U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Public Roads

VOL. 3, NO. 35 | WASHINGTON, D. C. | MARCH, 1921

ONE OF THE TRUCKS USED IN THE IMPACT TESTS

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1921

Owing to the necessarily limited edition of this publication it will be impossible to distribute it free to any persons or institutions other than State and county officials actually engaged in the planning or construction of highways, instructors in highway engineering, periodicals upon an exchange basis, and Members of both Houses of Congress. Others desiring to obtain "Public Roads" can do so by sending 15 cents for a single number or $1.50 per year to the Superintendent of Documents, Government Printing Office, Washington, D. C.

U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

PUBLIC ROADS

TABLE OF CONTENTS

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
15 CENTS PER COPY

THE MOTOR TRUCK IMPACT TESTS OF THE BUREAU OF PUBLIC ROADS

By EARL B. SMITH, Senior Assistant Testing Engineer, Bureau of Public Roads.

HIGH POINTS OF THE REPORT.

Impact depends largely upon the kind and condition of the tire.

Thin or worn solid rubber tires, even though they be very wide, produce very high impact forces.

Pneumatic tires offer the greatest influence in reducing impact forces, and with their use the impact increases only very slightly with the speed of the truck.

Cushion tires, that is, tires having a degree of softness and deflection between solids and pneumatics, offer corresponding advantages in reducing impact.

Impact increases with the speed of the truck, but it can not be said to increase according to any constant ratio or power of the speed.

Although heavy unsprung weight may give higher impact than lighter unsprung weight, it can not be said that this is the major controlling factor.

The relative destructive effect produced by light-weight, high speed trucks and heavy, slow-moving trucks has not been determined by these tests. They do, however, indicate that equal impact may be obtained under some conditions.

Impact may be as high as 7 times the static load on one rear wheel when a solid-tired truck strikes a 1-inch obstruction at 16 miles per hour, an average value being about 4 times. For pneumatic tires the maximum impact value is probably not more than 1¾ times the load at one rear wheel, and an average value is not more than 1¼ times the load.

When roads were built to carry the traffic of a few years ago they were built according to "experience" and empirical rules, and the actual weight or speed of the load was only generally considered. Much attention was paid to the question of whether the traffic was equipped with steel or rubber tires. Considerable stress was also placed on the relative tractive effort required on different types of surfaces. A definite analysis of the surface and supporting conditions of the road and a quantitative determination of destructive forces were not deemed necessary.

The transition from horse-drawn to automobile and truck traffic has changed the surface and strength requirements of a road. Heavy truck traffic has developed very rapidly. Within only a few months during the war the change was made from a tolerable traffic condition to that of heavy motor trucks operating at high speeds on solid rubber tires. This sudden development of a very severe form of traffic could not be met with an ample road-building program, nor could it be controlled or directed from the highways previously built and not suited for such traffic, with the result that many heretofore suitable roads were completely destroyed. With the realization that this heavy and severe traffic is here to stay and will probably increase in weight and density, means are being sought for constructing such roads as will carry this traffic. Engineers realize that the roads will have to be built according to very careful and thorough design, but are at once confronted with the fact that no design can be satisfactorily accomplished without knowing very definitely all the forces to which the road is subjected.

To obtain the value of the impact forces on roads has been the object of a series of investigations by the United States Bureau of Public Roads during the past two years. It is known that there are four important factors to be considered in road design, namely, impact, pressure or weight of the passing load, horizontal shear and tractive forces, subgrade and soil conditions. Each of these factors is being thoroughly investigated. More progress has been made in the study of impact than any of the other factors, and on this subject enough data has been collected to warrant a report at this time. This paper will deal only with the subject of impact.

ELEMENTARY STATEMENTS.

Some elementary statements of definition and fact will be necessary to understand the meaning and the limitations of the experimental data to be presented. The term "impact" in its ordinary use means the force with which a moving body strikes another body. The term is used here in this sense, and its specific application is to the force resulting when a truck wheel strikes

