surface should be compared with a total resistance of 80 pounds for smooth concrete at the same speed

SUMMARY

In summarizing the foregoing progress report, it is difficult to arrive at any definite conclusions It is of singular significance that we have, in the present equipment, an accurate and practical way of determining tractive resistance Furthermore, the separation of this item into its component parts has been accomplished with relative ease At the present time, the investigation is being carried on along the lines described in this paper It should result in a determination of values for impact resistance, surface resistance, etc , for different surfaces under different conditions The value of such knowledge to the highway engineering profession can hardly be over-emphasized

HIGHWAY GRADES AND MOTOR VEHICLE COSTS

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SYNOPSIS

The presentation of a direct method of computing the relative use of gasoline on grades and on the level at different constant speeds without recourse to the utilization of kinetic energy nor to the method which makes use of the potential energy for a "rise" of one foot Observed ranges of rolling plus air resistance are given

Grades, the descent of which at a specified constant speed require neither positive nor negative power from the engine are designated as "floating grades" Ranges of floating grades for passenger cars are computed

Comparisons of average amounts of gasoline for ascending and descending grades with amounts used on the level are made

No-extra-gasoline-cost grades are determined, although more data on straight-line characteristics of engines (and carburetors) of modern cars are needed for more precise determination

Examples of application and extension of the method to several individual up-to-date trucks are given in brief, and its application to the problem of justification of expenditures for grade reduction is discussed

Very careful consideration of the effects of highway grades upon motor vehicle costs is essential to the economic relocation of highways This article presents a direct method of determining the effects of different highway grades upon one of the main items of motor vehicle cost, that is, the cost of gasoline, when the vehicle is operated at a constant speed, thus omitting the consideration of kinetic energy and "rise and fall" by the potential energy method The general application of this direct method requires more data than are yet available, illustrations of its application are given, however, and some general conclusions are reached which show that the investments justified for reducing grades are very much smaller than appear to have been justified in previous computations

The utilization of the kinetic energy of motor vehicles on grades has been ably treated elsewhere as has also the potential energy method of determining the expenditure justified to reduce "rise" Of course, kinetic energy is ineffective when constant speed is maintained, so results obtained by making use of kinetic energy may supplement and extend somewhat the results obtained under this constant speed method The potential energy method neglects the fact that part at least of the potential energy which has to be supplied in overcoming "rise" is recovered in the corresponding "fall" Thus, it is definitely known that a "rise" of one foot means an increase of potential energy by 2000 foot-pounds per ton of vehicle weight Hence with rolling and air resistance of say 40 pounds per ton the distance on the level equivalent to one foot of "rise" is 50 feet, but one foot of "fall" means a decrease of potential energy by 2000 foot-pounds per ton of vehicle weight and is also equivalent to the same distance on the level, so part of the energy used in overcoming "rise" is recovered in the corresponding "fall," as it aids in propelling the vehicle on descending grades

The constant speed method conforms closely to actual operation and gives precise results when adequate data are available

In brief, the method is to consider operation at one constant speed on a length of level road followed by the same length of uniform grade of g per cent (grades up to 7 per cent are considered herein); and to compare the average amount of gasoline used in ascending and descending the grades with that used on the level by means of the relationship between the gasoline used and the brake-horsepower of the vehicle's motor Operations in both directions over this profile must be considered because there is practically the same traffic in both directions on highways and also individual vehicles usually make round trips and thus encounter annually practically the same number of feet of "fall" as of "rise" Consideration is given first to an individual car for which data have been determined in a series of tests This is then extended to passenger cars as a group though data, at present, are insufficient for the precise computations for any vehicle which the method affords Motor trucks differ much and drivers of them have to shift gears on grades and these together with the lack of data force us at this time to use a much less precise method and to consider individual light, medium, and heavy trucks In this connection it should be kept in mind that there is continual development of motor trucks particularly in the increase of horsepower and operating speeds

Air, rolling, and grade resistances and the tractive effort of motors are discussed first, followed by a development of the formula for brake-horsepower and the relation of the gasoline used to the brake-horsepower, before coming to the main discussion of the constant speed method

TRACTIVE RESISTANCE

The engine of a car delivers the power which propels it This may be measured in brake-horsepower at the motor shaft and also as in tractive effort in pounds, and in pounds per ton at the particular speed It is quite convenient to express tractive effort and the tractive resistances in pounds per ton of gross weight of the vehicle For motion at uniform speed the tractive effort of the engine exactly equals the sum of the tractive resistances, that is, the total resistance to motion As an equation, it is.

