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Tech Tips

Highway Design for Motor Vehicles: A Historical Review

PART 7: THE EVOLUTION OF HIGHWAY GRADE DESIGN

Early Studies of Road Grades

The systematic study of road grades began in the early 19th century, coincident with the surfacing with tone of the principal roads in Europe and England. Prior to this surfacing, the loads that could be hauled on the highways depended more on the condition of the road surface than on its gradient. Often, the most difficult sections to traverse were the low, poorly drained, level valley sections where the road might be a rutted quagmire, while the steeper, better drained sections were naturally easier to travel. When the roads were graded and surfaced, the reverse became true, focusing unfavorable attention on the hills.

About 1835, John Macneill, a Scotsman, made a recording dynamometer with, which he could measure the tractive effort required to draw load over road surfaces of varying roughness and gradient. This was a powerful spring balance operating in a cylinder filled with oil which was placed between the test vehicle and the team supplying the traction. With this machine, Macneill measured the pull exerted by the team in drawing a 2,400-pound wagon over various level roads as follows:

- Gravel road on earth foundation - 147 lbs. or 1⁄16 of the gross load.
- Broken stone road on earth foundation - 65 lbs. or 1⁄36 of the gross load.
- Broken stone on paved foundation - 46 lbs. or 1⁄51 of the gross load.
- Well-made pavement - 33 lbs. or 1⁄71 of the gross load
- Best stone trackways - 12 ½ lbs. or 1⁄179 of the gross load.(1)

Other investigators of the period - notably Parnell in England, and Poncelet and Morin in France - found that the *traction* or effort required to pull a vehicle on a road depended not only on the nature of the road surface, but also on the diameter of the vehicle wheel, the width of tire, and a slight extent on the velocity of travel, being greater for vehicles drawn at a trot than at a walk.(1) This last may be the first measurement of vehicular wind resistance.

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To draw the test wagon up a grade[1] an extra effort was required, which, as was already well known from the laws of mechanics, depended on the steepness of the gradient and the weight of the load, and could be figured by the formula:

$$F = W \frac{h}{l}$$

Where,
F = Force exerted parallel to the road surface.
W = Weight of the wagon and its load.
h = Rise through which the wagon is raised.
l = Distance measured on the road surface corresponding to the rise *h*.

Thus, if friction and road resistance are disregarded, the force required to pull a wagon up a 1 in 20 gradient (or to keep it from rolling down the slope) would be $\frac{1}{20}$ of the weight of the wagon and its load.

In the era of animal power the *angle of repose* was the desirable maximum gradient angle for descending grades. This was the angle at which the tractive resistance just balanced the force of gravity, and ideally was the slope on which a carriage and team could descend safely at a trot without using the brakes. The angle of repose depended on the road surface and for good macadam was equivalent to a slope of about 1 in 35 or approximately 2.85 percent. This was the preferred gradient for post roads where speed of travel was important, and on such a slope a coach could be safely drawn downhill at a speed of 12 mph.[(1)]

On the other hand, if the gradient were steeper than the angle of repose, the driver would have to slow down to half speed or less and use his brakes to control the vehicle. The time so lost might justify the selection of a longer but less steep route for the road.

Animal Traction Limits

The tractive power of draft animals placed a limit on ascending gradients. An ordinary team of horses weighing 2,400 pounds could be counted on to exert a pull of about 240 pounds traveling at 3 mph for a 10-hour day. This effort would pull a gross load of 6 tons on a level macadam road.[(2)]

On grades, horses could increase their effort; and, if the gradient were not more than about 2.5 percent, continue to draw about as much load as on the level. However, for steeper gradients their pulling power diminished from exhaustion while at the same time the force to be overcome increased, so that at 5 percent gradient a 2,400-pound

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1. A road grade is the plane created by cutting the hills and filling the valleys. When the grade is not level, the rate at which it ascends or descends is the gradient of the slope; but frequently the term grade is used also for the rate of slope. Gradient is now almost universally expressed as units of rise per hundred units of horizontal distance, or percent.

team could haul only about 3.4 tons on macadam, and at 7 percent only 2.4 tons. The tonnage that could be hauled over a road therefore depended on its steepest grades, for it was uneconomical to reduce loads for these grades, or, even worse, to hitch on an extra team that would be needed in only a few places.

