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Characteristics of Trucks Operating on Grades

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The many changes in truck engine displacement and power have indicated a need to reassess current climbing-lane design practices. This study presents new data characterizing trucks (and combinations) on grades. Field data collected at several locations in central and east Texas were analyzed, and speed versus distance curves were developed for a range of grade profiles. From an evaluation of the speed versus distance curves for the designated critical-truck class, composite critical-length-of-grade charts were derived for an 88-km/h (55-mph) approach speed and a range of speed-reduction values.

The criteria currently used for the design of climbing lanes for trucks have been developed over the last four decades and are based primarily on theoretical formulations and limited field observations.

This paper presents the findings of a study that obtained new field data about the operating characteristics of trucks on selected grades and related these data to geometric design standards for highway grades, with particular emphasis on the capacity and safety aspects of vehicle climbing lanes. The result of the project was the development of revised design charts relating the length and percent of a grade to the performance of a vehicle on that grade.

Most of the previous research on truck hill-climbing ability has been directed toward measurement of the elements that affect the performance of the vehicle. The roadway conditions, including rolling resistance, have been studied by Taragin (1) in his theoretical equation, and traffic conditions have been studied by Schwender, Normann, and Granum (2). The current American Association of State Highway and Transportation Officials (AASHTO) policy for the design of truck climbing lanes is based principally on data collected in 1954, and most states currently use a modification that accounts for special state and regional characteristics (13).

The performance of a vehicle operating on a highway is a function of the numerous variables associated with the principal elements that govern vehicular motion. These elements are the vehicle itself, the roadway and the environment in which the vehicle operates, and the behavior of the vehicle operator. The identification and evaluation of these elements provided an additional framework for the field study. Each element was described and arrayed for analysis in the mathematical modeling phase of the study.

GENERAL EVALUATION OF VEHICLE GRADEABILITY

Because of the limited scope of the conventional force and energy equations, the mathematical models used in previous research have not been entirely successful in evaluating the effects of these variables in relation to actual vehicle performance. However, the models might be improved if new experimental data that represent the actual vehicle operating characteristics under a wide variety of roadway and environmental conditions were available (3). With this information, the performance characteristics of representative vehicles could be modeled, and the present design criteria for grades could be evaluated.

Collection of the field data necessary to adequately identify the operating characteristics of heavy vehicles on grades is a complex operation because of the numerous combinations of variables involved. However, a majority of the variables can be represented by field data from three major areas: (a) the pertinent physical characteristics of the vehicles under observation, (b) the speed versus distance profiles of the vehicles at selected field sites, and (c) the geometric and environmental external conditions under which the vehicles operate.

Table 1. Roadway parameters of test grades.

Roadway Parameters	Grades[a] A	B	C	D	E
Length of grade, m					
Approach	244	122	244	183	213
Grade section	747	762	1737	823	1006
Recovery area	152	107	244	213	183
Steepness of grade, %					
Approach	0	0	-0.5	-0.5	0
Grade section[b]	5	3.4	2.6	3.7	2.6
Recovery area	0	-0.5	-0.5	-0.5	-0.5
Horizontal alignment[c]					
Cross section					
Number of lanes	4	4	4	4	4
Lane width, m	3.35	3.35	3.35	3.01	3.35
Shoulder width, m	–	2.44	2.44	2.44	2.44
Median width, m	–	9.14	6.01	6.01	6.01

Note: 1 m = 3.28 ft.

[a]Grade A is on US-183, and grades B, C, D, and E are on US-59.
[b]Maximum average cumulative grade.
[c]All test sites have essentially straight horizontal alignments.

Vehicle Characteristics

There are many characteristics in the makeup of a vehicle that can directly influence its operating characteristics on a grade. The three principal ones are (a) the vehicle type or classification, (b) the gross weight of the vehicle, and (c) the power of the vehicle. It is not possible to evaluate every identifiable vehicle factor in an experimental program, but representative information about these three areas should be obtained.

Speed Versus Distance Profiles

The second major group of data needed in an experimental program should be the speed versus distance profiles of representative vehicles. From these profiles, relations between the vehicle weight, the percent grade, and the performance of the vehicle on the grade can be established. The speed characteristics that should be observed are

1. The speed of the vehicle on entering the grade,
2. The speed-reduction rate on successive sections of the grade (the deceleration rate),
3. The minimum steady-state speed reached during operation on the grade (the crawl speed), and
4. The acceleration characteristics of the vehicle on adjacent level or downgrade areas.