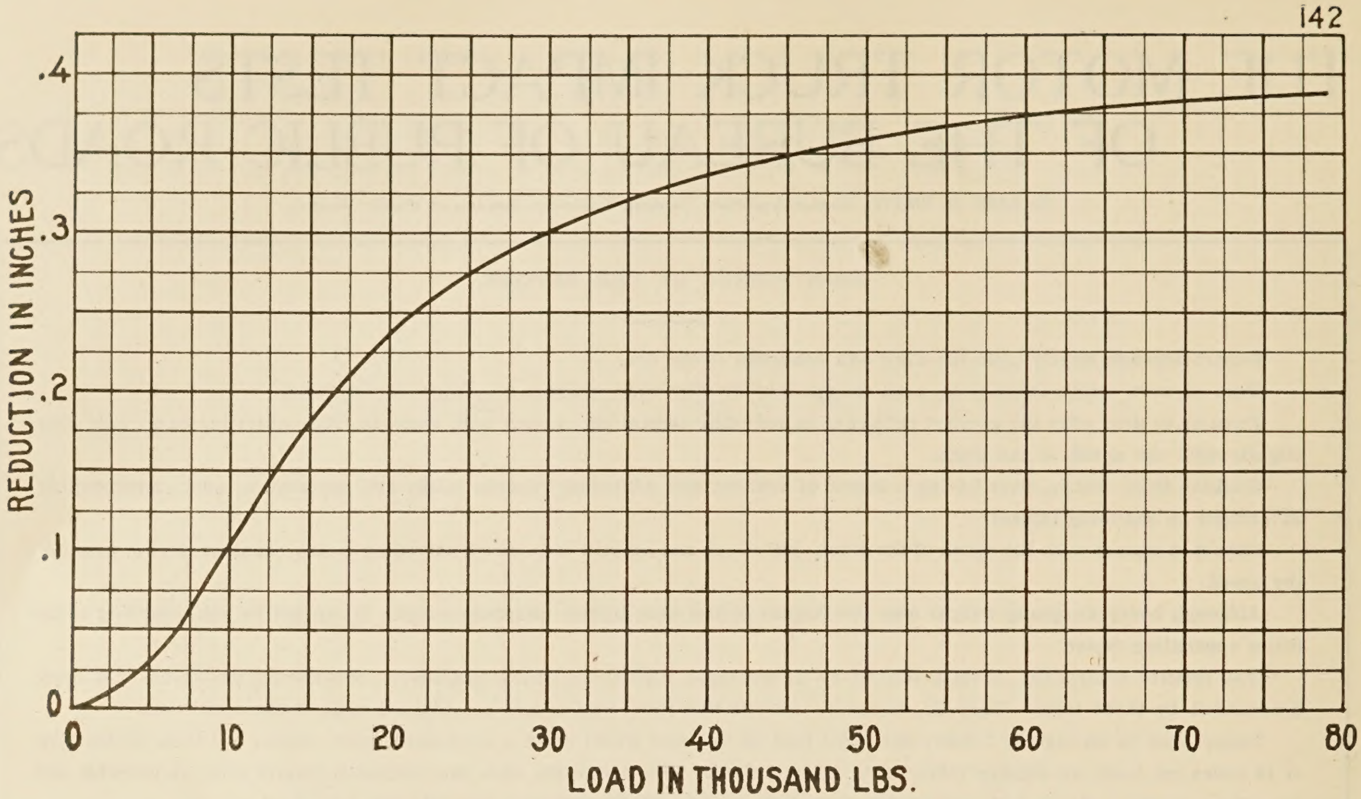


FIGURE 1.—STATIC LOAD DEFORMATION OF ½-INCH COPPER CYLINDERS.

the surface of a road. This action may occur when the wheel, traveling over the road surface, falls from one level to another, or when it strikes an obstruction and bounds upward and finally falls to the road surface. In the second case there is an impact reaction at the time of striking the obstruction and a second impact at the time of striking the road. The obstruction may be only an irregularity or wave in the road surface. The impact will vary in intensity with the speed of the truck. The impact considered here is only the force acting vertically or normal to the road surface. Other components will be less severe than the vertical, which is therefore the critical and controlling force.

IMPACT VS. STATIC FORCE.

The force of impact produces an effect somewhat different from that of a static force. Static forces produce simple deformations proportional to the force (within the elastic limit of the materials), but impact produces much more complex conditions of stress.

