off-Highway Haul Units", a publication prepared by the National Research and Appraisal Company, was used to ensure that all major truck manufacturers were considered and to supply additional data.

Specific engineering data assembled for each truck manufacturer's model included:

- Engine Horsepower
- Axle Weights (empty and fully loaded)
- Wheel Size
- Tire Size
- Wheel Base
- Axle Track
- Turning Radius
- Brake Type and Surface Area
- Dimensions (length, width, and height)
- Operator Location (height above ground)

- Gradability Performance
- Retarder Performance
- Drive Axle Ratio
- Transmission Ratios
- Torque Converter Ratio

Subtask B – Categorize Engineering Data

To facilitate comparison of data, truck models were first grouped into two types: rear dump and bottom dump. Rear dump models were further categorized according to whether they were conventional or tractor and trailer combinations. All truck models were then classified within the following SAE weight categories:

1. Less than 100,000 pounds GVW (single unit truck)
2. 100,000 to 200,000 pounds GVW (single unit truck)
3. 200,000 to 400,000 pounds GVW (single unit truck)
4. Over 400,000 pounds GVW (single unit truck)
    21. 100,000 to 200,000 pounds GVW (articulated truck)
    31. 200,000 to 400,000 pounds GVW (articulated truck)
    41. Over 400,000 pounds GVW (articulated truck)

Cross referencing between truck configuration and gross vehicle weight places all but a few of the truck models into categories convenient to this analysis. Fortunately, the unconventional models not contained in the above categories were either in developmental stages or not currently in extended use. A representation of engineering data collected is included in the following section.

Maximum and minimum values were established, and then averages computed for all of the categorized data. The resulting data is shown on Figures B through H.

Certain of these parameters could not be established for all of the manufacturer's models and body types. This was quite often the case for those specialty manufacturers who produce only bottom dump trailers for tractor-trailer combination haul units. Generally speaking, however, full data was available for all major vehicle manufacturers with well-established lines of off-highway trucks.

VEHICLE ENGINEERING DATA

CODE NO.	CATEGORY	RATING	WEIGHT OVER AXLE TRACK – EMPTY – AXLE FRONT	EMPTY REAR	EMPTY TRI	LOADED FRONT	LOADED REAR	LOADED TRI	WHEEL SIZE DIA	WHEEL SIZE WIDTH	TIRES SIZE	TIRES LOC	TIRES NO	WHEEL BASE FR AXLE TO DR AXLE	WHEEL BASE DR AXLE TO TRL AXLE	STEERING T.C. W. TRK	STEERING T.C. CLEAN	STEERING RATIO	BRAKES SERVICE TYPE	SERVICE AREA FR	SERVICE AREA DR	SERVICE AREA TRI	EMERGENCY TYPE	EMERGENCY FUNCTION
1	1	13 Ton	11,200 7' - 5½"	13,000 6' - 1½"	NA	13,800	36,400	NA	25"	8.5"	12x25	Front Rear	2 4	12' - 4"	NA	50' - 5¾"	53' - 10"	-	2 Shoe Internal Expanding	Total = 654		NA	-	-
2	1	13 Ton	11,644 7' - 1"	12,666 6' - 0"	NA	16,144	34,156	NA	24"	8"	12x24	Front Rear	2 4	11' - 0"	NA	46' - 0"	50' - 0"	-	Internal Expanding Air Oper.	Total = 712		NA	-	-
3	1	15 Ton	13,050 7' - 1"	18,350 7' - 1"	NA	16,550	44,850	NA	25"	10"	14x25	Front Rear	2 4	12' - 11"	NA	55.5'	-	-	Air Over Hydraulic	314	564	NA	Manual	Internal Shoe
4	1	20 Ton	13,250 7' - 1"	18,750 7' - 1"	NA	17,900	54,100	NA	25" 25"	10" 11.25"	14x25 16x25	Front Rear	2 4	12' - 11"	NA	55.5'	-	-	Air Over Hydraulic	314	564	NA	Manual	Internal Shoe
5	1	22 Ton	17,100 8' - 6"	19,450 6' - 6¼"	NA	22,820	57,730	NA	25"	11.25"	16x25	Front Rear	2 4	12' - 11"	NA	52' - 11"	56' - 2"	-	2 Shoe Internal Expand. Air Oper.	Total = 1,072		NA	-	-
6	1	22 Ton	15,900 7' - 4½"	20,000 6' - 8¾"	NA	20,300	59,600	NA	25"	11.25"	16x25	Front Rear	2 4	12' - 11"	NA	31' - 4"	54' - 2½"	-	2 Shoe Internal Expand. Air Oper.	252	536	NA		
7	1	23 Ton	21,000 6' - 6'	16,500 6' - 0"	NA	26,500	55,000	NA	25'	11.25"	16x25	Front Rear	2 4	11' - 8"	NA	55' - 8"	60' - 8"	-	Internal Expanding Cam Type Brakes Air Oper.	Total = 1,022		NA	-	-
8	1	25 Ton	17,600 7' - 7"	24,500 7' - 7"	NA	24,500	67,500	NA	25' 25"	11.25 Fr 13.00R	16x25 16x25	Front Rear	2 4	13' - 9"	NA	59'	-	-	Air Over Hydraulic Wedge Actuated	404	564	NA	Manual (Hand Brake)	Bendix
1	2	28 Ton	25,540 9' - 1"	23,360 8' - 7"	NA	34,900	70,000	NA	25"	13'	18x25	Front Rear	2 4	11' - 10"	NA	46' - 1"	56' - 0"	42	Air Over Hydraulic Internal Expanding Drum	520	648	NA	Air Over Hydraulic	Automatic or Manual Actuation
2	2	35 Ton	30,000 10' - 1"	30,760 8' - 1"	NA	43,590	87,170	NA	-	-	18x25	Front Rear	2 4	11' - 10"	NA	52' - 7"	59' - 1"	39	Air Over Hydraulic Front - Expanding Tube Type Rear - Disc Type	496	7869	NA	Air Over Hydraulic	Automatic or Manual Actuation
3	2	36 Ton	41,700 9' - 8"	[illegible]9,300 9' - 5'	NA	66,500	66,500	NA	-	-	16x25	Front Rear	4 4	10' - 10"	NA	59' - 6"	69' - 6"	-	Air Over Hydraulic 2 Shoe Internal Expanding Wedge	555	556	NA	Air Over Hydraulic	Automatic or Manual Actuation
4	2	35 Ton	20,110 7' - 7"	32,150 7' - 2"	NA	24,760	97,500	NA	-	-	14x25	Front Rear	2 8	15' - 0"	NA	-	-	-	Air Over Hydraulic Expanding Cam Type	Total = 1,70[illegible]		NA	Air Over Hydraulic	Automatic or Manual Actuation

DIMENSIONS: [illegible]	DIMENSIONS: [illegible]	DIMENSIONS: HEIGHT	[illegible]	RETARDATION (MAX. GRADE & SPEED - RANGE) EMPTY 1	2	3	4	5	6	GROSS VEHICLE WT. 1	2	3	4	5	6	CODE NO.
[illegible]	[illegible]	10'-7"	7.[illegible]	-	-	-	-	-	-	-	-	-	-	-	-	1
30'-10"	[illegible]	11'-0"	[illegible].75'	-	-	-	-	-	-	-	-	-	-	-	-	2
24'-0"	[illegible]	11'-1"	[illegible].75'	-	-	-	-	-	-	-	-	-	-	-	-	3
24'-[illegible]	[illegible]	11'-8"	9'	-	-	-	-	-	-	-	-	-	-	-	-	4
[illegible]	[illegible]	12'-4"	[illegible].75'	40% [illegible]	40% [illegible]	25% 14 mph	34% 19 mph	14% 27 mph	16% 33 mph	25% 7 mph	32% 10 mph	13% 14 mph	17% 15 mph	7.5% 27 mph	[illegible] 26 mph	5
[illegible]	[illegible]	12'-0"	8.0'	70% [illegible]	[illegible] 9 mph	29% 13 mph	34% 19 mph	14% 27 mph	17% 38 mph	25% 7 mph	32% 9 mph	12% 13 mph	16% 13 mph	5% 27 mph	0% 38 mph	6
24'-[illegible]	[illegible]-4 5/8"	11'-11"	9.0'	-	-	-	-	-	-	-	-	-	-	-	-	7
[illegible]-3"	[illegible]-0"	[illegible]-11"	9.3'	-	-	-	-	-	-	-	-	-	-	-	-	8
25'-2"	[illegible]	12'-5"	10.5'	30% 7 mph	30% 10 mph	22% [illegible] mph	15% 27 mph	10% 33 mph		25% 7 mph	15% 10 mph	10% 17 mph	[illegible] 27 mph	5% 33 mph		1
23'-7"	[illegible]	12'-10"	10.2'	-	-	-	-	-	-	-	-	-	-	-	-	2
25'-[illegible]	[illegible]	12'-0"	11.0	30% [illegible]	30% 10 mph	23% 13 mph	13% 19 mph	10% 27.5 mph	7% 34 mph	25% [illegible]	14% 10 mph	10% 13 mph	7% 19 mph	5% [illegible]	3% 38 mph	3
[illegible]	[illegible]-11"	11'-4"	9.5'	Continuous retardation 79% [illegible]						-	-	-	-	-	-	4

CODE NO.	PERFORMANCE (MAX. GRADE & SPEED - RANGE) EMPTY 1	2	3	4	5	6	GROSS VEHICLE WT. 1	2	3	4	5	6
1	40% 5 mph	24% 7 mph	11% 13½ mph	5.5% 24 mph	1% 30 mph		24% 3½ mph	10% 7 mph	5% 13 mph	2% 24 mph	1.5% 30 mph	
2	24% 6 mph	8% 13 mph	1% 25 mph	[illegible] 32 mph			15% 6 mph	[illegible] 13 mph	[illegible] 25 mph	1% 32 mph		
3	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	28% [illegible]	19% 9 mph	13% 13 mph	9% 17 mph	5% 25 mph	3% 36 mph	10% 6 mph	6% 9 mph	5% 13 mph	3% 17 mph	1% 25 mph	0.5% 36 mph
6	32% 5 mph	22% 7.5 mph	15% 10 mph	11% 15 mph	5% 21 mph	5% 29.5 mph	15% 5 mph	10% 7.5 mph	7.5% 10 mph	5% 15 mph	4% 21 mph	2.5% 29.5 mph
7	23% 5 mph	15% 8 mph	9% 11 mph	5% 16 mph	2% 23 mph	1% 31 mph	9% 5½ mph	5% 8 mph	2½% 11 mph	1% 16 mph	1% 23 mph	0.5% 31 mph
8	-	-	-	-	-	-	-	-	-	-	-	-
1		22% 9 mph	14% 13 mph	10% 20 mph	7% 28 mph			10% 9 mph	6.5% 13 mph	4.5% 20 mph	3.5% 28 mph	
2	-	-	-	-	-	-	-	-	-	-	-	-
3	30% 5 mph	30% 6 mph	22.5% 8 mph	6% 11 mph	11% 17 mph	7% 24 mph	30% [illegible]	17% 4 mph	13% 6 mph	7% 11 mph	5% 17 mph	3% 24 mph
4	30 [illegible]	20% [illegible]	14% 10.5 mph	[illegible] 15 mph	6% 21 mph	0% 34 mph	11% 5 mph	7% 8 mph	5% 10.5 mph	3% 15 mph	1% 21 mph	0% 34 mph

CODE NO.	REDUCTION RATIOS TRANSMISSION 1	2	3	4	5	6	REAR AXLE TOTAL	TORQUE CONVERTER RATIO	LOCK-UP	S.A.E. CONFORMITY BRAKES	STEERING	CABIN
1	5.37	3.40	1.74	1.00	0.79		12.78	-	-	-	-	-
2	3.8	1.84	1.00	.72			12.11	3.51	Integral Torque Converter & Lock-up	-	-	-
3	High Range 5.45 / Low Range 7.12	3.13 / 4.09	1.76 / 2.29	1.00 / 1.31	0.78 / 1.02		14.40	-	-	-	-	-
4	High Range 5.45 / Low Range 7.12	3.13 / 4.09	1.76 / 2.29	1.00 / 1.31	0.78 / 1.02		14.40	-	-	-	-	-
5	4.00	2.82	2.00	1.41	1.00	.71	14.15	-	Integral Torque Converter Lock-up & Toromatic Brake	-	-	-
6	4.0	2.82	2.00	1.41	1.00	.71	14.18	-	Auto All Ranges	-	-	-
7	4.00	2.82	2.0	1.41	1.0	0.71	15.14	2.80	Integral Torque Converter Lock-up & Toromatic Brake	-	-	-
8	High Range 5.45 / Low Range 7.12	3.13 / 4.09	1.76 / 2.29	1.00 / 1.31	0.78 / 1.02		16.56	-	-	-	-	-
1	-	-	-	-	-	-	11.48	-	Automatic Four Top Ranges	-	-	-
2	3 spd manual with auto shift between torque divider, direct and over drive						13.15	-	-	J-166	-	-
3	3.56	2.44	1.73	1.18	.81	5.75	20.35	2.25	Automatic All Ranges	-	-	-
4	4.0	2.68	2.01	1.35	1.0	.67	15.60	2.9	Automatic All Ranges	-	-	-

CODE NO.	CATEGORY	RATING	WEIGHT OVER AXLE TRACK						WHEEL SIZE		TIRES			WHEEL BASE		STEERING			BRAKES						
			EMPTY			LOADED													SERVICE					EMERGENCY	
			AXLE																	AREA					
			FRONT	REAR	TOT	FRONT	REAR	TOT	DIA	WIDTH	SIZE	LOC	NO	FR AXLE TO RR AXLE	RR AXLE TO RR AXLE	@ WHEEL	@ CLEAR	RATIO	TYPE	FR	RR	TOT	TYPE	FUNCTION
5	2	35 Ton	28,000 9' - 10½"	33,000 8' - 0"	NA	41,500	59,500	NA	25	13	18x2?	Front Rear	2 4	13' - 9"	NA	-	-	-	Air Over Hydraulic	404	404	NA	Air Over Hydraulic	Automatic or Manual Actuation
6	2	35 Ton	29,540 9' - 11"	28,820 8' - 3"	NA	41,590	86,776	NA	33	13	18x33	Front Rear	2 4	10' - 10"	NA	49' - 0"	-	42	Air Over Hydraulic Shoe Type Wedge Actuated	Total = 1,034		NA	Air Over Hydraulic	Automatic or Manual Actuation
7	2	35 Ton	29,400 10' - 2"	26,900 8' - 4"	NA	43,100	85,200	NA	25	13	19x25	Front Rear	2 4	13' - 9"	NA	54' - 2½"	51' - 4"	-	Air Over Hydraulic 2 Shoe Internal Expanding	570	564	NA	Air Over Hydraulic	Automatic or Manual Actuation
8	2	40 Ton	41,900 9' - 6"	20,500 9' - 9"	NA	71,200	71,200	NA	25	-	18x25	Front Rear	4 4	10' - 10"	NA	59' - 6"	69' - 6"	-	Air Over Hydraulic 2 Shoe Internal Expanding	550	556	NA	Air Over Hydraulic	Automatic or Manual Actuation
9	2	40 Ton	23,050 7' - 7"	28,840 7' - 2"	NA	26,400	105,500	NA	25	13	14x25	Front Rear	2 8	17' - 11"	NA	75' - 5"	78' - 4 3/4	-	Air Over Hydraulic Internal Expanding Cam Type	Total = 1,700		NA	Air Over Hydraulic	Automatic or Manual Actuation
10	2	40 Ton	33,400 10' - 11"	34,800 8' - 11"	NA	49,400	98,800	NA	35	13	16x33	Front Rear	2 4	13' - 0"	NA	57' - 5"	63' - 0"	20	Air Over Hydraulic Internal Expanding Drum	624	810	NA	Air Over Hydraulic	Automatic or Manual Actuation
11	2	45 Ton	24,800 6' - 6"	37,200 8' - 10"	NA	32,000	120,000	NA	25	.25	16x25	Front Rear	2 8	15' - 5"	NA	55' - 8"	7' - 5'	-	Air Over Hydraulic Internal Expanding Cam Type	Total = 1,785		NA	Air Over Hydraulic	Automatic or Manual Actuation
12	2	45 Ton	25,250 9' - 11"	51,250 8' - 11"	NA	31,450	135,050	NA	25	13	18x25	Front Rear	2 6	17' - 4"	NA	-	75' - 0"	-	Air Over Hydraulic	404	728	NA	Air Over Hydraulic	Automatic or Manual Actuation
13	2	50 Ton	37,625 10' - 6"	39,450 8' - 1½"	NA	53,975	117,100	NA	35	17	24x35	Front Rear	2 4	13' - 0"	NA	62' - 0"	-	41	Air Over Hydraulic 2 Shoe Internal Expanding	504	1060	NA	Air Over Hydraulic	Automatic or Manual Actuation
14	2	50 Ton	36,169 11' - 4"	39,174 9' - 3"	NA	56,440	116,300	NA	35	15	21x35	Front Rear	2 4	12' - 7"	NA	58'	-	-	Air Over Hydraulic Shoe Type Wedge Actuated	Total = 1,900		NA	Air Over Hydraulic	Automatic or Manual Actuation

CODE NO.	DIMENSIONS: LENGTH	DIMENSIONS: WIDTH	DIMENSIONS: HEIGHT	[illegible]	RETARDATION – MAX. GRADE % SPEED RANGE – EMPTY 1	EMPTY 2	EMPTY 3	EMPTY 4	EMPTY 5	EMPTY 6	GROSS VEHICLE WGT 1	GVW 2	GVW 3	GVW 4	GVW 5	GVW 6
5	24'-1"	12'-2"	12'-0"	10.7'	-	-	-	-	-	-	-	-	-	-	-	-
6	25'-4"	12'-0"	13'-1"	10.5'	-	-	-	-	-	-	-	-	-	-	-	-
7	27'-9"	11'-7"	12'-6"	10.5'	30% 5 mph	30% 9 mph	30% 11 mph	25% 16 mph	[illegible] 23 mph	12% 35.5 mph	35% 6 mph	25% 9 mph	17% 11 mph	10% 16 mph	6% 23 mph	3.5% 35.5 mph
8	25'-2"	10'-3"	12'-0"	10.0'	30% 4 mph	30% 9 mph	22% 13 mph	14% 19 mph	10% 26 mph	7% 39 mph	20% 6 mph	13% 9 mph	10% 13 mph	7% 19 mph	5% 26 mph	3% 39 mph
9	34'-1"	9'-11"	11'-0"	9.0'	-	-	-	-	-	-	-	-	-	-	-	-
10	27'-7"	12'-10"	14'-0"	11.75'	30% 6 mph	30% 10 mph	20% 13 mph	18% 20 mph	14% 26 mph	9% 39.5 mph	27% 6 mph	17% 10 mph	13% 13 mph	9% 20 mph	6% 73 mph	4% 39.5 mph
11	23'-3"	12'-0"	11'-11"	9.0'	-	-	-	-	-	-	-	-	-	-	-	-
12	31'-8"	12'-7"	12'-2"	10.25	-	-	-	-	-	-	-	-	-	-	-	-
13	30'-4"	13'-3"	14'-6"	11.5'	33% 6 mph	30% 9 mph	23% 12 mph	24% 18 mph	17% 25 mph	12% 37 mph	33% 6 mph	23% 9 mph	17% 12 mph	12% 18 mph	9% 25 mph	7% 37 mph
14	29'-11"	13'-5"	14'-2"	11.25'	-	-	-	-	-	-	-	-	-	-	-	-