Thus, the ideal maximum gradient to meet the requirements of both tractive effort and safe descending speed was between 2.5 and 3.0 percent. Thomas Telford, one of the founders of highway engineering, was a firm believer in keeping gradients low, and also in eliminating all unnecessary rise and fall of the gradeline. The most famous of his many roads was the Holyhead Road through the mountainous country of North Wales. In reconstructing this road he also relocated extensive parts of it to reduce the gradients - which were in many cases as steep as 10 or 16 percent - to a maximum of 3.33 percent.[1]

Later, Macneill measured road and grade resistances on the Holyhead Road with his dynamometer. He could then compute the ton-mile costs of haulage over any part of the road. By multiplying these costs by the number of tons which passed over the road in a year, he was able to compute the annual savings in user haulage costs attributable to the improvement.[3] Macneill's work, published in 1838, may be one of the earliest applications of what we know today as highway engineering economy.

Although the ideal maximum was around 3 percent, such low gradients were not practical in hilly and mountainous country because of the construction expense, and therefore most road authorities permitted steeper gradients under these conditions. In Prussia, for example, permissible gradients were 2.5 percent in level districts, 4 percent in hilly districts, and 5 percent in the mountains. In France, ruling grades depended on the political importance of the road rather than topography. National roads were limited to 3 percent gradient, departmental roads to 4 percent, and subordinate roads to 6 percent. In many States of the United States 5.0 and even 6.0 percent maximum gradients were permissible on main roads.[2]

In all countries engineers provided 0.5 percent to 1.5 percent minimum gradients to promote longitudinal drainage, but some authorities thought that level grades were satisfactory for fills.

SUPERIOR TRACTIVE ABILITY OF MOTOR VEHICLES

Trucks and automobiles got along very comfortably on the relatively light grades of the wagon roads built in the United States during the *Good Roads Movement*. However they were mechanically capable of much better grade performance than the prevailing 5 to 6 percent maximums. As early as 1916, one could buy a 5-ton truck that could ascend a brick-paved hill of 13 percent gradient in low gear and, with special gearing, 27 percent was possible.[2] Automobiles of this period could ascend 6 percent hills of considerable length in high gear if they could get a running start and did not have to reduce speed for sharp curves. Released from the restrictions of animal power, designers no longer had to wind through the country seeking the easiest grades: they could go directly across country ignoring all but the greatest obstacles.

Charles Upham, one of the most influential highway engineers of the period, stated in 1920:

> More stress has been laid upon the alignment of roads during the past two or three years than ever before. It simply shows that highways are passing through the same stage that the railroads passed through when, after exhaustive studies from an economic standpoint, they spent considerable money for the straightening of their lines.
>
> In considering the alignment of commercial roads, or direct routes, it must always be remembered that a straight line is the shortest distance between two points, and from a commercial standpoint the shortest way is not only the most direct, but with other things equal, is the most economical, therefore, it seems to be practically conceded that ideally aligned commercial roads are those that are laid out in absolutely straight lines.
>
> Where there are costly influences entering the problem that make it impossible or impracticable to follow the straight line, then the alignment should approach the straight line, and become a compromise of line, grade, and cost of construction.
>
> In most States it is impracticable and almost impossible to hold a grade as low as 6 percent. ...[(4)]

Upham's advice was widely followed by the engineers who executed the great road programs of the 1920's and 1930's in the United States. They shortened road distances in the aggregate by hundreds of miles and long tangents or straightaways became commonplace. To maintain these long *tangents* through rolling country they sometimes used gradients as steep as 9 percent, and in a summary of current practice made by the Bureau of Public Roads in 1929 it was stated:

> On main-line highways it is customary to adopt a maximum grade of 5 percent in gently rolling country and 7 percent in rough country, but it is no longer considered good practice to resort to sharp curvature in order to avoid grades somewhat steeper than 7 percent. If local conditions permit either a 7 percent grade with a sharp curve or a short 9 percent grade with a wider curve, the latter design is thought to be the better practice because it is safer for modern motor traffic.[(5)]

Grade Design for Early Motor Roads

Coincident with the widespread adoption of long-tangent location there arose two schools of thought as to how the vertical alignment or profile should be designed in rolling topography. Engineers of the *railroad* school preferred long easy grades connected by long flat vertical curves involving heavy cuts and fills, such as were the rule in railroad location then as now. On the other hand, engineers of the *rolling grade* or *humping* school preferred to follow the ground profile closely, using gradients up to 9 percent if necessary to avoid deep cuts and fills.[(6)]

Humping did save excavation - in some extreme cases as much as 20 percent - but it produced a *roller-coaster gradeline* with short sight distances between the humps and valleys. This, combined with the unlimited speed possible on tangents, made for a dangerous alignment, as well as a monotonous one.