Static loads or forces are measured as only a single factor, i. e., as weight or pressure. An impact force is the result of mechanical energy or of mass times acceleration; it is a function of weight, distance, and time. If impact is measured in terms of energy, then there is no rational equivalent between the foot-pounds of impact and the pounds of a static force. A mass in motion does not produce impact unless it strikes or collides with another mass, then the intensity of the impact depends upon how quickly it is brought to rest, or upon the rate of change of the velocity of motion. This rate of change is known as acceleration; the change itself may be positive or negative, i. e., the velocity may be increased or decreased. To increase the velocity of a given mass requires that energy be expended upon it; if the moving mass be suddenly stopped by collision with another body it delivers energy to the mass against which it strikes. The exact value of the force in pounds with which one mass strikes another is very difficult of determination. When the moving body strikes, it does work in overcoming resistances, and does not come to rest until all of its energy has been expended. The resistances met with are due to the inertia of the body struck, and to the deformation

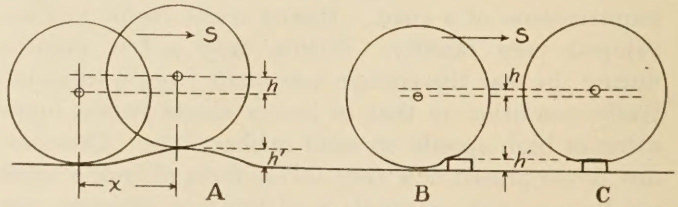


FIG. 2.

and heating of both bodies. The exact values of these resistances, as well as the distance through which they act, are difficult to determine. The other important factor in governing the value of the force of impact is time; if the time required to overcome the resistances, or the time consumed in coming to rest, is zero, then the force is indefinite. The longer the time required to come to rest the smaller will be the impact force.

TRUCK EQUIPPED WITH PNEUMATIC TIRES PASSING OVER OBSTRUCTION.

Although the exact value of impact forces is difficult of determination, there seems to be an approximate connection between the deformation effects of static and impact forces which may be utilized in making a comparison. In other words, since each force may be made to produce a deformation, we may express an impact force as equivalent to a static force which causes the same deformation. This is not, of course, entirely satisfactory; it is a permissible approximate comparison, and is only practical in its application when the load or force producing the impact is large and moving at a moderate velocity. It may readily be seen that a large weight moving at a small velocity will produce a different destructive effect than a small one moving at a very high velocity, although the kinetic energy measured in foot-pounds is the same in both cases. Two methods are available for determining the value of impact: (*a*) By receiving the impact on some material, the deformation of which will be proportional to the force applied, and comparing this deformation with that produced by a steadily applied or static force; (*b*) by determining autographically the velocity and maximum deceleration of the mass when it strikes the resisting body. A description of these two methods may be of interest.

METHODS OF DETERMINING IMPACT FORCES.

In employing the deformation method a copper cylinder is used as the body upon which the impact is received. These cylinders are cut from round copper rods one-half inch in diameter, and machined to 0.500 inch in length. They are heat treated to secure uniformity of stress resistance, that is, to make them all of equal softness. In use, one copper cylinder is placed in the bottom of a heavy cylinder under a loose but neat fitting plunger, and the impact is received on the head of the plunger. The deformation of the copper thus produced is then measured with a micrometer and compared with the deformations produced by static forces. This comparison has been simplified by determining and plotting a "deformation vs. static load" curve (see fig. 1); from which, knowing the deformation, it is easy to determine the equivalent static load. This method of determining impact values gives results that are reliable and can be closely checked. The disadvantage of it is that the copper cylinder itself introduces another factor in the result; it acts as a cushion and thus serves to reduce the value of the impact. It should also be remembered that the copper cylinder under impact does not measure force alone, but measures work, i. e., the work which is done upon it when the moving mass is brought to rest and its kinetic energy is overcome; moreover, the impact measured by the cylinder is an average value, not a maximum. At the instant of touching the copper cylinder the force of impact is zero, and at the point of coming to rest it is probably a maximum; then the average force or resistance of the copper multiplied by the deformation or distance through which it acts must be equal to the energy applied (heating and elastic effect neglected). It will, therefore, be seen that the deformation, or copper cylinder method, of determining impact values will show approximately the average force of impact. The maximum value of the impact force may be nearly twice as great, the exact value depending upon whether the load deformation curve of the copper is a straight line or is parabolic in shape.

THE AUTOGRAPHIC METHOD.

