REPORT OF THE COMMITTEE ON THE STRUCTURAL DESIGN OF ROADS

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Periodically, research should be viewed in retrospection The established facts should be studied and the points which still seem in doubt should be decided upon. Then, may new investigations be undertaken with considerable certainty that they are aimed in the right direction toward a definite goal.

During the past year the Committee on the Structural Design of Roads, having the above thought in mind, devoted its energies largely to a review of the facts established during recent years by research in its particular field A résumé of facts and strong indications is included in this report, together with recommendations for lines of future work

SUBJECTS INCLUDED IN THE REPORT OF THE COMMITTEE ON THE STRUCTURAL DESIGN OF ROADS

Subjects	Sub-committees
1 Motor Truck Impact Studies	James A Buchanan, *Chairman*
	E B Smith
2 Subgrade Studies	C A Hogentogler, *Chairman*
(a) Subgrade Soil Identification	F H Eno
(b) The Behavior of Soils when Subjected to Various Moisture Conditions	I B Mullis
	George H Henderson
(c) Compensation for Undesirable Subgrade Conditions by Sub-bases and Subgrade Treatment	V R Burton
	E R Hoffman
	G M Braune
(d) Landslides	Chas Terzaghi
3 Low Type Road Design	C N Conner, *Chairman*
(a) Sand-clay and Top-soil Roads	C M Strahan
(b) Top Dressing or Dry Maintenance Roads	Chas H Moorefield
4 Bituminous Pavements	George H Henderson, *Chairman*
(a) Bituminous Macadam	C L McKesson
(b) Bituminous Concrete	R B Dayton
(c) Bases and Sub-bases	

Subjects	Sub-committees
5 Portland Cement Concrete Pavements	L W Teller, *Chairman*
(a) Curing Studies	J T Pauls
(b) Fatigue of Concrete	W K Hatt
(c) Stress Measurements	H M Westergaard
(d) Theory of Design	C N Conner
(e) Planes of Weakness	C A Hogentogler
(f) Reinforcement Studies	H E Breed
	E R Hoffman
	W W Mack
	Frank Sheets
	P M Tebbs
6 Brick Pavements	J T Pauls, *Chairman*
(a) Studies of Thin Brick Pavements	L W Teller

REPORT OF SUBCOMMITTEE ON MOTOR TRUCK IMPACT STUDIES, BUREAU OF PUBLIC ROADS INVESTIGATION

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There probably is no important element in the structural design of a road surface more uncertain than that of the proper stress allowance for impact loading. During the past eight years there have been three distinct research projects which have had a primary objective in the measurement of the magnitude of the impact forces exerted by vehicular traffic on the highway and in the factors and conditions which govern the reaction

In 1920, the United States Bureau of Public Roads began a series of tests in which the magnitude of the impact pressure developed was measured by causing the reaction to occur of a special apparatus flush with and extending into a pit below the road surface. A small cylinder of specially heat-treated copper received the vertical component of the blow and the permanent compressional deformation determined by micrometer measurements indicated the magnitude of the force exerted. The assumption was made that impact and static forces of equal magnitude cause equal deformations of the copper cylinders and they were calibrated under static loads only.

In 1923, the Bureau of Public Roads, with the cooperation of the Rubber Association of America and the Society of Automotive Engineers, inaugurated a new series of motor truck impact tests in which the magnitude of the impact pressure developed was to be measured by means of instruments installed on certain test trucks. As none had been previously developed, a considerable time was spent in trying various types of instruments and it was finally decided that an accelerometer of the coil spring type was the best known device which would meet the practical conditions of the tests By means of special fittings, the instrument was made to faithfully follow the vertical motion of the right rear truck wheel and the records obtained were indices of the accelerations, or decelerations imparted to the unsprung mass of the wheel and axle The accelerometer was also constructed to record the relative positions of the truck spring, and the spring pressure at any instant was thus easily obtained The total pressure reacting at the instant of impact between the wheel and the pavement was computed according to a simple formula