CODE NO.	PERFORMANCE – MAX. GRADE % SPEED RANGE – EMPTY 1	EMPTY 2	EMPTY 3	EMPTY 4	EMPTY 5	EMPTY 6	GROSS VEHICLE WGT 1	GVW 2	GVW 3	GVW 4	GVW 5	GVW 6
5	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-
7	42% 5 mph	30% 7 mph	23% 9 mph	15% 13 mph	11% 17 mph	4.5% 27 mph	21% 5 mph	14% 7 mph	10% 9 mph	7% 13 mph	5% 17 mph	3.5% 27 mph
8	30% 4 mph	30% 5 mph	22% 8.5 mph	16% 12 mph	10% 17.5 mph	7% 26 mph	20% 4 mph	13% 5 mph	10% 8.5 mph	7% 12 mph	5% 17.5 mph	3% 26 mph
9	17% 5 mph	17% 7 mph	10% 10 mph	7% 15 mph	6% 21 mph	0% 30 mph	11% 5 mph	7% 7 mph	3% 10 mph	2% 15 mph	1% 21 mph	0% 50 mph
10	30% 5 mph	30% 8 mph	22% 10 mph	15% 15 mph	12% 20 mph	5% 30 mph	21% 5 mph	14% 8 mph	10% 10 mph	7% 15 mph	5% 20 mph	4% 30 mph
11	30% 5 mph	18% 8 mph	13% 10 mph	9% 15 mph	4% 21 mph	0% 30 mph	10% 5 mph	7% 8 mph	4% 10 mph	3% 15 mph	2% 21 mph	0% 30 mph
12	-	-	-	-	-	-	-	-	-	-	-	-
13	35% 6 mph	24% 9 mph	17% 12 mph	12% 17 mph	0% 24 mph	[illegible] 35 mph	15% 6 mph	11% 9 mph	7% 12 mph	5% 17 mph	3% 23 mph	1% 35 mph
14	-	-	-	-	-	-	-	-	-	-	-	-

CODE NO.	REDUCTION RATIOS – TRANSMISSION 1	2	3	4	5	6	REAR AXLE TOTAL	TORQUE CONVERTER – RATIO	LOCK OUT	S.A.E. CONFORMITY – BRAKES	STEERING	CABIN
5	4.0	2.68	2.01	1.35	1.0	.67	18.37	-	-	-	-	-
6	-	-	-	-	-	-	16.08	-	Automatic	-	-	-
7	4.0	2.68	2.01	1.35	1.0	.67	17.99	-	Automatic All Ranges	J-166	-	-
8	3.59	2.44	1.73	1.19	.91	.675	20.35	2.25	Automatic	-	-	-
9	4.0	2.68	2.01	1.35	1.0	.67	15.60	2.90	Automatic	-	-	-
10	-	-	-	-	-	-	17.65	-	Automatic All Ranges	-	-	-
11	4.0	2.68	2.01	1.35	1.0	.67	17.02	2.90	Automatic	-	-	-
12	4.0	2.68	2.01	1.35	1.0	.68	-	-	Automatic	-	-	-
13	4.00	2.68	2.01	1.35	1.00	.67	21.03	-	Automatic Lock-up	J-166	-	-
14	-	-	-	-	-	-	18.25	-	Automatic	J-166	-	-

CODE NO.	CATEGORY	RATING	WEIGHT OVER AXLE TRACK — EMPTY — AXLE — FRONT	EMPTY — REAR	EMPTY — TDL	LOADED — FRONT	LOADED — REAR	LOADED — TDL	WHEEL SIZE — DIA	WHEEL SIZE — WIDTH	TIRES — SIZE	TIRES — LOC	TIRES — NO	WHEEL BASE — FR AXLE TO FR AXLE	WHEEL BASE — DR AXLE TO DR AXLE	STEERING — FT W/BRK	STEERING — FT CLEAR	STEERING — RATE	BRAKES — SERVICE — TYPE	SERVICE — AREA — FR	SERVICE — AREA — RR	SERVICE — AREA — TDL	EMERGENCY — TYPE	EMERGENCY — FUNCTION
15	2	50 Ton	34,650 8' – 11"	39,800 8' – 11"	NA	52,650	121,860	NA	35	15	21x35	Front Rear	2 4	13' – 9"	NA	60' – 0"	–	–	Air Over Hydraulic	512	1064	NA	Air Over Hydraulic	Automatic or Manual Actuation
16	2	50 Ton	27,440 8' – 10"	33,550 9' – 4"	NA	31,740	129,250	NA	25	11.25	16x25	Front Rear	2 6	18' – 2"	NA	70' – 0"	–	–	Air Over Hydraulic Internal Expanding Cam Type	Total = 1,720		NA	Air Over Hydraulic	Automatic or Manual Actuation
17	2	50 Ton	50,500 9' – 7½"	22,200 9' – 7½"	NA	66,400	86,400	NA	25	–	18x25	Front Rear	2 4	11' – 8"	NA	62' – 9"	72' – 10"	–	Air Over Hydraulic 2 Shoe, Internal Expanding	555	555	NA	Air Over Hydraulic	Automatic or Manual Actuation
18	2	50 Ton	35,900 10' – 4"	43,100 9' – 0"	NA	50,700	121,300	NA	35	–	21x35	Front Rear	2 2	13' – 0"	NA	56' – 10"	72' – 6"	31	Air Over Hydraulic Disc Brakes	495	9340	NA	Air Over Hydraulic	Automatic or Manual Actuation
1	3	55 Ton	45,200 11' – 10"	48,000 9' – 10"	NA	57,000	135,400	NA	35	17	24x35	Front Rear	2 4	14' – 0"	NA	51' – 8"	70' – 8"	42	Air Over Hydraulic Internal Expanding Shoe Type	1245	1345	NA	Air Over Hydraulic	Automatic or Manual Actuation
2	3	65 Ton	43,500 11' – 4"	46,850 11' – 4"	NA	74,200	146,150	NA	33	17	24x35	Front Rear	2 4	13' – 9"	NA	–	60' – 0"	–	Air Over Hydraulic Disc	Total = 1,375		NA	Air Over Hydraulic	Automatic or Manual Actuation
3	3	75 Ton	36,250 9' – 3"	66,750 9' – 3"	NA	81,350	203,650	NA	33	13	18x33	Front Rear	2 6	17' – 10"	NA	–	50' – 0"	–	Air Over Hydraulic Disc	522	2128	NA	Air Over Hydraulic	Automatic or Manual Actuation
4	3	75 Ton	44,540 12' – 0"	49,360 10' – 10"	NA	81,100	162,300	NA	35	17	24x35	Front Rear	2/4 4	13' – 4"	NA	69'	–	–	Air Over Hydraulic Wedge Actuated, Shoe Type	Total = 1,960		NA	Air Over Hydraulic	Automatic or Manual Actuation
5	3	75 Ton	46,000 13' – 10"	52,000 11' – 3"	NA	54,000	157,000	NA	35	17	24x35	Front Rear	2 4	14' – 6"	NA	–	62' – 3"	–	Air Over Hydraulic Wedge Actuated, Shoe Type	800	1050	NA	Air Over Hydraulic	Automatic or Manual Actuation
6	3	90 Ton	65,000 12' – 4"	52,000 10' – 8"	NA	31,000	182,140	NA	49	17	24x49	Front Rear	2 4	15' – 0"	NA	67' – 0"	75' – 0"	38	Air Over Hydraulic Internal Expanding Shoe Type	905	1134	NA	Air Over Hydraulic	Automatic or Manual Actuation

Code No.	Dimensions			Weight	Retardation – Max. grade & speed range – Empty 1	Empty 2	Empty 3	Empty 4	Empty 5	Empty 6	Gross vehicle wt. 1	Gross 2	Gross 3	Gross 4	Gross 5	Gross 6
15	[illegible]	[illegible]	14' – 2"	11.30	-	-	-	-	-	-	-	-	-	-	-	-
16	34' – 3"	[illegible] – 9"	11' – 2'	9.0	-	-	-	-	-	-	-	-	-	-	-	-
17	30' – 4	[illegible] – 3"	12' – 3"	9.5	32% 7 mph	25% 11 mph	24% 15 mph	10% 25 mph	12% 35 mph		22% 7 mph	15% 11 mph	11% 10½ mph	8% 25 mph	6% 35 mph	
16	28' – 7"	[illegible] – 4"	14' – 1"	10.5	30% 7 mph	32% 11 mph	17% 29 mph				27% 7 mph	17% 11 mph	8% 29 mph			
1	[illegible]	14' – [illegible]"	14' – 10"	12.0	30% 7.5 mph	30% 11 mph	22% 15 mph	16% 22.5 mph	12% 30.5 mph	7.5% 45 mph	22% 7.5 mph	14% 11 mph	11% 15 mph	7% 22.5 mph	5.5% 30.5 mph	3.5% 45 mph
2	[illegible]	[illegible] – 2"	14' – 9"	12.0	-	-	-	-	-	-	-	-	-	-	-	-
3	34' – 5"	[illegible]	12' – 7"	11.0	-	-	-	-	-	-	-	-	-	-	-	-
4	[illegible]	[illegible]	13' – 9"	11.5	-	-	-	-	-	-	-	-	-	-	-	-
5	[illegible]	15' – 2"	15' – 5"	13.0	32% 7 mph	32% 12 mph	29% 17 mph	22.5 20.5 mph	17% 29 mph	12% 33.5 mph	32% 7 mph	17% 12 mph	12% 17 mph	9% 22 mph	7% 29 mph	5% 33.5 mph
6	35' – [illegible]	[illegible]	15' – 9"	12.20	30% [illegible] mph	20% 13 mph	30% 17 mph	25% 20 mph	19% 29 mph	14% 39.5 mph	20% 7 mph	[illegible] 12 mph	13% 17 mph	10% 20 mph	7.5% 29 mph	5.5% 39.5 mph

Code No.	Performance – Max. grade & speed range – Empty 1	Empty 2	Empty 3	Empty 4	Empty 5	Empty 6	Gross vehicle wt. 1	Gross 2	Gross 3	Gross 4	Gross 5	Gross 6
15	-	-	-	-	-	-	-	-	-	-	-	-
16	35% 5 mph	20% 7½ mph	13% 10 mph	8% 15 mph	5% 20 mph	1% 30 mph	12% 5 mph	5% 7½ mph	3% 10 mph	1% 15 mph	0% 20 mph	0% 30 mph
17	28% 6 mph	21% 10 mph	14% 15 mph	9% 23 mph	5% 32 mph		13% 6 mph	7% 10½ mph	4.5% 15 mph	2½% 23 mph	1% 32 mph	
16	30% 1 mph	23% 7 mph	9% 16 mph				30% 1 mph	10% 7 mph	3% 16 mph			
1	30% 6 mph	24% 9 mph	15% 12 mph	11% 17.5 mph	9% 23.5 mph	5% 35 mph	17% 6 mph	11% 9 mph	8% 12 mph	5% 17.5 mph	4% 23.5 mph	2.5% 35 mph
2	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	34% 5 mph	23% 9 mph	17% 13 mph	12.5% 15.5 mph	9.5% 21.5 mph	7.5% 30 mph	19% 5 mph	9.5% 9 mph	7% 13 mph	5% 10.5 mph	4% 21.5 mph	3% 30 mph
6	[illegible]	23% 9.5 mph	17% 13 mph	12% 17 mph	10% 22.5 mph	7% 30.5 mph	17% 5.5 mph	9% 9.5 mph	8% 13 mph	5% 17 mph	3.5% 22.5 mph	2.5% 30.5 mph

Code No.	Reduction Ratios – Transmission 1	2	3	4	5	6	Rear Axle Total	Torque Converter – Ratio	Lock Out	S.A.E. Conformity – Brakes	Steering	Cabin
15	4.00	3.04	2.01	1.35	1.00	.67	20.40	-	Automatic	-	-	-
16	4.00	2.68	2.01	1.35	1.00	.67	17.02	2.80	Automatic	-	-	-
17	3.43	2.17	1.53	1.00	.703		17.05	2.6	Automatic All Ranges	J-166	-	J-952b J-386
16	3 spd manual with auto shift between torque divider, direct and over drive.						17.46	-	Automatic thru Speed Sensing Valve	-	-	-
1	-	-	-	-	-	-	19.27	-	Automatic All Ranges	-	-	-
2	4.24	2.34	1.70	1.31	1.00	.72	-	-	-	-	-	-
3	4.24	2.34	1.70	1.3	1.00	.73	-	-	-	-	-	-
4	-	-	-	-	-	-	16.52	-	-	-	-	-
5	4.24	2.34	1.70	1.31	1.00	.72	21.53	-	Automatic All Ranges	J-166	-	-
6	-	-	-	-	-	-	22.75	-	Automatic All Ranges	-	-	-

CODE NO.	CATEGORY	RATING	WEIGHT OVER AXLE TRACK: EMPTY AXLE FRONT	EMPTY REAR	EMPTY TR	LOADED FRONT	LOADED REAR	LOADED TR	WHEEL SIZE DIA	WHEEL SIZE WIDTH	TIRES SIZE	TIRES LOC	TIRES NO	WHEEL BASE FR. AXLE TO DR. AXLE	WHEEL BASE DR. AXLE TO TR. AXLE	STEERING T.C. W THRU	STEERING T.C. CLEAR	STEERING RATIO	BRAKES SERVICE TYPE	SERVICE AREA FR	SERVICE AREA DR	SERVICE AREA TR	EMERGENCY TYPE	EMERGENCY FUNCTION
7	3	85 Ton	62,800 13' – 0"	59,300 11' – 1"	NA	97,500	188,000	NA	49	–	24x49	Front Rear	2 4	15' – 0"	NA	79' – 7"	88	30	Air Over Hydraulic Expanding Tube-Front Disc-Drive	532	2462	NA	Air Over Hydraulic	Automatic or Manual Actuation
8	3	85 Ton	52,797 14' – 0"	64,272 14' – 4"	NA	94,710	192,440	NA	49	22	24x49	Front Rear	2 4	15' – 0"	NA	–	50	–	Air Over Hydraulic Expanding Tube-Front Disc-Drive	–	–	NA	Air Over Hydraulic	Automatic or Manual Actuation
9	3	85 Ton	59,500 13' – 0"	55,100 10' – 10"	NA	95,300	189,300	NA	49	17	24x49	Front Rear	2/4 4	14' – 7"	NA	65' – 0"	–	–	Air Over Hydraulic Wedge Actuated, Shoe Type	Total = 2,750		NA	Air Over Hydraulic	Automatic or Manual Actuation
10	5	65 Ton	52,100 13' – 10"	50,700 11' – 3'	NA	92,100	190,700	NA	49	17	24x49	Front Rear	2 4	14' – 6"	NA	68' – 4"	75' – 4"	–	Air Over Hydraulic Internal Expanding Shoe Type	360	1350	NA	Air Over Hydraulic	Automatic or Manual Actuation
11	3	100 Ton	60,750 14' – 4"	70,750 14' – 7"	NA	109,493	222,[illegible]	NA	49	–	27x49	Front Rear	2 4	15' – 0"	NA	–	61	–	Air Over Hydraulic Expanding Tube-Front Disc-Drive	–	–	NA	Air Over Hydraulic	Automatic or Manual Actuation
12	2	105 Ton	66,500 10' – 7	50,500 10' – 7'	NA	174,600	172,400	NA	49	17	24x49	Front Rear	4 4	14' – 6"	NA	66' – 0'	63' – 9'	–	Air Over Hydraulic Internal Expanding Shoe Type	Total = 2,500		NA	Air Over Hydraulic	Automatic or Manual Actuation
13	3	120 Ton	71,465 14' – 9"	62,220 15' – [illegible]	NA	127,555	255,134	NA	51	22	30x51	Front Rear	2 4	17' – 0"	NA	–	75' – 2"	–	Air Over Hydraulic Expanding Tube-Front Disc-Drive	–	–	NA	Air Over Hydraulic	Automatic or Manual Actuation
1	4	120 Ton	75,235 15' – 4"	97,500 13' – 3"	NA	137,912	275,823	NA	51	22	30x51	Front Rear	2 4	16' – 10"	NA	60' – 0"	–	–	Air Over Hydraulic Expanding Tube-Front Disc-Drive	–	–	NA	Air Over Hydraulic	Automatic or Manual Actuation
2	4	130 Ton	71,765 14' – 9	84,273 14' – 5"	NA	128,563	287,498	NA	51	22	30x51	Front Rear	2 4	17' – 0"	NA	–	75' – 2"	–	Air Over Hydraulic Expanding Tube-Front Disc-Drive	–	–	NA	Air Over Hydraulic	Automatic or Manual Actuation
3	4	150 Ton	85,471 15' – 7"	93,551 15' – 7"	NA	160,457	321,3[illegible]	NA	51	24	33x51	Front Rear	2 4	17' – 6"	NA	82' – 0"	–	–	Air Over Hydraulic Expanding Tube-Front Disc-Drive	–	–	NA	Air Over Hydraulic	Automatic or Manual Actuation

DIMENSIONS: Length	Width	Height	[illegible]	RETARDATION (Max. Grade & Speed Range)	PERFORMANCE (Max. Grade & Speed Range)	REDUCTION RATIOS: Transmission 1–6	Rear Axle Total	TORQUE CONVERTER: Ratio	Lock Out	S.A.E. CONFORMITY: Brake	Steering	Cabin	CODE NO.
[illegible]	[illegible]	15' - 1"	13.5	Retardation provided via Service Brake System	Empty: 30% 5 mph; 20% 7 mph; 17% 10 mph; 15% 13 mph; 10% 17.5 mph; 3% 24 mph. Gross: 17% [illegible] mph; 12% 7 mph; 8% 10 mph; 6% 13 mph; 5% 17.5 mph; 3.5% 24 mph	7 speed automatic	21.25	-	Automatic All Ranges Except 1st	-	-	-	7
32' - 9"	17' - [illegible]	17' - 3"	14.0	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	3
[illegible]	[illegible]	15' - 5"	13.0	-	-	-	20.82	-	-	-	-	-	9
[illegible]	[illegible]	15' - 4"	13.75	Empty: 45% 5 mph; 45 11 mph; 32% 15 mph; 24% 19 mph; 16% 25 mph; 14% 34.5 mph. Gross: 30% 5 mph; 16% 11 mph; 12% 15 mph; 10.5% 19 mph; 7% 25 mph; 6% 34.5 mph	Empty: 42% 4.5 mph; 25% [illegible] mph; 18% 11.5 mph; 14% 15 mph; 10% 19 mph; 7.5% 25.5 mph. Gross: 18% 4.5 mph; 13% [illegible] mph; 7% 11.5 mph; 5.5% 15 mph; 4% 19 mph; 3% 26.5 mph	4.24; 2.34; 1.70; 1.31; 1.00; .73	25.53	-	Automatic All Ranges	J-166	-	-	10
[illegible]	[illegible]	17' - 5"	14.5	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	11
[illegible]	[illegible]	15' - 4"	12.0	Empty: 40% 5.5 mph; 40% 12 mph; 32% 15 mph; 24% 21 mph; 18% 27 mph; 14% 37.5 mph. Gross: 30% 5.5 mph; 17% 12 mph; 12% 16 mph; 10% 21 mph; 6% 27 mph; 4% 37.5 mph	Empty: 40% 5 mph; 22% 9 mph; 15% 12.5 mph; 12% 16 mph; 9% 21.5 mph; 7% 29 mph. Gross: 15% 5 mph; 7.5% 9 mph; 6% 12.5 mph; 5% 16.5 mph; 3.5% 21.5 mph; 3% 29 mph	4.24; 2.34; 1.70; 1.31; 1.00; .73	21.62	-	Automatic All Ranges	J-166	-	-	12
[illegible]	[illegible]	17' - 9"	15.0	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	13
[illegible]	[illegible]	16' - 6"	13.67	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	1
[illegible]	[illegible]	17' - 9"	15.0	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	2
[illegible]	[illegible]	15' - 9"	16.0	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	3