The autographic method is accomplished by the use of a curve drawn autographically on a tape of paper with a pencil operated by the vertical movement of the mass. The paper tape is moved at right angles to the pencil movement at a known uniform speed. This produces a "space-time" curve, the ordinates of which are space or distance passed over by the mass; the

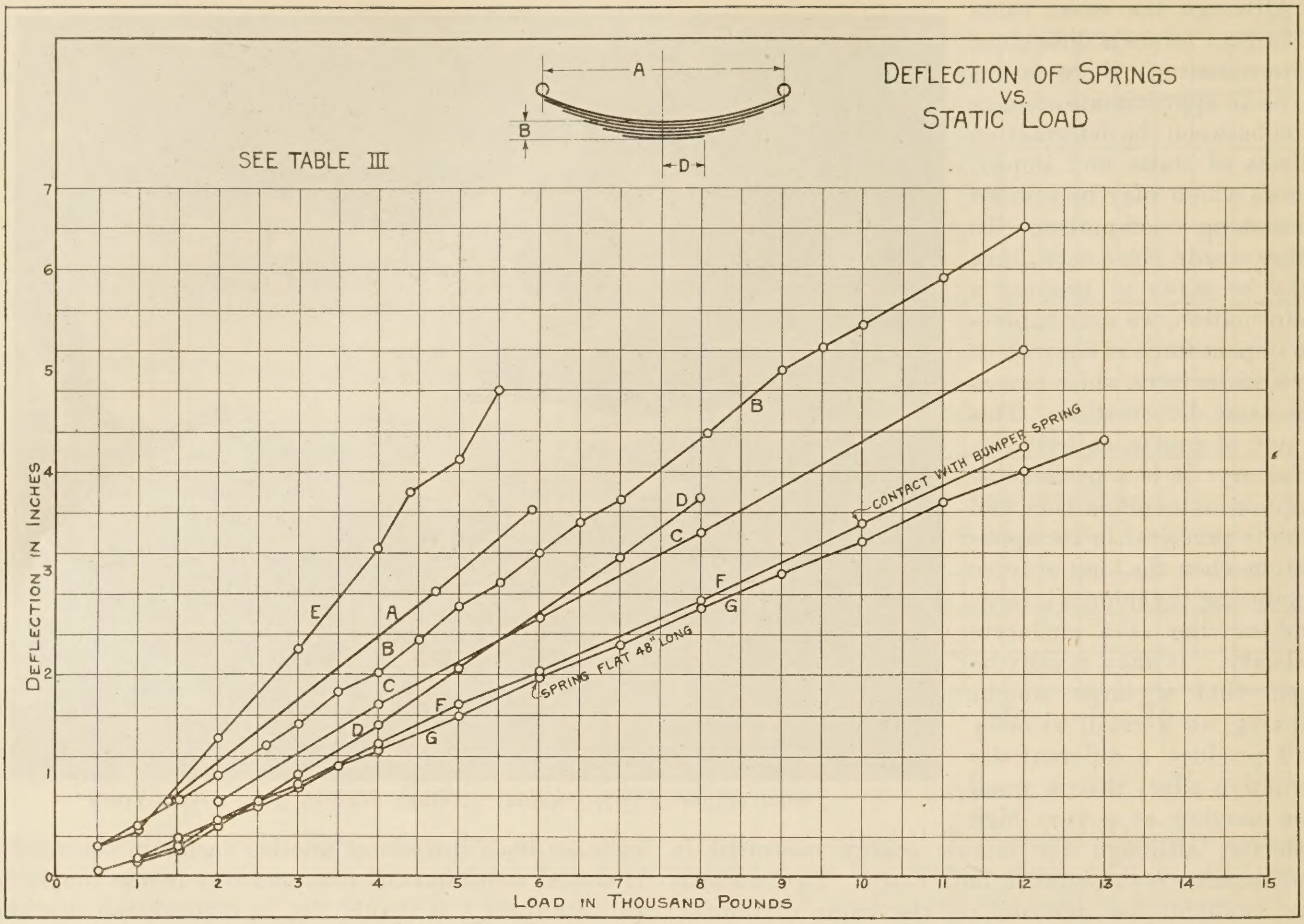


FIG. 3.—STATIC LOAD VS. DEFLECTION OF SPRINGS.