External Conditions

The third group of data needed should be records of the external factors that influence the operation of the heavier vehicles. The factors to be identified are the features of the roadway over which the test was run, the traffic and land use conditions at each test section, the climatic conditions at the time of each test, and the characteristics of the driver of each vehicle.

SITE SELECTION

The test sites were selected and characterized by the basic parameters associated with the roadway, the traffic, and the roadside. The search was concentrated in an area surrounding Austin, Texas, to minimize the cost. After an evaluation of several grades, several test sites were selected.

Roadway Parameters

Table 1 gives the roadway parameters for the grades selected. Each grade was divided into three distinct areas—approach, grade section, and recovery area—for the analysis of vehicle performance. (Ideally, the approach should be level so that the entry or approach speed for the vehicles will be relatively constant.)

The grade (test) section, over which vehicle performance was most closely monitored, begins where the grade actually begins, as determined from the profile plans, which were obtained from the Texas State Department of Highways and Public Transportation (SDHPT). The grade section is best described by the average cumulative grade (ACG) since this approximates the total effect of the grade on an ascending truck. The ACG is determined by computing the average grade for each 60-m (200-ft) section and then averaging this for the entire length.

Traffic Parameters

Speed estimates and average daily traffic compositions were obtained for each site. In 1972, 31 percent of the southbound vehicles on US-183 were combinations; the majority (80 percent) of them were five-axle, tractor semitrailer combinations. About 35 percent of the vehicles traveling on US-59 were trucks; of these, 42 percent (15 percent of the total vehicles) were combinations, and many carried logs or pulpwood.

Roadside Parameters

The conditions along the side of a roadway—the abutting land use, visual stimuli, and conflicting traffic flows—can indirectly or directly affect the operation of a vehicle by distracting or otherwise influencing its driver. At grade A, on US-183, the land on both sides of the roadway is agricultural, and there is a small gravel driveway at the top of the hill, past the study zone. There is a T-intersection with a seldom-traveled, farm-to-market roadway at the base of the grade, 90 m (300 ft) from the beginning, but this has little effect on the roadway since there is adequate stopping sight distance in both directions. There are no large signboards along the grade to distract the driver. The opposing traffic may influence vehicles in the inside lane because the four lanes are undivided, but all of the vehicles in this study were in the outside lane. Thus, it is assumed that the opposing traffic flow did not affect the vehicles tested on grade A.

On US-59, grades B and D have abutting land use that is agricultural. There is a light commercial area at the top of grade C that is visible from almost all points. Grade E has light commercial establishments along most of the grade, and there are crossovers in the median, and driveways and signs along all four grades. Thus, it is assumed that these interruptions and distractions will have some influence on driver behavior. Because of these differing effects on driver behavior, grade A was analyzed separately from grades B, C, D, and E.

DATA COLLECTION PROCEDURES

The techniques and instrumentation considered for this experimental program were evaluated by a number of criteria. In general, the equipment had to be relatively economical, practical for operation by project personnel,

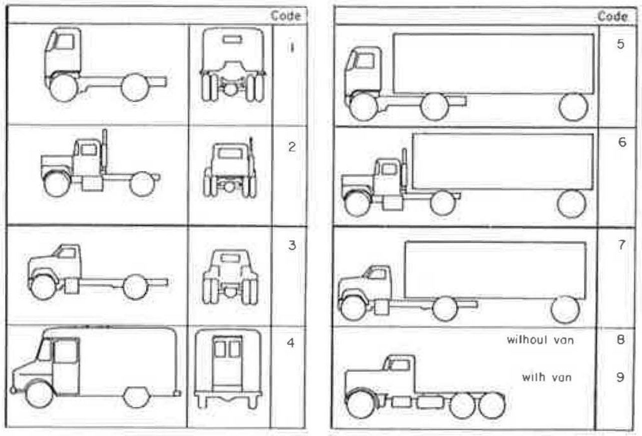


Figure 1. Truck classification by frontal configuration.

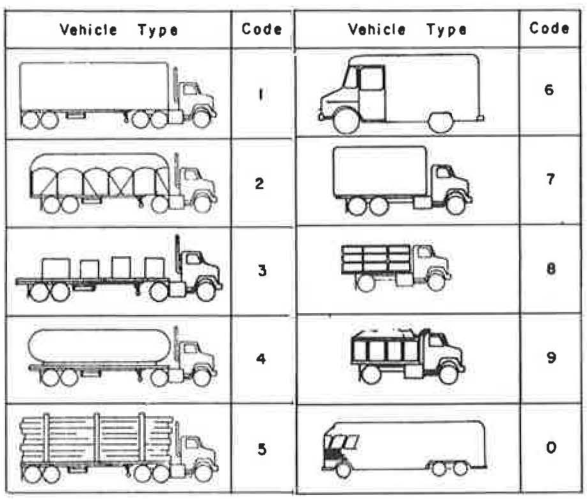


Figure 2. Truck classification by side configuration.

reliable, and accurate. It also had to be flexible and mobile enough to be used at different field sites and adaptable to the various conditions that might exist. As the system was going to be used for long periods of time, the availability of replacement equipment and the probable maintenance costs were also considered. Finally, the system had to be inconspicuous to the vehicle drivers so that the vehicles under test would be driven in a natural manner.