$$t\,e \;= r + K\frac{A}{T}V^2 \pm 20g \text{ - - - pounds per ton,}$$

where $t\,e$ is the tractive effort of the engine at its shaft, r is the rolling resistance caused by the resistance of the tires upon the particular road surface, and by the friction of bearings, clutch, and gears, and the churning of the lubricants $K\frac{A}{T}V^2$ is the air resistance, that is, the resistance to motion of the vehicle through still air

K is an experimental coefficient
A is the frontal area in square feet
T is the gross weight of the vehicle in tons, and
V is the speed in miles per hour

g is the per cent of grade, "$+ 20g$" is the grade resistance when the vehicle is ascending, and "$- 20g$" is the negative grade resistance when the vehicle is descending the grade, of g per cent

These tractive resistances vary so much and so differently that brief discussions of them are given Expressed in pounds per ton, they vary widely for different vehicles

The rolling resistance (in pounds per ton) varies with the temperature of the lubricants, with the speed, increasing as the speed is increased, with the mechanism of the chassis and inversely as the weight in tons That part of rolling resistance due to the tires, the "tire resistance," varies with the speed, considerably with the inflation pressure, and with the weight per tire It is customary to consider that the rolling resistance for an individual vehicle does not vary at different speeds, because of the much greater variations of air resistance The rolling resistance of passenger cars has been observed to range from 30 pounds per ton or less for cars weighing over two tons, to 50 pounds per ton for a car weighing 1 4 tons

The range of air resistances taken from the results of many experiments is approximately.

from 1 4 to 3 pounds per ton at 10 miles per hour
from 9 to 19 pounds per ton at 20 miles per hour

from 13 to 27 pounds per ton at 30 miles per hour
from 28 to 60 pounds per ton at 45 miles per hour

The combined rolling and air resistance of passenger cars usually falls within the following limits

between 40 and 65 pounds per ton at 20 miles per hour
between 50 and 80 pounds per ton at 30 miles per hour
between 70 and 100 pounds per ton at 45 miles per hour

The combined rolling plus air resistance of several individual trucks considered later ranges from 30 pounds per ton at 20 miles per hour to 70 pounds per ton for light trucks at 35 miles per hour

FLOATING GRADES

On descending certain grades at certain constant speeds the force of the minus grade is just sufficient to overcome the rolling plus air resistance and thus maintain uniform speed with zero tractive effort from the engine The car may be said to "float" down such a grade and the name "floating grade," is adopted to specify this condition The grade here designated as floating grade is the same as that designated "grade of repose" by Wellington in his "Economic Theory of Railway Location" in which he stated· "The grade which produces a longitudinal force precisely equivalent in pounds per ton to the 'rolling friction' of the car at any given velocity is called the *grade of repose* for that velocity, being that grade on which, if a car were descending, the accelerating force of gravity would just balance the resistance to motion " Wellington also stated that the term, "grade of repose," was "ill chosen " The term, "floating grade," conveys the ideas that the engine furnishes no power and no tractive effort for the car descending, and the car floats at the definite speed down the grade, whereas the tractive effort and power of the engine on ascending the floating grade are each twice those required on the level

When the tractive effort is zero, $-20g$ equals the rolling plus air resistance in pounds per ton, hence the per cent of the floating grade is the rolling plus air resistance in pounds per ton divided by 20 Thus with rolling plus air resistance of 40 pounds per ton the floating grade is 2 per cent, and with 100 pounds per ton 5 per cent Since the air resistance varies as the square of the speed the rolling plus air resistance and the per cent of floating grade are small at low speeds and increase with increase of speed, but not in direct proportion

Though not essential to the determination of comparative costs of gasoline on grades and on the level, the concept of the floating grade focusses attention upon a most interesting condition and helps determine the limits within which the costs of gasoline for operation up and down grade average the same as on the level

BRAKE HORSEPOWER OF AUTOMOBILE ENGINES

The relationship between tractive effort and the horsepower developed by an automobile engine is computed as follows.

