Total travel has been very nearly equally divided between rural highways and urban roads and streets since the end of the war As indicated in this article, the ratios of rural to urban travel for the past 3 years vary in a range of less than 2 percent

SURVEY OF UPHILL SPEEDS OF TRUCKS ON MOUNTAIN GRADES

WM E. WILLEY, *Engineer, Division of Economics and Statistics, Arizona Highway Department*

SYNOPSIS

The report represents a study of the uphill operational speeds of heavily loaded trucks on mountain grades as encountered on the highways in Arizona during 1948 The object of the survey was to provide basic data to determine how far a heavy truck will travel up various rates of grades before the crawl speed will be reached From these data will come indications as to when uphill truck lanes, or passing bays are necessary and how they can be incorporated in engineering design and planning Seven typical field locations on transcontinental routes were studied with mountain grades ranging from plus 2 to over plus 6 percent Elevations varied from sea level to 7200 ft. while traffic varied from 1000 to 3000 vehicles per day

Commercial trucks were stopped and the driver was interviewed while the vehicle was being weighed and measured The truck under observation was then followed up the mountain grade after normal operational speed had been resumed Observers in the survey vehicle recorded the speed of the truck with a calibrated speedometer and noted changes in speed in connection with identifying stations on the highway. When the lowest crawl speed was reached the vehicle was observed until the hill was negotiated at which time the same procedure was repeated with another truck A composite speed performance chart was plotted and it was determined that on a 6-percent grade a heavily loaded truck will lose speed at the rate of 23 mph per thousand feet of grade A distance of 1700 ft is required to reach the crawl speed of 7 mph from a level approach speed of 47 mph All other common grades are included in the report It was concluded that consideration could be given to changing the percentage of grade from plus 3 to plus 4 as the point at which the difference in elevation should be obtained in the shortest possible distance by going immediately to a 6 percent grade, in highway location and design It was also observed that within the same brake horsepower to gross vehicle weight group diesel and butane powered trucks gave a somewhat better speed performance than did the gasoline powered vehicles

Driver habits were also found to be an influencing factor in operational performance No difference in speed was noted for trucks operating on the same percent of grade at different locations ranging in elevation from sea level to 7200 ft Trucks operating in good mechanical condition had no trouble with overheating.

The Division of Economics and Statistics of the Arizona Highway Department completed in 1949 the field survey and office analysis of one phase of a study of the performance of heavily loaded motor vehicles on various mountain grades This survey was conducted at the suggestion of the Bureau of Public Roads and the Engineering Design Division of the Arizona Highway Department We are greatly indebted to the helpful comments and assistance of Mr O K Normann and Mr Carl Saal of the Bureau of Public Roads

Although there are three phases to this study the paper presented herewith will deal only with the first phase, i.e. "Uphill Speeds of Trucks on Mountain Grades." The second phase is now in progress and is a companion study having to do with, "Downhill Speeds of Trucks on Mountain Grades." The third and final report in this series will analyze the congestion caused by slow moving trucks on uphill grades We will attempt to show that the congestion caused on certain lengths of various grades with certain traffic volume, when eliminated, will result in sufficient savings to the motorist to pay for the cost of an uphill truck lane or as an aid, the construction of passing bays at certain critical points.

The object of the first study was to determine by observation the actual speeds of trucks on mountain grades, in order to assist the engineering division in the following:

1. Location of new highways by determining how far a heavy truck will travel up various rates of grade before the crawl speed will be reached.

2. Determination of the places on the present highway system where outside truck lanes or passing bays may be needed.

Figure 1. US Hwy. 89—Yarnell Hill—36 Mi. South of Prescott, Arizona — Many Sharp Curves—Steep Grades (5 to 7 percent)—Rise 1500 Ft. in $5\frac{1}{2}$ Mi.

3. The provision of comparative data desired by the Bureau of Public Roads in connection with truck studies in other states.

