EFFECT OF SIX-WHEEL VEHICLES ON HIGHWAY DESIGN

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In this discussion the approach to the subject involves two distinct phases, the physical and the economic. After a long series of investigations and detailed research projects extending widely into each of these fields, sufficient information has been developed, analyzed and made available for use, to enable us with much confidence to support definite conclusions as to the utilization of the motor vehicle and its effect upon improved highways.

The question has been frequently asked: "What is the effect of the motor vehicle upon highways?" It may with equal pertinency be countered with: "What is the effect of highways upon the motor vehicle?" That is, there is a mutual relationship from which each must profit, or each must suffer. There must be a mutual adjustment if real economy is to result. Such a mutual adjustment precludes uneconomic restrictions upon the size, weight and speed of the motor vehicle, just as surely as it excludes undue size, weight or speed restrictions from the road.

The general conclusions which may be fairly drawn from the presentations here included are these:

(1) The six-wheel vehicle offers a desirable and effective answer to the problem of the load above the normal desirable limit for the four-wheel truck.

(2) The six-wheel truck offers a desirable and effective answer to the problem of the load equal to the heavier four-wheel truck in areas where road conditions do not permit maximum wheel concentration.

In these conclusions are combined both the physical and economic phases of highway transport in a manner to promote real economy. They embody the principle of mutual adjustment of the motor vehicle and the road. To support these conclusions the physical data are first submitted. Many factors determine road design. Considered as a load supporting structure, the concentrated load of the heaviest truck wheel becomes the determining factor in fixing the necessary strength of the roadway. It is evident that only those types of construction for which the stresses may be computed or measured, lend themselves to structural design. The design of other types must be more or less based on experience, but the consideration of the so-called flexible types of pavements would not lead to very different conclusions. The data presented are confined to the influence on road design from the single angle of the concentrated wheel load on types of roadways on which the stresses are determinative, - that is, the so-called rigid types. Since it may be assumed that the interest of the automotive engineer does not extend to competitive types of road construction or materials, this discussion may be further limited to the relative effects on the design of the road as a structure from the application of the maximum load through a single wheel or single axle and through multiple wheels or axles.

Influence of four-wheel and six-wheel vehicles on rigid pavements.

Passing for the moment the matter of the magnitude of permissible truck wheel load concentration, the following conclusions were reached by the Bureau of Public Roads in 1925, after a series of tests in which the elastic behavior of a rigid pavement was studied when subjected to the influence of four-wheel and six-wheel vehicles: 1/

(1) The deflection of a concrete pavement is directly proportional to the load applied (within the limits of this investigation).

(2) A load passing along the test pavement (uniform thickness 6 inches) 9 inches from the edge of the pavement produced approximately twice the fiber deformation in the edge of the pavement that was caused by the same load passing along a path 21 inches from the edge.

(3) The tension produced in the top of the pavement due to counter flexure between the wheels of a six-wheel vehicle is less than the tension produced in the bottom of the pavement directly under the wheel, regardless of the axle spacing.

(4) In the case of six-wheel vehicles, the maximum tension produced in the pavement seems to be a function of the wheel load and not of the axle spacing, at least between the limits of 3 feet and 10 feet.

(5) Within the deformation limits obtained in this investigation (maximum unit fiber deformation of about 0.0001 inches per inch)

1/ Public Roads, Vol. 6, No. 8, Oct. 1925. The Six-Wheel Truck and the Pavement.

the fiber deformation in the pavement is directly proportional to the load.

(6) In a pavement slab of uniform thickness the maximum deformation occurs along the edge of the slab for both four-wheel and six-wheel vehicles.

During the following year Dr. H. M. Westergaard made a theoretical analysis of the stresses produced in concrete pavements by wheel loads by purely mathematical methods. In this study the case of the six-wheel vehicle was investigated. 1/ For the conditions assumed, the following important conclusion was drawn:

"One may draw the conclusion that the main part of the state of stresses at a given point is due to a wheel load right over the point. In the case examined the contribution due to the three additional rear wheels of the six-wheel truck is of less importance than that due to the one additional rear wheel of the four-wheel truck."

Subsequently, the Illinois State Highway Department carried out a series of tests along lines quite similar to those pursued by the Bureau of Public Roads and their findings are entirely in harmony with the conclusions quoted above. 2/

1/ Public Roads, Vol. 7, No. 2, April, 1926, Stresses in Concrete Pavements Computed by Theoretical Analysis.

2/ American Highways, Vol. 6, Oct. 1927, pp. 29-30, Recent Developments in Highway Research.

Impact relations of the four-wheel and six-wheel vehicles.

