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 the equipment is or is not safe to operate, can best be determined by maintenance personnel.

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 haulage 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 criterion 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 13 and 14, distances between runaway-truck safety provisions are given for various road grades and maximum permissible velocities or terminal vehicle velocities. 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 13 and 10 mph for table 14. Although operating speeds may vary considerably depending on policies at each mine, 10- and 20-mph initial velocities constitute a sufficient range for the grades given.

TABLE 13. - Distance between runaway truck safety provisions, feet

(Initial speed at brake failure is 20 mph)

Equivalent downgrade, percent	Maximum permissible vehicle speed or terminal speed at entrance to safety provision, mph							
	25	30	35	40	45	50	55	60
1	752	1,671	2,757	4,010	5,431	7,018	8,772	10,694
3	251	557	919	1,337	1,811	2,340	2,924	3,565
5	151	335	552	802	1,086	1,404	1,755	2,139
7	108	239	394	573	776	1,003	1,254	1,528
9	84	186	307	446	604	780	975	1,189
11	69	152	251	365	494	638	798	973
13	58	129	212	309	418	540	675	823
15	51	112	184	268	362	468	585	713

NOTE.--Equal to haulage road downgrade (percent divided by 100) minus roadway rolling resistance (pounds per ton).

TABLE 14. - Distance between runaway truck safety provisions, feet

(Initial speed at brake failure is 10 mph)

Equivalent downgrade, percent	Maximum permissible vehicle speed or terminal speed at entrance to safety provision, mph							
	15	20	25	30	35	40	45	50
1	418	1,003	1,755	2,674	3,760	5,013	6,433	8,021
3	140	335	585	892	1,254	1,671	2,145	2,674
5	84	201	351	535	752	1,003	1,287	1,604
7	60	144	251	382	537	716	919	1,146
9	47	112	195	297	418	557	715	892
11	38	92	160	243	342	456	585	730
13	33	78	135	206	290	386	495	617
15	28	67	117	179	251	335	429	535

NOTE.--Equal to haulage road downgrade (percent divided by 100) minus roadway rolling resistance (pounds per ton).

Computation of values was accomplished through the formula

$$S = \frac{\Delta V^2}{2g\ (\sin\theta - b)},$$

where S = distance traveled until "maximum permissible vehicle speed" or entrance to runaway truck safety provision is reached, feet;

ΔV = difference in velocity between travel speed at loss of braking and retardation and the speed of travel at safety provision, feet per second;

$g = 32.2\ \text{fps}^2$;

θ = angle of descent, degrees;

and b = coefficient of rolling resistance (expressed as a mean value of 0.05 to encompass the majority of mine road and tire situations), 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 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 nonconsolidated screened fines and placed at crucial points within the haulage operation. If the brakes and retarder of a vehicle fail during operation, the driver alines the vehicle so that it straddles the collision berms, and rides 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 sections and the height of the berm in relation to the undercarriage of the vehicle. The spacing between berms must be sufficient to allow a runaway vehicle to aline itself with the berm before impact. If properly alined, 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 alined, 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 26 and 27.

A table is provided with figure 26 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 vehicles of different sizes 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.

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.