In this report, the term "truck" is used to denote a single unit truck, or any of the truck and trailer or semi-trailer combinations encountered in the survey. Arizona's laws limiting gross length to 65 ft., prohibits the use of the longer combinations sometimes found on the highways in other states. As it is, however, gross weights from 90,000 to 100,000 lb. are not uncommon.

Seven typical field locations were chosen to cover mountain grades from +2 to over +6 percent. These sites were in general on transcontinental routes such as US 60; US 66; US 70; US 80; US 89 and were at elevations ranging from a few hundred feet up to seven thousand feet. The volume of traffic varied from less than a thousand upward to about 3000 vehicles per day. The period covered by the survey was from September 1948 to January 1949. One week was spent at each location.

The survey crew consisted of eight men working over a period of approximately three months. Sufficient time was spent at each location to assure the acquisition of a typical sample. The figures were expanded in all cases from machine traffic counts and manual classification counts to represent an average 24-hr. day on a yearly basis.

Prior to the start of the survey when tests were begun, each site was investigated and test runs were made. As a result of these preliminary observations, pertaining to the shifting of gear at certain points, sight distance,

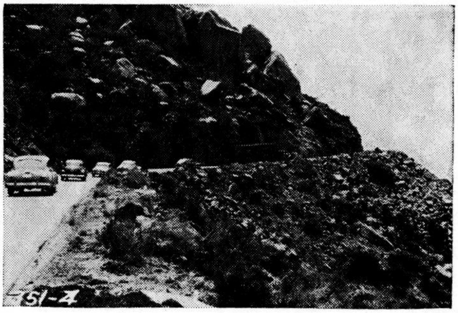

Figure 2. A 6-percent Grade on Yarnell Hill

safety on the hill and other considerations, a station arrangement was established for each grade. These stations were indicated on the side of the highway by using marked lath for day as well as night operation. These identifying stations, or markers, were tied in with the survey stations shown on the engineering plans for the section under investigation.

A work sheet was drawn for each station, on which all characteristics of the roadway were indicated. A regular highway profile sheet was used to show the profile of the road in relation to engineering stations, elevations and percentages of grades, together with vertical curvature. The alignment was shown by a straight line diagram directly above the profile.

The procedure was relatively simple and consisted of making a standard loadometer measurement check of the truck under study, together with observations of the same truck on the hill. At the start an attempt was made to observe the truck without the driver knowing that he was being followed, however, this was soon changed. In many cases there was not enough room at the top of the hill to drive the truck off the highway while it was being weighed and measured Another reason was that after the truck negotiated the up grade it went down hill so fast that it was difficult to even catch up with it until another grade was encountered. For these reasons it soon became standard practice to stop the truck some distance from the hill under observation and to do the weighing with portable loadometer scales We are certain that the fact the driver then knew he was to be followed had no effect on the results of the survey since the truck would soon level off at the lowest crawl speed and stay there The usual delay to each vehicle at the interview and weight station amounted to 4 min. and 5 sec. After the weight and horsepower data and all other characteristics of the truck were obtained, the driver was instructed to proceed and to gain his normal approach speed before reaching the survey area It was determined from field observations that 47 mph. was the average approach speed from a level grade and this figure was used as the common entrance speed for all charts at each station The speed observations were checked by using a calibrated radar speedmeter manufactured by the Electric Signal Corporation.

Three men traveled in the observation car, which used the speedometer portion of a calibrated odometer A safe and relatively constant distance was maintained back of the truck, and as each of the marked stations were passed the time and speed were noted. Other observations were made when gears were shifted; the number of cars back of the truck that had no opportunity to pass, the number that took chances and did pass; the number of accidents that happened as well as other observations that would assist in the office analysis when the field work had been completed. When the crawl speed of the truck had been reached it was followed until the hill had been cleared, at which time the survey car returned to the weighing crew where another truck was waiting to be surveyed The operation was repeated until a typical sample was obtained of various weights of trucks with various horsepower engines and with diesel as well as gasoline being used as the fuel

All stations were operated at night as well as during the day because of the heavy overnight movement of commodities by truck between Arizona and California The heat of the desert was an influencing factor that caused many of the trucks to operate by night during the summer months