Since the 1930's, the cost of earth-moving has been so greatly reduced by mechanization that earth work has become a relatively less important component of the total cost of road-building, and grade-rolling is much less pronounced. In fact, for heavy-traffic roads we have for all practical purposes returned to the *railroad gradeline*.

Railroad engineers have known for many years that track resistance increases on curves, especially sharp ones. To compensate for this added resistance they flattened the gradient a little on the sharper curves so that the train would not have to slow down too much when going upgrade around these curves.

Highway engineers of the 1920's, many of whom had been trained as railroad engineers, carried the idea of *grade compensation* over into highway engineering and by 1928, it was customary to compensate or reduce the gradient on curves of less than 500-feet radius. The amount of compensation was purely empirical. Grade compensation is less important today because trucks and automobiles are more powerful, and permissible grades and curvature are more moderate than they were 40 years ago. Nevertheless, it is still considered good design in mountainous areas to flatten the grade slightly on curves of less than about 800-feet radius.

Vertical Curves

In the days of animal power, road-builders paid little attention to vertical curves. After all, the angular difference between two 5 percent grades was only about 6° and this was hardly enough of a peak or valley to cause discomfort to a vehicle traveling only about 3 or 4 mph.

With the increasing road speeds that came with the automobile, road engineers began to worry about sight distances, especially over hill crests, and in 1919 one authority recommended that "vertical curves between grade tangents should be of large enough radius to provide for a proper line of sight between vehicles approaching each other from opposite sides of the hill." This radius should be, it was stated, not less than 50 feet in most cases.(6) With the high-silhouette cars of that day this rule gave about 300 feet sight distance over a summit between two 5 percent grades.

Another authority of the same period recommended parabolic vertical curves with lengths varying according to the algebraic difference between the intersecting grades. "Experience has proved that the following lengths will make satisfactory curves: 100ft., 200 ft., 300 ft., for algebraic differences in grades between 1 and 3, 3 and 6, and more than 6 percent, respectively."(6)

In 1929 the American Association of State Highway Officials (AASHO), in one of its earliest standards, recommended "that horizontal and vertical curves be used which provide a sight distance of at least 500 feet." At this time, in U.S. practice, sight distance was measured from an assumed operator's eye level of 4.5 feet above the road surface to another point on the road ahead, also 4.5 feet above the surface.

In the early 1930's, the German engineers were designing their *Autobahnen* for 370 meters (1,215 feet) minimum stopping sight distance - more than double the AASHO 1929 minimum. Furthermore, they measured this sight distance from an assumed operator eye height of 3.9 feet to an obstacle on the road that was only 8 inches high - assumptions which required much longer summit vertical curves than the American practice described earlier. The very long sight distances used by the Germans resulted from using a very high design speed - 180 km/h (112 mph) - in the kinetic energy formula for stopping sight distance. To provide such sight distances the German engineers used circular vertical curves with radii as long as 54,700 feet for summits and 16,000 feet for sags[2].[(7)]

In 1939 when the AASHO Committee on Planning and Design Policies considered the problem of sight distance, all members agreed that the American rule for measuring sight distance was risky because it did not allow for small obstacles such as fallen rocks or small animals on the pavement. Some members thought that the driver should be able to see the surface of the pavement ahead for the full distance required to stop from the design speed. However, calculations showed that such a rule would require vertical curves so long that construction cost would be prohibitive. Eventually, the Committee adopted a modification of the German rule. They retained the 4.5-foot driver eye level but measured sight distance to an obstacle projecting 4 inches upward from the pavement surface[3]. The vertical curves required by this so-called dead cat rule were much longer than those needed by the old rule, but were still within economic limits. The new rule also resulted in a better balance between horizontal and vertical sight distances.

Agg's Theory of Grades

We have seen how the design speed concept provided engineers with a logical means of achieving consistent, *balanced design* for horizontal alignment, and also for vertical curvature. The designer had only to select a design speed, and the other dependent design elements - sight distance, horizontal radius, super-elevation, length of spiral, length of vertical curve - were to a large extent decided for him. However, it was not nearly so easy to arrive at a logical maximum or limiting gradient to be used for a particular design speed.