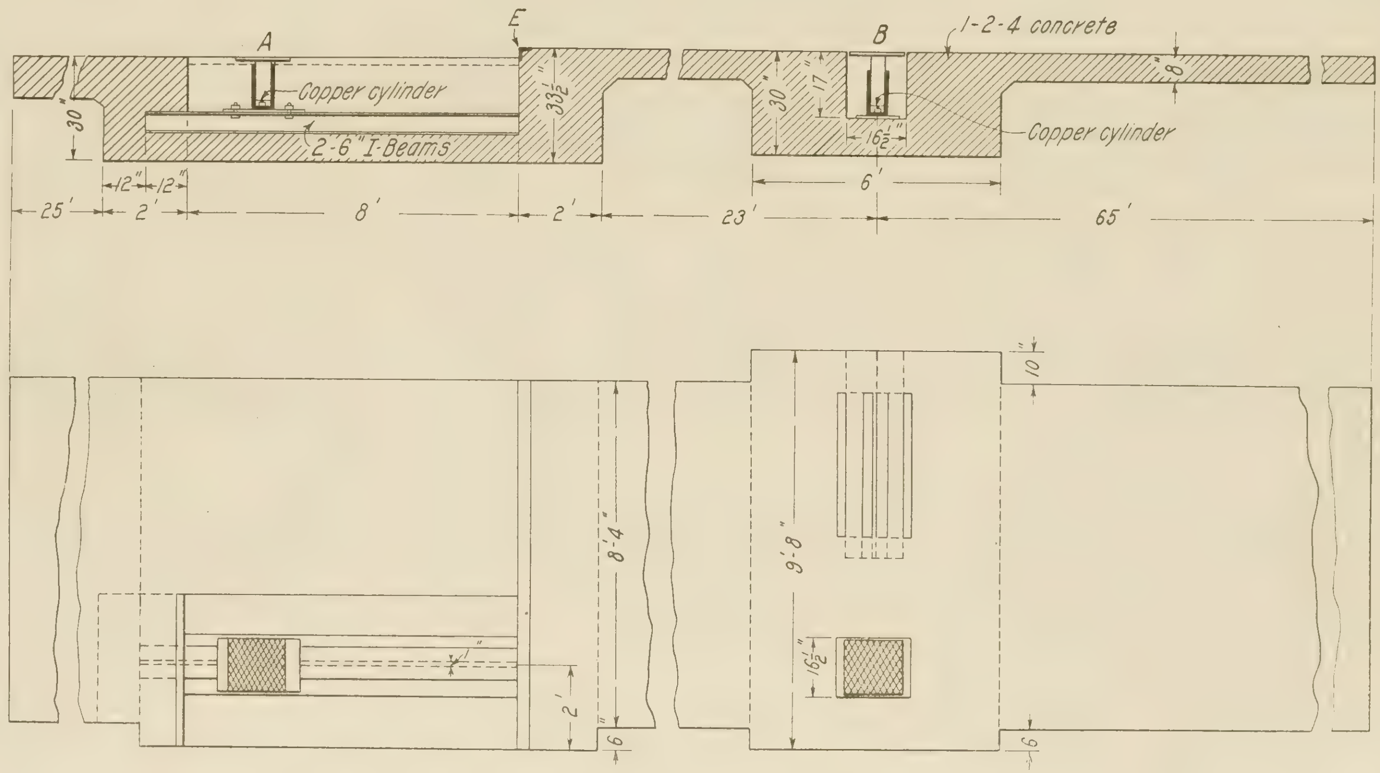
abscissæ being the corresponding units of time. The second derivative of this curve will give the acceleration at any desired point. The maximum acceleration will be at or near the point of impact; then knowing the mass and its acceleration we have the result from the fundamental relation, "mass multiplied by acceleration is equal to force." This is the force of impact. The method just described has been used only to a very limited extent and none of the results given in this paper was obtained in this way. But in subsequent tests, when actual road conditions will be investigated, this method will have to be used, since the copper cylinder method is not practical under such conditions.

THE ACTION OF A MOVING TRUCK.

A truck wheel moving over a perfectly smooth and rigid plane surface will produce on that surface a pressure equal to the total weight of the wheel and its load. But if the surface is uneven, wavy, or rough a pressure may be produced which will be greater than the static load, its magnitude depending upon several factors. The resulting pressure or force upon the surface will be considered to be an impact when it is greater than the static load of the wheel.

A motor truck consists essentially of four wheels carrying a body on intervening springs, and an impact may occur at any one or all of the wheels. The characteristics of a truck and the factors which enter into the determination of impact values are the sprung weight, or all weights and loads above the springs; the unsprung weight, which includes wheels, tires, axles, springs, and all other effective weights under the spring; the kind and condition of the tire; the spring characteristics, which include its deformation or deflection under different loads and its period of vibration; the horizontal speed of the truck; the size and shape of the obstruction, or irregularity in the surface over which the wheel passes; and the character of the road surface.

The greater proportion of the weight of a truck is carried on the rear wheels, and while the front wheels do cause some impact the rear wheels, in general, will cause greater impact. In all discussions of impact forces from motor trucks it is the effect at one rear wheel only which will be considered, since here the force of impact is greatest and it is at this point that the controlling factors have the greatest influence. Of course, if both rear wheels are subjected to the same road influences at the same time, the impact of each wheel will be the same and the result will be the application of equal impact forces to the road surface at the two wheel points.