CODE NO.	CATEGORY	RATING	WEIGHT OVER AXLE TRACK: EMPTY – AXLE FRONT	EMPTY – REAR	EMPTY – TR	LOADED – FRONT	LOADED – REAR	LOADED – TR	WHEEL SIZE: DIA	WHEEL SIZE: WIDTH	TIRES: SIZE	TIRES: LOC	TIRES: NO	WHEEL BASE: FR AXLE TO DR AXLE	WHEEL BASE: DR AXLE TO TR AXLE	STEERING: [illegible] W/DIST	STEERING: [illegible] CLEAR	STEERING: RATE	BRAKES: SERVICE – TYPE	SERVICE – AREA FR	SERVICE – AREA [illegible]	SERVICE – AREA TR	EMERGENCY – TYPE	EMERGENCY – FUNCTION
4	4	150 Ton	123,994 10'-3"	128,231 13'-0"	NA	176,767	375,455	NA	51	26	36x51	Front Rear	2 4	18'-0"	NA	102'-0"	-	-	Air Over Hydraulic Disc	-	-	NA	Air Over Hydraulic	Automatic or Manual Actuation
5	4	170 Ton	95,815 15'-9"	109,907 15'-9"	NA	173,097	356,728	NA	51	26	36x51	Front Rear	2 4	17'-6"	NA	79'-2"	-	-	Air Over Hydraulic Internal Expanding Shoe Type	1872	2160	NA	Air Over Hydraulic	Automatic or Manual Actuation
6	4	170 Ton	99,700 17'-5"	112,500 14'-5"	NA	154,200	358,300	NA	51	26	36x51	Front Rear	2 4	17'-10"	NA	83'-0"	-	-	Air Over Hydraulic Expanding Tube-Front Disc-Drive	-	-	NA	Air Over Hydraulic	Automatic or Manual Actuation
7	4	170 Ton	105,200 17'-7"	105,700 13'-6"	NA	183,400	357,500	NA	51	29	36x51	Front Rear	2 4	18'-6"	NA	81'-0"	-	-	Air Over Hydraulic Expanding Tube-Front Disc-Drive	-	-	NA	Air Over Hydraulic	Automatic or Manual Actuation
8	4	200 Ton	137,492 20'-0"	147,159 20'-0"	NA	239,610	444,990	NA	57	29	40x57	Front Rear	2 4	22'-0"	NA	32'-0"	-	44	Air Over Hydraulic Expanding Tube-Front Disc-Drive	-	-	NA	Air Over Hydraulic	Automatic or Manual Actuation
9	4	210 Ton	143,000	117,000	NA	340,500	339,500	NA	51	26	36x51	Front Rear	4 4	20'-0"	NA	100'-0"	-	-	Air Over Hydraulic Expanding Tube-Front Disc-Drive	-	-	NA	Air Over Hydraulic	Automatic or Manual Actuation
10	4	235 Ton	130,000 15'-5"	247,000 16'-2"	NA	156,000	672,000	NA	51	-	36x51	Front Rear	2 8	27'-11"	NA	97'-3"	115	Rt. 25 Lt. 23	Air Over Hydraulic Disc	2 19" disc on all 8 wheels			Air Over Hydraulic	Automatic or Manual Actuation
[illegible]	4	250 Ton	171,500 26'-0"	176,500 26'-6"	NA	416,500	433,500	NA	51	26	36x51	Front Rear	4 4	25'-0"	NA	140'-0"	-	-	Air Over Hydraulic Internal Expanding Shoe Type	Total = 5,343			Air Over Hydraulic	Automatic or Manual Actuation

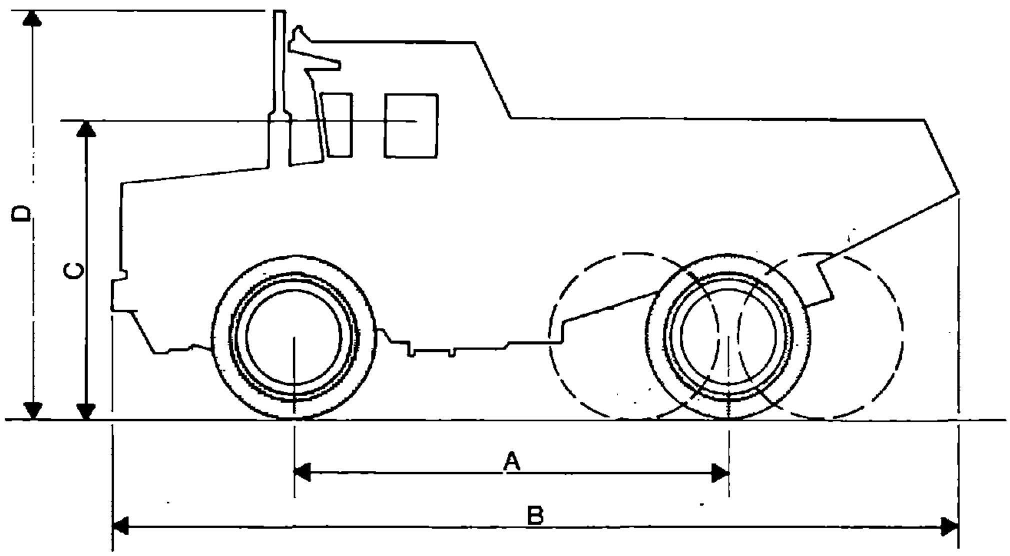
DIMENSIONS			[illegible]	RETARDATION	PERFORMANCE	REDUCTION RATIOS		TORQUE CONVERTER		S.A.E. CONFORMITY			CODE NO.
[illegible]	[illegible]	[illegible]		MAX. GRADE / SPEED / RANGE — EMPTY / LOADED VEHICLE WT.	MAX. GRADE / SPEED / RANGE — EMPTY / LOADED VEHICLE WT.	TRANSMISSION	REAR AXLE TOTAL	RATIO	LOCK OUT	BRAKES	STEERING	CABIN	
40' – 0	[illegible]	21' – 0'	17.0	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	4
40' – 11'	[illegible]	18' – 7"	[illegible]	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	5
35' – 9"	[illegible]	19' – 0"	[illegible]	Dynamic Retardation	NA (Electric Drive	NA	NA	NA	NA	-	-	-	6
33' – 0'	[illegible]	20' – 0"	15.33	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	7
[illegible]	[illegible]	[illegible]	[illegible]	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	J-156	-	-	8
[illegible]	[illegible]	21' – 0'	[illegible]	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	9
[illegible]	[illegible]	[illegible]	[illegible]	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	10
[illegible]	[illegible]	[illegible]	[illegible]	Dynamic Retardation	NA (Electric Drive)	NA	NA	NA	NA	-	-	-	11

CODE NO.	CATEGORY	RATING	WEIGHT OVER AXLE TRACK — EMPTY — FRONT	EMPTY — REAR	EMPTY — TRL	LOADED — FRONT	LOADED — REAR	LOADED — TRL	WHEEL SIZE — DIA	WHEEL SIZE — WIDTH	TIRES — SIZE	TIRES — LOC.	TIRES — NO.	WHEEL BASE — FR AXLE TO DR AXLE	WHEEL BASE — DR AXLE TO TRL AXLE	STEERING — TO WALL	STEERING — TO CLEAR	STEERING — RAD.	BRAKES — SERVICE — TYPE	SERVICE — AREA — FR	AREA — DR	AREA — TRL	BRAKES — EMERGENCY — TYPE	EMERGENCY — OPERATION
1	21	33 Ton	NA	40,720 9'-11"	16,995 9'-1"	NA	59,772	63,903	29	-	30x29	Drive Trail	2 2	NA	21'-9"	-	33'-0"	90	Air Over Hydraulic Internal Expanding Shoe Type	NA	735	73	Air Over Hydraulic	Automatic or Manual Actuation
2	21	33 Ton	NA	37,300 7'-5½"	16,500 9'-1"	NA	56,558	53,232	29 29	- -	30x29 30x29	Drive Trail	2 2	NA	20'-2"	-	32'-0"	90	Air Over Hydraulic Internal Expanding Shoe Type	NA	690	735	Air Over Hydraulic	Automatic or Manual Actuation
3	21	40 Ton	NA	44,973 7'-10"	19,127 9'-6"	NA	70,745	73,355	25	-	30x25	Drive Trail	2 2	NA	21'-10"	-	35'-0"	90	Air Over Hydraulic Internal Expanding Shoe Type	Total = 1873			Air Over Hydraulic	Automatic or Manual Actuation
4	21	40 Ton	31,094	25,667	23,690	38,361	47,192	75,827	29 29 35	- - -	30x29 30x29 33x35	Front Drive Trail	- - -	12'-1"	15'-6"	-	-	-	Air Over Hydraulic Internal Expanding Shoe Type	-	-	-	Air Over Hydraulic	Automatic or Manual Actuation
1	31	63 Ton	26,900 10'-1"	32,157 9'-1"	24,453 10'-4"	26,352	83,492	109,066	33 33 39	- - -	19x33 16x33 35x39	Front Drive Trail	2 4 2	11'-10"	29'-10"	-	63'-5"	-	Air Over Hydraulic Expanding Type-Front Disc-Drive	496	7663	1151	Air Over Hydraulic	Automatic or Manual Actuation
2	31	63 Ton	17,030 7'-8¼"	34,340 9'-2"	30,175 9'-1 3/4	22,330	55,440	99,775	25 25 33 40 33 49	- - - - - -	16x25 16x25 36x33 18x49 36x33 18x49	Front Drive Trail	2 2/4 2/4	11'-8"	33'-10"	57'-0"	-	-	Air Over Hydraulic Internal Expanding Shoe Type	Total = 2408			Air Over Hydraulic	Automatic or Manual Actuation
3	31	70 Ton	17,030 7'-8¼"	34,740 9'-2"	31,400 9'-1 3/4"	22,430	90,940	109,800	25 25 33 49 33 49	- - - - - -	16x25 16x25 38x33 18x49 38x33 18x49	Front Drive Trail	2 2/4 2/4	11'-8"	33'-10"	57'-0"	-	-	Air Over Hydraulic Internal Expanding Shoe Type	Total = 2498			Air Over Hydraulic	Automatic or Manual Actuation
4	31	72 Ton	25,512 9'-11"	24,323 9'-3"	24,510 10'-4"	36,150	72,456	110,034	33 33 39	13 13 -	18x33 18x33 35x39	Front Drive Trail	- - 2	10'-10"	29'-0"	-	63'-5"	42	Air Over Hydraulic Wedge Actuated, Shoe Type	Total = 2443			Air Over Hydraulic	Automatic or Manual Actuation
5	31	100 Ton	22,000 9'-4"	34,000 9'-4"	42,000 13'-0"	22,000	132,000	154,000	49 49 49	- - -	- - 24x49	Front Drive Trail	2 4 2	12'-4"	34'-3"	-	48'-0"	-	Air Over Hydraulic Cam Type Expanding Shoe	Total = 1305.8			Air Over Hydraulic	Automatic or Manual Actuation
6	31	100 Ton	36,925 10'-4"	47,693 9'-0"	41,507 12'-5"	48,162	134,246	134,857	35 35 49	- - -	21x35 21x35 21x49	Front Drive Trail	2 4 4	13'-0"	34'-10"	-	-	-	Air Over Hydraulic Expanding Type-Front Disc-Drive	626	1040	1141	Air Over Hydraulic	Automatic or Manual Actuation
7	31	100 Ton	14,210 9'-7½"	26,150 9'-7½"	42,452 16'-0"	44,043	81,807	156,000	35 25 49	- - -	18x25 18x25 21x49	Front Drive Trail	4 4 4	11'-8"	34'-0"	-	-	-	Air Over Hydraulic Wedge Actuated, Shoe Type	[illegible]	[illegible]	1151	Air Over Hydraulic	Automatic or Manual Actuation

DIMENSIONS			[illegible]	RETARDATION — MAX. GRADE & SPEED / RANGE — EMPTY						GROSS VEHICLE WGT.						PERFORMANCE — MAX. G.A. — EMPTY						GROSS VEHICLE WGT.						REDUCTION RATIOS — TRANSMISSION						REAR AXLE TOTAL	TORQUE CONVERTER — RATIO	TORQUE CONVERTER — LOCK-OUT	S.A.E. CONFORMITY — ROPS	S.A.E. CONFORMITY — STEERING	S.A.E. CONFORMITY — CABIN	CODE NO.
							1						1	1					4			1								3										
33'-5"	[illegible]	[illegible]	6.7	-	-	-	-	-	-	-	-	-	-	-	-	10% 7 mph	[illegible] 9 mph	1[illegible]% 15 mph	12% 17 mph	16% 23 mph	[illegible] 32 mph	14% 7 mph	10% 9 mph	7% 13 mph	5.5% 17 mph	4% 23 mph	3% 32 mph	-	-	-	-	-	-	-	-	Ranges 3 thru 8	-	-	-	1
32'-1"	[illegible]	[illegible]	9.20	-	-	-	-	-	-	-	-	-	-	-	-		23% 6 mph	17% 9 mph	12% 13 mph	[illegible]% 16 mph	5% 25.5 mph		11% 6 mph	8% 9 mph	5.5% 13 mph	4% 16 mph	2.5% 25.5 mph	4.00	2.83	2.00	1.41	1.00	.71	16.32	-	Top 3 ranges	-	-	-	2
35'-11"	10'-6"	12'-10"	9.25	-	-	-	-	-	-	-	-	-	-	-	-	30% 5 mph	24% 7 mph	18% 10 mph	13% 13 mph	10% 17 mph	7% 23 mph	14% 5 mph	10% 7 mph	8% 10 mph	6% 13 mph	5% 17 mph	3.5% 23 mph	-	-	-	-	-	-	-	-	Ranges 3 thru 8	-	-	-	3
36'-10"	-	12'-10"	10.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
53'-2"	13'-[illegible]	13'-0	10.33	-	-	-	-	-	-	-	-	-	-	-	-	30% 4 mph	15% 8 mph	5% 21 mph				13% 4 mph	5% 8 mph	2% 21 mph				-	-	-	-	-	-	-	-	Ranges 1 thru 3	-	-	-	1
[illegible]	[illegible]	[illegible]	9.0	25% 7 mph	28% 10 mph	20% 14 mph	14% 20 mph	10% 28.5 mph	7% 40 mph	17% 7 mph	11% 10 mph	8.5% 14 mph	6% 20 mph	4% 28.5 mph	3% 40 mph	25% 5 mph	19% 7.5 mph	15% 12 mph	9% 15 mph	7% 20 mph	4% 30 mph	11.5% 5 mph	9% 7.5 mph	6% 12 mph	4% 15 mph	3% 20 mph	2% 30 mph	4.00	2.56	2.01	1.35	1.00	.67	21.63	-	Automatic All Ranges	J-166	-	-	2
[illegible]	[illegible]	[illegible]	9.0	25% 7 mph	25% 10 mph	20% 14 mph	14% 20 mph	10% 28.5 mph	7% 40 mph	15% 7 mph	10.5% 10 mph	9% 14 mph	6% 20 mph	4% 28.5 mph	2.5% 40 mph	25% 5 mph	19% 7.5 mph	15% 12 mph	9% 15 mph	7% 20 mph	4% 30 mph	11% 5 mph	7.5% 7.5 mph	5.5% 12 mph	4% 15 mph	3% 20 mph	2% 30 mph	4.00	2.56	2.01	1.35	1.00	.67	21.63	-	Automatic All Ranges	J-166	-	-	3
53'-9"	13'-5	13'-0"	11.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
52'-10"	[illegible]	13'-2"	9.35	30% 10 mph	22% 13 mph	15% 17 mph	10% 24 mph	8% 32 mph	7% 43 mph	11% 10 mph	6 13 mph	6% 17 mph	4% 24 mph	3% 32 mph	2% 43 mph	30% 7 mph	15% 9 mph	11% 12 mph	8% 17 mph	6% 23 mph	4% 30 mph	7% 7 mph	5% 9 mph	4% 12 mph	3% 17 mph	2% 23 mph	2% 30 mph	-	-	-	-	-	-	-	-	-	-	-	-	5
61'-[illegible]	15'-[illegible]	13'-3	11.25	-	-	-	-	-	-	-	-	-	-	-	-	30% 3 mph	15% 8 mph	6% 19 mph				13% 3 mph	6% 8 mph	2% 19 mph				-	-	-	-	-	-	-	-	Ranges 1 Thru 3	-	-	-	6
52'-[illegible]	15'-[illegible]	13'-3	9.0	14% 6 mph	14% 10.5 mph	14% 13.5 mph	10% 21 mph	8% 29.3 mph		13% 6 mph	[illegible] 10.5 mph	9% 13.5 mph	4% 21 mph	3% 29.3 mph		14% 4 mph	14% 6 mph	13% 8 mph	9% 13 mph	6% 19 mph		11% 4 mph	7% 6 mph	5% 8 mph	3% 13 mph	2% 19 mph		-	-	-	-	-	-	-	-	Ranges 1 thru 5	-	-	J-052b J-386	