Busses and house trailers were not included in the study. Busses in general were of the latest high speed type and since they carry mail and operate on a definite schedule it was decided not to cause them the delay and inconvenience of being weighed The number of house trailers encountered during the time of the survey was negligible, and a good sample could not be obtained

In order to make the results of the survey more useable to all concerned it was decided to classify each vehicle in two different ways. They were listed in a ratio of gross vehicle weight to gross brake horsepower as follows·

Group A—Up to 199 lb. per BHP
Group B—200 to 299 lb per BHP
Group C—300 to 399 lb. per BHP
Group D—400 and over lb per BHP

The gross brake horsepower came from the manufacturers rating of the truck being surveyed. They were also listed as light, medium, heavy and very heavy by gross vehicle weight as follows.

Light	Up to 15,000 lb
Medium	15,000 to 30,000 lb.
Heavy	30,000 to 50,000 lb.
Very heavy	50,000 and over lb.

It is seen from the above two tables that, within a limited range, each indicates the same classification and both are shown on the performance charts

In the report published in May 1949 there were a total of ten speed profile sheets drawn for the seven stations This was due to the fact that at some of the sites it was possible to observe vehicles in one direction on one side of the hill and in the opposite direction on the other side of the hill

A typical speed profile sheet was that for survey station 4-E (eastbound) on US Highway 66 near Flagstaff, Arizona, at an elevation of 7200 ft. There was a hill 3000 ft. long including vertical curves and about 1600 ft. of +6 per cent grade with a long level approach There was a 38 ft. roadway at nearly interstate standards with a portland cement concrete surface 22 ft wide, and mixed bituminous shoulders Traffic volume was 2239 vehicles per day of which 10 8 percent were of commercial type. The Arizona Highway 1949 adjusted sufficiency rating for the section was 90 points, a very good highway. There were 9 vehicles observed in the group A classification, with an average gross weight of 16,334 lb , and a ratio of pounds per brake horsepower of 116. These vehicles had an almost constant rate of deceleration except at the vertical curves From a level approach at an entrance speed of 41 mph and on a +6 per cent grade it required a distance of 1500 ft before the crawl speed was reached The crawl speed for this particular example was 16 mph.

At this station four vehicles were studied in group B with an average gross weight of 36,450 lb. and a ratio of pounds per brake horsepower of 240. These vehicles required the same distance as group A (1500 ft.) however the rate of deceleration was greater and the crawl speed was 8 mph. or just half of what it was for the light trucks At this particular station, because of a West Coast gasoline strike at the time, the sample of heavy and very heavy vehicles was small. One group C vehicle with a gross weight of 44,600 lb. had a crawl speed of 8 mph. in 1500 ft.

Better samples were obtained in the same area when trucks were observed at station 4-W (westbound). Here it was found that trucks of all types required approximately 2000 ft. to reach their crawl speed on an average of 5 3 per cent grade being negotiated. The group A vehicles with an entrance speed of 42 mph. reached a crawl speed of 18 mph., group B with an entrance speed of 47 mph. reached a crawl speed of 14 mph.; group C with an entrance speed of 45 mph reached a crawl speed of 10 mph. and for group D, consisting of 7 very heavy vehicles, with an entrance speed of 41 mph., the crawl speed went as low as 7 mph The posted legal speed limit at the locations just described was 60 mph.

After the profile speed charts were drawn for each station and studied in the office a general idea was obtained as to how the analysis should proceed. About nine percent of the surveyed trucks were eliminated for the following reasons if the speed varied more than 10 mph from the group average.

1. Extreme (20 percent) overloading compared to other similar powered trucks
2. Trucks reported by the operator to be in poor condition
3. All trucks compelled to slow down any time by an uncontrollable cause, such as: a slower vehicle ahead; cattle on the road; parked cars, etc.