Speed-Reduction Profile

The three principal elements of data necessary for the construction of the speed versus distance profiles for each vehicle are (a) the speed reduction (deceleration) of the vehicle, (b) the entry speed for each grade, and (c) the minimum speed (crawl speed) reached on the grade.

The speed versus distance profile for each vehicle observed was determined by monitoring the time versus position relation for the vehicle as it progressed through the test section. Several systems were examined and evaluated (4) for possible use in obtaining this information. Two methods proved to be feasible: a photocell technique and an automobile-following method. A comparative study between the automobile-following technique and the photocell procedure showed that their accuracies were equal, but that the automobile-following procedure was much easier to adapt to local field conditions (12).

Physical Characteristics of Vehicles

The license numbers of the observed vehicles that were registered in Texas were submitted to the State Motor Vehicle Division (MVD) for a computer search of registration records. A typical registration printout gives the following useful information about a vehicle: (a) its empty weight, (b) its gross weight, (c) its age (model year), (d) its manufacturer, (e) its classification, (f) its identification number, (g) the name and address of its owner, (h) a number identifying its title on microfilm records, and (i) whether or not the engine is diesel (trucks). The microfilm records were then searched to determine the individual vehicle model numbers.

Vehicle Classification

From field observation and MVD records, each truck was assigned a particular classification according to its axle configuration. The following classes, which are based on SDHPT and AASHTO standards, were used:

Class	Description
Single-unit trucks	
SU-2A	2 axles, single wheels
SU-2D	2 axles, dual rear wheels
SU-3A	3 axles, all single wheels
SU-3D	3 axles, tandem dual rear wheels
Truck combinations	
2-S1	2-axle tractor, single-axle semitrailer
2-S2	2-axle tractor, 2-axle semitrailer
3-S1	3-axle tractor, single-axle semitrailer
3-S2	3-axle tractor, 2-axle semitrailer

However, because there are various models, types, loading configurations, and sizes within each axle class, each vehicle was also classified by its frontal and side configurations.

Figure 1 shows the classification by frontal configuration. The configuration is based on tractors pulling vans that are, on the average, 0.9 m (3 ft) higher than the cab and on tractors with trailers other than vans. Usually, other trailer combinations are lower than the tractor, which makes the frontal configuration of the tractor the governing factor.

Figure 2 illustrates the various side configurations. Since the vehicle lengths vary only slightly within a particular combination class, the side classifications are designed to include several axle groups each. The vehicle-type codes are described below.

Code	Description
1	Truck combinations with van trailers or cattle trailers
2	Truck combinations with trailers with stake sides
3	Truck combinations with flatbed trailers
4	Truck combinations with tank trailers
5	Truck combinations with logs
6	Single-unit truck vans
7	Single-unit, chassis-with-cab trucks with vans
8	Single-unit trucks with flatbeds or stake sides
9	Single-unit dump trucks (including concrete mixers)
0	Buses

Vehicle Gross Weight

A system that weighs vehicles in motion was used to determine the gross weight of each truck and truck combination in the field. This in-motion weighing system, which was developed by the Center for Highway

Research at the University of Texas at Austin and the SDHPT for use by its Planning and Research Division (5), uses special wheel-load transducers. Measurements of dynamic wheel forces are obtained and can be used to estimate the weight of a vehicle moving at speeds of up to 113 km/h (70 mph) with an accuracy within 10 percent. The use of this technique does not influence driver behavior, allows on-site weighing, and permits 100 percent sampling.

Basically, the system consists of two loop detectors and two loading pads placed in the outside lane of travel. The loops and scales are connected to a digital computer in a van beside the road. A display console with a special keyboard allows the van operator to classify each truck according to axle arrangement and type. The system information is stored on magnetic tape and later transferred to a computer listing.

The weighing-in-motion system produces the following information for each vehicle: (a) its speed, (b) its length, (c) the number of axles, (d) the distance between each two axles, (e) the gross weight of each axle, and (f) the gross weight of the vehicle.