In 1922, the Bureau of Public Roads, in cooperation with the Engineering Experiment Station of the Iowa State College, initiated a series of experiments to determine the impact pressures developed on floor slabs and other elements of highway bridges In these tests the magnitude of the reaction was likewise computed from records obtained with a special accelerometer attached to the rear axle of the truck This investigation also included measurements of stresses in the bridge elements and resulted in a somewhat definite relation between the impact pressure and the simultaneous stresses in the stringers and floor beams

Each of the above described series of tests included a considerable range in each of the primary factors which influence the magnitude of motor truck impact reactions Many kinds and capacities of trucks were used and they were equipped with such a variety of tires and tire arrangements that the field may safely be considered to be adequately covered Truck speeds and wheel loads were varied up to the maxima which could safely be employed and the artificial obstructions and actual road surfaces represent the range in road roughness generally encountered by traffic In addition, the magnitude of the impact pressure has been determined by two methods which are basically different. For these reasons, the following facts may be regarded as definitely established and the indications as deserving considerable weight

The facts which have been established are:

1. a The total vertical reaction is resolvable into sprung and unsprung forces which are simultaneous and additive.

b The sprung component is the truck spring pressure at the instant of impact and varies with the deflection of the truck spring.

c The unsprung component results from the acceleration (or deceleration) of the unsprung mass and is generally considerably greater than the sprung component It may amount to 75 to 95 per cent of the total reaction under normal operating conditions

2 a The duration of motor truck impact pressures is very brief, a pneumatic tire being deformed beyond its static load deformation for only about 0 08 second and a badly worn solid tire for only about 0 02 second

b. That part of the impact pressure which is within 10 per cent of the maximum exists for only one-fourth of the above intervals

3 a Motor truck operation on highways involves four factors whose variations exert major influences on the vertical reactions between the truck wheel and the road surface. These factors are road surface roughness, tire equipment, wheel load and vehicle speed

b. The influence of any one of the above factors should not be separately established in detail without due regard for and knowledge of the conditions of the other three factors.

4 a When pneumatic tire equipments are used the impact pressures seldom exceed twice that of the static wheel load

b. When new cushion tire equipments are used the impact pressure may reach amount corresponding to four or five times that of the static wheel load

c When new solid tire equipments are used the impact pressures which may be developed correspond to five or six times that of the static wheel load

d As cushion and solid tires become worn the impact reactions increase and badly worn solid tire equipments may easily permit the occurrence of impact pressures corresponding to ten times that of the static wheel load

5 a Other conditions remaining equal, a wide tire causes higher impact reactions than a narrow tire. For certain test conditions an increase in tire width of 50 per cent caused an increase in impact reaction of about 30 per cent.

b. Other conditions remaining equal, increasing the profile height of rubber has a very marked effect in reducing road impact reactions in both single and dual mountings.

c. Appreciable variations in cross-section of rubber or breaks in the continuity of a tire cause heavy repeated impacts to be delivered on the road at each revolution of the wheel.

d According to present operating practice, dual mounted tires generally cause greater impact reactions than the replacement sizes of singly mounted tires.

e. Oversize tire equipments generally cause greater impact reactions than the smaller sizes.

6. a. As the static wheel load increases, the road impact reaction increases, but the ratio of the impact reaction to its static load decreases.

b. As the static wheel load increases, the relative influences of tire equipment and truck characteristics become less.

7. a. For conditions in which the truck wheel encounters a raised obstruction in the road surface, increases in truck speed cause increases in impact reaction in approximate direct proportionality

b For conditions in which the truck wheel falls under the influences of gravity and of the truck spring, from a higher level to the road surface, the relation of impact force to speed is complex, and is dependent upon the variations in the downward velocity imparted by the truck spring to the unsprung mass and also upon variations in the truck spring pressure at the instant of impact There generally is a critical speed between 12 and 15 miles per hour.

8 a The average unsprung component of the impact reaction of the rear wheel of a four-wheeled truck is approximately twice as great as that of the rear wheel of a six-wheeled truck which carries on two rear axles the same load carried on the single rear axle of the four-wheeled truck. (This conclusion has been strengthened by stress measurements in slabs under static loads derived from four- and six-wheeled vehicles.)