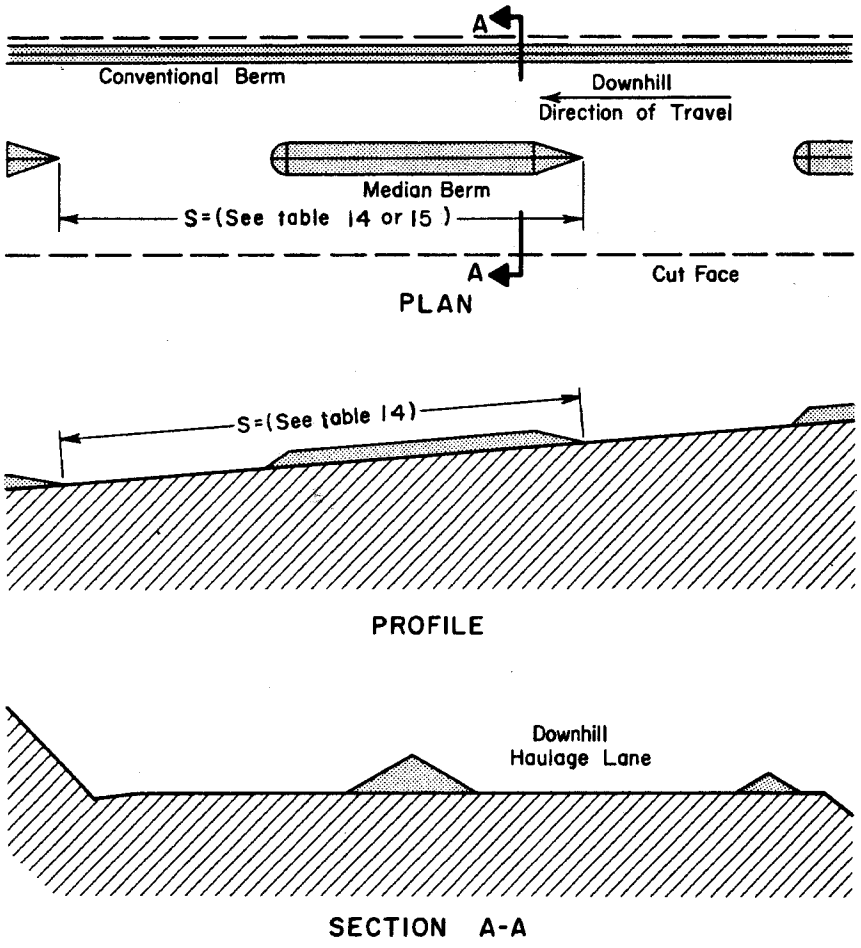
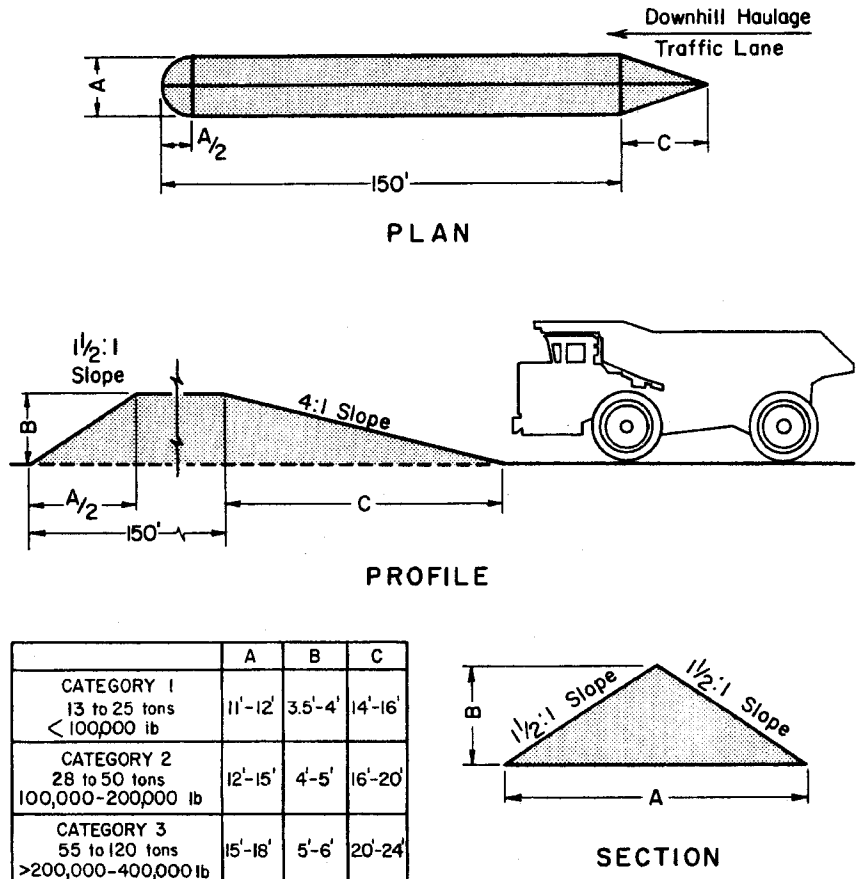


FIGURE 26. - Runaway-vehicle collision berms.