As early as 1919, Thomas R. Agg, one of the modern founders of the discipline of highway engineering economy, proposed a method for solving location problems involving grades, based to a large extent on the already well-established railroad theory of grades.[(8)] Agg believed that grades should be designed to take into account the inherent characteristics

2. For two intersecting 5 percent grades these radii are approximately equivalent to simple parabolas 5,500 feet and 1,360 feet long, respectively.

3. In 1965 AASHO changed this rule to provide for an operator eye level of 3.75 feet and an obstacle height of 6 inches.

of the motor vehicle especially its motive power - then supplied with few exceptions by the throttle-governed, four-cycle internal combustion motor. This motor was most efficient when operating at or near full load at the speed for which it was designed. He analyzed the mechanical characteristics of several makes of automobiles and trucks, and then prepared tables showing the tractive effort that could be exerted by a composite average truck and a composite average automobile at various gear ratios. Then, using these values and assuming some loss of velocity on the hill, he was able to compute the maximum gradient that the vehicle could surmount at full power in high gear without dropping below a minimum acceptable velocity, which for trucks was 15 mph and for autos 25 mph.

Agg believed that the most economical descending grade was one that would “permit the vehicle to descend without the use of power or the brakes, and without attaining an unsafe speed.” He assumed that an automobile would reach the top of a hill traveling 25 mph and then gather momentum under the pull of gravity until it was traveling 40 mph when it reached the foot of the hill. (Corresponding speeds for trucks would be 15 and 25 mph.) During its descent the vehicle would be urged forward by the pull of gravity but at the same time restrained by air resistance, rolling resistance, and the inertia of the vehicle’s rotating parts.

Agg found that ideal gradients - those that were most efficient and resulted in the least fuel consumption - were about 4 percent steeper for ascending grades than for descending grades, so the problem of economical grade design was to find average gradients that would yield the greatest overall economy. In a real situation he recommended that the designer lay a tentative gradeline and then, knowing the traffic count and percentage of trucks, calculate the average fuel consumption. He could then lay another, easier gradeline and recompute the fuel consumption. If the annual savings of fuel were equal to or greater than the annual construction cost of the grade reduction, the change could be deemed economical.

Although straightforward in principle, Agg’s analysis was somewhat laborious in practice, and it is safe to say that it was not widely used in ordinary highway design. The economy of gradeline design continued to be judged more by the balancing of cut and fill volumes and savings in construction cost than by the economics of vehicle operation.

Measuring the Grade Ability of Trucks

In the late 1930’s and early 1940’s, studies of highway capacity by the Public Roads Administration (PRA) (the former Bureau of Public Roads) and the States opened a new approach to the design of highway grades. One of these studies, made in 1938, measured the hill-climbing ability of motor trucks.[9] This study was undertaken partly because of the PRA’s desire to evaluate the traffic congestion caused by slow vehicles on the highway, and partly because of the desire of the vehicle manufacturers and truckers to head off restrictive legislation that would limit the weight of cargoes or impose high power requirements on trucks. (A widely advocated requirement of the period was that trucks be able to maintain 20 mph on a 4-percent grade.)