As 88 feet per minute is equivalent to one mile per hour and 33000 foot-pounds per minute to one horsepower, the equation for the brake horsepower of a motor vehicle engine is

$$\text{Brake hp} = \frac{88}{33{,}000} \times T \times V \times t\,e = \frac{8}{3{,}000} \times T \times V \times t\,e$$

where T is the gross weight of vehicle and load in tons,
V is the speed in miles per hour, and
$t\,e$ is the tractive effort of the engine at its shaft, in pounds per ton

For example, with a car weighting $1\frac{2}{3}$ tons $T = 1\frac{2}{3}$

$$\text{Bhp} = \tfrac{8}{90} \times t\,e \text{ at } V = 20 \text{ mph},$$
$$\text{Bhp} = \tfrac{12}{90} \times t\,e \text{ at } V = 30 \text{ mph}, \text{ and}$$
$$\text{Bhp} = \tfrac{18}{19} \times t\,e = 0\ 2\,t\,e \text{ at } V = 45 \text{ mph}$$

This formula is used to compute the brake horsepower from the weight of the car in tons, its speed in miles per hour and the tractive effort in pounds per ton

Using the ranges of rolling plus air resistance stated above we find the following ranges of brake horsepower for a car weighing $1\frac{2}{3}$ tons on good level road surfaces:

from 3 6 to 5 8 brake horsepower, at 20 miles per hour,
from 6 7 to 10 7 brake horsepower, at 30 miles per hour,
from 14 to 20 brake horsepower, at 45 miles per hour,

To be more specific a car weighing $1\frac{2}{3}$ tons and having rolling plus air resistance of 90 pounds per ton at a speed of 45 miles per hour will float down a $4\frac{1}{2}$ per cent grade and the tractive effort and brake horsepower of the engine will be:

	Down floating grade of 4½%	On level	Up floating grade of 4½%
Pounds per ton of tractive effort	0	90	180
Brake horsepower	0	18	36

On a $7\frac{1}{2}$ per cent grade, the tractive effort and brake horsepower will be

	Down 7½% grade	On level	Up 7½% grade
Pounds per ton of tractive effort	−60	90	240
Brake horsepower	−12	18	48

FUEL USED VS BRAKE HORSEPOWER

The brake horsepower of an automobile engine, that is, the power it delivers to the car at the engine shaft, may be computed with considerable accuracy, when the vehicle is operating at constant speed on level road and up and down a known grade It remains to find the average amount of gasoline used on grades (up and down) and compare it with the amount used on the level For this purpose recourse is had to a known characteristic of automobile engines operating at a constant speed and supplied with a constant fuel mixture, which may be called the "straight line characteristic " That the gallons per hour of a particular gasoline plotted against the brake horsepower gives a straight line under the conditions of constant speed and constant fuel mixture has been observed in many tests, for years, and it is confirmed as a first approximation at least by theory Some texts state this relationship definitely, for instance, Polson is his "Internal Combustion Engines," l c 160, says: "The total gasoline used per hour increases directly with the brake horsepower, similar to the Willan's line for a steam engine "

On the same page is given a graph which shows this straight line characteristic for a 6-cylinder engine at a constant speed of 1600 r p m in which the total gasoline in pounds per hour is plotted against brake horsepower from 0 to 35 Bhp Constant fuel mixture is not mentioned, but it is a definite condition for the straight line characteristic Many published results of tests show the graphs of gasoline in pounds per brake horsepower per hour plotted against brake horsepower, and a number of these have been studied and found to reduce to the straight line characteristic Such laboratory tests as have been supplied on request show this straight line relationship, except one for a tractor using kerosene in which the line is straight up to 20 Bhp and then turns upward, and a Diesel engine test which shows very much the same as the kerosene engine, though the Diesel engine is beside the point as it does not have a constant fuel mixture

A number of engineers have supplied information and discussion, from which it appears that there is little doubt that the characteristic of fuel consumption vs power at constant speed is a straight line, at least as a first approximation both from theory and from tests, with the definite condition that the fuel mixture remains constant There is lack of published data as to the positive and negative limits to the straight line for different cars One investigator suggested that the straight part of the line would be short for modern cars, giving as his reason richer fuel mixture from about half to full power, and also at negative horsepower To investigate the negative limit to the straight line, the writer and James Fontaine made tests of a Dodge coupe on a drum dynanometer in the Engineering Experiment Station at North Carolina State College in the summer of 1932, the results of which are shown on Figure 1

In these tests the cooling of the engine by extra cooling water was such as to permit temperature variations and consequently the observed values do not fall exactly on the straight line, though close to it