The strong indications are:

1. Cushioning devices above the truck springs should have relatively little influence on the reaction between the wheel and the road.

2. That cushioning equipment which causes a vertical velocity to be altered through a greater distance, and, consequently, requires a greater time interval to accomplish the change in velocity, will permit lower accelerations and, therefore, lower impact forces.
3. When tires are to be used in dual mountings they should be placed so that the tread designs, if any, are in staggered relation.
4. The static unsprung weight of a truck is not necessarily a major factor in controlling impact reactions

Other researches concerning the magnitude of motor truck impact pressures have been completed during the past year. As the data have not yet been released for publication, the projects may only be briefly described here.

1. The influence of the height of visible rubber (*i. e.*, the radial rubber thickness beyond the steel flange of the tire) on the magnitude of the impact reaction has been investigated. In this project various makes and sizes of cushion and solid tires were cut down progressive amounts in order that the impact reactions at the various stages (corresponding to different percentages of tire wear) might be compared.
2. A comprehensive series of special tests have been made, in which the interrelated effects of road roughness, tire equipment, wheel load and vehicle speed on the impact reaction have been determined through wide ranges of each of the several factors involved. The purpose of this is to supply data in a more useful form upon which rational engineering and legislative practices may be based.
3 There have been numerous opinions advanced concerning the cushioning qualities of certain pavement types. Tests recently completed are intended to establish the relative influences of various pavement types on the magnitude of the motor truck impact pressures which are developed

There is an investigation at present in progress which is concerned with the influence of the type of truck wheel on the magnitude of the impact reaction. This series of tests was inaugurated in order to find out whether or not certain types of rigid and non-rigid truck wheels are instrumental in reducing impact reactions on the road.

Considerable interest has been shown in a project which has been authorized but not started, and is concerned with the impact reactions of motor busses when operated at speeds up to 50 or 60 miles per hour.

The same general methods of testing will be followed throughout these investigations, and the factors being studied are to be varied through sufficient ranges to establish their influences.

The research projects completed, under way and contemplated will probably supply information on all the factors which exert major influences on the magnitude of motor-truck reactions The influence of other factors might be suggested, and some of them may be desirable subjects for research in the future They should not be undertaken with the idea of exhaustively studying all the minute details. The magnitudes of motor-truck impact reactions vary so greatly under actual operating conditions and they are so drastically affected by variations which may and do actually occur in the major factors which have been investigated, that studies of the lesser variable factors are not warranted unless they may be shown to exert critical influences

This report would not be complete without a brief mention of three allied research projects which are being continuously carried forward in conjunction with the impact tests They concern the instruments and methods of calibrating them, the correlation of data for static and impact test conditions and the development of an instrument for measuring the relative road roughness The status of this work is generally encouraging, although no definite reports may be made at the present time

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REPORT OF SUBCOMMITTEE ON SUBGRADE STUDIES

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Present information indicates that subgrade efficiency is dependent upon the magnitude and uniformity of support afforded to the various pavement surfaces This magnitude and uniformity of support are dependent upon the moisture content of the subgrade, and this moisture content, in turn, seems to be dependent upon many factors, among which are climatic conditions including frost action, topography, soil type, soil structure, and, to some extent, type of pavement

Subgrade research, therefore, has been confined mainly to the development of fundamental laws for: (1) Soil identification, (2) the behavior of soils when subjected to various moisture conditions, (3) the improvement of subgrades having unsatisfactory or varying support, and (4) the compensation for undesirable subgrade conditions with variation in pavement design

The present status of information developed by subgrade research subdivided into groups representing the various phases of the problem is given below. In addition to the four divisions noted above, there is included, also, a chapter on Landslides.

I SUBGRADE SOIL IDENTIFICATION

A. FIELD MAPPING

The purpose of field mapping is to present a picture of the soil type and structure in the field, together with topography and other perti-