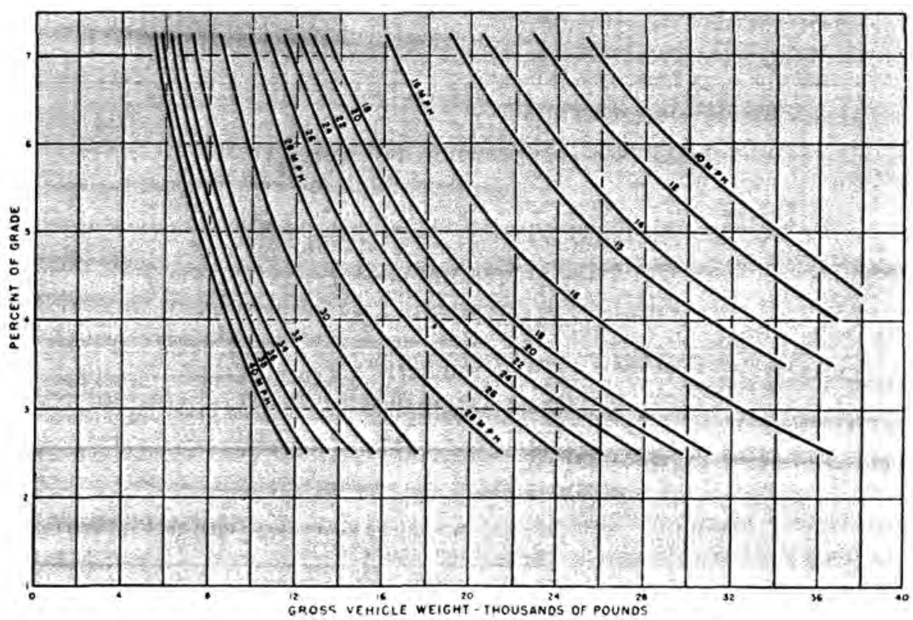

Figure 1: Grade ability of light trucks and tractor trucks (without governor).

In the course of this study the researchers measured the maximum sustained speeds - the speeds after exhaustion of any initial momentum that could be maintained on grades by 47 typical new and used trucks. The trucks were of various models from heavy to light and they were tested on actual grades of 3.2, 4.0, 4.5, 6.0, and 7.0 percent. The investigators placed known loads on each truck starting with the maximum weight that could be hauled in the lowest gear, and the truck's speed performance was measured on one of the grades with an extremely accurate bicycle wheel chronograph mounted on the front bumper. The load was then reduced by 1,000 pounds and the test run was repeated in the same gear. This procedure was repeated in successive decrements of 1,000 pounds until the observed road speed corresponded to the maximum engine speed recommended by the manufacturer. The test was then run over again in the next higher gear. The full range of tests was then performed on the other grades. Figure 1 shows the speed performance of light trucks as measured by these tests. Similar graphs were compiled for medium and heavy vehicles.

The most significant information that stands out in figure 1 is the small increase in speed that results from a reduction in gradient. Thus, for an average light tractor-truck weighing 24,000 pounds gross, a reduction in gradient from 6 percent to 5 percent would improve speed only 1.3 mph (from 14.0 mph to 15.3 mph). To significantly increase speed say to 23 mph, the gradient would have to be reduced to 3 percent. Looking at it another way, to maintain a speed of 23 mph on a 6 percent grade the same truck could carry a gross load of only 14,000 pounds. The reduction would have to come out of the payload which originally was about 12,000 pounds, so there would be a net loss to the trucker of 83 percent.

Another way to increase speed is to increase engine power, but the researchers found that to obtain a road speed increase of 3 mph on a 6 percent grade would require an increase of 45 percent in the engine power of a typical 24,000-pound vehicle.

The investigators agreed that there was no single comprehensive solution to the problem and that any solution would probably involve some grade reduction coupled with a reduction in weight/power ratios for trucks. They stated, “Before a final conclusion can be reached, the reasonable minimum speed must be determined and the relative economics of the three basic methods [grade reduction, load reduction, power increase] and of their combinations must be determined.” For the immediate future they thought the best policy was to widen roads at the points of most serious congestion, that is by adding climbing lanes, since an improvement in weight/power ratios would come only very gradually.[9]