CODE NO.	CATEGORY	RATING	WEIGHT OVER AXLE TRACK						WHEEL SIZE		TIRES			WHEEL BASE		STEERING			BRAKES					
			EMPTY			LOADED													SERVICE				EMERGENCY	
			AXLE																	AREA				
			FRONT	REAR	TRL	FRONT	REAR	TRL	DIA	WIDTH	SIZE	POS.	NO.	FR. AXLE TO DR. AXLE	DR. AXLE TO TR. AXLE	[illegible]	[illegible]	RATIO	TYPE	FR	DR	TR	TYPE	FUNCTION
8	31	100 Ton	52,930 9' - 7½"	28,318 9' - 7½"	45,416 12' - 5"	62,647	85,259	165,749	25 25 49	- - -	18x25 18x25 21x49	Front Drive Trail	4 4 4	11' - 8"	39' - 0"	-	-	-	Air Over Hydraulic Wedge Actuated, Shoe Type	556	556	1151	Air Over Hydraulic	Automatic or Manual Actuated
9	31	100 Ton	36,971 11' - 4"	39,334 9' - 3"	44,850 12' - 5"	50,197	110,422	157,241	35 35 49	- - -	21x35 21x35 21x49	Front Drive Trail	- - 4	12' - 7"	33' - 9"	-	-	-	Air Over Hydraulic Wedge Actuated, Shoe Type	Total = 3111			Air Over Hydraulic	Automatic or Manual Actuated
10	31	100 Ton	57,300 10' - 4"	52,500 9' - 0"	48,100 9' - 11"	49,500	104,800	153,000	35 35 49	- - -	24x35 24x35 24x49	Front Drive Trail	2 4 4	-	56' - 6"	67' - 2"	72' - 6"	51	Air Over Hydraulic Expanding Tube-Front Disc-Drive	456	5340	1105	Air Over Hydraulic	Automatic or Manual Actuated
11	31	100/110 Ton	23,100 5' - 10½"	49,100 5' - 6"	42,700 11' - 0"	30,500	129,600	150,700	25 49 49	- - -	16x25 21x49 21x49	Front Drive Trail	2 4 4	12' - 2"	40' - 1"	61' - 0"	-	-	Air Over Hydraulic Internal Expanding Shoe Type	Total = 3160			Air Over Hydraulic	Automatic or Manual Actuated
12	31	100/120 Ton	37,340 10' - 3½"	55,315 9' - 4"	35,620 11' - 1½"	46,240	114,515	140,420	33 35 43 43 49 49	- - - - - -	16x33 21x35 21x49 24x49 21x49 24x49	Front Drive Trail	2 4 4	15' - 10"	34' - 4½"	62' - 6"	-	-	Air Over Hydraulic Wedge Actuated, Shoe Type	Total = 3170			Air Over Hydraulic	Automatic or Manual Actuated
13	31	120 Ton	35,330 10' - 11"	48,270 8' - 11"	40,000 10' - 6"	53,500	146,700	170,000	35 35 35	- - -	24x35 24x35 24x35	Front Drive Trail	2 4 4	13' - 9"	34' - 3"	-	-	-	Air Over Hydraulic Wedge Actuated, Shoe Type	544	1093	1098	Air Over Hydraulic	Automatic or Manual Actuated
14	31	120 Ton	41,600 12' - 0"	46,500 10' - 10"	40,700 9' - 8"	56,400	135,300	175,100	35 35 43	17 17 17	24x35 24x35 24x49	Front Drive Trail	2 4 4	13' - 4"	35' - 4"	90' - 0"	-	45	Air Over Hydraulic Wedge Actuated, Shoe Type	Total = 2555			Air Over Hydraulic	Automatic or Manual Actuated
15	31	120 Ton	42,640 12' - 0"	48,450 [illegible]	63,340 15' - 0"	64,956	126,756	202,720	35 35 49	17 17 17	24x35 24x35 24x4[illegible]	Front Drive Trail	2 4 4	13' - 4"	35' - 6"	99' - 0"	-	33	Air Over Hydraulic Wedge Actuated, Shoe Type	Total = 3690			Air Over Hydraulic	Automatic or Manual Actuated
1	41	150 Ton	59,850	72,225	42,525	80,375	136,850	201,675	43 43 43	17 17 17	27x43 27x43 27x43	Front Drive Trail	2 4 4	14' - 7"	40' - 6"	60' - 0"	-	-	Air Over Hydraulic Wedge Actuated, Shoe Type	-	-	-	Air Over Hydraulic	Automatic or Manual Actuated
2	41	150 Ton	61,600	52,400	71,000	93,505	218,175	213,260	43 49 49	19.5 19.5 19.5	27x49 27x49 27x49	Front Drive Trail	2 4 4	15' - 10"	45' - 3"	-	31' - 0"	40	Air Over Hydraulic Internal Expanding Shoe Type	1150	2284	4264	Air Over Hydraulic	Automatic or Manual Actuated
3	41	180 Ton	67,600	90,440	74,000	70,500	246,240	296,700	51 51 51	22 22 22	30x[illegible] 30x[illegible] 30x[illegible]	Front Drive Trail	2 4 4	15' - 0"	45' - 0"	70' - 0"	-	-	Air Over Hydraulic Drum or Front-Trail Disc-Drive	-	-	-	Air Over Hydraulic	Automatic or Manual Actuated

Dimensions: Length	Dimensions: Width	Dimensions: Height	Capacity [illegible]	Retardation (Max Grade & Speed Range) Empty 1	Ret. Empty 2	Ret. Empty 3	Ret. Empty 4	Ret. Empty 5	Ret. Empty 6	Ret. Gross Vehicle Wt 1	Ret. Gross 2	Ret. Gross 3	Ret. Gross 4	Ret. Gross 5	Ret. Gross 6	Performance (Max Grade & Speed Range) Empty 1	Perf. Empty 2	Perf. Empty 3	Perf. Empty 4	Perf. Empty 5	Perf. Empty 6	Perf. Gross Vehicle Wt 1	Perf. Gross 2	Perf. Gross 3	Perf. Gross 4	Perf. Gross 5	Perf. Gross 6	Reduction Ratios: Transmission 1	Trans. 2	Trans. 3	Trans. 4	Trans. 5	Trans. 6	Gear Axle Total	Torque Converter: Lag	Torque Converter: Lock Out	S.A.E. Conformity: Brakes	S.A.E.: Steering	S.A.E.: Cabin	Code No.
64'-6"	13'-6"	13'-7"	9.0	14% 6 mph	14% 9.5 mph	14% 13.5 mph	10% 21 mph	6% 29.5 mph		10% 6 mph	8% 9.5 mph	6% 13.5 mph	4% 21 mph	3% 29.5 mph		14% 4 mph	14% 6 mph	12% 8 mph	9% 13 mph	6% 19 mph		11% 4 mph	7% 6 mph	5% 9 mph	3% 13 mph	2% 19 mph		-	-	-	-	-	-	-	-	Ranges 1 thru 5	-	-	J-952b J-386	5
60'-2"	16'-6"	13'-2"	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
55'-7"	15'-0"	14'-0"	11.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.48	-	-	-	-	-	10
63'-10"	15'-2"	12'-5"	9.25	25% 7 mph	22% 11 mph	17% 14 mph	11% 21 mph	9% 23.5 mph	4.5% 42.5 mph	12% 7 mph	8% 11 mph	6% 14 mph	4% 21 mph	3% 28.5 mph	2% 42.5 mph	25% 6 mph	16% 8.5 mph	14% 11.5 mph	9% 17 mph	7% 23 mph	5% 34 mph	10% 6 mph	7% 8.5 mph	5% 11.5 mph	3% 17 mph	3.5% 23 mph	1.75 34 mph	4.00	2.58	2.01	1.35	1.00	.87	21.63	-	Automatic All Ranges	J-166	-	-	11
68'-3"	15'-6" 16'-2"	14'-1" 15'-8½"	11.0	25% 6 mph	23% 13 mph	15% 19 mph	11% 26 mph	8% 33 mph		20% 6 mph	9% 13 mph	6% 19 mph	4.5% 26 mph	3% 33 mph			14% 10 mph	10% 14 mph	7% 20 mph	5% 28 mph			5.5% 10 mph	4% 14 mph	3% 20 mph	2% 25 mph		4.24	2.34	1.70	1.31	1.00	.73	21.63	-	Automatic All Ranges	-	-	-	12
59'-8"	14'-0"	13'-0"	11.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.24	2.34	1.70	1.31	1.00	.73	20.40	-	-	-	-	-	13
65'-2"	15'-11"	14'-11"	11.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.24	2.34	1.70	1.31	1.00	.73	16.52	-	-	-	-	-	14
65'-5"	20'-5"	14'-5½"	11.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.24	2.34	1.70	1.31	1.00	.73	16.52	-	-	-	-	-	15
74'-7"	15'-8"	13'-10"	11.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.32	-	-	-	-	-	1
78'-1"	15'-8"	15'-11"	13.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24.42	-	-	-	-	-	2
78'-2¾"	20'-6"	17'-10"	14.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	NA	NA	NA	-	-	-	3



		Minimum	Maximum	Average
A	Wheel Base	11' - 0"	13' - 9"	12' - 6"
B	Length	20' - 10"	25' - 7"	24' - 2"
C	Operator's Height above Ground	7.5'	9.25'	8.75'
D	Height of Vehicle (Empty)	10' - 7"	12' - 4"	11' - 6"
	Width of Vehicle	8' - 6½"	11' - 5"	10' - 7"
	Wheel Track-Front	7' - 1"	8' - 8"	7' - 6"
	Wheel Track-Rear	6' - 0"	8' - 0"	7' - 0"
	Vehicle Weight (lbs.)	24,200	42,300	33,845
	Gross Vehicle Weight (lbs.)	50,200	92,300	73,445
	Service Brake Area (in^2)	645	1,072	882
	Gross Engine Horsepower	160	318	223
	Turning Circle Clearance	50' - 0"	64' - 2½"	57' - 4"

Standard transmission ratios within this category	Range					
	1	6.37	3.80	7.12	5.45	4.00
	2	3.40	1.94	4.09	3.13	2.82
	3	1.74	1.00	2.29	1.76	2.00
	4	1.00	.72	1.31	1.00	1.41
	5	0.79		1.02	.78	1.00
	6					.71

REAR DUMP OFF-HIGHWAY TRUCKS TO 100,000 Lbs. GWV (8 VEHICLES)

Figure B

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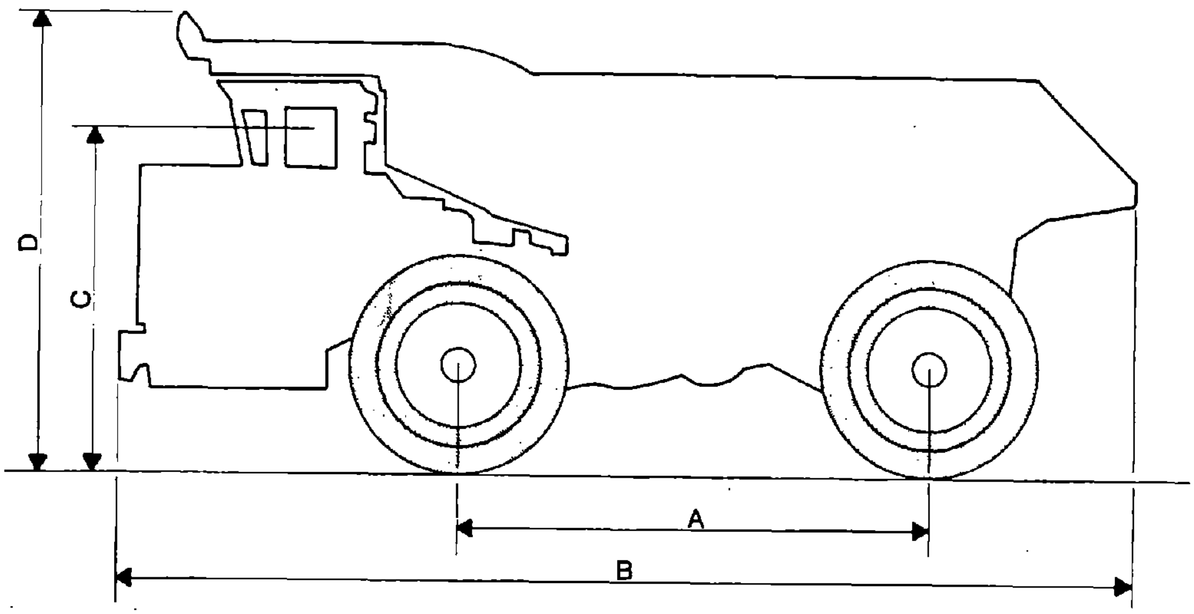


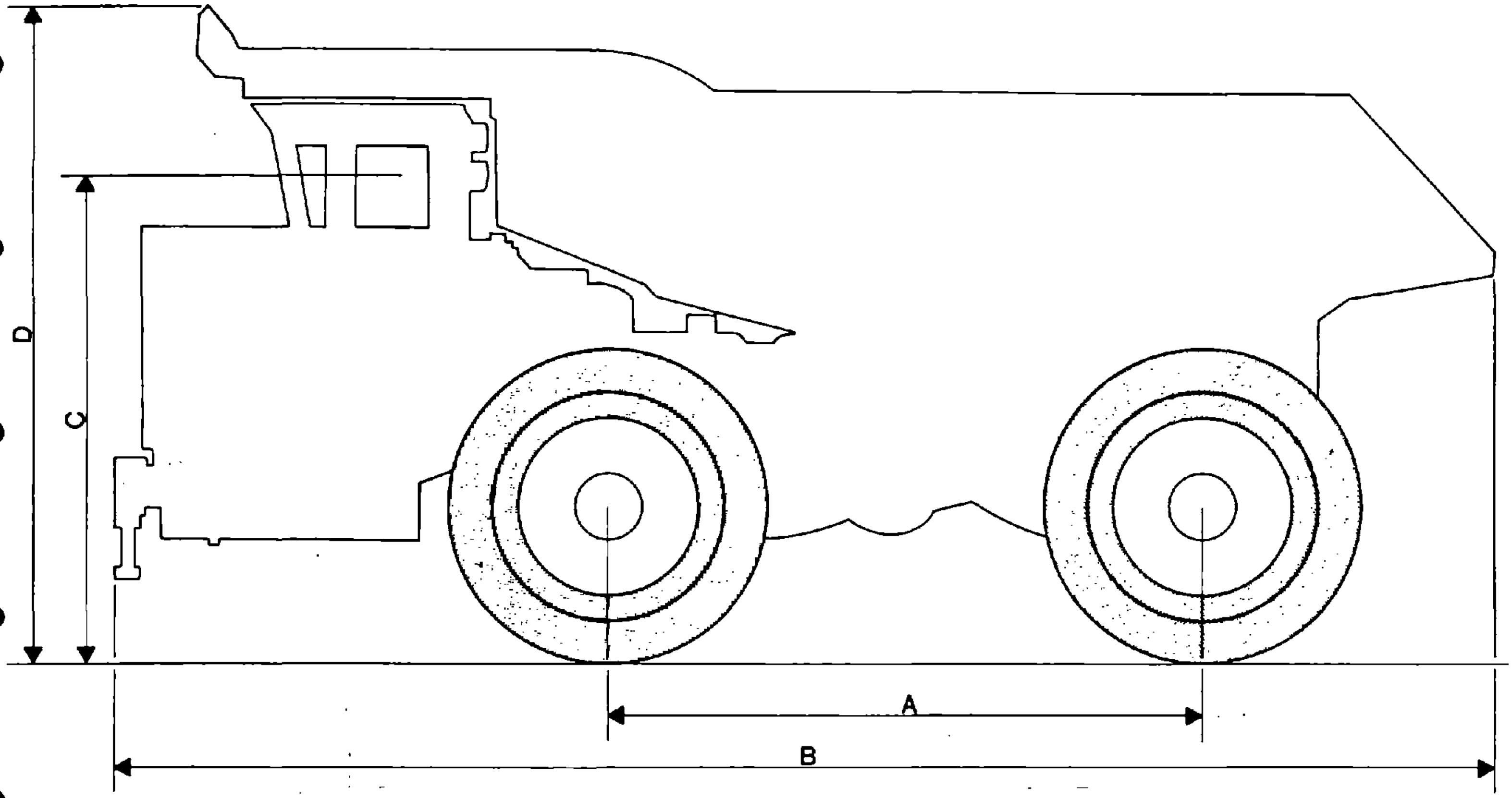
		Minimum	Maximum	Average
A	Wheel Base	10' - 10"	18' - 2"	13' - 7"
B	Length	25' - 2"	34' - 3"	28' - 5"
C	Operators Height above Ground	8.5'	11.75'	10.25'
D	Height of Vehicle (Empty)	11' - 0"	14' - 5½"	12' - 9"
	Width of Vehicle	9' - 11"	13' - 10"	12' - 4"
	Wheel Track-Front	7' - 7"	11' - 4"	9' - 7"
	Wheel Track-Rear	7' - 2"	9' - 8"	8' - 8"
	Vehicle Weight (lbs.)	48,900	82,000	64,816
	Gross Vehicle Weight (lbs.)	104,900	182,000	147,910
	Service Brake Area (in^2)	968	1,960	1,440
	Gross Engine Horsepower	350	635	472
	Turning Circle Clearance	56' - 0"	78' - 5"	68' - 1"

Standard transmission ratios within this category

Range			
1	3.59	4.0	3.43
2	2.44	2.68	2.17
3	1.73	2.01	1.53
4	1.19	1.35	1.00
5	.81	1.00	.703
6	.575	.67	

REAR DUMP OFF-HIGHWAY TRUCKS - 100,000 TO 200,000 Lbs. GVW (18 VEHICLES)

Figure C



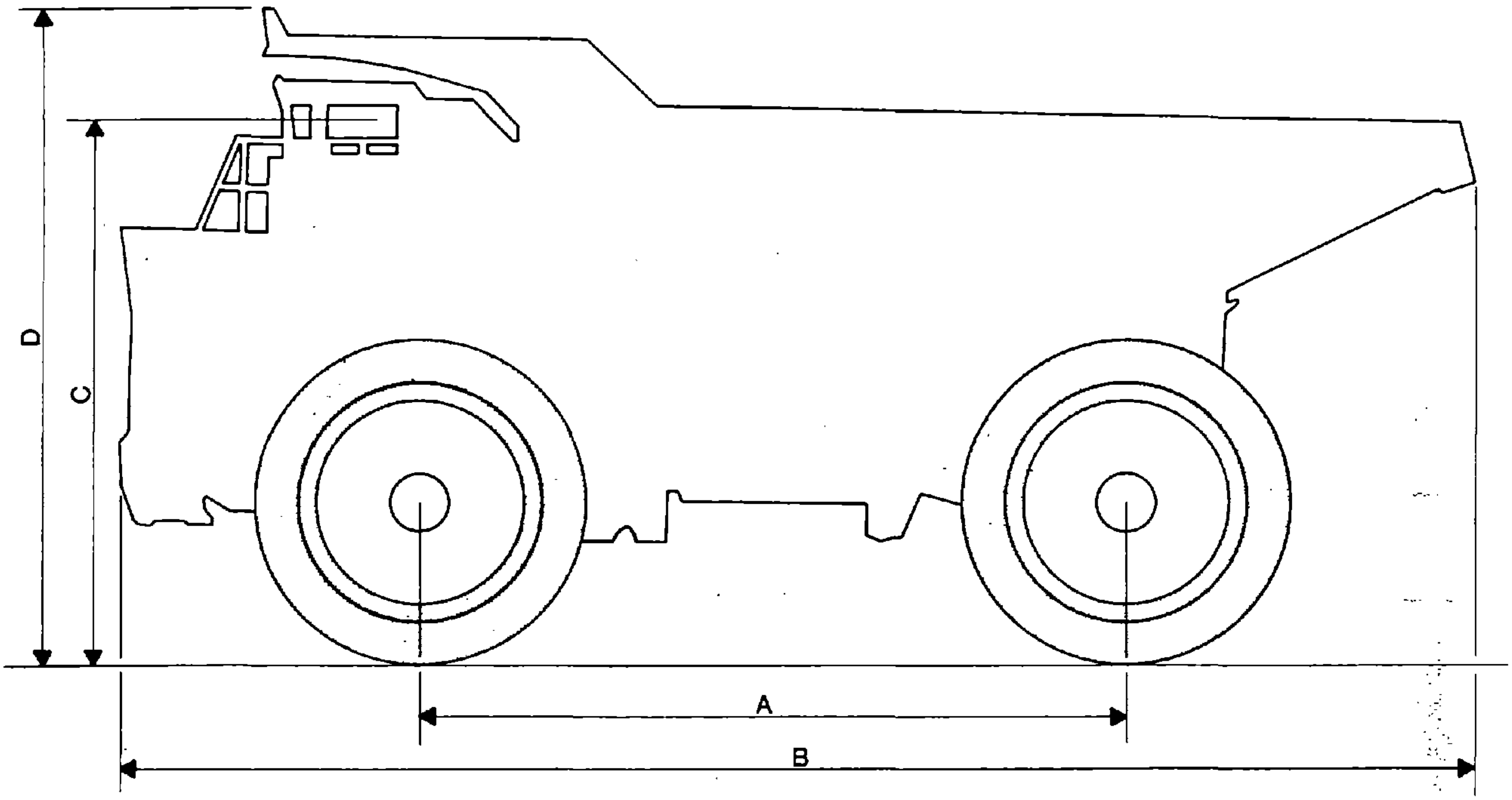
		Minimum	Maximum	Average
A	Wheel Base	13' - 4"	17' - 0"	14' - 11"
B	Length	30' - 0"	35' - 11"	32' - 7"
C	Operators Height above Ground	11.0'	15.0'	13.0'
D	Height of Vehicle (Empty)	13' - 7"	17' - 9"	15' - 10"
	Width of Vehicle	13' - 2"	18' - 9"	15' - 0"
	Wheel Track - Front	9' - 3"	14' - 9"	11' - 9"
	Wheel Track - Rear	9' - 3"	15' - 1"	11' - 10"
	Vehicle Weight (lbs.)	90,350	153,689	116,058
	Gross Vehicle Weight (lbs.)	203,200	393,689	288,916
	Service Brake Area (in^2)	1375	2750	1982
	Gross Engine Horsepower	665	1200	905
	Turning Circle Clearance	60' - 0"	83' - 9"	64' - 10"

