Design of Surface Mine Haul Road

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Abstract

This Bureau for design of surface mine haul road covers such aspects of haul road design as road alignment (both vertical and horizontal), construction materials, cross slope, and drainage provisions. Traffic control and design of proper lane widths to promote safe vehicle movement are included, as are suggested criteria for road and vehicle maintenance and for runaway vehicle safety provisions. The aim of this publication is to provide those involved with the surface mine haul road design with a complete detail of recommended practices that, if implemented, will promote safer, more efficient haulage routes.

Keywords: cross-section, switchbacks, manoeuvring, haulageway, berms

I. INTRODUCTION

During the past 30 years, surface mine haulage equipment has developed from trucks capable of moving 20 tons of material to vehicles that 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 occur every year. A number of these mishaps can be attributed to operator error. However, far too many are caused by road conditions that are beyond the vehicle's ability to negotiate safely. With this history of haulage related problems in mind, the Bureau of Mines undertook a project to produce a design manual that would ultimately guide surface mine road planners toward safer, more efficient haulage systems. Design guidelines for each weight category, including velocity stopping distance curves, vertical curve controls, haulage way widths, curve widening, and spacing of runaway devices, drainage provision, are presented in this report.

II. FOUR BASIC LAYERS OF HAUL ROAD

- Sub-grade
- Sub-base
- Base course
- Surface course

Fig. 1: Typical haul road cross-section
III. STOPPING DISTANCE

Specifications for brake performance provided by most truck manufacturers are generally limited to an illustration of the speed that can be maintained on a downgrade by use of dynamic or hydraulic retardation through the drive components. Although this is an efficient method of controlling descent speed, it does not replace effective service brakes. When the retardation system fails, wheel brakes become the second line of defence to prevent vehicle runaway.

Recognising the need for effective brake performance standards, the Society of Automotive Engineers (SAE) developed test procedures and minimum stopping distance design criteria for different weight categories of large, off-highway trucks. It is uncertain how brake performance may vary with changes in grade, road surface conditions, initial speed, or, indeed, with brake system wear or contamination with dust, oil, water, etc.

To assess stopping distances for different grades and speeds, Kaufman and Ault (1977) developed an empirical formula based on the SAE stopping distance limitations:

\[ SD = \frac{1}{2} gt^2 \sin \theta + V_0 t + \left[ \frac{gt \sin \theta + v_0}{2g(U_{min} - \sin \theta)} \right]^2 \]

Where:
- \( SD \) = Stopping distance (m)
- \( g \) = gravitational acceleration (9.81 ms)
- \( t \) = elapsed time between driver’s perception of the need to stop and the actual occurrence of frictional contact at the wheel brakes (s)
- \( \theta \) = angle of descent (degree)

IV. SIGHT DISTANCE AND VERTICAL CURVE

Sight distance is defined as "the extent of the peripheral area visible to the vehicle operator." It is imperative that sight distance be sufficient to enable a vehicle travelling 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.

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

Vertical alignment in road design requires judicious selection of grades and vertical curves that permit adequate stopping and sight distances on all segments of the haul road. The relationship between operator sight distance and vehicle stopping distance is illustrated on Figure 2-1 for safe and unsafe conditions.

![Fig. 2: Sight distance diagram for horizontal and vertical curves](image-url)
V. SUPER ELEVATION

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

\[ e + f = \frac{v^2}{15R} \]

Where,
- \( e \) = superelevation rate (feet per foot)
- \( f \) = side friction factor
- \( v \) = vehicle speed (miles per hour)
- \( R \) = curve radius (feet)

VI. HAULAGE WIDTH

The haulage road designer must be very concerned about the road width. Sufficient room for manoeuvring must be allowed at all times to promote safety and maintain continuity in the haulage cycle. Width criteria for the travelled 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.

VII. SHARP CURVE DESIGN

Switchbacks or other areas of haulage ways requiring sharp curves must be designed to take into consideration the minimum turning path capability of the vehicles. 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. Widths required by vehicles in each weight category vary with the degree of curve.
Asphaltic concrete, crushed stone or gravel, and stabilized earth are the most practical construction materials for developing a haulage road surface that will insure maximum safety and operational efficiency. Because each of these materials has merits that are applicable to specific haulage situations, they are discussed separately in the following points.

**A. Asphaltic Concrete:**

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

**B. Compacted Gravel and crushed stones:**

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

**C. Stabilized Earth:**

Stabilized earth is defined as any soil that, through special procedures or additives, has been transformed from a natural 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.

**IX. CROSS SLOPE**

Cross slope is defined as the difference in elevation between the road edges which must be given consideration during haulage road design and construction. From the standpoint of reducing a driver's steering effort, a level surface would be most beneficial. The recommended rate of cross slope for surfaces normally constructed on mine haulage roads is a 1/4 inch to 1/2 inch drop for each foot of width. Cross slopes of one quarter inch per foot are applicable to relatively smooth road surfaces that can rapidly dissipate surface water.
Table – 1
Road gradient for max and min crossfall

<table>
<thead>
<tr>
<th>Road Gradient</th>
<th>Minimum crossfall- low rainfall or smooth surface</th>
<th>Maximum crossfall- high rainfall or rough surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3%</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>4-6%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>6-10%</td>
<td>1%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

X. Rules of Thumb for Safety Berm Construction

A. Recommended Height:
- Minimum of half the wheel height for conventional berms.
- Equal to tire height for boulder-faced berms.

B. Recommended Placement:
- Along the edge of the dump area
- Along all haul road edges with gaps for drainage
- Check your local mining regulations

XI. Drainage Provisions

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

Fig. 6: Drainage problem on road

XII. Ditch Configuration

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

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

XIII. Dust Control

- Watering removes dust hazard and maintains compaction.
- Use “checkerboard” or “spot” intermittent pattern on slopes to reduce slippage risk during braking grades.
- “Spot” watering works well for areas with limited water supply.

XIV. Dust Suppressants

- Emulsified asphalt
- Calcium chloride
- Calcium lignosulfonate
- Surfactants
XV. MEASURES TO REDUCE HAUL ROAD DETERIORATION

- Keep ditches and culverts clear of obstructions to minimize potential erosion factors.
- Use different areas of the haulage lane to avoid rutting
- Load vehicles within limits to prevent spillage
- Minimize dust problems with water trucks or sprinklers
- Employ support equipment (Motor Graders, Wheel Dozers, etc) to maintain cross slopes, remove spills, and fill and smooth surface depressions.

XVI. CONCLUSIONS

Surface mining, regardless of mineral commodity being sought through its inception, is a highly competitive business and, like any other business, a beneficial cost to profit ratio must be maintained. It is important to insure that cost efficiency does not impinge upon the intangible aspects of mining such as operator safety and proper equipment utilization. From the sites selected as being representative of typical mining operations, it became apparent that in many instances haulage road construction is not considerate of operator safety; not as a result of disregard, but rather a lack of awareness of correct design principles. The most obvious disparity between existing haulage road construction practices and criteria recommended for safety lies in the areas of alignment and drainage.

REFERENCES