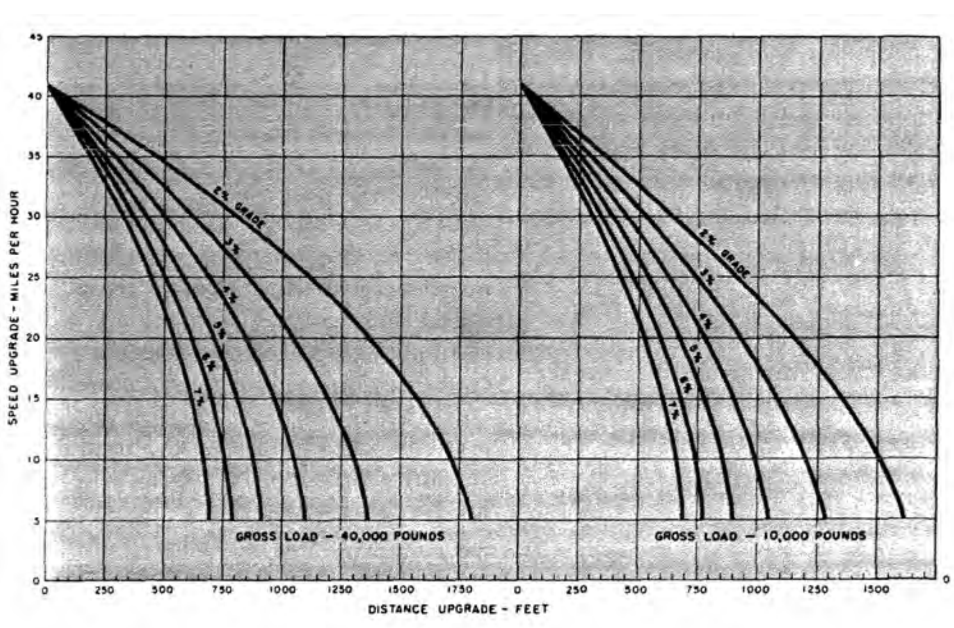

Figure 2: Distance upgrade that the momentum alone will carry vehicles traveling at various speeds (engine disengaged).

The Effect of Momentum

The 1938 truck study specifically excluded the effects of momentum from consideration. However, under actual traffic conditions momentum is always present and it very materially increases the ability of vehicles to surmount grades. Realizing this, A. Taragin of the PRA in 1945 analyzed the data from the 1938 tests to determine the tractive effort exerted by the test vehicles for the various sustained speeds that were measured[10] This tractive effort, added to the vehicle's kinetic energy or momentum, is expended in lifting the vehicle up the grade and in overcoming tractive resistance. Taragin was able to show, for example, that if a 40,000-pound vehicle approaches a 4 percent grade at 41 mph with the engine disengaged, it will coast 770 feet before its speed drops to 20 mph (fig. 2). If instead of coasting, the operator approaches the grade at a speed of 41 mph and applies the engine power, momentum plus tractive effort will take the vehicle 1,500 feet up the grade before the speed drops to 20 mph (fig. 3). Only on grades that are longer than 2,500 feet would the vehicle have expended all of its momentum and be reduced to its *sustained speed* of 12.7 mph.

The PRA analysis showed that short grades do not seriously slow down trucks if the road conditions are such that they can get a running start and enter the grade at substantial speed. On longer grades the speed progressively drops until it reaches the maximum sustained speed or *crawl speed* of which the vehicle is capable. If the length of grade requiring operation at sustained speed is appreciable, satisfactory operation can only be achieved with auxiliary climbing lanes.

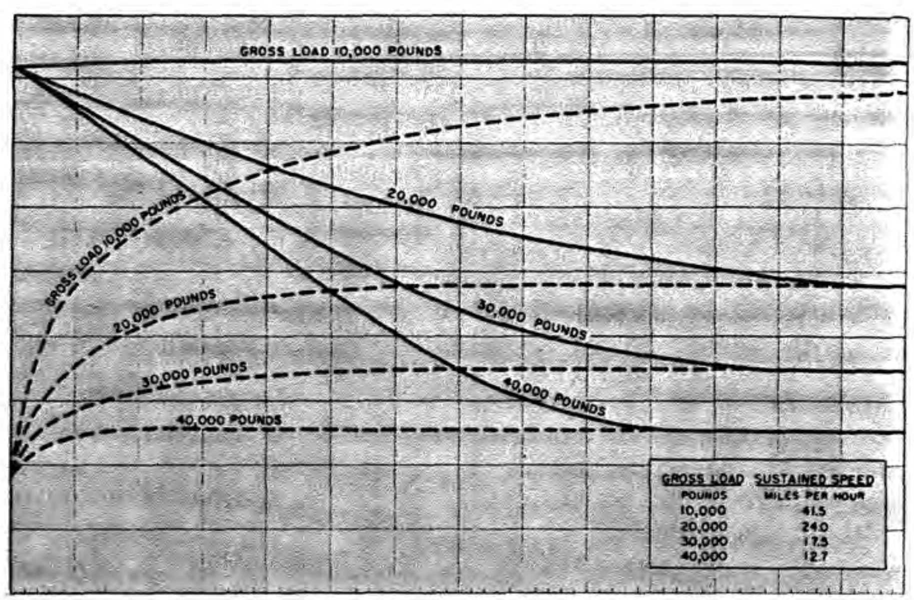

Figure 3: Effect of gross load on the speed of medium motor vehicles on a 4.0 percent grade