Vehicle Power Rating

Gross power is the maximum power output of an engine without any encumbrances, and net power is the maximum power output of the engine as installed in the vehicle. Net power includes the effects of such encumbrances as the fan belt, alternator, water pump, and other standard accessories, and in recent years, any emission-control devices. If an engine is older or in a poor state of repair or both, the net power will be affected accordingly.

Because of all of the variations in standard equipment and the differences in emission controls and in maintenance procedures, it is difficult to establish a specific net power for any group of vehicles. Most manufacturers advertise and guarantee a specific gross power output for an engine, but a net power rating is available only theoretically. However, the gross-weight-to-power ratio on which AASHTO bases climbing-lane design theory uses net power.

For this reason, net power was used in the analysis in this study, and it had to be calculated for almost every vehicle. With a few exceptions, the annually published specifications for vehicle engines give gross power. The supplement to the Society of Automotive Engineers handbook (6) suggests reducing gross power by 10 percent to obtain net power. However, in view of the variations in standard accessories on different models of vehicles, the higher emission-control standards for new engines, and the decreasing state of repair on older vehicles, a standard 15 percent reduction in gross power was used to calculate the net power for the vehicles tested. This factor provides a margin of safety for design purposes. [A good discussion of the differing theories for using gross or net power has been given by the Western Highway Institute (7, 8).]

Driver Variables

The driver is probably the most difficult element to characterize in developing a complete speed profile for a particular class of vehicle, although truck drivers generally should not have large variations in experience and ability. In the attempt to identify more clearly the human aspects of truck operating characteristics, the field-data collection procedures were designed to reduce the influence on the driver of any awareness that he or she was being monitored and to provide a sample of driver age and experience. Additional information, such as the ages and years of experience of the drivers, was obtained from a questionnaire mailed to them.

DATA ANALYSIS

A stepwise multiple regression analysis was performed on the data. The procedures followed in preparing and performing the analysis included (a) a sample size calculation, (b) consideration of the variables to be analyzed, (c) determination of speed-history groups, (d) statistical multiple regression analysis to determine best-fit equations, (e) selection of the equations that best predict and describe the behavior of vehicles on grades, and (f) speed versus distance and critical-length-of-grade curve plotting.

Sample Size and Variables

A sample size of 22 vehicle speed histories was shown to give results that fell within a 95 percent confidence interval.

The factors used in characterizing the hill-climbing ability of vehicles were developed from past research and field observation. A total of 11 factors were analyzed:

1. Length of grade,
2. Percent of grade,
3. Approach speed,
4. Weight of the vehicle,
5. Power of the vehicle,
6. Frontal area of the vehicle,
7. Side area of the vehicle,
8. Length of the vehicle,
9. Experience of the driver,
10. Age of the driver, and
11. Age of the vehicle.

A stepwise regression analysis was performed on the data; in it the speed profile of each vehicle was entered as the dependent variable (Y), and the remaining factors or variables were entered as independent variables (X_1, X_2, $X_3, \ldots, X_n$). The length of the grade was entered on a cumulative basis with respect to the starting point, which coincided with the vertical point of curvature. The percent of the grade was entered as an average percent weighted with respect to the point of curvature. The approach speed, the gross weight of the vehicle combination, and the net power of the vehicle were entered directly. The frontal area and the side area were each given as a relative number, from 0 to 9, that depends on the size of the vehicle and its type. The last three variables—driver experience, the age of the driver, and the age of the vehicle—were given in years. Since it was not possible to obtain sufficient information about the ages of the drivers and their experience for all of the vehicles and sites, these factors were included in a reduced sample.

Predictive Equations

The different vehicle categories were tabulated before the data analysis. Vehicle data from each site were first considered separately, and then data for similar vehicle categories from two or more sites were combined. Table 2 summarizes the predictive equations developed, their characteristics, the number of independent variables entering each equation, and the weighted percent grade for which each was developed. To combine data for similar vehicles on two or more grades into one equation, it was assumed that the slight horizontal curvature differences among the grades would not have differing

Table 2. Summary of predictive equations for trucks on grades.

