COMPARISON OF METHODS FOR DETERMINING THE HILL CLIMBING ABILITY OF TRUCKS

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(In Abstract)*

In cooperation with a number of truck manufacturers, the Quartermaster Corps of the United States Army, and the National Bureau of Standards, the U S Bureau of Public Roads is determining the hill-climbing ability of some 30 new trucks, covering the range of sizes and makes most generally encountered in the eastern portion of the country Methods are as follows

(1) Actual grade tests made by applying various loads to vehicles and observing the speeds which they can maintain on a series of known grades, (2) theoretical hill-climbing ability computed from engine-torque and power curves, (3) acceleration tests by which the drawbar effort available at various road speeds over the entire useful speed range of each gear is determined, and (4) drawbar dynamometer tests which measure the drawbar pull available over the entire useful speed range of each transmission gear

The grade tests are the most satisfactory in that no question can be raised as to their adequacy These tests are laborious and expensive, and thus would not be practical where it is necessary to test a large number of trucks in a short period of time One of the purposes of the study now being conducted is to develop a method by which accurate results can be obtained more quickly and economically The results of the grade tests will be used to evaluate the results obtained by other methods

This report discusses the results obtained from tests made by the various methods on one truck designated as truck A operating in third gear on five grades The grade ability, as determined by the grade tests, is expressed in terms of the gross vehicle weight that the truck can pull up the particular grade at a given speed The results obtained by the other methods are converted to the same units

Grade tests In the grade tests known loads are applied to the truck, and the maximum speed that it can maintain on known grades with each load is determined The maximum gross vehicle weight that the truck can pull up the grade at a constant speed in a given gear is determined by trial, using the performance indicated by an ability formula as a guide Starting with the maximum weight that can be hauled in a given gear, the load is decreased by 1,000 pound decrements and the maximum sustained speed for each load determined The gross vehicle weight is decreased until the road speed observed corresponds to an engine speed that approximates the maximum recommended by the manufacturer for safe operation of the engine. As soon as the tests in one gear are completed, they are repeated in the gear with the next higher gear ratio

Several test runs on the grade are required to determine the maximum sustained speed for each load The test truck approaches the grade at a speed estimated to be one that can be sustained over the entire length of the grade All test runs are made with full throttle An observer in the cab of the truck records the speed indicated by the truck speedometer at the start and finish of the run, and determines whether a sustained

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speed is reached If the vehicle accelerates or decelerates on the first test run, the grade is entered on the next run at the speed that was recorded when the truck left the test course on the preceding run. After a constant climbing speed is observed on one run, it is verified by a check run Generally the grade is reentered at speeds first above and then below that finally determined The speedometer is used only as a guide in the field work, the actual speed maintained on the grade being measured by means of a time-distance recorder

Theoretical Performance The theoretical performance of a vehicle is computed by reducing the engine torque through the transmission gears, axle gears, and driving wheels to rim pull or tractive effort. The tractive effort is the force produced at the tire surface of the driving wheels which is available to act against the resistances that oppose the motion of the vehicle

The performance formula is derived by equating the tractive effort to the rolling resistance plus grade resistance The tractive effort is obtained by dividing the torque at the driving axle by the rolling radius The torque produced at the driving axle for a given engine speed is the product of the engine torque, the total gear reduction, and the over-all efficiency The grade resistance is the component of the gross vehicle weight along the grade and is the product of the tangent of the grade and the gross weight for all small grades, since the sine and the tangent of such angles can be considered equal without introducing substantial error The rolling resistance is the product of the coefficient of rolling resistance, and the gross vehicle weight The following formula then results tractive effort is equal to grade resistance plus rolling resistance

The torque as determined from engine performance curves for any given engine speed can be substituted in the formula The engine speed can be converted to road speed by reducing it by the total gear reduction and multiplying by the circumference of the driving wheels In this manner the gross vehicle weight that can be pulled up a given grade at a given road speed can be determined

Comparison between the hill-climbing ability indicated by the performance formula and that determined by actual grade tests shows the accuracy of the engine torque curves and of assumptions made concerning efficiency and rolling resistance

Acceleration and Deceleration Tests These tests are made on a level section of road The truck is accelerated in each transmission gear at full throttle, starting at the slowest speed at which the engine will operate smoothly and continuing to the maximum recommended engine speed The drawbar pull or force produced at the drive wheels of the truck for any given road speed throughout the useful speed range of any gear is a function of the acceleration at that road speed and the mass of the truck

Deceleration tests are made on the level by first attaining a desired speed and then permitting the truck to coast with transmission in neutral The deceleration measured at a given road speed is proportional to the force that opposes the motion of the vehicle This force or tractive resistance is composed principally of the friction between the tires and the road surface, and air resistance