Arizona Grade Studies

The 1945 PRA study was a theoretical analysis based on the performance of 1938-model trucks. To update the BPR findings engineers of the Arizona Highway Department in 1949 observed the performance of 160 light, medium, and heavy trucks on various mountain grades, ranging from 2.0 percent to over 6 percent. The trucks were stopped several miles from the test grades and were weighed, and pertinent data as to horsepower and load were obtained from the driver. The truck was then allowed to proceed. Observers in a following car noted the truck's speed on arrival at the foot of the test grade and the distance at which the vehicle reached crawl speed.[(11)]

The observers found that the average speed of the trucks when they reached the foot of the grade was 47 mph, but many were clocked at speeds up to 65 mph. Thereafter, they lost speed at a rate which varied with the grade and also with the skill of the driver in knowing when to change gears. Typically, the loss of speed varied from 2 mph per thousand feet of grade on 2 percent grades to 33.5 mph per thousand feet of grade on 7 percent grades. Figure 4 is a composite of the speed-grade performance of heavy and medium trucks loaded to capacity or nearly so.

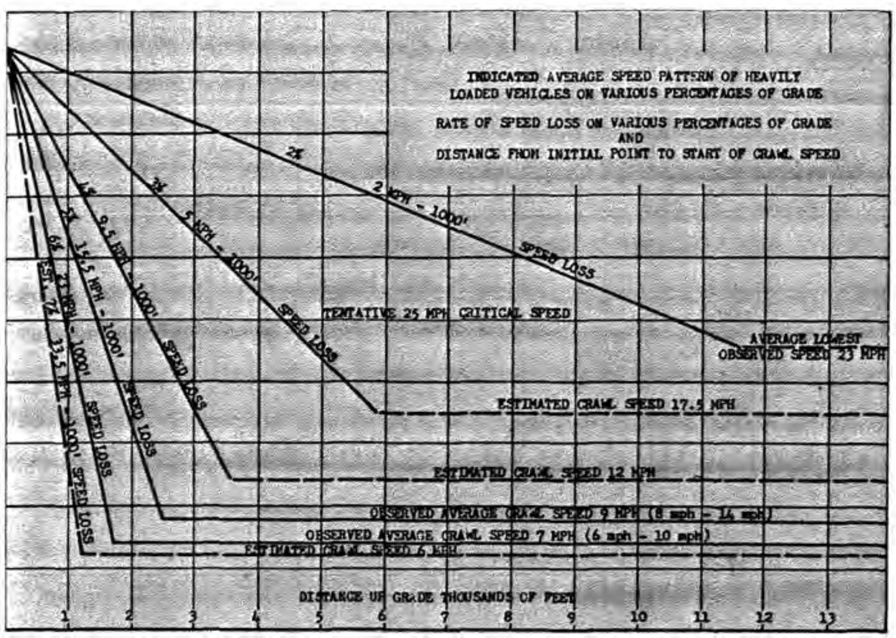

Figure 4: Speed patterns on various grades.

The Arizona engineers were concerned over the slow crawl speeds for the steeper grades not only because of congestion, but also for safety. They proposed a minimum critical speed of 25 mph on grades. If the hill was long enough to slow heavy vehicles down below that speed, they proposed to provide a climbing lane so that the slow vehicles could get out of the traffic stream and let the fast ones go by. The point at which the speed dropped to 25 mph would be the place to begin the climbing lane. Thus, in figure 4 if a 5 percent grade is longer than 1,500 feet, a climbing lane will be required upgrade from the 1,500- foot point.

The Texas Heavy Test Vehicle

In 1953, the Texas Highway Department made a series of road tests with a 29-ton tractor-semi-trailer test vehicle. The tests were made on various grades and the speeds attained during the test runs were automatically recorded by road detectors and graphic recorders. The average results of 118 test runs were plotted on speed-distance curves similar to figure 4 which the Texas engineers used to determine the beginning and ending of climbing lanes for a minimum critical speed of 30 mph.(12)

Determining Critical Speed

In both the Arizona and Texas procedures the important factor for deciding when to use climbing lanes was the *critical speed* below which traffic operation became intolerable. This speed was a matter of judgment - Arizona opting for 25 mph and Texas for 30 mph. In 1954, the AASHO Committee on Planning and Design Policies studied the available research information and decided that a reduction of 15 mph below the average running speed for level sections of the same highway would be “tolerable” and recommended that this value be used for grade design.(13) Applying this rule to average running speeds measured in 1963 results in the following tolerable minimum speeds(14):