Equation Number	Grade	Type of Vehicle	Characteristics: Sample Size	R^2	Coefficient of Variation (%)	Length of Section (m)	Weighted Percent Grade	No. of Variables in Equation
1	A	SU-2D	69	0.7721	9.9	1052	4.8	16
2[a]	A	2-S2	19	0.9818	5.4	1052	4.8	13
3	A	3-S2	37	0.8944	6.85	1052	4.8	29
4	A	3-S2	127	0.8309	10.84	1052	4.8	21
5	B	3-S2	37	0.7837	9.39	762	3.5	9
6	C	3-S2	37	0.8838	9.66	1737	2.6	15
7[b]	D	3-S2	34	0.7106	9.96	823	3.7	18
8[a]	E	3-S2	20	0.6463	8.56	1006	2.6	18
9[a]	A B, C, and D	2-S1	15	0.8653	9.6	927	4.9	10
10	B, C, and D	2-S2	43	0.8657	11.23	1094	3.1	6
11	B	Log	37	0.8275	9.2	762	3.5	14
12	C	Log	37	0.9244	8.5	1737	2.6	23
13[b]	D	Log	31	0.7824	10.7	823	3.7	12
14[c]	C	3-S2	26	0.9178	7.98	884	-2.3	7

Note: 1 m = 3.28 ft.

[a] Not considered, sample size too small. [b] Not usable, equation invalid. [c] Downgrade.

Table 3. Range of percent grade for test grades.

Grade	Average Percent Grade[a]	Distance (m)	Comments
A	6.00	457	Upgrade
	5.00[b]	914	Upgrade
B	5.00	457	Upgrade
	0.00	305	Level
C	2.50	1219	Upgrade
	3.00	975	Upgrade
	-2.87[c]	884	Downgrade
D[d]	4.00	518	Upgrade

Note: 1 m = 3.28 ft.

[a] Average percent grade of tangent section only.
[b] Grade varies from 4 to 6 percent; 5 is used as an average.
[c] Grade varies from -2.35 to -3.387 percent; -2.87 is used as an average.
[d] Not used after analysis of speed profiles (equation inadequate).

effects on the operating characteristics of the vehicles.

After the data were arrayed, 431 truck-speed histories were available for analysis. The 14 equations summarized in Table 2 were analyzed, and such factors as R^2, the sample size, the length of the grade, the vehicle type, and the coefficient of variation were evaluated before selecting equations to represent the operating characteristics of trucks on upgrades (11).

Equations 1, 3, 4, 5, 6, 10, 11, and 12 were selected. They represent the vehicle operating characteristics of single-unit trucks and semitrailers. Two of the equations, 11 and 12, represent log trucks. All of the equations have a correlation (R^2) above 83 percent. The coefficient of variation is within 10 for all but one equation.

These equations were developed by using a range of grade of 0 to 6 percent and a length of grade of 0 to 1980 m (0 to 6500 ft). A weighted-average percent grade of the tangent section only and the corresponding distance were used to represent the characteristics of each site. The resulting range of percentage and length for each site are given in Table 3.

Speed Profiles

From the information given in Table 3 and weighted-average grade profiles for the entire length of each grade, curves were plotted to apply the predictive equations. The average values for the variables in each equation are given in Table 4. The greatest total speed losses were those of 3-S2 semitrailer combinations and log trucks, which are characterized by equations 3, 5, 6, 11, and 12.

Figure 3 represents truck behavior over the selected upgrades given in Table 3 and provides direct comparisons between vehicles with different weight-to-power ratios [130, 228, 230, and 243 kg/kW (213, 375, 378, and 400 lb/hp)], varying grades (2.5 to 6 percent), and current design criteria versus those developed in this research. The family of curves compare speed versus distance and emphasize the differences between the current and the newly developed relations. The importance of approach speed can be seen by comparing the initial (or entering) speeds given.

The average gross-weight-to-net-power ratios of 3-S2 combinations and log trucks on US-59 are 218 and 324 kg/kW (359 and 385 lb/hp) respectively. The average ratio for all 3-S2 combinations on US-183 is 140 kg/kW. Present design procedures are based partly on the assumption that vehicle performance is a function of the weight-to-power ratio, but an analysis of Figure 3 shows that differences in the rates of deceleration on the upgrades depend mainly on the effect of the entering speed.

CRITICAL LENGTH OF GRADE

The term critical length of grade indicates the maximum length of a designated upgrade on which a vehicle can operate without an unreasonable reduction in speed. From the data given in Figure 3, a series of critical lengths of grade for 8, 16, 24, and 32-km/h (5, 10, 15, and 20-mph) reductions in speed, based on approach speed ranges rather than on specific speeds, are shown in Figures 4 and 5. The figures cover two speed ranges [79 to 87 and 84 to 100 km/h (49 to 54 and 52 to 62 mph)], are representative of trucks with weight-to-power ratios of approximately 225 and 234 kg/kW (370 and 385 lb/hp), and assume a reasonably level approach. Figure 4 was developed from log-truck speed profiles. These graphs are representative of all trucks, since they are based on the operating characteristics of the most critical trucks. The present critical-length-of-grade design curves are given in Figure 6 for comparison.