It was decided to plot individual speed charts for each of the 160 trucks observed during the study. These charts were drawn for 3, 4, 5 and 6 percent grades and for each of the four weight groups. The speed in miles per hour was shown on the vertical axis and the distance up grade in feet on the horizontal axis. From the slope of the resulting curves an indicated deceleration curve was determined in each category The rate of change of slope of the curve was plotted as a straight line and was moved up the scale until the starting point in all cases was 47 mph.

The charts plotted for a 3 percent grade were relatively simple while those for a 6 percent grade were correspondingly complex. For the purpose of illustrating the analysis Figure 3 showing several charts drawn from the data obtained in the 5 percent grade group is included. The first chart is for group A (or light) vehicles at six different survey stations. The speed was plotted vertically against the observed distance up the mountain grade which was shown on the horizontal axis. Entrance speeds ranged from 23 to 42 mph. while the lowest, or crawl, speed varied from 17 to 25 mph The deceleration line, or average slope of the various curves, was determined by graphic analysis and an indicated slope was determined for the group It was concluded that the continuous indicated deceleration curve could be plotted by adding curves with lower entrance speeds to the lower end of a higher entrance speed curve Then, as previously stated, this average slope line was moved parallel to itself to a point on the chart indicating an entrance speed of 47 mph The same method was applied to vehicles in the other three groups as illustrated in Figure 3.

The deceleration curve became steeper as the weight of the vehicles became larger and of course the crawl speed became less and less The lowest speed indicated on this series of charts was approximately 8 mph.

After all curves had been drawn they were studied with the view in mind of picking out similar characteristics so that a composite performance curve could be assembled Such a chart is shown in Figure 4 and represents the end point of the first phase of this problem.