It should be comparatively easy to get quite accurate measurements of gasoline used at different negative and positive horsepowers with dynamometer tests as made in manufacturer's laboratories Such results, however, are not at present available It is evident, however, from these tests with rather inadequate means, that for this particular car the lower, or negative, limit is beyond minus 12 horsepower and minus 60 pounds per ton of tractive effort at the constant speed of 45 miles per hour, and beyond minus 8 horsepower and the corresponding minus 60 pounds per ton at 30 miles per hour It is assumed that at the constant speed of 20 miles per hour the negative tractive effort will be beyond minus 60 pounds per ton, that is beyond minus 5 horsepower, though tests were not carried so far as to prove this, as with 30 and 45 miles per hour

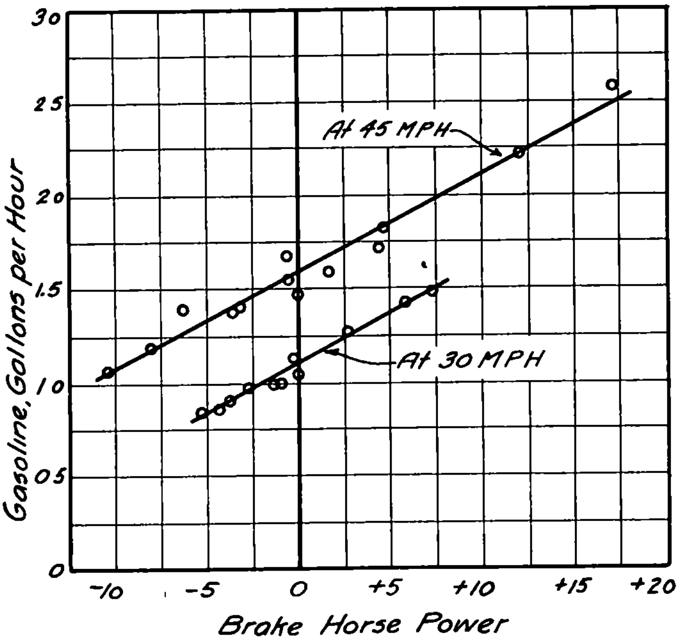

Figure 1 Tests on a Dodge Coupe in 1932

The tests were carried to only 18 horsepower, positive, at 45 miles per hour and 7½ horsepower at 30 miles per hour, but road tests of this same car indicate that the straight line extends to at least 50 horsepower, positive, at 45 miles per hour, and study of the carburetor indicates that constant fuel mixture obtains up to the 50 horsepower, positive, at 45 miles per hour, and that the throttle was not so nearly closed as to give richer fuel mixture at minus 12 horsepower, with corresponding figures at the other constant speeds

On Figure 2 is plotted the straight line characteristic for the 1930

Dodge Coupe, gallons of gasoline per hour against brake horsepower with the negative limit at minus 12 horsepower and the positive limit above 48 horsepower at constant speed of 45 miles per hour The dotted portions of the curve beyond the straight line are not known from the test The rolling plus air resistance of this car on smooth concrete roads has been measured to be 90 pounds per ton at 45 miles per hour

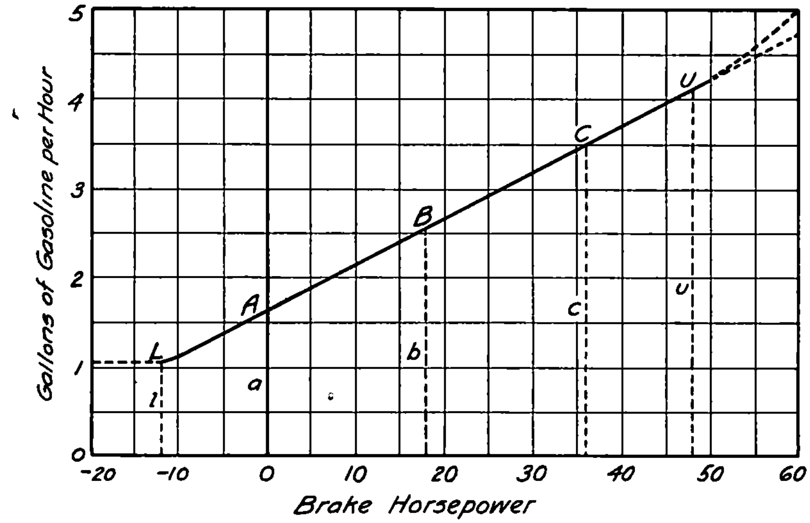

Figure 2. 1930 Dodge Coupe Straight Line Relation of Fuel Used to Brake Horse Power at Constant Speed of 45 M.P.H. and Constant Fuel Mixture

which permits computations of brake horsepower and relative gasoline consumption on grades, as shown in the following tables:

	On level	Up floating grade of 4½%	Down floating grade	Average up and down
Pounds per ton of tractive effort	90	180	0	90
Brake horsepower	18	36	0	18
Gallons of gas per hour from curve sheet	ordinate b	ordinate c	ordinate a	$\frac{a+c}{2}=b$

	On level	Up 7½% grade	Down 7½% grade	Average up and down
Pounds per ton of tractive effort	90	240	60	90
Brake horsepower	18	48	12	18
Gallons of gas per hour	b	u	l	$\frac{u+l}{2}=b$

Translated into more exact terms the gallons of gasoline used per hour by this car at 45 miles per hour, when ascending a 7½ per cent grade was found to be 147 per cent of that used on the level, and on descending 53 per cent of that used on the level, so the average use of gasoline on the

7½ per cent grade is the same as the use on the level, for this particular car at the constant speed of 45 miles per hour

In general it may be said that so long as the straight line relationship holds and the speed is kept constant the extra amount of gasoline used in ascending is balanced by the decreased amount in descending the same grade, which results in an average use of gasoline on the grade the same as that on the level

Consideration of the foregoing computations of this particular car on grades up to 7½ per cent, together with comparative studies of other cars, leads to the belief that passenger cars built since 1928 will show no extra gasoline cost on grades up to 6 per cent at 45 miles per hour, in other words, that the maximum no-extra-gasoline-cost grade is at least 2 per cent more than the floating grade

This conclusion has been reached without consideration of the possible saving by utilization of kinetic energy, and by a method differing from that which computes the cost per foot of "rise" from consideration of potential energy

Despite a general belief to the contrary, there appears to be no extra cost for lubrication on grades. That the quantity of oil used for operation on grades is the same as at the same speed on the level is clearly explained by Ricardo in his "High-Speed Internal Combustion Engines" where he states (page 241)· "In spite of such evidence, however, the theory is quite fallacious, for the actual quantity of oil passing the rings is found to be a function of the speed, and of the speed alone, the pumping pressure set up by the rings being of far too high an order to be influenced appreciably by any slight differences of pressure in the cylinders "

Indications point to greater tire wear and consequently greater tire costs on grades than on the level, but this and the possible extra cost for maintenance as well as for the drivers time are omitted from this discussion

Tests made by the State College of Washington in 1926 and published in "Engineering Bulletin No 18," showed that the average amount of gasoline used in ascending and descending a long 4 5 per cent grade was 10 per cent more than the amount used for the same distance on the level Ascending the car required 160 per cent of the gasoline used on the level, and descending, 60 per cent Considering the increased speed and power of newer cars, this actual test tends to confirm the previous computations and the straight line characteristic

"Engineering Bulletin No 17" of the State College of Washington showed from 0 008 to 0 011 more gallons of gasoline were used per mile on 8 miles of grades averaging 4 2 per cent, which gives 1774 feet of rise, practically continuous, and of fall The gasoline cost per car per foot of rise and fall is computed from these data, to be about one-thousandth of a mill instead of from a third of a mill to a mill which has elsewhere been computed to be the annual cost of one foot of rise per vehicle

MOTOR TRUCKS ON GRADES

Trucks are much heavier than passenger cars, usually operate at lower speeds and consequently show smaller rolling-plus-air resistance. Consequently "floating grades" for trucks are less steep than for passenger cars, moreover trucks differ widely, so data were obtained for four new trucks, typical of the trend in truck production, and used in further discussion.

TABLE I

GRADES REQUIRING NO EXTRA GASOLINE COST

	Typical passenger car	Modern 1½-ton truck	Modern high power 2-ton truck	Low speed heavy duty 3½-ton truck
	Rolling plus air resistance, pounds per ton			
miles per hour				
15	46	42	36	28
20	50	46	40	31
30	62	60	50	
35	70	66	56	
45	90	86		
	Maximum grade in high gear			
15	8%	7.0%	6.5%	2% (?)
20	8%	7.5%	6.2%	2% (?)
30	8%	6.5%	5.6%	
33	8%	5.4%	5.0%	
45	8%			
	Floating grades			
15	2.3%	2.1%	1.8%	1.4%
20	2.5%	2.3%	2.0%	1.5%
30	3.1%	3.0%	2.5%	
35	3.5%	3.3%	2.8%	
45	4.5%	4.3%		
	Estimated grades for no extra gasoline cost			
15	4.8%	4.0%	3.0%	1.5%
20	5.0%	4.3%	3.5%	1.5%
30	5.5%	5.0%	4.0%	
35	6.0%	5.2%	4.3%	
45	7.0%	6.0%		