A time-distance record of each acceleration and deceleration run is obtained with the same time-distance recorder that is used in the grade tests The time-distance record obtained is divided into two-second intervals, and instantaneous speeds are computed at each time interval Time-speed curves are plotted whose abscissae are time in seconds and ordinates are speed in miles per hour Thus the slope of the time-speed curve at any point is the acceleration or deceleration of the test truck. The acceleration or deceleration in miles per hour per second is determined at various road speeds and plotted against speed in miles per hour The values of acceleration and deceleration as shown by these curves are used to compute the drawbar pull and the tractive resistance

The total force produced at the tire surface of an accelerating vehicle at any given speed is equal to the drawbar pull plus the tractive resistance of the test vehicle This force can be utilized to pull a certain gross vehicle weight up a given grade at the road speed for which the force is measured The force is equated to the component of the gross vehicle weight along the grade and the tractive resistance of the vehicle on the grade.

Drawbar Dynamometer A special dynamometer, called a "field" dynamometer, developed by the Ordnance Department of the United States Army, was made available for these studies This dynamometer consists of a 10-ton truck on which two fire pumps are mounted The pumps are connected to the main propeller shaft back of the transmission by means of a two-speed auxiliary transmission When the dynamometer vehicle is towed by the test vehicle, the rear wheels of the truck actuate the pumps, forcing water from a tank through a pipe with an adjustable orifice and then back to the tank By regulating the size of orifice the discharge pressure of the pumps can be increased or decreased, which in turn increases or decreases the torque required to turn the rear wheels In this manner various loads can be applied to the vehicle pulling the dynamometer

Drawbars are mounted on the front and rear of the dynamometer truck. Each drawbar is composed of a cylinder and piston, the former being held stationary relative to the dynamometer truck, while the latter is connected to the drawbar eye. Thus when the test vehicle tows the artifically loaded dynamometer truck, the pressure in the cylinder is recorded through an oil line and spring gage on a metallic chronograph tape. Simultaneously a time-distance record is obtained on the chronograph tape to permit, by relatively easy means, the computation of the available drawbar pull at various road speeds Resistance to traction is determined by towing the test vehicle behind the dynamometer truck. All drawbar-pull tests are conducted on a level course at full throttle, the artificial load and, correspondingly, the speed of the vehicles being regulated by an operator who varies the size of the orifice as indicated by an electric tachometer

Although the results obtained by this test do not compare too favorably with actual grade results, the method offers a distinct advantage in that relatively little computation is required to interpret results Should a lighter dynamometer be available, it is likely that very accurate results could be easily and economically obtained

Conclusions Results thus far obtained lead to the following conclusions:

1 Testing under actual load conditions over several grades will, of course, provide results of the greatest accuracy, however, this method is so laborious and expensive as to preclude its general usefulness.

2 The computation of grade ability from manufacturer's torque curves, provided reliable factors for overall efficiency and rolling resistance at various speeds are available, may be expected to yield reasonably accurate results

3. The computation of grade ability from acceleration and deceleration tests will yield accurate results, especially in the more generally used range of engine speeds, and requires no data from the manufacturer. Complete tests require but a few hours in the field, but office computations are laborious The method is, however, far cheaper than the actual

grade tests, and the Bureau is now considering the development of instruments for a more precise determination of acceleration rates, in view of the probability of adopting this method for future work.

4 The towing dynamometer, or some similar device such as a chassis dynamometer, can undoubtedly produce accurate results quickly and in a usable form Their high initial cost limits their use to operations requiring the testing of a large number of vehicles quickly

DISCUSSION ON HILL CLIMBING ABILITY OF TRUCKS ·

MR N CHERNIACK, *Port of New York Authority Need for Developing a Scientific Truck Rating:* To insure safety and speed in the operation of the newly opened (Dec 22, 1937) first tube of the Lincoln Tunnel under the Hudson River which handles two-way traffic, one lane in each direction, the Port Authority decided to exclude "slow" trucks. Anticipating the necessity for such a rule in the first stages of operation of this tunnel, the staff made observations at the Holland Tunnel of "slow" trucks (those making 10 M P H. or less) and noted such of their characteristics as would permit these trucks to be recognized before entering a tunnel. A few of the results of our observations may be of interest to this group in connection with the paper presented by Mr Saal.

1 A total of 1,095 trucks were observed emerging at 10 miles per hour or less from the two tubes of the Holland Tunnel at their maximum exit grades of 3 percent in the north tube and 3 5 percent in the south tube. The "slow trucks" represented 1 6 percent of all the trucks passing through the tunnels in the test period and averaged about 100 per 12 hour day.