Standard transmission ratios within this category

Range	
1	4.24
2	2.34
3	1.70
4	1.31
5	1.00
6	.73

REAR DUMP OFF-HIGHWAY TRUCKS 200,000 TO 400,000 Lbs. GVW (13 VEHICLES)

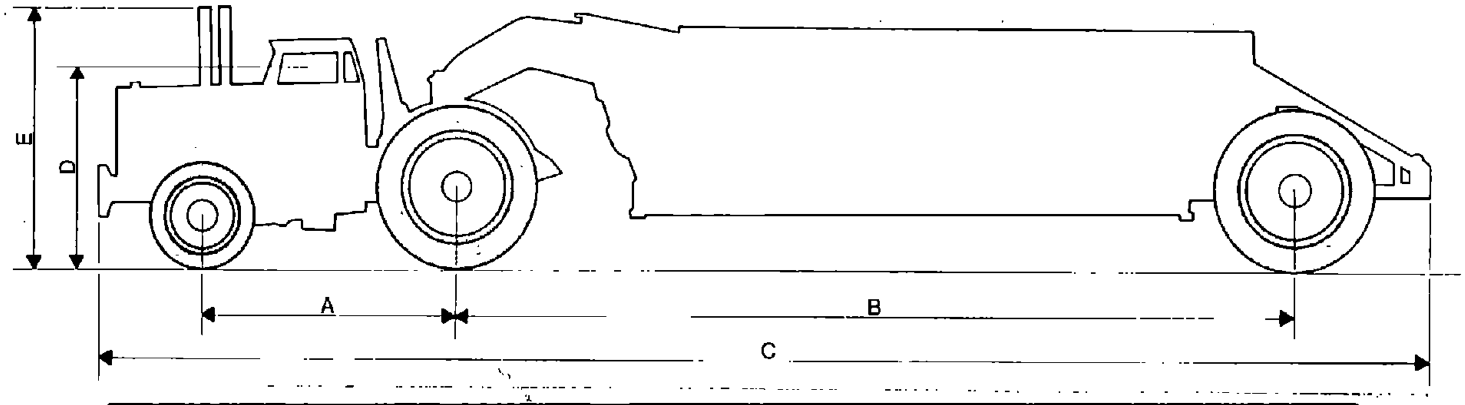
Figure D



		Minimum	Maximum	Average
A	Wheel Base	16' - 10"	22' - 0"	19' - 9"
B	Length	34' - 9"	52' - 6"	40' - 8"
C	Operator's Height Above Ground	13.7'	17.0'	15.7'
D	Height of Vehicle (Empty)	16' - 8"	22' - 7"	18' - 11"
	Width of Vehicle	18' - 6"	28' - 0"	22' - 6"
	Wheel Track - Front	14' - 9"	26' - 6"	17' - 9"
	Wheel Track - Rear	13' - 0"	26' - 6"	16' - 4"
	Vehicle Weight (lbs.)	156,061	370,000	240,608
	Gross Vehicle Weight (lbs.)	413,735	850,000	596,064
	Service Brake Area (in^2) *			
	Gross Engine Horsepower	1050	3000	1704
	Turning Circle Clearance	81' - 0"	140'- 0"	93' - 5"

All vehicles in this category are electric drives
*Sufficient service brake area data was not available

REAR DUMP OFF-HIGHWAY TRUCKS OVER 400,000 Lbs. GVW (11 VEHICLES) Figure E

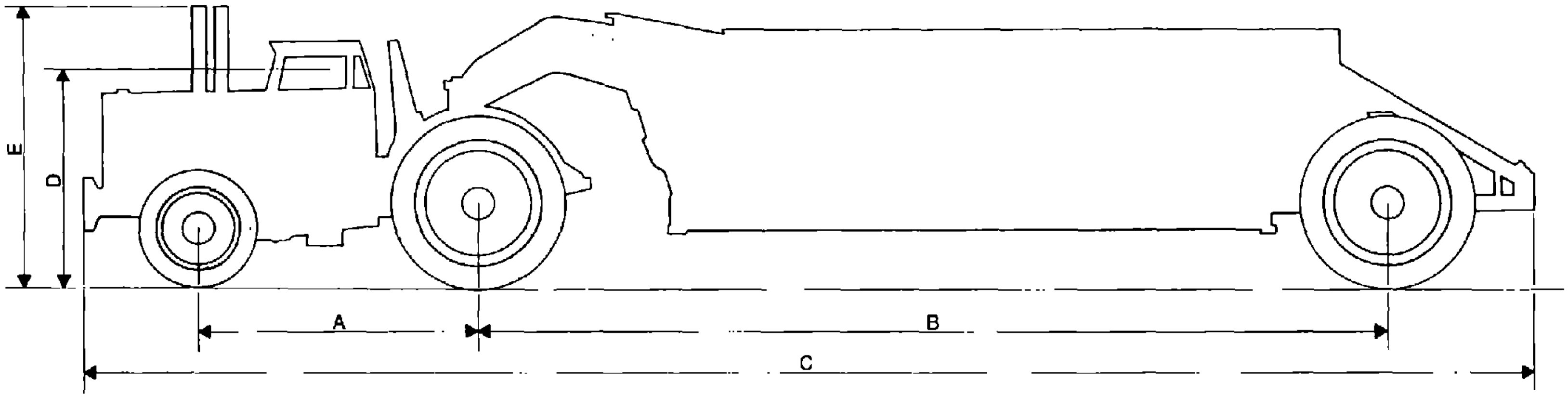


		Minimum	Maximum	Average
A	Wheel Base - Front wheel to drive wheel	10' - 4"	12' - 1"	11' - 2"
B	Wheel Base - Drive wheel to trailer wheel	21' - 3"	29' - 0"	25' - 8"
C	Length	42' - 5"	46' - 9"	44' - 6"
D	Operator's Height above Ground	8.5'	11.0'	9.5'
E	Height of Vehicle (Empty)	10' - 0"	11' - 4½"	10' - 10"
	Width of Vehicle	10' - 5"	12' - 1"	11' - 5"
	Wheel Track - Front	8' - 9"	8' - 9"	8' - 9"
	Wheel Track - Drive	6' - 10"	7' - 10"	7' - 6"
	Wheel Track - Trailer	7' - 9"	9' - 7"	8' - 10"
	Vehicle Weight (lbs.)	47,300	79,200	61,001
	Gross Vehicle Weight (lbs.)	107,300	161,200	133,501
	Service Brake Area (in^2) *			
	Gross Engine Horsepower	318	525	408
	Turning Circle Clearance	37' - 0"	50' - 0"	42' - 4"

* Reliable service brake and transmission data was not available.

BOTTOM DUMP OFF-HIGHWAY TRUCKS - 100,000 TO 200,000 Lbs. GVW (4 VEHICLES)

Figure F



		Minimum	Maximum	Average
A	Wheel Base - Front axle to drive axle	10' - 10"	15' - 10"	12' - 7"
B	Wheel Base - Drive axle to trailer axle	29' - 0"	40' - 1"	34' - 10"
C	Length	53' - 2"	66' - 3"	60' - 11"
D	Operator's Height above Ground	9.0'	11.25'	10.1"
E	Height of Vehicle (Empty)	11' - 1"	15' - 8½"	13' - 4"
	Width of Vehicle	12' - 7½"	20' - 5"	15' - 5"
	Wheel Track - Front	7' - 8½"	12' - 0"	9' - 11"
	Wheel Track - Drive	8' - 1"	15' - 11"	9' - 5"
	Wheel Track - Trailer	9' - 1 3/4"	15' - 0"	11' - 3"
	Vehicle Weight (lbs.)	74,650	154,440	113,970
	Gross Vehicle Weight (lbs.)	207,545	393,440	303,502
	Service Brake Area (in^2)	2160	3170	2547
	Gross Engine Horsepower	450	800	604
	Turning Circle Clearance *			

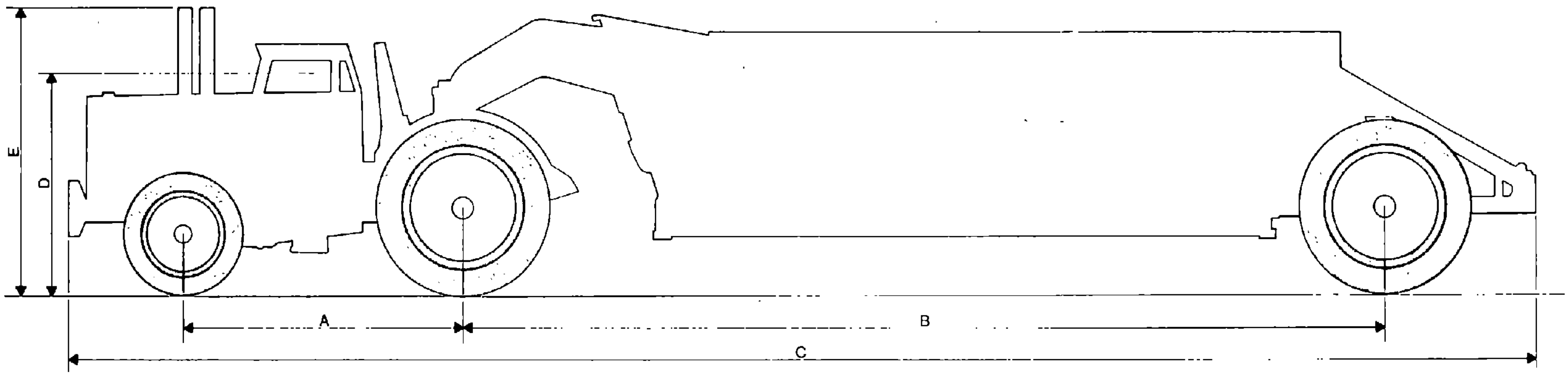
Standard transmission ratios within this category

Range	
1	4.24
2	2.34
3	1.70
4	1.31
5	1.00
6	.73

* Reliable turning circle clearance data was not available.

BOTTOM DUMP OFF-HIGHWAY TRUCKS - 200,000 TO 400,000 Lbs. GVW (19 VEHICLES)

Figure G



		Minimum	Maximum	Average
A	Wheel Base – Front wheel to drive wheel	14' – 7"	15' – 10"	15' – 2"
B	Wheel Base – Drive wheel to trailer wheel	40' – 8"	45' – 3"	43' – 8"
C	Length	74' – 7"	78' – 3"	76' – 11"
D	Operator's Height above Ground	11.0'	14.0'	12.7'
E	Height of Vehicle (Empty)	13' – 10"	17' – 10"	15' – 10"
	Width of Vehicle	16' – 8"	20' – 6"	17' – 9"
	Wheel Track – Front*			
	Wheel Track – Drive*			
	Wheel Track – Trailer*			
	Vehicle Weight (lbs.)	175,000	232,300	209,433
	Gross Vehicle Weight (lbs.)	478,900	596,200	532,033
	Service Brake Area (in^2)*			
	Gross Engine Horsepower*			
	Turning Circle Clearance*			

Transmission Data not available

* Sufficient data not available

BOTTOM DUMP OFF-HIGHWAY TRUCKS - GREATER THAN 400,000 Lbs. (3 VEHICLES)

Figure H

Task 4 - Field Investigation

In order to gain additional insight into specific haulage road difficulties, several field investigations at active mines were conducted. The specific mines that were visited represented various types of surface mining operations in areas of differing geology, geography, and climate. Some site visitations were made for the dual purpose of supplying information for this and other projects simultaneously.

Factors that were considered in selecting mines to be visited (in descending order of importance) were:

1) Mining operations where investigation work on haulage equipment and/or haul road design has been accomplished. In this category the mining company tested or explored various solutions to equipment or road problems before selecting the best method. Ongoing company research oriented toward these problems is also practiced by these companies.

2) Mining operations containing unusual haul road problems that required corrective measures to overcome the problem with standard techniques.

3) Mining operations containing haul road problems remaining to be solved.

Characteristics of each site visited are described in the following section.

Mine A is located in the northwestern section of the United States. Gently rolling hills cover the area being mined. The vegetation is characterized by commercial grade timber on the ridges with grassy fields covering the valley floors. Bituminous grade coal is surface mined at this operation. The temperature ranges from 20°F to 90°F with an annual precipitation rate of 70 inches.

The relatively high rate of precipitation combined with marshy valley floors create a special haul road maintenance problem. Haul road bed stability is obtained by building a four foot sub-base with overburden material secured from the mining operation. Road surfaces are covered with gravel obtained from a pit adjacent to the coal mine operation.

Mine A has an average coal production rate of 400,000 tons per month. The complex geology of the area necessitates a pre-mine analysis of each pit to determine the optimum mining method. Major mining equipment includes a Bucket Wheel Excavator and Conveyor System used in a ridge-top removal/valley-fill operation; drag lines and shovels used in a modified box-cut operation; trucks, front-end loaders, and shovels used in a haul-back operation.

Total haulage fleet is twenty-seven (27) 85 ton four wheel drive vehicles. Twenty of these vehicles are kept running during a three-shift, five day week operation.

Haulage cycles include one to three mile runs from pit to preparation plant with coal. Overburden transport is several hundred yards from pit to areas of reclamation. All haulage is accomplished on private roads built and maintained by the mining company. A maximum grade of 12% exists for short hauls out of the pit; however, average grades are held to less than 7%. Six inch crowns are designed in the 80' wide haulage roads with superelevation up to 6' on 90° curves. Roads are widened at curves by 20' as a safety precaution.

Berms are applied only when required by a governmental regulating agency. Berm height is designed to the wheel radius of major haulage equipment.

Maximum speed allowed by the company is 30 miles per hour during good driving conditions. Several haulage equipment accidents have occurred during the past five years when operators lost control of vehicles; however, there were no fatalities. Records do not show a detailed explanation for the cause of the accidents. Reflectors mark the haulage roads; flame pots are added during foggy nights.

Maintenance programs for haul vehicles include a 100 operating hour check list and a 30 day check list. During the latter the vehicle is pulled from the active fleet for 24 hours.

The company's driver training program includes 4 hours of formal classroom training. New drivers must accompany, and then be accompanied by, experienced drivers for a one week minimum period.

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Mine B is located in the western section of the United States. Steep hills cover the area being mined. Vegetation is sparse with little or no trees and marginal grass cover. Copper ore is pit mined at this operation. Temperature ranges from -20°F to 110°F with an annual precipitation rate of 14 inches.

The extremely low winter temperatures create a special haul road maintenance problem. Special care must be taken to maintain sound surface conditions when ground frost occurs in order to prevent bad winter surfaces. Spring thaw also hampers operating efficiencies as vehicle traction and control are greatly reduced.

Mine B handles 1.25 million tons of ore per month. Major mining equipment includes 11 power shovels, 1 drag line, 12 front-end loaders, 29 dozers, 10 road graders, and 2 scrapers.

Total haulage fleet includes one hundred fifteen (115) 100 ton, and eleven (11) 150 ton, rear dump trucks. Seventy trucks are kept running during a three-shift, seven-day week operation.

Ore, leach, and waste material from the pit is hauled an average distance of 3.2 miles or 6.4 miles per cycle. All haulage is over private roads built and maintained by the mining company. A maximum grade of 7% was established due to horsepower restrictions on older vehicles. Currently an engineering analysis is being made to consider 8, 9, and 10%

grades on future road construction. The study will include factors such as tire wear, motor wear, cycle time, and fuel cost.

Berms are used throughout the entire pit operation. Berm height is 8 to 10' with a base width of 15'. The 90' wide roads do not have crowns or superelevation.

Maximum speed is 12 mph out of the pit, loaded, and 30 mph, unloaded, on the empty return downgrade. Several fatalities have occurred in past years when small support vehicles were run over by haul trucks. Blind areas in the field of vision were listed as the cause of the accidents. Several non-fatal accidents have occurred with haul trucks when operators fell asleep. In addition, berms have successfully stopped several runaway trucks and avoided serious accidents.*

Maintenance programs for haul vehicles include a 150 operating-hour inspection. The vehicle is pulled out of the active fleet if the inspection reveals a problem.

New drivers must accompany, and then be accompanied by, experienced drivers for a one week period.

*An escape lane was designed and constructed for a haul road at a supplemental operation located adjacent to the major pit. This small operation is no longer active; however, records show the escape lane was utilized on at least one occasion when a haulage vehicle lost power in a downhill loaded run.

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Mine C is located in the western section of the country. The area being mined is flat or slightly rolling grazing land with medium agricultural value. Sub-bituminous coal is surface mined by advance area mining techniques. The annual precipitation rate of 14" usually occurs during a two month period in springtime but does not cause serious haulage problems.

Mine C has an annual coal production rate of 9 million tons. Drag lines are utilized for most overburden removal; however, pan scrapers are being employed to increase production rates on a short term basis. Both methods embody advanced reclamation techniques to restore mined areas to pre-mine agricultural value.

Nine (9) 80 ton and two (2) 150 ton bottom dump haulers are used in a double shift, five day per week coal haulage operation.

Haulage cycle includes one mile run from pits to storage pile or unit train loading area. Overburden is transported by pan scrapers over several hundred yards of haul road. All haulage is accomplished on private roads built and maintained by mining companies.

Berms are not used at this operation since average grade is only 4%. Maximum one-way traffic grade is 12% for two hundred yards of one pit cycle, however, two-way traffic is restricted to 6% maximum grade. Superelevation is not constructed in road curves but slight crowns are incorporated to improve water removal during rainstorms. Road widths of 80' are maintained for two-way traffic. The width of one-way traffic is reduced to 40'. Company imposed speed limits of 25 mph loaded and 35 mph empty are strictly enforced by a resident safety officer who also conducts periodic driver education meetings with operators. Several minor accidents due to driver inexperience have occurred with haulage equipment but no lost time injuries are recorded.

A daily maintenance check (during lunch period) and a 500 operating hour check is performed on all haulage equipment. Driver training sessions are required for all new operators.

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Mine D is located in the southwestern section of the United States. The land is dotted with mountains connected by broad flat plains. Vegetation is sparse consisting mostly of scrubs and clumps of wild grasses. The soil is primarily gravel and sand.