With the all too inadequate data on the limits to the straight-line characteristics of the engines of present day vehicles, a conservative assumption of the grades on which there will be no extra cost for gasoline is made as follows:

Old heavy trucks on floating grades,

Modern heavy trucks on grades 1 per cent greater than floating grades, Modern light trucks on grades 2 per cent greater than floating grades, and

Passenger cars on grades 2 5 per cent greater than floating grade

With these assumptions Table I has been computed from available data

These computations lead to the belief that grades of five per cent need not be reduced at all in order to save gasoline for passenger car operation even when the traffic is so great as to reduce the speed to 15 or 20 miles per hour, that there is little extra cost for gasoline for modern light or medium weight trucks for grades of three to four per cent for speeds of 20 miles per hour, and for grades of up to five per cent for speeds of 30 or 35 miles per hour, but that grades over 1 5 per cent require extra gasoline for heavy trucks and for lighter trucks which are not so heavily powered as those instanced in the table

For grades steeper than those estimated to require no extra gasoline, the extra gasoline cost remains to be computed Were typical fuel-power characteristics of engines of present day vehicles known both as to the extent of the straight line and as to the bending upward beyond the positive and negative limits, the method already outlined could be used, lacking such data, another much less precise method is presented using a $3\frac{1}{2}$-ton truck as an example

In this method the relative amount of gasoline used in ascending grades is computed by assuming it proportional to the mean effective pressure on the pistons and the relative amount of gasoline used in descending grades is found by comparison from a number of tests made by others

On the basis that the amount of gasoline used is in direct proportion to the mean effective pressure on the pistons at constant engine speed the ratio of gasoline used in ascending a grade to that used on the level =

$$\left[\frac{\dfrac{\text{air resistance} + \text{rolling resistance} + \text{grade resistance}}{\text{gear reduction}} + \text{engine friction}}{\text{air resistance} + \text{rolling resistance}}\right] \text{gear reduction}$$

To illustrate this approximate method, estimates and computations are made for a $3\frac{1}{2}$-ton truck

Estimates

Truck capacity	$3\frac{1}{2}$	tons
Gross weight	10	tons
Speed in high gear	20	miles per hour
Speed in third gear	10	miles per hour
Speed in second gear	5	miles per hour
Speed in low gear	2 86	miles per hour

The gear reductions from high gear are, 2 to 1 for third gear, 4 to 1 for second gear and 7 to 1 for low gear.

Air plus rolling resistance	31 pounds per ton
Engine friction	20 pounds per ton

Using the approximate formula and these estimates, the percentages of gasoline used on ascending grades are computed, and the percentages used on descending grades are deduced from careful study of available tests, and the results shown in detail in Table II.

TABLE II

Computations for 3½-Ton Truck

Grade in per cent	Air, rolling, and grade resistance in pounds per ton	Air, rolling, and grade resistance plus engine friction (at pistons) pounds per ton	Brake horse-power	Per cent of gasoline to that on the level			
				Level	Ascending	Descending (deduced from study of tests)	Average up and down
			In high gear				
0	31	51	16.5	100			
1	51	71	27.2		139	78.5	109
1.5	61	81	32.6		159	66.5	113
2	71	91	37.9		178	55.5	117
2.5	81	101	43.2		198	46.5	122
3.0	91	111	48.5		218	42.5	131
			In third gear				
3.5	101	70.5	26.9		277	40	158
4.0	111	75.5	29.6		296	40	168
4.5	121	80.5	32.3		316	40	178
5.0	131	85.5	34.9		335	40	188
			In second gear				
5.5	141	55	18.8		433	40	237
6	151	58	20		453	40	247
6.5	161	60	21.5		473	40	257
7	171	63	22.8		493	40	267

From Table II, the approximate costs of gasoline per vehicle-mile on different grades are estimated, using 20 cents per gallon as the cost of gasoline (Table III). From Table III the data in Table IV are deduced.