All of the foregoing researches concerned static load or rolling loads with very little impact. The Bureau of Public Roads in the course of its investigations of motor truck impact, a research in which this Society has actively cooperated, has obtained some data on the relative impact reactions of four-wheel and six-wheel vehicles. 1/ These data indicate that, for two trucks carrying the same load and identical except as to the rear end construction, the unsprung component of the impact reaction of the six-wheel vehicle is about one-half that of the four-wheel vehicle, all conditions of the test being the same.

Desirability of the pneumatic tire.

Generally speaking, the heaviest loads are carried on solid tires but all the investigations prove the advantage to the road of the pneumatic tire. Were it possible to build perfectly smooth roads and to maintain them so, there would be no substantial difference between the two, carrying equal loads, in road deteriorating influence; but such a condition is not possible to maintain. It is not necessary here to go into an elaborate discussion of construction practices, effect of frost and moisture on the subgrade, fatigue of materials of construction, thermal changes with attendant distortion of the road slabs, and many other influences. The fact that the road builder

1/ Public Roads, Vol. 7, No. 4, June, 1926, pp. 79-80-81, Motor Truck Impacts as Affected by Tires, other Truck Factors and Road Roughness.

contends with a variety of adverse conditions, many beyond his control, is certain to produce road surfaces that are not perfect planes and cannot be maintained as such. Such surfaces suffer much more from the impact of truck wheels carrying solid tires, than from pneumatic tires. The impact of a solid tire exerts a pressure on a pavement which may be equal to two or three times the static load, under the same conditions that the pressure exerted by the pneumatic tire would be only a small additional percentage above that of the static load. This does not imply an unusually rough road surface; rather, it is a condition which might be called a normal operating condition. The conclusion is apparent then, that to carry the same load the multiplication of wheels, if this changes the wheel load concentration so that pneumatic tires are economical, is a very great advantage to the road.

The application of physical facts to economic transport.

Up to this point the discussion has considered only the physical relations and effects. Unfortunately engineering discussions have all too frequently stopped here, to the detriment of engineering leadership. The proper goal of both the automotive engineer and the highway engineer is exactly the same, - the most economical highway transportation. Each in his particular field must work back from this objective not independently but with intelligence and sympathy. Thus while the physical facts are important, the economic application is the real objective.

With limited exception the roadways of this country are relatively new. The construction of our modern highways by the application of engineering principles and under engineering supervision, had its inception with the establishment of the first state highway departments about 1890 in a few of the eastern states. From the beginning the same necessity has been a large factor in the design of highways. The engineer has been constantly faced with the problem of producing the maximum mileage of serviceable roads. So the design of roads has been as light as possible consistent with the traffic. The road surfaces were placed on new subgrades. This does not mean that always the surfacing followed at once the grading, but even where the first settlement had taken place the roadbeds were far from final consolidation.

Since state road building started and acquired some momentum in the east, say a quarter century ago, it would seem that the roadbeds at least would have become well consolidated, and such is true. But these first roads were designed for the traffic of the day, the horse-drawn vehicle, with sections, alignment and locations adapted to that type of traffic. The new traffic differing so much in speed and wheel load concentrations demanded relocations, realignments and heavier construction. To some degree the earlier construction was such that it has been possible by increasing the thickness and width of road metal to use these old roads as part of the modern system. This is true to a limited extent in the New England States and in the states east of the Alleghenies. Here we find conditions somewhat corresponding to those in England and on the Continent, - adequate roadways really built through continuous betterment and maintenance over a long period. But it is only necessary to observe casually to become aware of the very large extent to which new roadbeds are being required as an integral part of these oldest highways. Sections where the alignment is being straightened, corners rounded by easy curves, by-pass roads around city congestion and widening of existing roadways, all require new roadbeds.

In the rest of the country, and by far the larger part, prior to about 1914, practically no rural highways adequate for present traffic existed.

From this brief review it is evident that highways for modern traffic are new. By far the major portion of our paved rural highways have been built since 1920. The insistent demand has been for greater mileages. The highway engineer has had no option; he has had to design roads as light as he believed would reasonably serve the traffic in order to secure the maximum mileage. This is the typical highway problem of the United States as it is with all other of the newer countries. In a sense, this country departed from all established standards and historical precedents. The old Roman roads we have estimated if built under modern conditions would cost about $300,000 per mile, perhaps more. No nation could afford them in quantity. The highway engineers and officials of the United States are carrying the greatest tonnage on the lightest built roads that is being attempted anywhere in the world. And the time has not yet come when this policy may be changed. Nor is it to the advantage of the motor vehicle industry to have it otherwise. Every new mile adds to the potential service of the motor vehicle.