SPECIAL CONCRETE ROAD CONSTRUCTION FOR IMPACT TESTS OF TRUCKS ON ROADS

FIG. 4

SPRUNG AND UNSPRUNG WEIGHTS.

The sprung weight of a truck produces deflection in the spring and tire and consequently a pressure on the road surface. This weight takes on a comparatively slow up-and-down movement when the truck wheel strikes an obstruction or irregularity. This movement which is slight at the instant of contact, increases to a maximum, at some time after the wheel impact and produces intensified road pressures which may be greatly more than the static load.

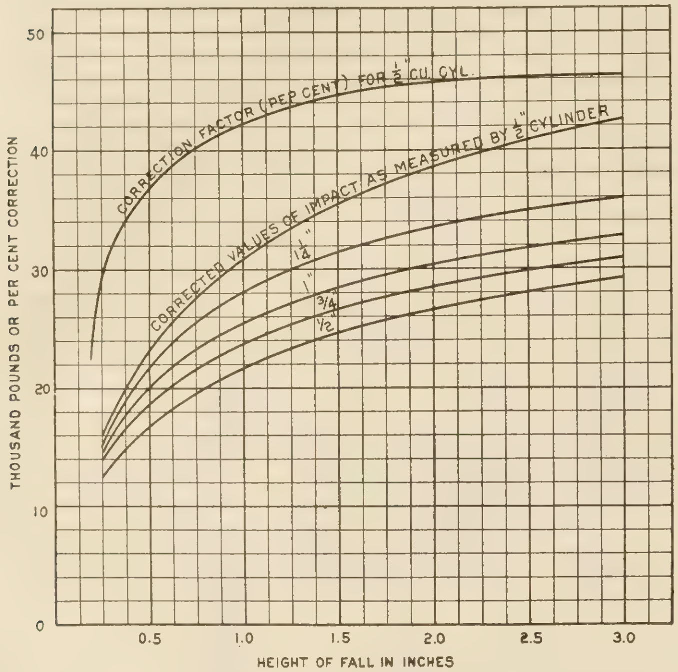


FIG. 5.—CUSHIONING EFFECT OF COPPER CYLINDER.

The unsprung parts of the truck act in an entirely different manner. When the wheel strikes an obstruction in the road it acquires an upward velocity depending upon the height of the obstruction and the speed of the truck. The reaction or impact on the road surface is a force depending for its value upon the vertical acceleration of the wheel, the mass of the unsprung parts and the spring pressure. The wheel may continue to move upward even after passing the obstruction until the movement is overcome by spring pressure and inertia, it is then shot downward by the combined action of gravity and spring pressure, and thus produces another impact on the road surface. The vertical reaction of this movement of the unsprung parts serves of course slightly to retard the fall of the body or sprung parts of the truck; but when the body does fall and is cushioned on the springs, it produces an additional pressure on the road surface, but strictly speaking not an impact. It will readily be seen that the magnitude of the impact as the wheel passes over obstructions and irregularities, and also the oscillations of the sprung weight are dependent upon the speed of the truck.

It is the unsprung weight and the value of the spring pressure which produces the actual impact, and since impact is a force resulting from a moving mass being brought to rest with a negative acceleration, it is greatest when "mass times acceleration" is a maximum. Acceleration being the change of velocity within a certain time, it is seen that if the final velocity is zero the greater the actual velocity just before impact the greater will be the value of the negative acceleration, or deceleration.