The procedure for the use of these graphs can be illustrated by reference to Figure 4. If an average percent grade of 4 and an approach speed between 79 and 87 km/h (49 and 54 mph) are assumed, the corresponding critical length of grade for a 24-km/h (15-mph) speed reduction is 378 m (1240 ft). If the approach speed is in a different range, the critical length of grade will also be different. The table below gives a comparison of the critical lengths of grade derived by the use of Figure 4 and an entering speed range of 79 to 87 km/h (49 to 54 mph), Figure 5 and an entering speed range of 84 to 100 km/h (52 to 62 mph), and Figure 6 and an entering speed of 76 km/h (47 mph) for a 24-km/h (15 mph) speed reduction (1 m = 3.28 ft).

Table 4. Characteristics of trucks by vehicle type and grade used in developing speed versus distance curves.

			Vehicle Characteristics						
Equation Number	Grade	Type of Vehicle	Approach Speed (km/h)	Net Power (kW)	Gross Weight (kg)	Weight/Power (kg/kW)	Age of Vehicle (years)	Frontal Area[a]	Side Area[a]
1	A	SU-2D	93	124	8 209	66	5.89	3.5	6.4
2	A	2-S2	90	139	15 057	107	3.76	5.3	2.1
3	A	3-S2	99	166	21 023	130	3.6	5.3	2.0
4	A	3-S2	97	158	21 578	140	4.15	4.6	2.3
Avg					21 301				
5	B	3-S2	97	151	34 345	223	2.46	2.9	3.9
6	C	3-S2	88	149	33 936	228	2.66	3.2	3.6
7	D	3-S2	100	152	33 781	223	2.6	3.2	3.6
8	E	3-S2	89	163	31 888	199	2.85	4.6	2.3
Avg					33 488	218			
9	B, C, and D	2-S2	80	139	30 887	223	4.02	3.0	5.0
10	B	Log	88	142	33 937	238	3.24	2.9	—
11	C	Log	77	145	34 138	230	3.14	2.8	—
12	D	Log	93	145	33 912	234	3.13	2.9	—
Avg					33 996	234			
13	A	2-S1	80	118	12 382	105	5.17	3.0	5.0
14	C	3-S2	53	151	34 602	230	2.61	3.4	3.4

Notes: 1 km/h = 0.62 mph; 1 kW = 1.34 hp; 1 kg = 2.204 lb.
Values represent an average (the mean) of those vehicles included in the study.
[a]Given on a scale from 0 through 9.

Figure 3. Speed versus distance curves for typical heavy trucks as compared with present design curves.

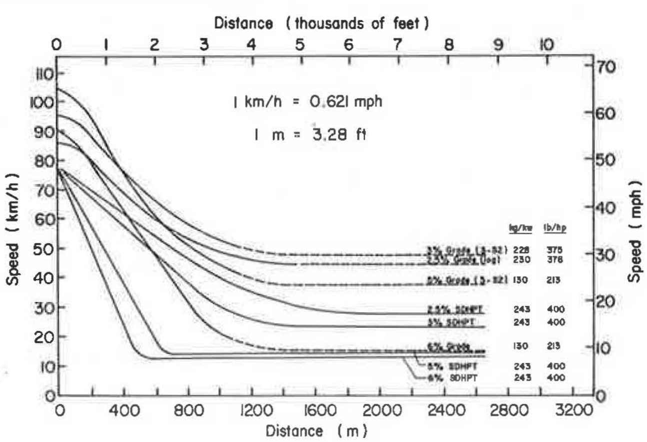


Figure 5. Critical lengths of grade for trucks with a weight-to-power ratio of 225 kg/kW (370 lb/hp) and an approach speed range of 84 to 100 km/h (52 to 62 mph).

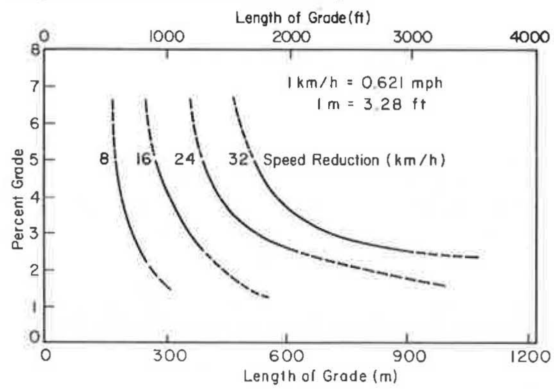


Figure 4. Critical lengths of grade for trucks with a weight-to-power ratio of 234 kg/kW (385 lb/hp) and an approach speed range of 79 to 87 km/h (49 to 54 mph).