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

FIGURE 27. - Median application of collision berms.

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 and before the vehicle has accelerated beyond a reasonable speed.

At one mine site in Australia with extremely severe grades (8% to 12%), these median collision berms have been in use for 3 years. Within that time, runaways have occurred on an average of once every 2 to 3 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 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, the berms must be 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 roadbed 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 haulageway 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 haulage 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 15 lists maximum horizontal curves as related to vehicle entrance speeds and superelevations. Superelevations less than 0.06 fpf or greater than 0.10 fpf are not recommended due to difficulties with curve development and drainage.

TABLE 15. - Maximum permissible horizontal curves for escape lane entrance

Superelevation, feet	Vehicle speed at escape lane entrance, mph					
	40		45		50	
	Degrees	Radius, ft	Degrees	Radius, ft	Degrees	Radius, ft
0.06/1.....	12	477	10	596	8	716
0.08/1.....	13	441	10	578	8	716
0.10/1.....	14	409	11	235	9	637
	55		60		65	
	Degrees	Radius, ft	Degrees	Radius, ft	Degrees	Radius, ft
0.06/1.....	6	930	5	1,146	4	1,432
0.08/1.....	7	835	6	955	5	1,146
0.10/1.....	7	796	6	955	5	1,146

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 16 for various vehicle categories.

TABLE 16. - Recommended escape lane widths

Vehicle weight, pounds	Minimum width, feet
<100,000.....	15
100,000 to 200,000.....	18
>200,000 to 400,000.....	22
≥400,000.....	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 17 relates escapeway lengths to vehicle entrance velocities and percent grade of the escape lane. The formula used in computing escapeway length is

$$S = \frac{V^2}{2g\ (\sin\theta + b)}, \tag{7}$$

where S = required length of escape lane for deceleration from entrance speed to a full stop, feet;

V = entrance speed from tables 13 and 14, fps;

g = 32.2 fps^2;

b = coefficient of rolling resistance, dimensionless;

and θ = angle of ascent, degrees.

It is important to note that a coefficient of rolling resistance of 0.2 or 400 ppt (pounds per ton) was used to compute the 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 haulage 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 materials are best suited for roadbed use in deceleration areas since these materials tend to retard vehicle movement. It should also be noted that distances given in table 17 are to be applied from the end of the entrance area; that is, at the end of the horizontal and vertical curves. Also, surface material characteristic of that used on the main haulage road should be employed to the end of these curves.

TABLE 17. - Length of escape lane, feet

Grade of escape lane, percent	Vehicle speed at entrance to escape lane, mph				
	15	25	35	45	55
20.....	19	53	103	170	253
15.....	22	60	117	194	289
10.....	25	70	137	225	337
5.....	30	84	164	271	405

NOTE.--Assumes coefficient of rolling resistance is 400 ppt or 0.2.

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

Stopping

After a vehicle has been slowed through the deceleration grade and high-rolling-resistance roadbed, 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:

1. A level section of roadway at the end of the escape lane.

2. 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.

3. 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.

4. Road Bumps.--Road bumps, whether constructed by excavating trenches or establishing mounds across the lane, retard vehicle movement by trapping

in "designed ruts." Mounds or bumps must be thoroughly compacted to insure integrity under the weight of a truck.

5. Manual Steering.--If it is not practical or possible to do any of the foregoing, 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 28-30 depict typical plan, profile, and section views of an emergency escape lane.