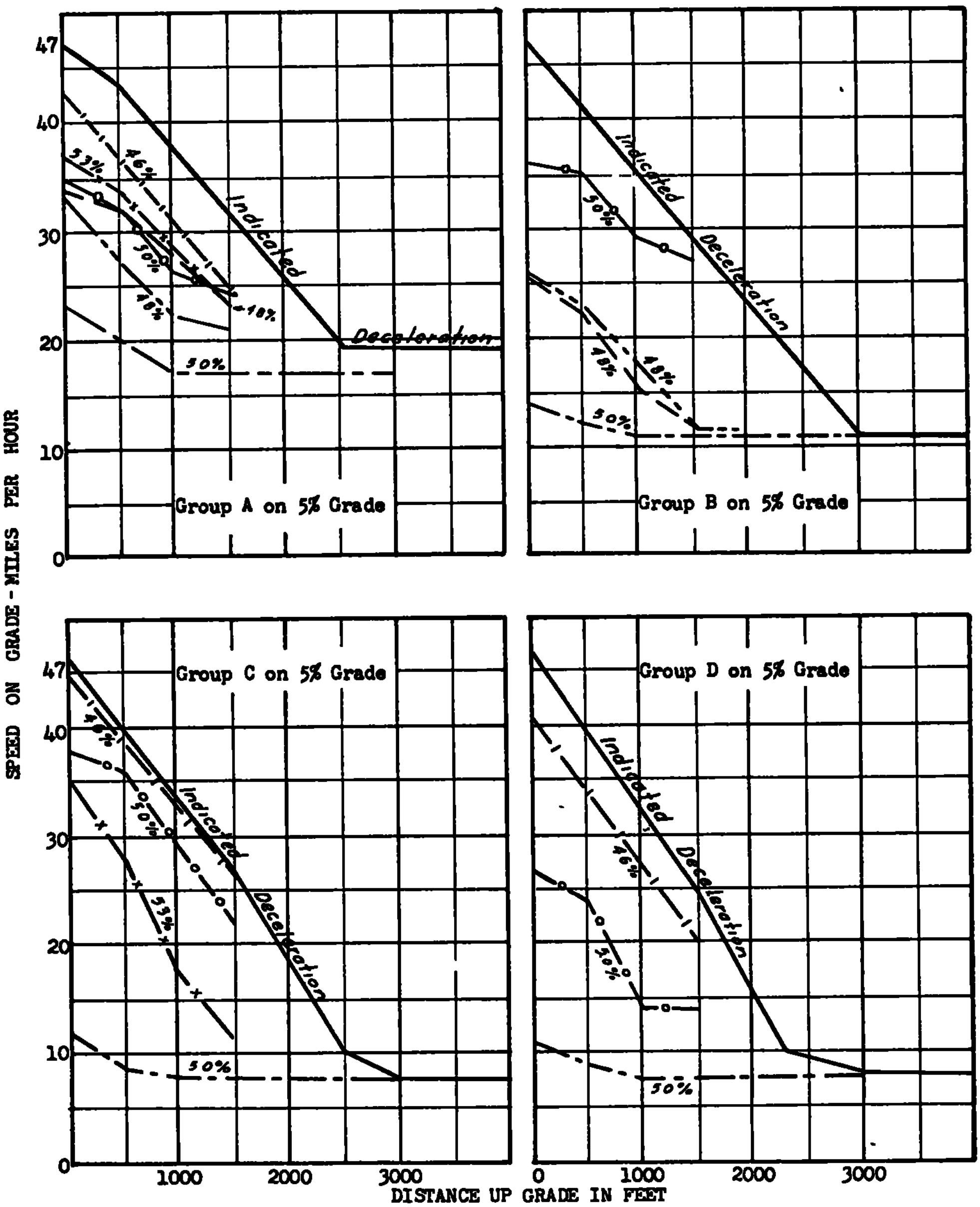

Figure 3. Loadometer-Grade Survey—5-percent Grade

Indicated on this chart is the average speed pattern of heavily loaded vehicles on grades ranging from +2 to +7 percent By heavily loaded vehicle is meant a truck loaded to capacity, or very nearly so. Speeds of light trucks were not used in preparing this graph.

On a 2-percent grade a composite truck will lose 2 mph per 1000 ft. With an approach speed of 47 mph. this same vehicle will travel 11,600 ft. before reaching a crawl speed of 23 mph.

For a +6 percent grade, reading from the chart, the loss in speed is 23 mph per 1000 ft of grade. It requires a distance of only 1700 ft to reach the average crawl speed of 7 mph. For this example the lowest crawl speed observed was 6 mph. while the highest was 10 mph Nearly ideal conditions were found for the +6 percent grade since the grade was approached by two miles of level highway Speeds ranging up to 65 mph were noted for many trucks