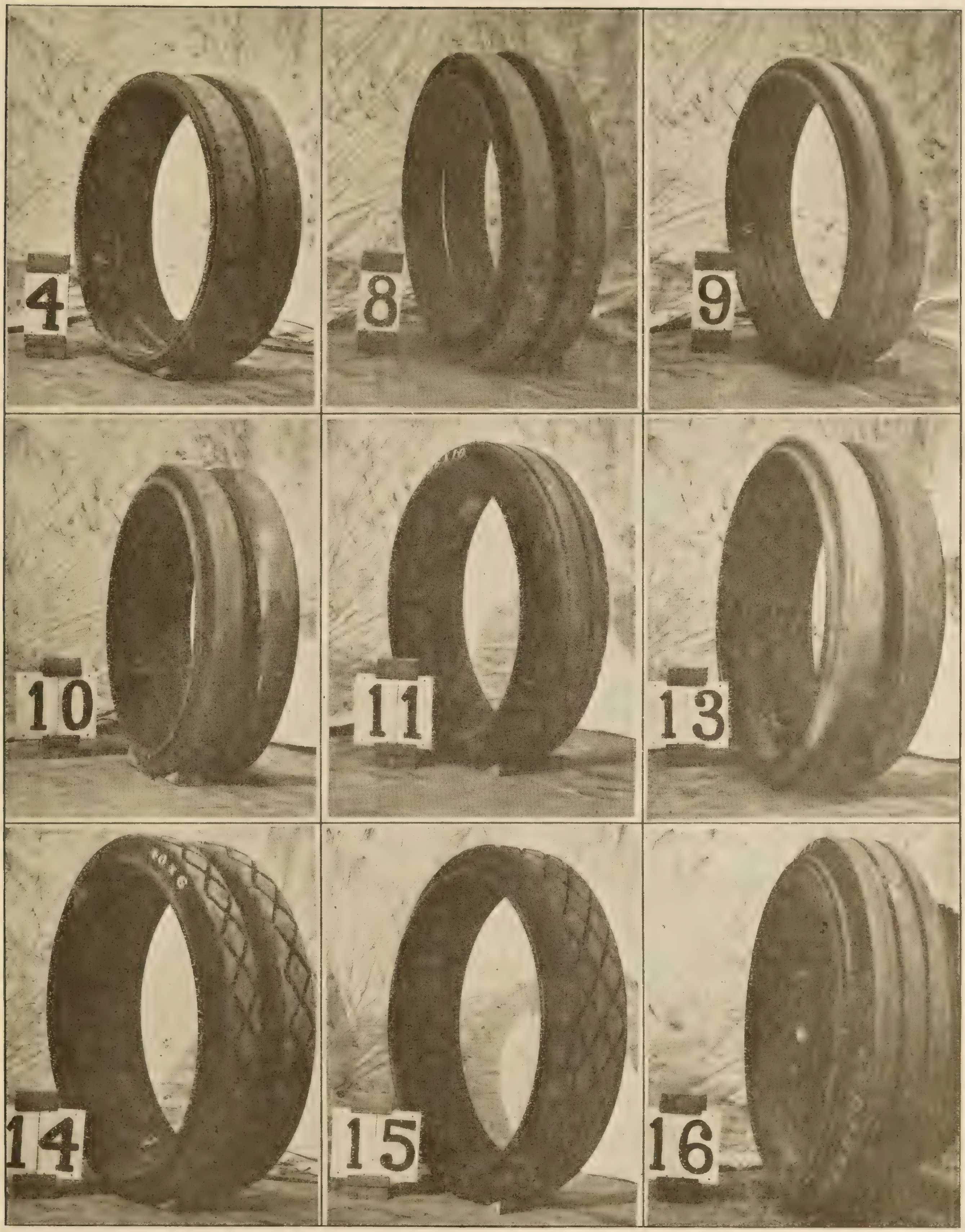
In the case of a wheel striking an obstruction or a wave the vertical velocity depends upon the horizontal speed, the height and form of the obstruction, and the indentation or the deflection of the tire when striking. Taking the simpler case (fig. 2A), the wheel mounts the wave gradually with a more or less localized tire deflection and must attain the height h, while the wheel is passing horizontally over the distance x, at the speed S. In this case the vertical velocity

$$v=\frac{1.46Sh}{x} \quad \ldots \ldots \ldots \ldots \quad (1)$$

where S is measured in miles per hour, and h and x are measured in feet; the resulting velocity v is in feet per second.

If the wheel strikes a sharp obstruction, as in figure 2B, the tire action has considerable influence upon the result. After striking, the wheel rises and approaches the position at C. Somewhere between these two positions the vertical velocity will be a maximum. The mean velocity is given by the same relation as in equation (1), except that h is the height of rise of the wheel and not the height of the obstruction. How greatly these two values will differ depends upon the character of the obstruction and the tire. One extreme is where the tire and obstruction are practically incompressible, as a steel tire and stone block, then $h=h'$. The other extreme would be with a soft pneumatic tire which would indent or deflect an amount equal to h', then $h=0$, and $v=0$. In this consideration it should be noted that in obtaining the vertical velocity the weight of the sprung or unsprung parts is not a factor, while the speed of the truck is a main factor. It is also assumed that the radius of the wheel is at least five times the height of the obstruction, so that the horizontal retardation of the truck is of no appreciable consequence.