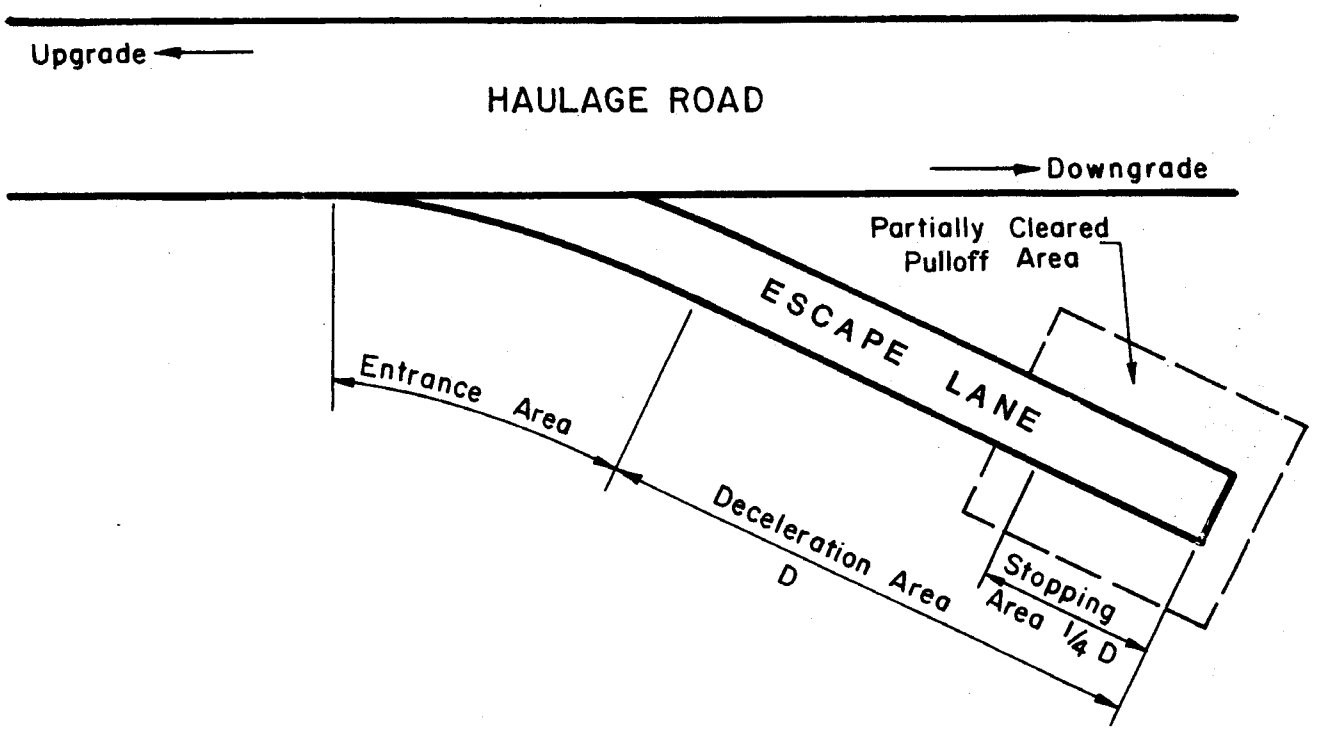


FIGURE 28. - Plan of haulage road escape lane.