Copper is mined and processed at this huge open pit operation. Temperatures range from 20°F to 110°F with an annual precipitation rate of 10 inches. Although the annual precipitation is quite low, it causes problems when it does arrive. The roadway capping material easily washes away, exposing the larger rocks of the bed below. Tires are cut by these exposed rocks, causing down time and major maintenance expense.

The mine is an old established operation with mining progressing at many different levels. The nine shovels are served by 52 trucks varying from 100 ton to 230 ton bottom and rear dumps. Work continues on a 24 hour basis with drivers changed on the fly. An operation dispatcher structures truck assignments to keep the shovels supplied. Hence, the haulage cycle of any one vehicle may vary throughout the shift, within the range of 3 to 6 miles.

Haulage roads have been constructed at an 8% grade. All hauling is upgrade. Roadway widths are between 100' and 130' with two lanes up and one lane down. The lower level roads have a minimum width of 80' and two lanes. No superelevation or crown is in evidence on any of the roads. The berms are very small, and not designed to contain runaways.

The haulage roads are extremely dry and require constant watering. The watering truck constantly traverses the roads and performs a double duty by reporting road repair requirements.

Truck retarders have been set to control the downhill speed at 20 mph. Uphill, the loaded trucks run at top speed passing slower vehicles. Accidents occur approximately once per month, with driver error nearly always the cause. A typical accident would find the driver falling asleep and colliding into the rear of a slower vehicle. An average of two runaways a year have occurred. Most operators ride the berm until the vehicle comes to a halt.

Each vehicle has a daily tire check at the refueling station and is given a bi-weekly inspection in the shop. Additional standby vehicles replace those not in service.

A new driver receives classroom instruction and an in-the-cab check out before going solo on any vehicle.

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Mine E is located in the Southwest. The land is primarily broad, flat, dry plains dotted with mountains. Vegetation consists mostly of scrubs and clumps of wild grasses on soil composed of gravel and sand.

Most characteristic of Mine E is the cohabitation of trucks and conveyors in the copper mining process. Temperatures range from 20°F to 110°F with an annual precipitation rate of 10 inches. The haulage roads, constructed from available overburden, have a very stable surface and are not appreciably affected by rain.

As in most copper mines, different elevations of the operation are active constantly. The conveyors are fed by dozers, front-end loaders, and scrapers. The trucks, attending shovels throughout the mine, are in the 100 to 120 ton size, and are about 40 in number. Haulage cycles for the trucks vary from 2 to 4 miles. Because the operation is a five day mine, all vehicle and conveyor maintenance is performed on weekends.

Although all new haul road construction observes a maximum grade of 8%, some previously constructed roads are 10%. No superelevation was planned but the cross slope is into the highwall. Road widths vary from 100' to 80', the narrower roads at the lower elevations.

Wide berms with dikes have been constructed extensively throughout the operation. These plus long flat benches at each level are designed for protection of runaway vehicles.

Truck retarders limit the downhill speed to 20 mph. Uphill, the trucks run at full capability. The accident frequency is about one per month with driver error the chief cause. Location of the accidents has been, many times, a busy intersection. Trucks are notoriously blind on the right. Traffic control signs have reduced the number of these accidents.

The haulage roads' surfaces are maintained by a front-end loader and scraper. Their job is primarily one of cleanup rather than patching.

Driver training is extensive. New drivers have classroom instruction and in-cab checkout prior to solo operation. Prospective drivers of any new piece of equipment receive instructions on the vehicle's capabilities and limitations before operation.

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Mine F is located in the southwestern United States. The terrain is mountainous rolling land covered with trees and wild grasses. The chief mineral of this huge open pit mine is copper, with minute amounts of other minerals.

The climate is moderate with temperatures ranging from 10°F to 90°F and with an annual precipitation rate of 20 inches. The climate produces almost perfect mining conditions — many clear days with sufficient moisture to control dust. However, due to the high elevation of the site, morning fog creates a hazard and has occasionally forced a temporary halt to the operation.

Vehicles in the mine include shovels, dozers, scrapers, and 85 to 100 ton bottom and rear dump trucks. Daily tire check is made at the refueling stop. Biweekly maintenance is performed in the shop.

Many elevations of the mine are active continuously. Some hauling is upgrade and some downgrade. Maximum grade is 8% with 100' minimum width. In the areas of downgrade haul, runaway turnoff ramps have been constructed at 600' intervals.

There was no planned superelevation or crown on the haul roads and some soft spots do appear periodically. Holes develop quickly due partly to the high ground water, but mainly to the continuous truck traffic. A small stone crusher strategically located produces material for repair of the depressions. A front-end loader and dump truck transport and spread the crushed stone, which is a subbase type gradation.

Drivers are instructed to test their dynamic brakes before reaching the crest of the downhill haul, and to then proceed at a speed not to exceed 20 mph. If the vehicle exceeds 22 mph the brakes will fade. Drivers are then directed to take the next runaway ramp. For uphill hauls, trucks run at full capability.

Haul road accidents occur at the rate of about two a year. Driver error in judgment is the prime cause. Driver training includes classroom instruction and in-cab apprenticeship for up to a week before assignment to a vehicle.

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Mine G is a two pit contour operation located in the northern coal fields of West Virginia. Steep mountainous terrain surrounds these mines, with major ground cover in small to commercial grade pulpwood timber. Bituminous coal is surface mined, using the truck haulback and valley-fill method. The temperature ranges from 24°F to 86°F and precipitation is 48 inches annually.

Haul road problems in these pits include restricted horizontal and vertical sight distance, severe gradients, and dust and wet weather rutting. All mine roads traverse previously mined coal benches, dozed spoil piles, progressive hollow fills, or very steep outslope conditions. These mines are relatively high on very steep slopes. Haul roads are generally temporary in nature.

This mine produces 4,000 tons of coal per month. Topographic conditions are the prime factors in selection of the method and equipment for mining this area. Major equipment used in these pits include dozers, trucks, front-end loaders, overburden drills, and a large backhoe. Steep side slopes and a somewhat long, narrow pit require mobility, range, and selective placement of overburden provided by this equipment.

Total haulage fleet is 6 – 50 ton overburden trucks, two in the smaller pit and four in the larger area. All are company owned and operated, two shifts daily, five days per week. Coal haulage is provided by local contract operators, using 4 to 8 – 25 ton tri-axle end dump trucks usually loading two shifts per week. Overburden haulage is a maximum of 1,500 feet per round trip. The average grade along the mine bench is 1%; however, maximum grades of 10% for a distance of 200 to 300 feet are near backfill areas. The pit access roads can reach maximum grades of about 20%. No safety berms are provided and horizontal sight distance is restricted on the coal bench due to the rapid direction changes in the outcrop line. Vertical sight distance is severely impaired at the intersection of the coal bench and the mine access road.

Maximum speed allowed in the mine is 15 mph during good driving conditions. Travel on public road is limited to 25 mph due to steep gradients and rather bad horizontal alignment. Records of accidents in the mines do not show any major bodily injury or death. Occasionally skidding due to steep grades and wet weather causes some minor accidents.

Haul road maintenance is a constant problem requiring almost continuous grading to eliminate rutting. The coal company has taken over the maintenance and repair of a state road used as a coal haulage route. Very strict dust control measures to protect private property are in effect. Some areas are treated with road oil in addition to the use of water trucks during hauling cycles. Often pick-up trucks equipped with flashers are used to warn the public of oncoming heavy equipment. These safety provisions are limited to a 2 mile length of state route with very poor horizontal and vertical alignment and restricted sight distance. This roadway is about 30 feet wide with no superelevation, safety berms or runaway protection.

Vehicular inspection of company-operated equipment is performed daily. Major overhauls or equipment replacement is performed by manufacturers' representatives. Contract operators are subject to public vehicle inspection codes as applied by the state, in addition to their own daily and routine maintenance programs.

The mining company employs a safety engineer, responsible for the safe conduct of all mining personnel, even in the instance of travel on the portion of state road maintained by the company. His duties include instruction in safe operation, periodic inspection of vehicles, and the power to reprimand any violators of safe mining practices.

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Mine H is located in the upper Appalachian coal fields of West Virginia. Mountainous terrain surrounds the mining area. Most ground cover is suitable commercial grade timber. Bituminous grade coal is surface mined, using the truck haulback method of ongoing reclamation to the approximate original contour. The temperature ranges from 24°F to 86°F and precipitation is 48 inches annually.

Haul road problems in this area include restricted sight distance on some vertical curves, and some surface water ponding in sag curve conditions. These conditions occur only in areas where haul roads traverse previously mined areas, which will be reclaimed on completion of mining. The remaining roadway is a permanent installation constructed of rock base and selected stable surface materials. Most material used in this construction is mine run spoil. Dust and wet weather rutting are the only other problems associated with this roadway. Total length of the mine roadway from pit to state road is about 1.5 miles.

This mine produces 2,200 tons of coal per month. Topography and equipment availability were the prime factors in selecting the truck haulback method. This area was previously stripped, with no previous reclamation and poor outslope conditions. The miner felt the current method provided the mobility, range and selective placement of material to provide for better contour reclamation. Major mining equipment used includes dozers, front-end loaders, overburden drills and trucks.

Total haulage fleet is two 50 ton end dump overburden trucks owned and operated by the mining company. These vehicles operate two 8 hour shifts daily, five days per week. Coal haulage is provided by contract operators using 25 ton tri-axle end dumps, usually hauling coal two shifts per week. Unit availability will range from 4 to 8 units. Overburden haulage is about 1,400 feet round trip with a maximum grade of 9% and an average grade of 4%, spanning a time frame of approximately 5 minutes per cycle.

Coal haulage cycles average one hour per round trip covering 44 miles and traversing public roadways for 41 miles. The maximum haul road gradient noted is about 30%. Road surface ranges from selected material to asphaltic surface averaging 24 inches thick. Mine roads are 15' to 25' in width, with no safety berms, escape lanes, or superelevated curves. Horizontal sight distance is good; however, vertical sight distance in some areas is unusually bad.

Maximum speed allowed by the mining company is 15 mph. No accidents involving company owned vehicles have been reported; however, some contract coal haulers have lost control enroute either on mine roads or public highways. Most often these accidents are the result of excessive speed, and the consultant has no evidence of bodily injury, property damage or fatality.

Maintenance of company owned vehicles is performed according to manufacturers' specifications, or when necessary. All major overhaul or repair work is performed by manufacturers' representatives.

Driver training is not a part of the mine safety program. Mine safety inspectors are employed by the mine company with the responsibility to instruct or reprimand violators of accepted safety practices.

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Mine I is located in the upper Appalachian coal fields of West Virginia. Steep hills with moderate timber cover and ample grasslands surround the mine area. Bituminous grade coal is surface mined, using the truck haulback method. Reclamation is to approximate original contour and is concurrent with mining. The temperature ranges from 24°F to 86°F and precipitation is 48 inches annually.

Haul road problems here are limited to dust and wet weather rutting, with occasional icing conditions. Major mine haul roads are constructed of mine run spoil and rock with a stable top of selected material. These roads are permanent installations, graded to drain and with good sight distance. In-pit haul roads are very mobile, quickly constructed units built only to serve the life of the pit — 3 months in most instances. Minimal consideration is given to surface water runoff or sight distance, while maximum consideration is given to selection of shortest route and flattest gradients.

This mine produces 8,100 tons of coal per month. Topographic conditions play the most important role in the haulback method of mining this area. Steep sloping hillsides and lack of large continuous coal beds would make any other form of surface mining inordinately costly. This mine now uses trucks, front-end loaders, and dozers.

Total haulage fleet consists of two - 50 ton overburden transport vehicles running two shifts daily, 5 days per week. These trucks are owned and operated by the mining company, with a one-way maximum run of 600' from pit load out to dump point. Coal haulage vehicles are owned and operated by contract haulers, using 25 ton tri-axle end dump trucks. These units operate an average of 2 1/2 days per week for one shift, and have a one-way haul to the coal company tipple of 6 miles, via public highways. Maximum grades within the mine are 6% with an average gradient of 2%. Maximum grades on the public road are 8% with an average grade of 3%.

Mine roads average 25' to 30' wide, with most curves widening to 40'. All permanent mine roads are crowned 4" at the most, with no superelevation on curves. No safety berms are provided; however, most outslope areas are graded and seeded with grass.

Maximum speeds are governed by weather conditions and good sense, in addition to numerous "safety first" signs in the mine. Equipment used here is capable of a maximum speed of 30 mph.

Vehicle maintenance is a daily matter with repairs made as needed. Ninety percent of the major repair work is handled by the manufacturers or distributors of the trucks. Most maintenance provided by the mining company deals with filter replacement, and other small items.

Haulage equipment accidents within the mine are generally minor with no bodily injury and no equipment downtime. Runaways or vehicles out of control have not been a problem due to the slow speeds and relatively flat grades in the mine.

Driver training is not a mine program, however, the potential operator must demonstrate his knowledge and skill in driving to the mine foreman before acceptance.

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Mine J is located in the upper Appalachian coal fields of West Virginia. Rolling hills and grasslands surround the mine area. Bituminous coal is surface mined, using the truck haulback method. Reclamation is concurrent to mining and is to approximate orginal contour. The temperature ranges from 24°F to 86°F and precipitation is 48 inches annually.

Haul road problems in this mine are limited to dust and wet weather rutting. Major haul roads are constructed of rock base with mine run spoil stabilizing the traveled surface. In-pit haul roads are very mobile, hastily built over prior spoil material, with little compaction or stability except that provided by haul trucks. These in-pit roads are most severely affected by wet weather conditions and can affect the performance of coal haulers.

This mine produces 9,800 tons of coal per month, with major mining equipment including off-road trucks, dozers, front-end loaders and a coal dozer. Equipment availability and topography are the most important reasons for the truck haul back and dozer usage in this mine. This equipment allows the miner to maintain two smaller more mobile coal production pits.

Total haulage fleet is three 50 ton overburden trucks and four 40 ton coal haulers; occasionally the 40 ton trucks are used to move overburden. All equipment is company owned and operated two shifts per day, 5 1/2 days per week. Overburden haulage routes have a maximum grade of about 17.5% with an average of 12% for a distance of about 900 feet maximum. Coal haul routes have a maximum grade of about 17.5% with an average grade of 3% for a distance of 1.5 miles.

The coal haulage route is unusual in that a manually controlled traffic light is installed at a state road intersection with the haulage route. The state route has a blind vertical curve near the haul road intersection, raising the potential for accidents. This signal is manned by coal company personnel at the crest of the state route curve, situated such that clear sight of all oncoming traffic is available. Flashers attached to warning signs are in place approximately 500' to either side of the intersection.

Mine roads are on the average 40' in width with a 5' widening on curves and no superelevation. Berms are 10' wide, at least, and graded similar to a conventional highway shoulder. All road slopes are seeded with grasses.

Maximum speed allowed in the mine is 25 mph, or approximately the top speed of the coal haulers. Mine road grading and maintenance is done to facilitate the smoothest travel of the coal haulers. Some loss of operator control has been reported, usually in muddy or icy conditions. None of these reports include any bodily injury or vehicular damage.

Maintenance programs are conducted to at least satisfy original equipment specifications. All operators are responsible for daily inspections at the beginning of their shift. Most problems discovered in these inspections or during operation are repaired in the mine shops. Major equipment failure is usually repaired by a representative of the manufacturer.

Driver training is not a mine program as such. The potential driver must demonstrate his knowledge and skill in operation to the mine foreman prior to acceptance. The mining company employs a safety engineer with the power to reprimand any employee guilty of unsafe practices in the mine.

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Mine K is located in Eastern Kentucky. The topography is steep and rugged with little or no soil cover. Vegetation is characterized by commercial grades of eastern hardwoods and pines, usually with a thick cover of underbrush. High quality, low sulfur bituminous rank coal is surface mined in multiple seams by the mountain-top removal method.

The temperature ranges from 0° to 90°F with a mean annual precipitation of 45 inches. The steep terrain combined with high precipitation rates create haul road stability and erosion problems. Haul roads must be continually graded and maintained to minimize road surface degradation.

This mine has an average coal production rate of 17,200 tons per month. Although the geology is very complex and extremely variable, at least three thick seams are consistently mined. Major mining equipment includes 24 cubic yard tandem scrapers pushed by large dozers and a 5½ cubic yard excavating shovel to accomplish the mountain-top removal -- valley fill operation. The coal is cleaned and loaded with a variety of 12 to 14 cubic yard front-end loaders. Coal haulage is handled by 25 ton on-road trucks on a contract basis. Fifteen to twenty of these trucks make daily trips from the mine to a rail head 12 miles away.

The main haul road is about 25 feet wide and sloped toward the mountain for drainage. The road reaches a maximum slope of 18% and averages around 15%. Berms, installed by the operator prior to government regulations, have prevented several potentially fatal accidents. Owing to the steep terrain, several coal haulage trucks have lost control, but, because of the berm, suffered only minor damage with no operator fatalities being recorded. Several "switch-back" curves and the presence of berms have created severe erosion problems. This has necessitated the installation of drainage culverts and continuous road maintenance.

Since coal haulage is conducted on a contract basis with private operators, maintenance records are virtually nonexistent. Consequently, little data is available for the analysis of haul road accidents.

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Mine L is located in eastern Kentucky. The topography is characterized by steep rugged hillsides with little or no soil cover. Vegetation is comprised mainly of commercial grade eastern hardwoods and pines and a thick cover of underbush. High quality low sulfur bituminous rank coal is mined in multiple seams by the mountain-top removal—valley fill method.

The temperature ranges from 0° to $90^{\circ}F$ with a mean annual precipitation of 45 inches. The high precipitation rate, the variety in temperature, and the steep terrain often create road stability problems. Consequently, roads must continually be graded and maintained.

This mine has an average coal production rate of 92,400 tons per month. Although the geology in this area is extremely complex and variable, 4 seams are consistently mined by the mountaintop method. Major mining equipment includes a 24 cy front-end loader, three 50 ton rock trucks, and large dozers for overburden excavation. Coal is cleared and loaded by 15 cy front-end loaders. Coal haulage is conducted by 25 ton on-road trucks on a contract basis. Fifteen to 20 of these trucks make daily trips to a rail head 25 miles away.

The main haul road maintains a nearly constant 10% slope until it connects with the public road. In addition to on-site road maintenance, the public roads are maintained and watered by the company. On-site roads are 25 to 30 feet wide and gently sloped toward the mountain for drainage. All haul roads constructed by this company are pre-engineered and their construction supervised by company engineers. Berms, constructed by government regulatory agency request, have created severe erosion pro-lems and have necessitated the installation of drainage culverts. Only minor mishaps with no fatalities have been recorded by this company.

A regular maintenance program is conducted on all company owned equipment. In addition, comprehensive computerized files are kept of maintenance, repairs, parts, and equipment problems for all company equipment. Since, however, coal haulage is conducted on a contract basis with private haulers, little data is available on that equipment.

Operations at this mine are conducted in two-ten hour shifts per day, 6 days per week. The remaining four hours per day are devoted to routine equipment maintenance and repair.

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Mine M is a two-pit operation located in western Pennsylvania. Rolling mountains with somewhat wide flat valleys surround these mine areas. Vegetation ranges from heavily wooded hilltops to farm and pasture lands on the valley floors. Bituminous grade coal is surface mined in this operation using the modified block cut method. All overburden is moved with large bulldozers and front-end loaders. The temperature ranges from 18°F to 84°F and precipitation averages 42 inches annually.