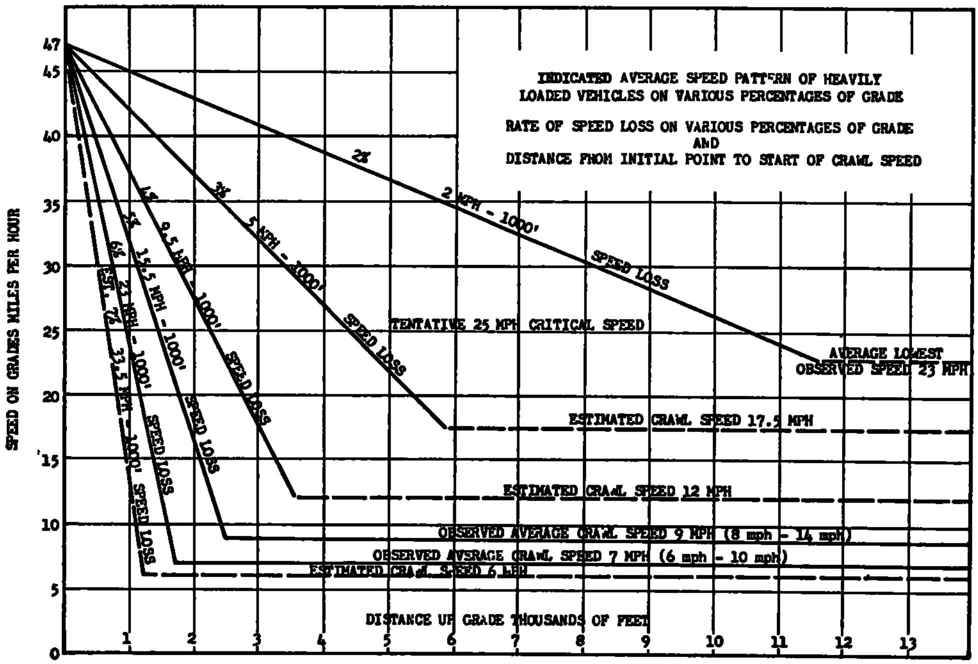

Figure 4. Speed Patterns on Various Grades

It requires only a glance at this chart to see that slow moving vehicles present a real hazard to highway safety as well as a menace to the ever increasing highway congestion. The Arizona Highway Department is considering the design policy that no passenger vehicle should travel slower than 25 mph. under any condition. With this in mind a tentative 25-mph speed line was added to the chart To use the chart in Arizona it is only necessary to study the highway location plans and proposed profile in connection with the portion above the 25-mph line If a 5 percent grade is longer than 1500 ft., or a 6 percent grade is longer than 1000 ft. then some design provisions should be made to allow room for the slow trucks to move over and provide access for the higher speed vehicles to pass without undue congestion and resultant loss of time.

It was also noted that the rate of change of the slope of the lines for the different percentages of grades was quite rapid until a 4 percent grade was reached. At this point the change to a 5-, 6- and 7-percent grade was considerably reduced.

It has been said for many years in highway location and design that if a certain difference in uphill elevation is to be made and that if the percent of grade is over 3 percent then it is most economical to go immediately to a +6 percent and make the difference in elevation in the shortest possible distance We can now consider amending this somewhat basic concept and say that up to a 4 percent grade can probably be used instead of a 3 percent grade as previously stated

For three years heavy mountain work has been going on to reconstruct all of US 60 and US 70 between Superior and Miami, Arizona. The last link in this program calls for a tunnel through solid rock for 1200 ft. This tunnel is on a +6.34 percent grade and is on the only tangent for some distance on each side of the portal. The engineering department analyzed the situation from the results of the truck-speed report and determined that trucks inside the tunnel would have a crawl speed of 6 mph.

In order to eliminate congestion and to facilitate passing as well as vehicular movement to assist in pumping out the exhaust gases it was decided that an uphill truck lane should be provided Previously a two-lane tunnel with a width of 26 ft was advocated, however, with the assistance of data obtained from the truck-speed study a 40-ft width consisting of two 12-ft uphill lanes, a dividing strip and one 12-ft. downhill lane was requested.

Final approval was just recently received from the Bureau of Public Roads Here then is a concrete example of beneficial results already obtained in Arizona from this study.

Several interesting side lights were noted during this survey and included these observations:

a) As nearly as could be determined with the instruments at hand and technique applied there was no great difference in speed performance of heavy vehicles at elevations from sea level to over 7000 ft

b) The performance of diesel and butane powered trucks appeared to be better than the same weight vehicle powered with gasoline. On the long sustained grades the diesel engine trucks traveled from 2 to 10 mph. faster than gasoline powered trucks. One reason for this probably is the great reserve of power usually associated with the diesel trucks; however, this observation was made between vehicles in the same power group of around 150 HP.

c) It had previously been rumored that overheating of heavy trucks limited their performance on mountain grades. During the course of this survey it was found that no truck in good mechanical condition had trouble with overheating.

d) The gross vehicle weight of trucks operating through the survey station varied through wide ranges for the same type vehicle. One new Ford, F-8 type, rated as a 3-ton truck 2-S1, was found hauling 43,200 lb. GVW of steel balls for a mine ball mill, while another identical truck was hauling only 14,400 lb. GVW of bulky aluminum castings. This represents a difference of 14.5 tons moved by identical power plants Such conditions were noted throughout the survey.

e) Individual driver habits were quite important An experienced driver traveling over a known route and shifting gears at just the right time could travel a greater distance up a given grade, before reaching the crawl speed, than could a driver with less experience.

Copies of the complete report may be obtained by writing to Mr. W. C Lefebvre, State Highway Engineer, 1701 W Jackson Street, Phoenix, Arizona

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