The cooperative highway transport surveys which have been carried out by the Bureau of Public Roads and various state highway departments, and which have covered many typical states, have accented the utility of freight carrying motor vehicles but have conclusively shown that except for certain areas such as terminal areas in industrial districts and the arterial highways connecting them, the five-ton truck is the maximum size selected for general use. Above this size the number is very small. Here apparently is abundant proof that economical transportation is secured outside of the relatively limited areas named by not over a five-ton net load limit. The wheel concentrations called for by such a unit are within the safe load limit for the modern standard types of rural pavements. But there is a very large percentage of the mileage that is not safe for loads beyond this and there is no evidence at this time to justify heavier construction.

Reasonable wheel load limits.

Thus it would seem that the road and the freight carrying vehicle might be brought together by adopting weight limitations for rural roads as follows:

For general use on improved roads - 8,000 lbs. per wheel.

For terminal areas and arterial
roads connecting these - - - -- 9,000 lbs. per wheel.

For municipalities - Limits as prescribed by ordinance.

These maximum wheel loads may be applied to either the four or six wheeled trucks.

If bridges are designed under the standard specifications of the American Association of State Highway Officials, they will carry without serious over-load the six-wheel truck with these wheel loads.

The maximum truck wheel load is not the only factor influencing road design. Speed, tire equipment, width, sprung and unsprung weight, have an important bearing. These, however, are common to all trucks, and the subject of this discussion is the relative influence of the six-wheel truck. It should be emphasized, however, that the wheel loads here proposed must be strictly held to apply only to the manufacturers' rated capacity. Any regulation should embody stringent prohibition of over-loading, and should require a minimum of unsprung weight in the design of the truck. Tire equipment also must be carefully specified and required to be maintained in perfect condition. These factors are all of such importance in a regulation to provide for the proper use of the pavements that they must be assumed to be fully and intelligently provided as a condition precedent to any discussion of scientific road design.

Low cost roads.

What has been said so far applies to those areas in which on the state highway systems standard pavements are being built. In those states, however, there is a very large mileage of roads which cannot within any reasonable time be improved with paved surfaces. Likewise, in a very large section of the country, particularly that section lying west of the Missouri River and extending to the Pacific Coast states, there is little hope for many years of any considerable mileage of paved roadways on the main highways capable of carrying trucks with 8,000 lbs. wheel load concentration. We are devoting the Federal-aid funds to the improvement of a system consisting of 7 per cent of the public road mileage in each state. The state highway systems are somewhat larger, comprising at this time less than 10 per cent of the public road mileage. The only hope for adequate surfaces not only upon a large part of the secondary mileage constituting 90 per cent of the whole mileage, but also of a considerable percentage of the mileage included within the state highway systems, is to build up and strengthen relatively light low-cost surfacings through continuous betterment and maintenance methods. The same plan is responsible for many of the roads abroad which are today capable of carrying heavy loads. During the dry seasons untreated gravel or crushed stone surfaces are capable of carrying heavy loads, but on such untreated surfaces dust has become more than a nuisance. It is a serious menace to the safety of the road and an evidence of the rapid loss of the surfacing material and there is an insistent demand for the application of bituminous treatments to these surfaces. These surfaces will carry a large amount of traffic with moderate maintenance, but cannot safely withstand wheel concentration of the intensities suggested for the standard pavements.

In these areas speed is also an important factor; in fact, speed seems to be growing in importance in its relation to truck transportation.

The solution for the problem here is not load limitation below the economic requirements of transportation, but rather the limitation of wheel concentration by permitting the introduction of the six-wheel trucks and pneumatic tires. There is every reason to believe that this is the proper solution, rather than the drastic limitation through legislation of the gross loads which may be carried on any type of truck.

In conclusion, it seems apparent from the above discussion that there is sufficient evidence to point the way toward a truly economic transportation; that is, economic loads without the imposition of unsafe loads upon highway surfaces, through the use of the six-wheel trucks; also to prove their use may extend with different wheel loads to the most concentrated industrial centers and to the most sparsely settled areas. There is nothing to indicate that the conclusions first stated are unsound from the standpoint of reasonable use of our improved highways.

This whole discussion is built on the consideration of the rural highway, and not upon the application of wheel loads to city streets, which presents a very different problem. The critical stresses are induced in the very edge of rural pavements, and it has been found by careful observation that the heavy truck follows very closely the edge of the paved strip on rural roads. There are a number of critical conditions prevailing on the relatively narrow strip of roadway with which our rural roads are now improved, which do not prevail on city streets, and the problem of the wheel load for city streets becomes quite different.

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