Design speed						
(mph)	30	40	50	60	70	80
Average running speed at low volume						
(mph)	28	36	44	52	58	64
Tolerable minimum speed on grades						
(mph)	13	21	29	37	43	49

The truck tests resulted in rather general agreement among engineers that grades should if possible be kept below 3 percent for highways carrying large volumes of heavy trucks. However, such low grades are expensive to construct, even in fairly easy country, so when AASHO issued its design standards for primary highways in May 1941, it made no recommendations for maximum grades, simply acknowledging that “agreement has not been reached on maximum grade or length of sustained grade to be used for various combinations of terrain and traffic density. Grades long enough to be classed as ‘sustained grades’ should be less than the maximum grade used on that section of highway.”(15)

Search for a Consensus on Grades

In 1941 President Roosevelt appointed a distinguished committee "to investigate the need for a limited system of national highways to improve the facilities now available for interregional transportation, and to advise the Federal Works Administrator as to the desirable character of such improvement."(16) The Secretary of this Interregional Highway Committee, H. S. Fairbank of the Public Roads Administration, assembled an outstanding technical staff in Washington, D.C., consisting of the traffic and design experts who had been in the forefront of highway traffic research during the preceding decade.

The Committee's report, which appeared in 1944, recommended a system of 33,920 miles of highways designed for high-speed travel:

> All rural sections of the system shall be designed at all points and in all respects for safe travel by passenger vehicles at a speed of not less than 75 miles per hour, and by trucks and tractor combinations at a speed of not less than 60 miles per hour in flat topography. In more difficult terrain the speed for which the highway is designed may be reduced; but in no case to less than 55 miles per hour for passenger vehicles and 35 miles for trucks and tractor combinations in mountainous topography. All rural sections shall provide a sufficient number of traffic lanes and other facilities so that at no time, except during infrequent peak hours, will it be necessary because of the interference of other vehicles to reduce the average running speed to less than 50 miles per hour.(16)

The recommended system was enacted into law in the Federal Aid Highway Act of 1944, but Congress left the selection of the system and its design standards to the "joint action of the State highway departments of each State and the adjoining States." The design standards for the Interstate System adopted by the American Association of State Highway Officials in 1945 fell considerably short of those recommended by the Interregional Highway Committee, the minimum permissible design speeds being only 60, 50, and 40 mph for flat, rolling, and mountainous topography, respectively. The AASHO recommendations for gradients were equally cautious: "The maximum gradients preferably shall not exceed 5 percent and in any case shall not exceed 6 percent. On short lengths only, gradients of 7 percent may be used."(15)

In 1954, AASHO's Committee on Planning and Design Policies observed that "Design values have been determined and agreed upon for many highway features but few conclusions have been reached on roadway grades in relation to design speed." The Committee went on to state, "In the States which utilize design speed control, nearly one-half specify maximum grades of 3 to 4 percent for a design speed of 70 mph, and only a few States use a maximum of 6 percent for this design speed. If the more important highways only are considered it appears that a maximum grade of 7 or 8 percent would be representative for 30 mph design speed."(13)

By 1956 the States had reached agreement on maximum gradients for the Interstate System, and the AASHO standards approved that year stated:

> For design speeds of 70, 60, and 50 miles per hour, gradients generally shall be not steeper than 3, 4, and 5 percent, respectively. Gradients 2 percent steeper may be provided in rugged terrain.[17]

However, not until 1961 did the States reach a consensus on what maximum gradients to use for highways other than freeways. AASHO standards adopted December 27, 1961, recommended the grades shown in table 1. Short grades less than 500 feet long and one-way down grades may be 1 percent steeper. For low volume rural roads, grades may be made 2 percent steeper.

Table 1: Maximum grades in percent[18]

Topography	Design speed, mph				
	30	40	50	60	70
Flat	6	5	4	3	3
Rolling	7	6	5	4	4
Mountainous	9	8	7	6	-

The design speed concept for geometric design became AASHO policy in September 1938, yet 23 years elapsed before there was sufficient agreement among the States for AASHO to feel free to bring out a national policy on grades. This illustrates an important aspect of highway policy in the United States: Design practice generally evolves slowly over a long period, and crystallizes into formal *standards* only after a strong consensus has developed among informed engineers and administrators. We will examine this evolutionary development of standards in Part 8.

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