The application of the estimates is illustrated by two examples, for heavy traffic and for light traffic. Readers are cautioned to be very careful in applying these data both because of the approximations and estimates it has been necessary to make, and also because individual trucks differ so much. It may be noted that only 3.5 ton trucks are listed as heavy trucks.

TABLE III

APPROXIMATE COSTS OF GASOLINE IN CENTS PER VEHICLE-MILE

	Per cent grade						
	0	2.5	3	3.5	4	5	6
Passenger cars	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Commercial vehicles, 1½ tons and less	2	2	2	2	2	2.4	2.6
Commercial vehicles, high speed, 2½ tons	3	3	3	3	4	4.9	5.4
3½ ton trucks	4	4.9	5.2	6.3	6.7	7.5	9.9

TABLE IV

ESTIMATED EXTRA COST FOR GASOLINE OVER THAT ON THE LEVEL IN CENTS PER VEHICLE MILE

	Per cent of grade						
	0	2.5	3	3.5	4	5	6
Passenger cars	0	0	0	0	0	0	0
1½ ton and smaller trucks	0	0	0	0	0	0.4	0.6
2 and 2½ ton trucks	0	0	0	0	1	1.9	2.4
3½ ton trucks	0	0.9	1.2	2.3	2.7	3.5	5.9

TABLE V

EXAMPLE A—HEAVY TRAFFIC

Approximate Extra Annual Cost Per Mile of Different Grades

	Number of vehicles per mile of road per annum	Grades in per cent						
		0	2.5	3	3.5	4	5	6
Passenger cars	15,000,000	0	0	0	0	0	0	0
1½ ton trucks	1,700,000	0	0	0	0	0	$6,800	$10,200
Medium weight trucks	400,000	0	0	0	0	$4,000	7,600	9,600
3½ ton trucks	200,000	0	$1,800	$2,400	$4,600	5,400	7,000	11,800
Totals	17,300,000	0	$1,800	$2,400	$4,600	$9,400	$21,400	$31,600

TABLE VI

EXAMPLE B—LIGHT TRAFFIC

Approximate Extra Annual Cost Per Mile of Different Grades

	Number of vehicles per mile of road per annum	Grades in per cent						
		0	2.5	3	3.5	4	5	6
Passenger cars	850,000	0	0	0	0	0	0	0
1½ ton trucks	90,000	0	0	0	0	0	$360	$540
Medium weight trucks	40,000	0	0	0	0	$400	760	960
3½ ton trucks	10,000	0	$90	$120	$230	270	350	590
Totals	990,000	0	$90	$120	$230	$670	$1,470	$2,090

The results shown in Example A are admittedly approximate, yet they show clearly that the larger extra costs for gasoline on grades are for the heavy vehicles and that these extra costs increase greatly with grades from 2 5 to 6 per cent

Using these results to compute the expenditure justified to reduce one mile of continuous six per cent grade to a mile of 2 5 per cent grade the table shows that the difference in gasoline cost per mile between six per cent and 2 5 per cent grade is $29,800, which capitalized at 6 per cent amounts to $497,000 for a difference in rise of about 185 feet, which reduces to a justifiable expenditure of about $2700 per foot of rise

From these estimates the expenditure justified to reduce a mile of six per cent grade to 3 5 per cent is computed by capitalizing $2090 minus $230, or $1860, at 6 per cent interest rate to be $31,000 for a reduction of 132 feet of rise, that is, a justifiable expenditure of less than $250 per foot of rise eliminated

Summarizing, the following general statements may be made.

1 The cost of "rise and fall" for passenger cars and for light commercial vehicles is so small as to be negligible on grades up to at least four per cent even at low speeds and heavy traffic

2 That grade reductions of grades up to six per cent must be justified mainly by the medium and heavy truck traffic

3 That heavy trucks, buses, and trucks with trailers should be investigated individually, and the traffic counted carefully in order to arrive at more exact estimates of justifiable expenditures for reducing grades

In conclusion it may be said that the comprehensive determination of the fuel-power characteristics of motor vehicle engines will enable accurate computations of the effects of grades and changes of grades upon the cost of gasoline for motor-vehicle operation, which herein have been approximate and estimated because of the lack of sufficient data Yet enough has been proved to indicate that the justifiable expenditures for eliminating rise and fall are very much smaller than those determined by the potential energy method

Thus in a way we have come back by an entirely different method to the findings of Wellington some 50 years ago that the heavy-unit, slow-speed traffic mainly is determinative of grade reductions