All major haul roads are township or state routes, which function as coal transportation avenues from the pit to the tipple. Pit haul roads are narrow, simply constructed roads following existing contour closely, usually built to last one year. These pit roads are constructed of mine run spoil with no stabilization, and are a major problem to coal haulers due mostly to rutting in wet weather.

This mine has an average production rate of 1500 tons per month. The method of mining is accepted practice by the company and is not related to geology or topography. One pit is located in steep terrain with shale overburden, while the other is located in relatively flat terrain and massive sandstones. Equipment used in these mines includes 2 large dozers, 2 front-end loaders, one overburden drill, and 5 coal trucks.

Coal haulage equipment is provided by local contract haulers on a per ton basis. All maintenance, repair, inspection schedules, and operator safety of these vehicles is the responsibility of the contractor. The mining company has 5 coal trucks, in addition, which operate one shift daily, five days per week, traveling 8 miles to the tipple. A maximum grade of 22% was observed on a pit haul road with the average being 6%. Maximum grades on public highways are 10% with an average of 2%.

Berms, superelevation of curves, protection for runaway vehicles, and horizontal or vertical sight distance are not part of road design for this pit. These roads average 12' wide and disturb very little area due to their temporary nature. Maximum speeds on these pit roads are limited to 5 mph. The mining company reports an average of 1 accident per month, almost always due to the slippery condition of pit haul roads. No bodily injury or property damage has been reported.

Vehicle maintenance is of prime importance to this company. All company owned vehicles traveling public highways undergo a weekly inspection, in addition to semi-annual state inspection. Tires usually are taken out of service at 20,000 miles, and trucks equipped with retarders have new brakes installed at 30,000 to 40,000 miles. All repairs are performed in company shops, except for engine repair.

Driver training is an integral part of company safety practices. A constant alert to safe operation is provided with various signs at the sites, in truck cabs, and other buildings owned by the company. A mine safety foreman is employed by the company to oversee this program.

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Mine N is located in the western Pennsylvania coal fields. Gently rolling countryside surrounds this mine area, with farm and pasture lands the primary surface use. Bituminous grade coal is surface mined using the truck haulback modified block cut method. This surface operation is stripping the outcrop line of a new deep mine complex in its initial stages. Portals are now being driven in a portion of the outcrop stripped and completely removed by this surface operation. The temperature varies from 18°F to 84°F and precipitation averages 42 inches per year.

Major haul roads are permanently constructed units built to serve as access and haul routes for the adjoining deep mine. All are constructed of rock base and selected material to stabilize the road bed. These roads are 40' wide with seeded berms and relatively flat grades. In-pit and overburden haul roads are very narrow, mobile, and usually quickly constructed with a dozer. Horizontal and vertical alignment is dictated by pit conditions and restrictions. The foreman stated that actual pit haul road location can change in one day without seriously interrupting overburden haulage.

The mine has an average coal production rate of 1,600 tons per month. The equipment used in this operation will provide for more selective placement of overburden and should enable the miner to return the land to productive surface use more rapidly. Major mining equipment includes 2 - 75 ton overburden trucks, a front-end loader and two bulldozers.

Total haulage vehicles are two 75 ton overburden trucks and from four to eight 25 ton tri-axle end dump coal trucks. All vehicles are owned and operated by the coal company or a subsidiary construction company. Overburden haulage units operate two shifts per day, five days per week.

Coal is hauled a distance of three miles from a deep mine stockpile to a tipple. Overburden transport is several hundred feet from pit to reclamation areas. All overburden haulage is on company built roadways and coal haulage equipment uses township and state highways. Mine haul roads have no crowns, superelevation on curves, runaway vehicle protection or curve widening.

Maximum speed in the mine is 20 miles per hour; however, overburden haulage equipment will attain a maximum of 5 to 6 mph. No haulage equipment accidents have been reported in the mine area. Some accidents have been reported with coal haulage on public roadways. Records indicate no fatalities have occurred. Other accident details are included in driver personnel files which the company regards as privileged information.

Maintenance programs for all vehicles conform at least to manufacturers' specifications. Each operator is responsible for a daily inspection prior to shift operation. All vehicles traveling via public roadways are subject to state motor vehicle inspection and registration.

No formal driver education program is included in the mine operations. A mine safety inspector or engineer is employed by the company to oversee and instruct employees on all safety practices.

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Mine O is located in the western Pennsylvania coal fields. Moderately steep, mostly wooded terrain surrounds the mine area. Some narrow lowland areas show some development as small farms and home plots. Bituminous grade coal is surface mined using the dozer-loader method of modified block cut mining. The temperature ranges from 18°F to 84°F and precipitation totals 42 inches annually.

Mine haul roads are very narrow, temporary units, traversing regraded spoil. Spoil piles, very close to the roadway, limit horizontal sight distance. Surface water ponding is a major problem due to lack of proper drainage facilities. This mine uses a continuous process of opening small 150 foot square pits and returning overburden to the previously mined out areas. Haul road mobility and/or extension is a prime consideration and is the major reason for many of the haul road problems.

The mine haul road is presently 1/2 mile long and the remaining 5 mile haul is on public roadway. The mine road is 12 to 15 feet wide with a maximum grade of 14% and an overall grade of 4% to the public highway. The maximum speed on mine roads is 5 mph. The major road maintenance problems are dust and road bed stability in wet weather. One smaller dozer is at this mine serving as a pit back-up and haul road maintenance vehicle.

Safety berms, superelevation on curves, and runaway protection are not provided due to the slow speeds in the mine area. The public roadways are narrow with all of the above deficiencies, except that curves are super-elevated.

Maintenance programs for the coal transporters are controlled by the individual contractors. Generally each driver is responsible for daily routine inspections prior to the day's work. Each vehicle must pass a semi-annual state inspection, usually requiring a complete tire change at 20,000 to 30,000 miles and brake lining replacement at 40,000 miles. The mileage for brake linings will be reduced to 20,000 miles or less if the vehicle is not equipped with a retarder.

Each contractor is responsible for the safe operation of his vehicle. However, in the mine area, a mine safety representative or foreman is responsible for overall safety.

* * * * *

Mine P is located in the western Pennsylvania coal fields. Gently rolling countryside surrounds the mining area. The primary surface use is farm and grasslands, with some scattered timber available. Bituminous grade coal is surface mined using the area mining method. The temperature ranges from 18°F to 84°F and precipitation totals 42 inches per year.

Haul roads to this area are very narrow one-way roadways with some areas of poor horizontal sight distance. All are constructed over regraded stripped areas and are temporary in nature. Stability in wet weather and dust control are the major problems these roads present.

The mine has an average production rate of 2,000 tons per month. Major mining equipment includes a dragline, reclamation dozers and front-end loaders for coal loading. All coal is hauled by local contractors using tri-axle end dump trucks of 25 to 30 ton capacity. These vehicles are suitable for highway use and most are equipped with engine retarders.

Haulage routes consist of a 3/4 mile mine access road and 6 miles of state or township highway, to a company tipple. Maximum grades in the mine are 5%, maximum speed in the mine is 5 to 8 mph, due mainly to haul road conditions. The maximum public highway grade is 6%, with an overall average grade of 2%.

Safety berms, sight distances, superelevation of curves, or runaway protection are not provided in the mine roads. Low travel rates are cited as precluding the need for these precautions. Horizontal sight distance is restricted by the presence of some reclamation stockpiles.

Maintenance programs for the coal transporters are controlled by the individual contractors. Generally, each driver is responsible for daily routine inspections prior to the day's work.

Each vehicle must pass a semi-annual state inspection, usually requiring a complete tire change at 20,000 to 30,000 miles and brake lining replacement at 40,000 miles. The mileage for brake linings will be reduced to 20,000 or less if the vehicle is not equipped with a retarder.

Each contractor is responsible for the safe operation of his vehicles. However, in the mine area, a mine safety representative or foreman is responsible for overall safety.

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Observations made during field visits indicated an overall lack of familiarity with proper road design. As a result, safe vehicle operation, in the majority of cases, required significant reductions in operating speed. Conversation with a number of haul road designers revealed a desire to become more knowledgeable of various methods which could be employed to reduce hazards and increase operational efficiency.

In addition, mine visits reinforced the consciousness of our own personnel with respect to the economic feasibility of "ideal" design in adverse topography. In mountainous and constantly changing terrain, operating speeds will have to be reduced to avoid incurring the high construction costs associated with the best possible road alignment.

Task 5 - Delineate Requirements Impossible to Include

The purpose of this work task was to examine brake performance recommendations set forth by SAE and determine their feasibility as restrictions to surface mine haulage road design. Conclusions were reached by comparing the limitations prescribed by SAE with characteristic surface mine operating conditions.

Emergency Brakes

The maximum stopping distance for emergency brake systems in J166 is three times that of the service braking system. J166, of course, relates performance requirements of testing on a clean swept, level, dry concrete surface - not at all the environment of a mine haul road. Therefore, the mathematical extrapolation of SAE data was necessitated (as discussed in Task 2). Many truck manufacturers related, however, that the emergency braking system alone could not stop the vehicle when descending a haul road at normal operating conditions. Normal operating conditions here mean those typically present at current operations that utilize downhill grades of any consequence. Therefore, in keeping with the policy of applying the most restrictive requirements, it is obvious that defining haul road grade as a function of emergency brake stopping potential is a requirement that would be difficult to include. Nevertheless, stopping distances based on SAE recommendations can be developed from the data presented in Task 2.

Service Brakes

The maximum service brake stopping distances, associated with various coefficients of road adhesion, were discussed in Task 2. Using SAE J880a and J257, it was possible to assign minimum brake horsepower ratings required for various vehicle weights. These minimum horsepower requirements are defined by:

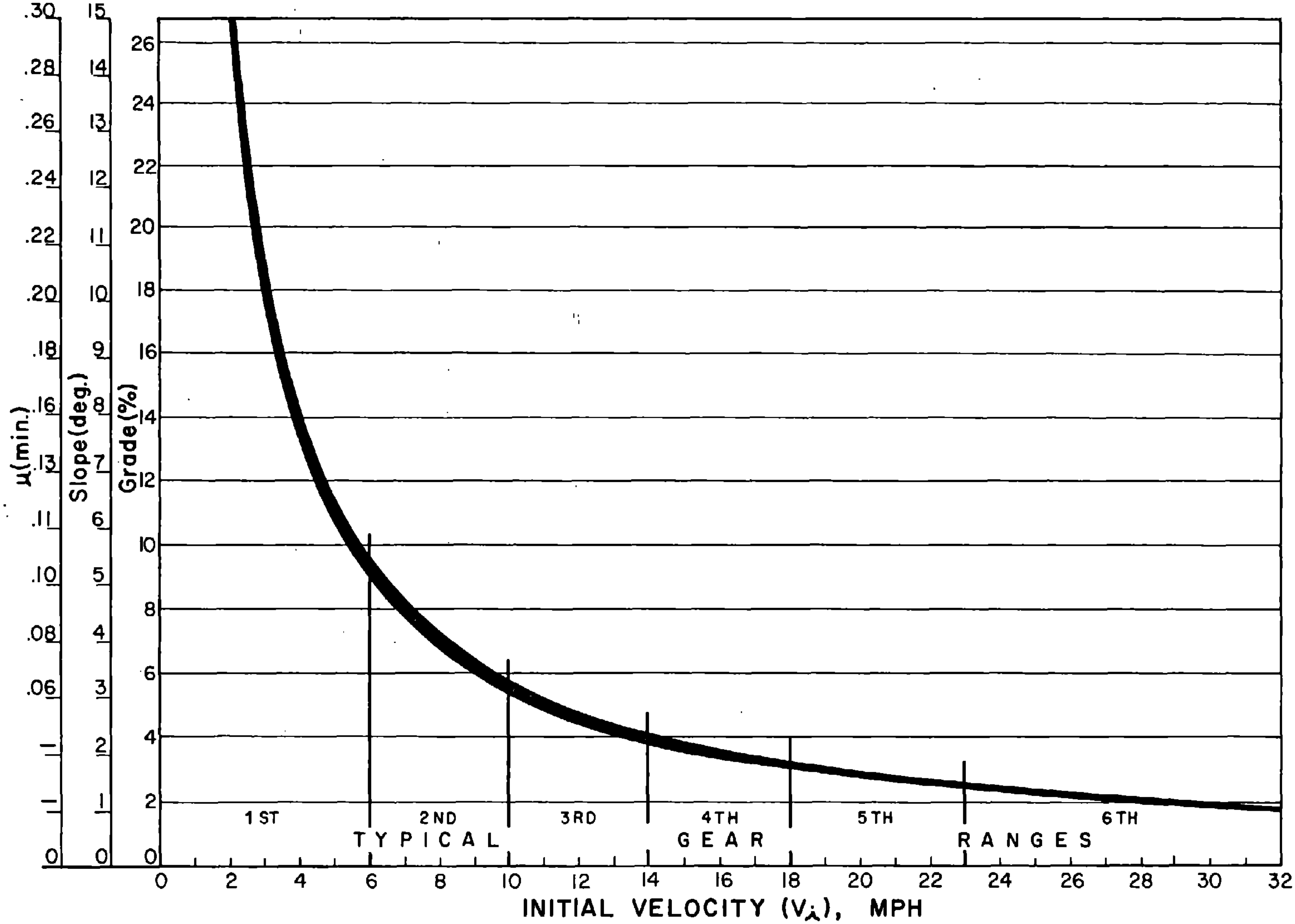
$$BHP = 12 + \frac{1.4\ gvw}{1000}$$

where BHP is the brake horsepower and gvw is gross vehicle weight in pounds. The maximum grade and velocity that a vehicle with this brake horsepower should attempt, with the assurance that it can stop, is shown in Figure I.

The minimum coefficient of road adhesion, u, is the minimum required for the roadway to accept the energy from the vehicle's braking system, and is included in the developed charts. This u is a mathematically derived minimum at which the vehicle can be stopped in a finite distance. It is also the minimum coefficient of friction required to hold a vehicle stationary on the associated grade. The value of u (min) is computed from:

$$u\,(min) = \frac{G - 100f}{\frac{100\ Lf}{L} \pm \frac{HG}{L}}$$

where G is grade in percent, f is coefficent of rolling resistance, Lf is the distance in inches from the vehicle's center of gravity (C.G.) to the front axle, L is the wheelbase in inches, H is the height of the C.G. above the ground in inches. The plus denotes a downward pointing vehicle. For example, Figure I shows that a vehicle can operate on a 10° slope at 3 mph and be brought to a stop when u = 0.2. With a u of 0.1, the vehicle could



GRADE AND VELOCITY LIMITS FOR SERVICE BRAKE PERFORMANCE

Figure I

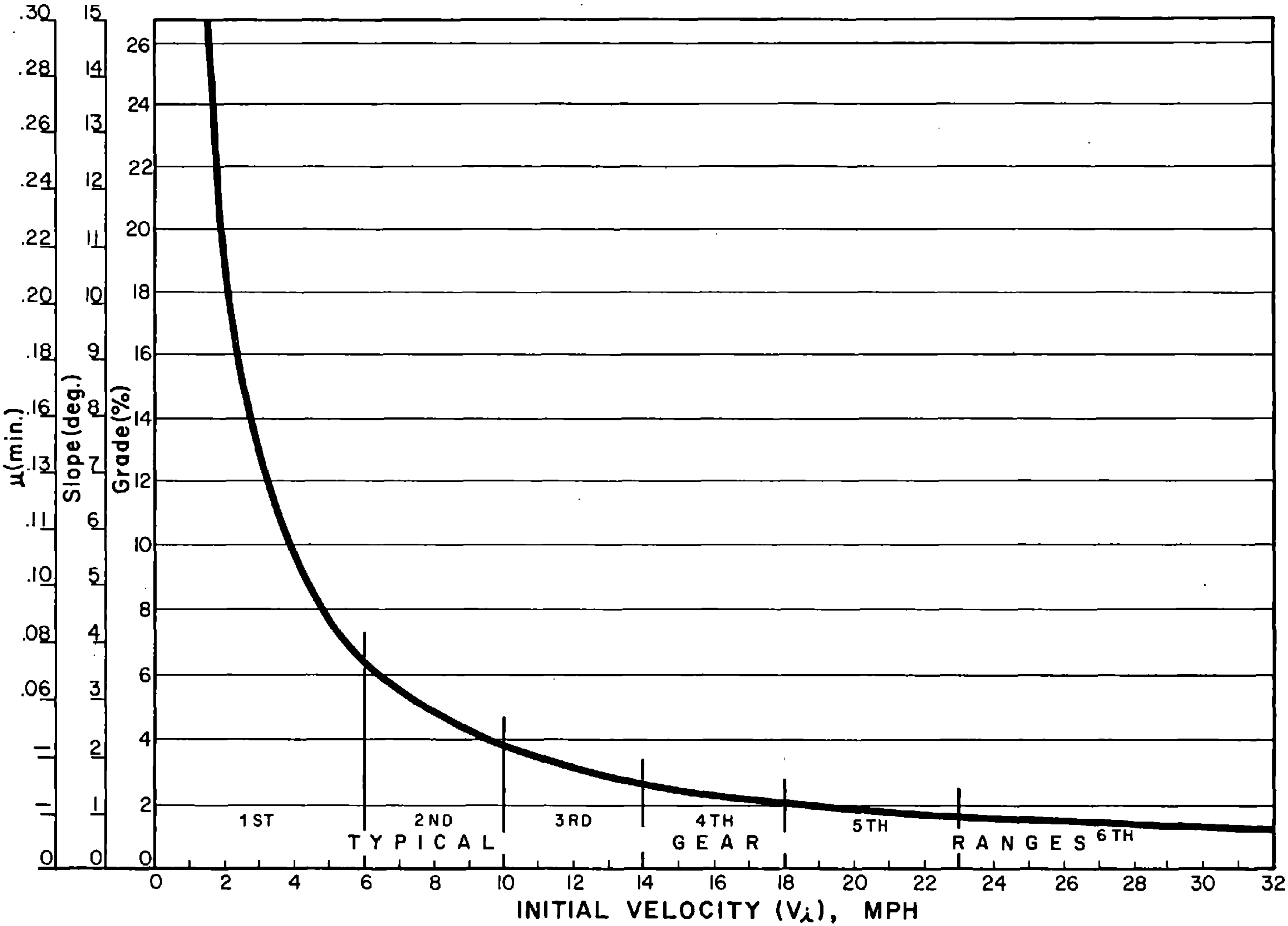
not stop or maintain its velocity and would accelerate down the grade.

Service Brake Recovery

Service brake system recovery required by SAE J166 is such that, "All service braking systems shall have the capability to deliver 70% of full braking capacity to the brakes, when applied at the rate of three applications per minute with the engine at maximum governed rpm". Therefore, BHPSR = 0.7 BHP, where BHPSR is service brake horsepower system recovery. Performance characteristics of Θ and V as a function of BHPSR are shown in Figure J.

The retardation potential of most modern haulage vehicles precludes the necessity of repetitive service brake applications. In fact, the use of service brakes is normally restricted to specified stopping points such as load and dump locations, marked intersections, grade approaches, etc. Since the majority of modern haulage vehicles possess retardation systems, brake system recovery is not considered a primary grade limiting factor. If grades are designed in compliance with specified stopping distance criteria, service brake recovery will suffice in emergency situations. However, following an emergency stop, brakes must be allowed to cool before any attempts are made to move the equipment.