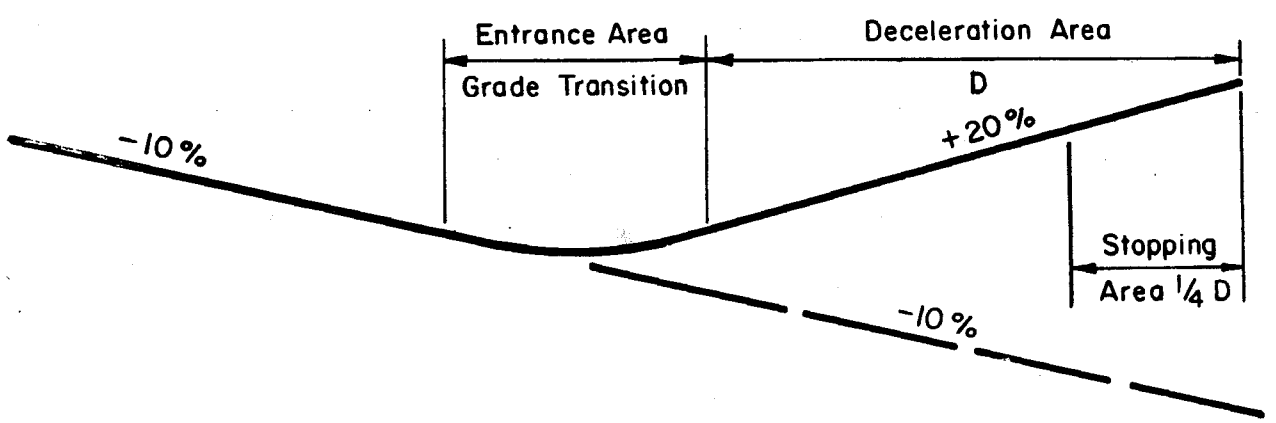


FIGURE 29. - Profile of haulage road escape lane.

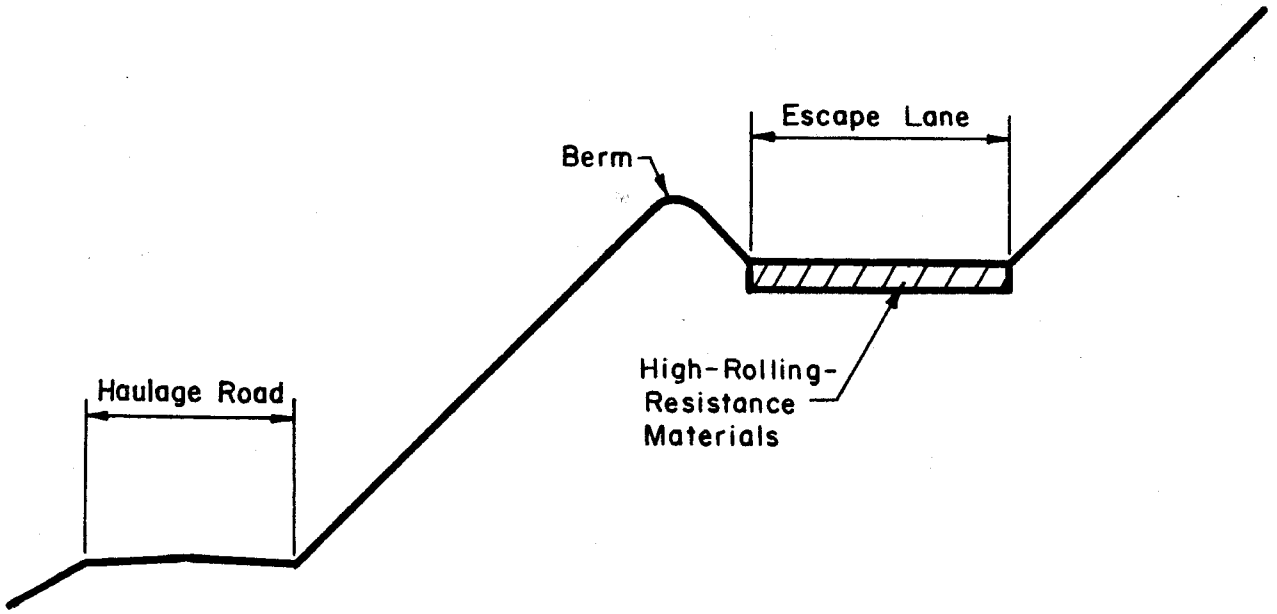


FIGURE 30. - Cross section of haulage road escape lane.

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 alinement and drainage.

Sustained haulage road gradients at many eastern surface mines exceed the 10% maximum stipulated for safety in the Haulage Road Design Study. In most cases, the rationale for constructing a greater gradient is obvious--to keep haulage distances as short as possible through steep mountainous terrain. Superelevation on curves, tangent roadway cross slopes, and vertical curves at grade crests are other design factors seldom applied.

In general, application of adequate roadway drainage provisions are also lacking. Severely scoured and rutted road surfaces, roadside ditches eroded to excessive depths, water-filled depressions in the roadway, and unstable or slippery road segments are common sights throughout the eastern surface-mining region.

As illustrated by table 18, costs associated with haulage road construction to remedy safety hazards such as those mentioned can be considerable. At the surface coal mine sites, for example, construction expenditures exceed $200,000. It must be noted, however, that the haulage roads of each of the