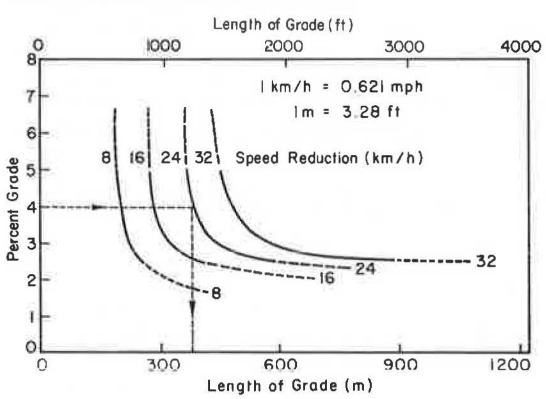
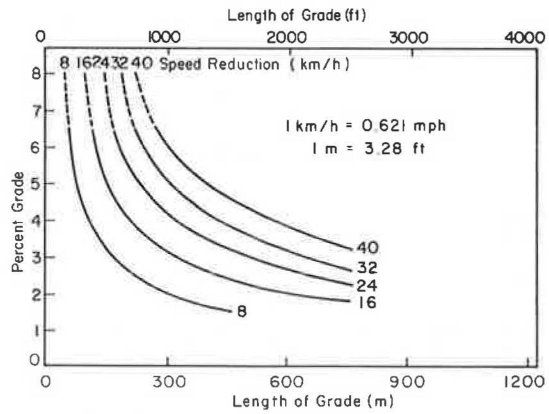


Figure 6. Current critical lengths of grade for trucks with a weight-to-power ratio of 243 kg/kW (400 lb/hp) and an approach speed of 76 km/h (47 mph).



Grade (%)	Critical Length of Grade (m)		
	Derived From Figure 4	Derived From Figure 5	Derived From Figure 6
3	1420	1700	1680
4	1240	1420	1100
5	1190	1280	750
6	1180	1200	600

The relations among approach speed, critical length of grade, and percent grade are not consistent between the two speed range categories, which confirms earlier findings that the distance and the percent grade are very important elements in any speed profile for trucks and truck combinations.

From these analyses, composite charts were developed for typical heavy trucks using an approach speed of 89 km/h (55 mph). Figure 7 shows the critical lengths of grade at different percent grades together with the associated speed reductions for a range of 8 to 32 km/h (5 to 20 mph) in 8-km/h (5-mph) increments.

Figure 8 shows the speed versus distance relations for a range of upgrades from 2 to 7 percent in 1 percent increments. The approach speed for all grades is 89 km/h (55 mph). The lengths of climbing lanes for the percent grade and speed-reduction criteria can be evaluated from these charts.

CONCLUSIONS AND RECOMMENDATIONS

The object of this study was to obtain new field data concerning motor-vehicle operating characteristics on selected grades and to relate these data to current and future geometric design standards for highway grades and the related capacity and safety aspects of vehicle climbing lanes.

The following recommendations, based on the findings of this research, are made.

1. The composite critical-length-of-grade speed versus distance curves (Figures 7 and 8) should be applied to the evaluation of the need for and the design of climbing lanes for trucks.
2. An approach speed of 89 km/h (55 mph) should be used for the evaluation and design of climbing lanes.

Further evaluation and study are recommended in the following areas:

1. The 16 versus the 24-km/h (10 versus 15-mph) speed-reduction criteria,
2. The current justifications for climbing lanes,
3. Vehicle equivalencies,
4. Roadway signing and marking of climbing lanes, and
5. The effect of driver behavior and experience on vehicle performance.

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The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas State Department of Highways and Public Transportation or of the Federal Highway Administration, nor do they constitute a standard, specification, or regulation.

Figure 7. Critical lengths of grade for a composite truck weight-to-power ratio and an approach speed of 88 km/h (55 mph).