For vehicles which are not equipped with retardation systems,



GRADE AND VELOCITY LIMITS FOR SERVICE BRAKE RECOVERY PERFORMANCE

Figure J

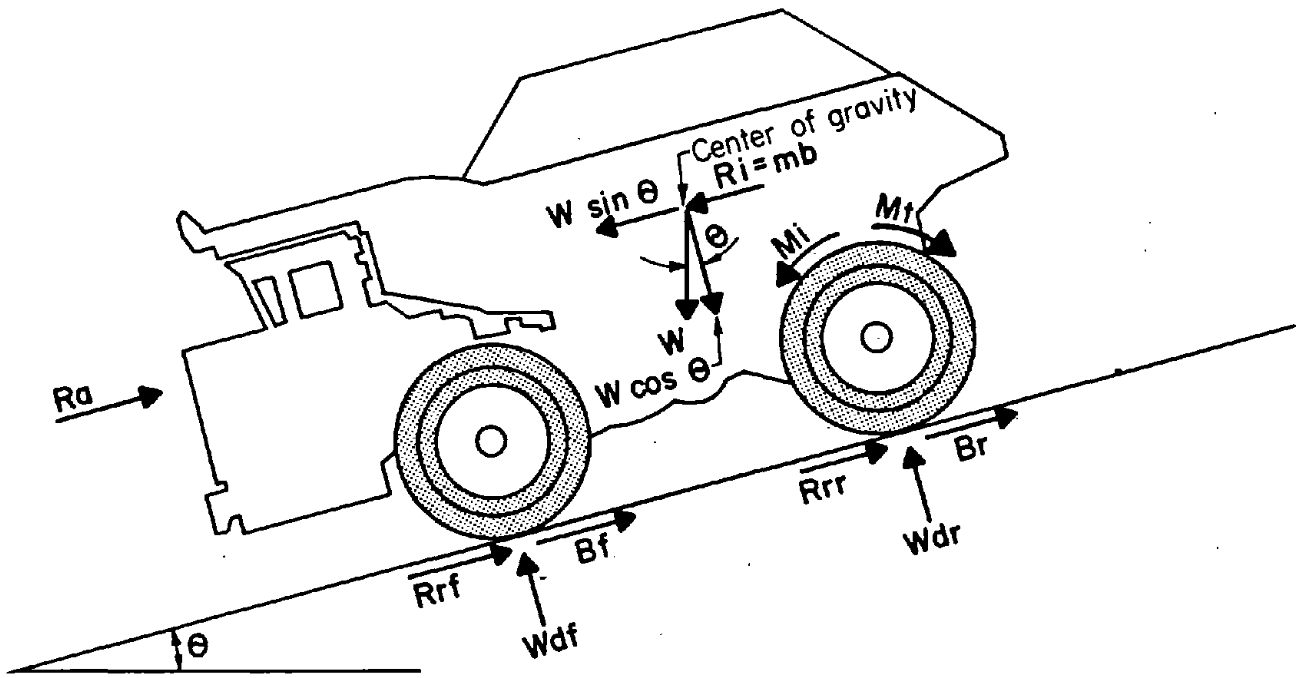
grade length should not exceed specified emergency stopping distance before reaching a level or ascending grade condition. By following this procedure, the vehicle is presented with an ideal stopping area if service brake fade is detected while traveling down hill.

Retarder Potential

A controlled vehicle coming down a grade develops horsepower at the wheels, which must be held in check by the retardation system to hold the vehicle at a steady, safe downgrade speed. The forces acting on a truck rolling downgrade are shown in Figure K. The rolling and air resistance factors are excluded from the retarder performance curves which follow in order to provide for margins of safety. The air resistance factor is generally minimal anyway, as is rolling resistance at 5 mph or less.

The braking potential of the retardation system is assumed equal to the vehicle engine horsepower. Operationally, this is not always the situation, as many manufacturers provide greater retardation than engine horsepower. Doing so enables a vehicle to descend a steeper grade, fully loaded and at a controlled constant velocity, than it could climb. In order to provide an added margin of safety the engine and retardation horsepowers are assumed equal.

From the equipment specifications that were listed in Task 3,



b	=	Deceleration (ft./sec.^{2})
Br, Bf	=	Braking forces
Mi	=	Moment inertia of moving parts
Mt	=	Total resistance moment of engine and transmission
Ra	=	Air resistance
Ri	=	Inertia resistance of the translatory mass
Rrf, Rrr	=	Rolling resistances
W	=	Vehicle weight
Wdr, Wdf	=	Dynamic axle weights

FORCES ACTING ON A LOADED TRUCK IN DECELERATED MOTION DOWNHILL

Figure K

ranges of horsepower per gross vehicle weight can be established for retardation systems of all vehicles. These ranges are compiled in Table V. (It should be noted that many factors will influence retarder potential such as: vehicle weight, manufacturers' modifications and options, transmission type, gear reduction ratio, and tire size.) The ranges in Table V are the minimums most likely to be encountered in actual service operations.

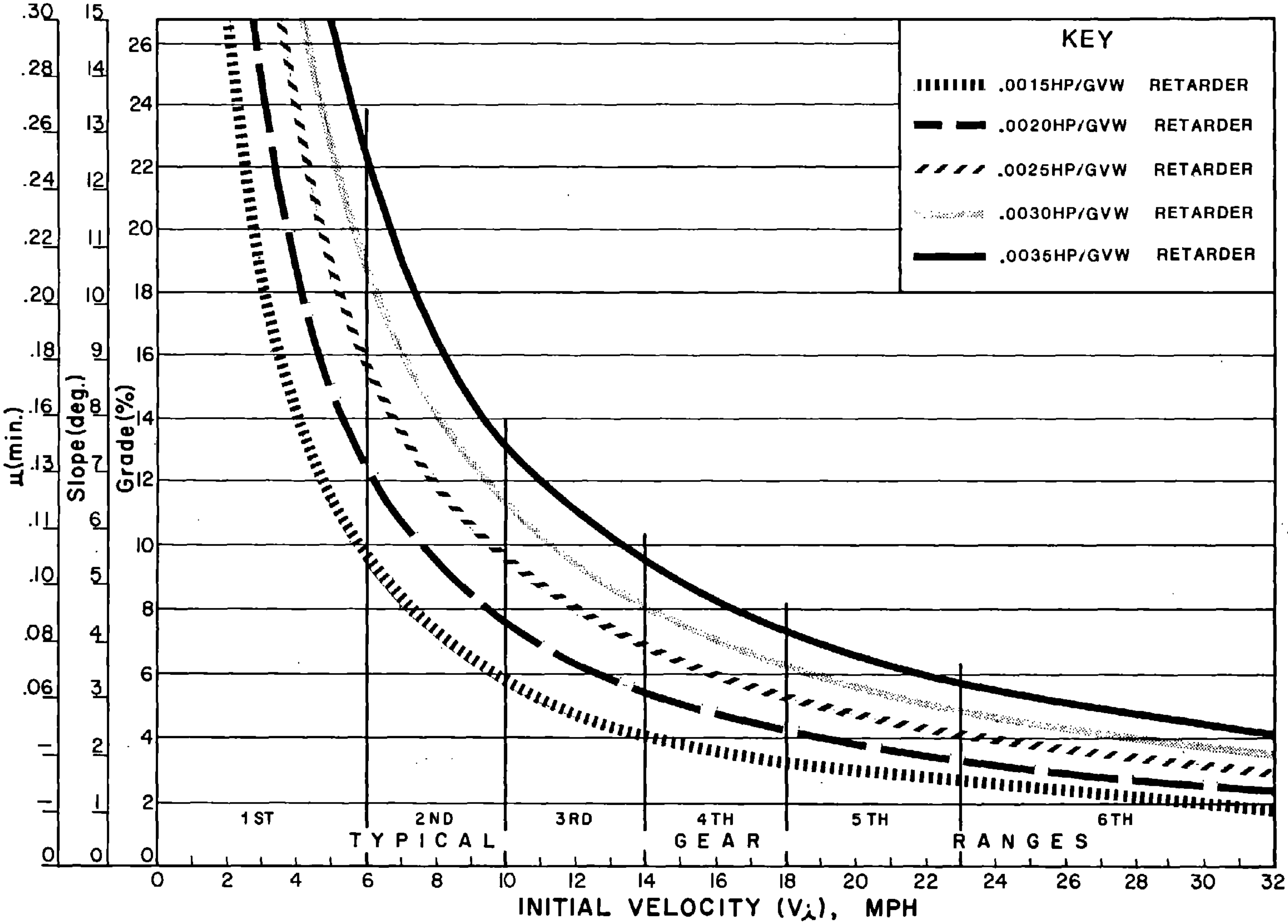
From Table V, performance capabilities shown in Figure L for 5 inclusive hp/gvw ranges were developed. These curves show the limits of grade and velocity that should be attempted by the vehicle whose retardation system can dissipate the required horsepower. Bottom dump vehicles have a smaller hp/gvw ratio than rear dump. This generally precludes their operation on haul roads in terrain that necessitates steep slopes (such as Appalachia and Rocky Mountain areas).

Table V

RETARDER HORSEPOWER RANGES

Truck Size (lb)	Truck Type*	Range hp/gvw	Range lb/hp
<100,000	Rear dump	.0027 - .0032	370-313
100,000 - 200,000	Rear dump	.0026 - .0033	383-286
200,000 - 400,000	Rear dump	.0021 - .0035	476-286
>400,000	Rear dump	.0023 - .0033	435-303
100,000 - 200,000	Bottom dump	.0030 - .0033	333-303
200,000 - 400,000	Bottom dump	.0018 - .0023	556-435
>400,000	Bottom dump	.0017 - .0027	588-370

*Bottom dumps generally do not utilize steep slope haul roads.



GRADE AND VELOCITY LIMITS FOR RETARDER BRAKING POTENTIAL

Figure L

The performance characteristics using both the retardation potential ranges and service brake capabilities are shown in Figure M. Also shown is the curve for service brakes only, included to emphasize that in the event of failure in the retardation system the service brakes alone must stop the vehicle. Thus, for determining emergency stopping distances in safe haul road design, service brake capabilities should be the primary consideration.

The haul road grades in Figures I, J, L, M are inclusive of current operational grades. As shown in these figures, the grade of the haul road is limited only by the speed of the vehicle traversing it.

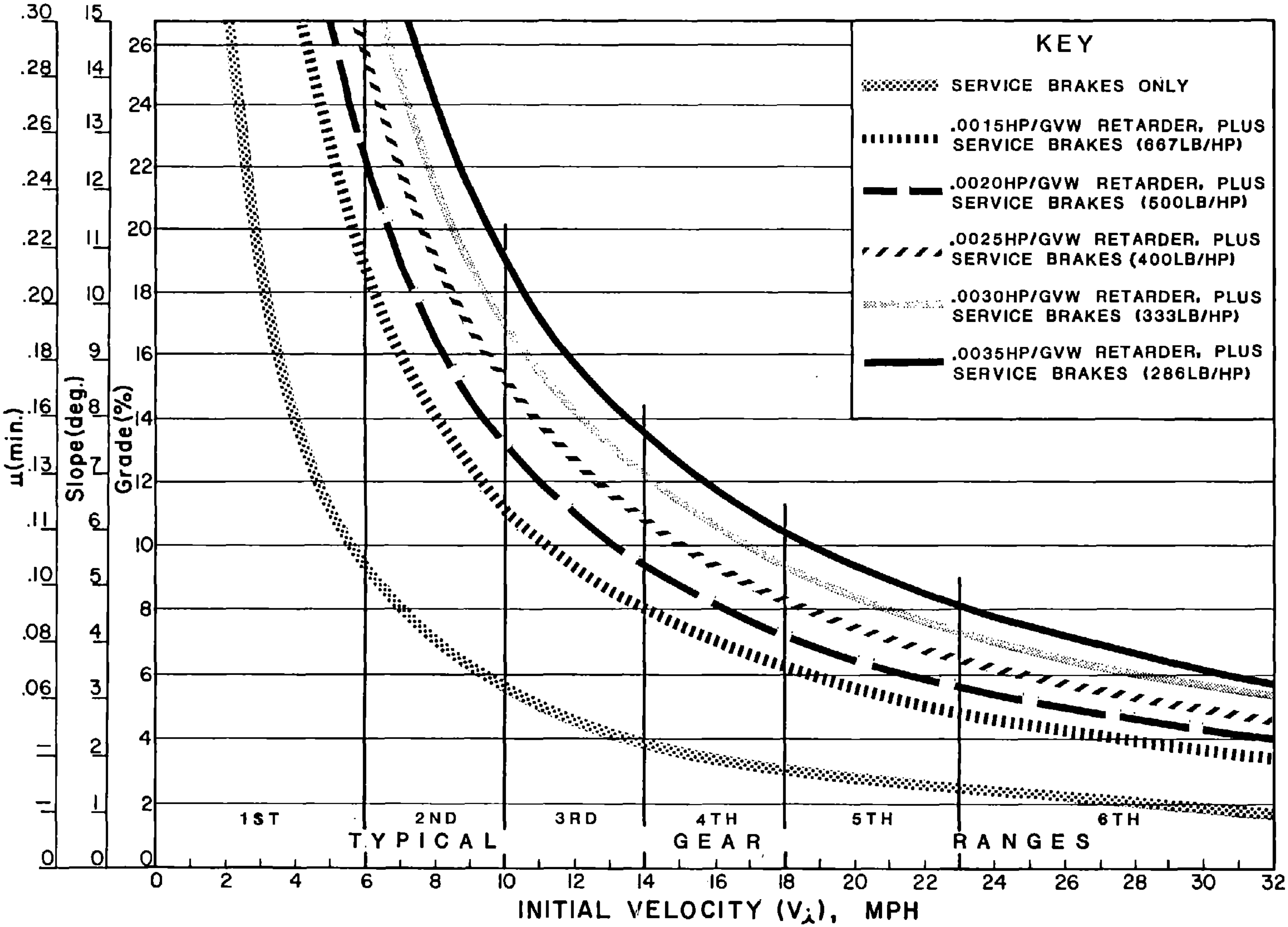
Some state government agencies mandate haul road criteria. Regulations relevant to haul road grades are shown in Table VI. As listed, the maximum grade permitted is from 15 to 20% for a total length of up to 300 feet. The maximum sustained grade permitted is 10%.

Table VI

STATE GOVERNMENT REGULATIONS GOVERNING HAUL ROAD LENGTH AND GRADE

	Maximum		Sustained		Maximum Switchback
State	%	Length (ft.)	%	Length (ft.)	Grade (%)*
Kentucky	20	300	<10		5
Tennessee	15	300	<10		<10
Indiana	15		10		
Virginia	15		10		
West Virginia	15	300	<10		<10

*Switchback grade is required to always be less than the approach grade.



GRADE AND VELOCITY LIMITS FOR SERVICE BRAKE PERFORMANCE AND RETARDER BRAKING POTENTIAL

Figure M

The total length of a sustained grade of 10% or less is governed by the heat dissipation abilities of the retardation system or oil-cooled service brake system. The performance capabilities of dynamic braking are red-lined by a retarder oil temperature of 250°F. The amount of energy that must be absorbed by the braking system in a vehicle of weight W descending a grade of G percent at a steady speed of V mph is:

$$Ng = \frac{WGV}{37,500}$$

where Ng is horsepower absorbed, W is weight in pounds, G is grade in percent, and V is speed in mph. For example, a 300,000 pound vehicle descending a grade of 10 percent at 10 mph must have a retardation potential of at least:

$$Ng = \frac{(300,000)\ (10)\ (10)}{37,500} = 800 \text{ horsepower or } 0.0027 \text{ hp/gvw.}$$

The hp/gvw value falls within the ranges plotted in Figures L and M.

In summation, the extrapolation of SAE minimum criteria for various grade/speed situations as road design criteria would be overly restrictive. The braking systems on most trucks currently manufactured can exceed the capabilities required by SAE. Therefore, it would be unrealistic to base grade limitations and other haul road design criteria solely on information such as that previously illustrated. A more feasible basis for design is presented in the main part of the report.

PHASE II - PRELIMINARY DESIGN

Phase II of the study, as the title implies, involved the development of complete haul road design criteria. Information for this phase was based on data developed during Phase I, the expertise of professional civil and mining engineers within our organization, and numerous books, manuals and publications. Our literary references are listed in the Bibliography.

At the onset of work during this phase, a significant problem became apparent. Although a great deal of reference material concerning conventional highway design was available, only a few publications contained data relevant to haul road construction. As a result, it was necessary to develop many design specifications based on design principles from other areas of engineering construction. Manuals dealing with construction of railroads, airports, bridges, and buildings are examples of sources used to gather design data that would accommodate the extreme weights of haulage trucks.

All design parameters were separated into individual categories and discussed in the order they would normally be considered during actual design and construction. The results of work performed in Phase II are similar to the final design criteria presented in the main part of the report.

PHASE III – REVIEW AND EVALUATION

Phase III was designed to offer industry the opportunity to review the preliminary design standards developed in Phase II and present constructive criticism. Since design recommendations affected separate industrial interests (mining and equipment manufacturing), copies of Phase II were distributed to companies representative of both categories.

A total of ten organizations were selected as reviewers: five manufacturing concerns and five mining companies. Of the manufacturing companies, four were major producers of off-highway haulage equipment. The fifth was a supplier of brake components for off-highway haulage vehicles.

Mining companies were chosen to represent differences in mining method, size, and location. In this manner, we anticipated receiving reviews which would reflect design criticisms as affected by various economic and environmental operating circumstances. The mining companies included: two large corporate coal mining concerns operating in the Eastern United States; one small coal mining company in the Eastern United States; a large corporate ore mining concern in the Western United States; and a medium size stone quarrying operation in the Eastern United States.

PHASE IV - FINAL DESIGN

Phase IV of the project involved the development of final haul road design criteria. Work during this phase involved a complete reevaluation of Phase II preliminary standards to take into account the comments and notations made by industry, engineers in our own organization, and the United States Bureau of Mines.

First priority was given to industry comments concerning changes in Phase II recommendations. Each company's suggestions were evaluated by an engineering team to ascertain their validity before incorporating them as a change. Recommended alterations considered a personal opinion with no supporting rationale were dismissed. There were few comments of this nature, however. Overall, recommendations of industry were well founded, and they were incorporated to make Phase II preliminary standards more refined.

The most constructive comments received from participating reviewers were concerned with two areas of the Phase II Design Criteria: Stopping Distance Curves, and Vertical Curve Design Requirements. Changes to original design criteria were therefore concentrated in these two areas.

New stopping distance curves were developed for all truck weight categories. Comments received from reviewing organizations illustrated that significant changes to brake system reaction time were necessary if calculations were to reflect SAE test conditions. The alterations resulted in curves which compare closely with results of actual brake performance tests.

Changes to vertical curve design requirements were recommended to present alternatives based on various eye heights. The original design requirements assumed the worst possible conditions. As pointed out by reviewers, however, a sliding scale for vertical curve lengths would be more appropriate since conditions at surface mines vary. To incorporate design flexibility, new vertical curve data were developed for driver's eye heights from six to twenty feet.

During this project phase, the validity of Phase II design criteria was reinforced in two ways. First, no review comments were received which suggested or even inferred that major alterations were necessary. Second, many requests for copies of Phase II were received from mining companies who had been exposed to it through various sources.

In summation, except for minor changes, Phase II standards were adopted as final surface mine haulage road design criteria. All data relevant to these criteria are presented in the main section of the report.

PHASE V - FINAL REPORT

After checking all data and finalizing design criteria, information was collated into this document as the final report.