2. About 5 percent of the slow trucks made less than 5 M P H

3. Roughly, 70 percent of the slow trucks were of the heavy type, over 5 tons carrying capacity; 26 percent were in the medium class, 2 to 5 tons carrying capacity; and 4 percent were small trucks, 2 tons and less.

4. About 85 percent of the slow trucks in the medium class (2 to 5 tons carrying capacity) were overloaded with such heavy commodities as coal, lumber, paper, beer, sugar, etc There were only few overloadings in trucks of the light and heavy classes

5 No particular make of truck, nor any particular geographic location stood out as a predominant contributor of slow trucks.

While these and other observations were interesting, they yielded no one single criteria by which an officer stationed on the plaza could, with any degree of certainty, spot a slow truck before it actually entered the tunnel To make absolutely certain that slow trucks would not enter the tunnel, it was necessary to prepare either a "black list" of slow trucks, or a "white list" of fast trucks The policy finally adopted was to exclude all large trucks of over 5 tons gross weight Subsequently, permits to transit the tunnel were issued to such trucks as could prove their ability to negotiate, fully loaded, maximum tunnel exit grades of 3 5 percent at a speed of 20 M.P.H., while being conveyed through the tunnel by an officer on a motorcycle

Not only can slow trucks not be readily recognized, but there is, today, lack of a definite, universally recognized method for classifying trucks with respect to their carrying capacities. Our own studies of large samples of trucks using Port Authority crossings as well as similar truck studies by the U S Bureau of Public Roads and other agencies, on typical state highways, have indicated that present manufacturers' rated carrying capacities of trucks are highly arbitrary and do not truly represent maximum actual loads carried. In practice, truck owners increase • carrying capacities through changes in engine power and tires in accordance with the road conditions under which their trucks are operated. The closest single indicator of gross weight capacities of trucks which we have discovered as a result of our own studies (although still permitting wide variations between actual maximum full loads and indicated capacities and giving no clue to truck speeds up grades) is the gross tire capacity of a given unit as determined from the number and sizes of its tires

There exists today a real problem of classifying vehicles from a load capacity standpoint in terms not only of their "static" characteristics (i e , frame, springs, and tires) but also of their "dynamic" ability (engine power) to maintain minimum speeds up grade and their ability to control down-grade speeds (braking power) These are matters of common concern to all agencies having to do with traffic control

For purposes of properly regulating motor truck transportation with respect to safety of operation, damage to roadways, capacities of highways, inconvenience to passenger car travel, and for use as bases for taxation, we feel there should be developed a truck classification which would reflect (a) the ability of a truck to haul loads up reasonable grades and at reasonable speeds without undue delay to other traffic on the road and (b) its ability, on steep down-grades, to slow down to permit non-commercial traffic to pass at convenient points and to stop within reasonable distances in emergencies These should, of course, be determined in conjunction with structural loads, limited by chassis, springs, tires, etc

Such a classification would prove exceedingly helpful to state highway departments, state tax units and other public agencies interested in the planning, construction and operation of highway facilities and to the Interstate Commerce Commission in carrying out, effectively, certain provisions of the Motor Carrier Act

MR J S. BURCH, *North Carolina State Highway and Public Works Commission*· We have all recognized for years the dangerous situation created by slow-moving trucks approaching the top of a hill being following by several passenger vehicles which want to move faster The added outer lane has the disadvantage, from the safety standpoint, that when a truck wishes to re-enter the traffic stream, the driver is often unable to see traffic approaching from his rear because of the wide body and load, therefore he has to stop the truck and crane his neck in order to detect the approach of vehicles behind him Also in stopping his truck he loses what momentum he has, and for that reason truck drivers and operators are not prone to re-enter the traffic stream with care As an improvement on that feature we have thought for some time about the feasibility of doing in effect what the railroads have done, that is put in truck sidings It seems to me that this siding or additional one-lane road, if you care to call it that—might well be placed on these long steep grades, especially on heavily traveled roads, and that this lane (extra road) might be moved completely out from the highway to a distance of 50 ft or more,—perhaps 75 ft It would not have to be more than a few hundred feet long to accommodate four or five trucks, the trucks would be allowed to stop out on the siding if they liked, or they could continue The lane would be brought back into the highway at the hillcrest at an angle of 45 degrees, or even 90 degrees with flared corners

In that way any traffic behind the truck could do the same thing that the fast moving trains do on railroad systems The truck takes the siding and comes back into a point where he can view oncoming traffic, and the faster vehicles can get away over the hill, thus relieving the congestion I believe that this method could be very easily policed and enforced by signs stating that all slow-moving traffic must take the turn-out I have talked it over with quite a few large truck operating concerns and they are quite favorable to it They say if the highway commissions would build them, they would be glad to use them