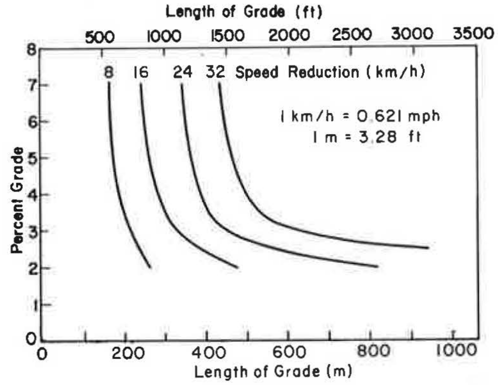
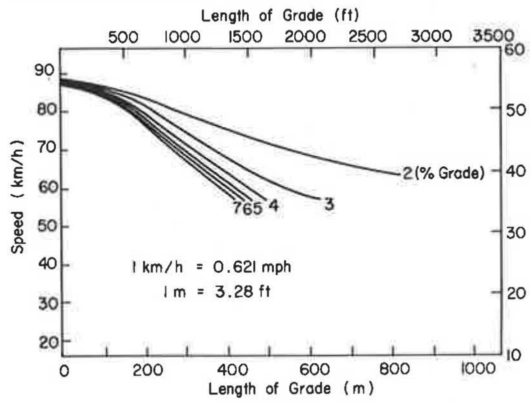


Figure 8. Composite speed versus distance curves for typical heavy trucks on selected upgrades.



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Rest-Area Wastewater Treatment

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To develop guidelines for rest-area wastewater-treatment systems that are capable of complying with the requirements of Public Law 92-500, the principal treatment situations encountered at rest areas have been identified. The quantity and quality of wastewater produced at rest areas were examined through a literature survey and through visits to various state highway departments. The common categories of wastewater-treatment systems in use at rest areas are discussed, and their capability for compliance with the requirements of Public Law 92-500 was investigated. An extended-aeration, activated-sludge plant was shown to be capable of meeting these requirements. Initial results of the study indicated that lack of adequate design criteria results in major problems in planning, designing, and operating rest-area wastewater-treatment facilities. To meet this deficiency, new design criteria and operation guidelines were developed to assist the state highway departments responsible for providing and maintaining wastewater-treatment facilities at rest areas.

The advent of the Interstate highway system has resulted in an increase in travel by a more mobile American public. To accommodate these travelers, the Federal Highway Administration (FHWA) and the state highway departments provide roadside rest areas on the highways.

One of the main problems in the construction of rest areas is that of providing adequate facilities for the treatment and disposal of wastewater. The wastewaters produced at rest areas are characterized by large variations in flow and composition, and the use of sophisticated treatment systems to accommodate these variations requires frequent attention from skilled operators, who are scarce.

The Federal Water-Pollution Control Act amendments of 1972 [Public Law 92-500 (Pub.L. 92-500)] and an increased public concern for environmental quality have prompted FHWA to initiate a program designed to minimize the environmental impact of the highway system. One of the purposes of this program is to develop a treatment technology for rest-area wastewater that will comply with the 1977 requirements of the 1972 amendments. This FHWA-funded research is designed to assist the state highway departments by providing information and guidelines for the design and upgrading of rest-area treatment and disposal facilities.

One segment of the FHWA research was a two-phase study by the Environmental Effects Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES) at Vicksburg, Mississippi. The first phase emphasized the survey and assessment of the operating characteristics of existing rest-area treatment systems. The second phase emphasized the development of specific design and operating guidelines.

The phase 1 research collected information about the conditions of existing rest-area facilities. The types and sizes of existing wastewater-treatment systems and their operational characteristics and design parameters were inventoried. The applicable literature was reviewed, and field visits were made to 21 states.

The phase 2 effort consisted of the identification of wastewater-treatment systems that comply with the 1977 requirements of Pub.L. 92-500; the investigation of an extended-aeration, activated-sludge treatment plant with emphasis on its ability to meet the 1977 requirements of Pub.L. 92-500; and the preparation of design guidelines, criteria, and recommendations for selecting wastewater-treatment systems for rest areas.

LITERATURE REVIEW

Before a wastewater treatment system is designed, the flow and concentrations of the various constituents of the wastewater must be determined or estimated. Because of the absence of more definitive information, most of the existing rest areas were designed by using the concentrations of an average domestic wastewater. However, since 1971, there have been four important studies of rest-area wastewater and the treatment facilities for it.

Washington Rest Areas

Sylvester and Seabloom (1) studied the wastewater characteristics at four rest areas in Washington. In comparing the characteristics of the rest-area wastewater with those of domestic wastes, they concluded that rest-area wastewater

1. Has essentially no grease or scum materials,
2. Is high in nitrogen, which indicates a preponderance of urine,
3. Has suspended solids (SS) and a 5-day biochemical oxygen demand (BOD_5) that are between those of weak and average domestic wastewaters,
4. Has a chemical oxygen demand (COD) equal to that of a strong wastewater (because of the paper content),