Let us consider the action of a truck wheel in falling from one elevation to another, or in falling after having been thrown upward as a result of striking a wave or obstruction with sufficient horizontal velocity to make the wheel jump clear from the road surface. In such cases, the wheel is acted upon by gravity and the downward spring pressure. If the wheel and truck body as a whole have been thrown upward to some considerable height, say 1 to 2 feet, then the spring pressure becomes zero. While the truck is in flight the wheel vibrates up and down freely under the influence of the spring, and practically comes to rest with respect to the truck body before it strikes the road surface



TYPES OF TIRES USED IN THE EXPERIMENTS.

33108—21——2

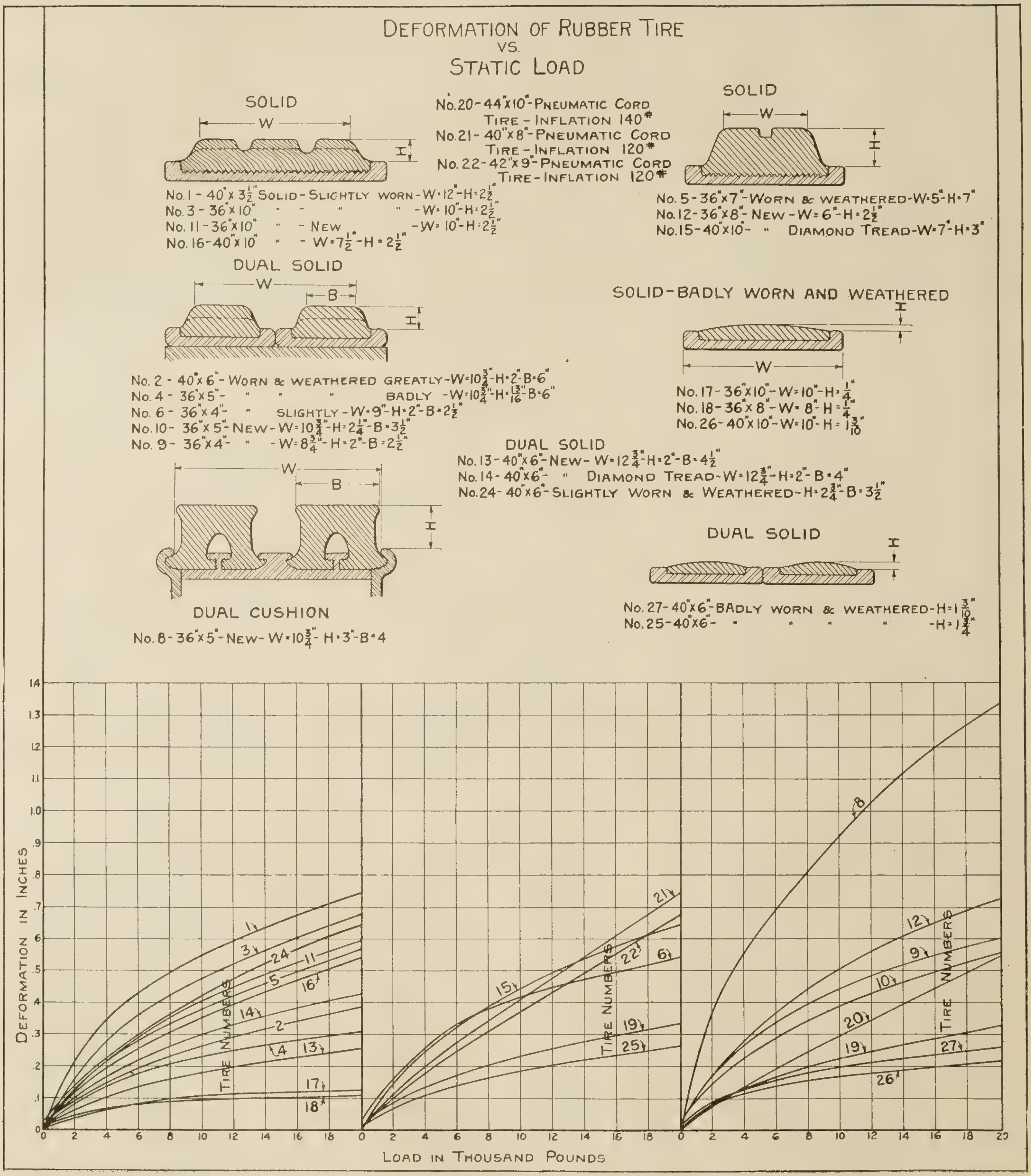
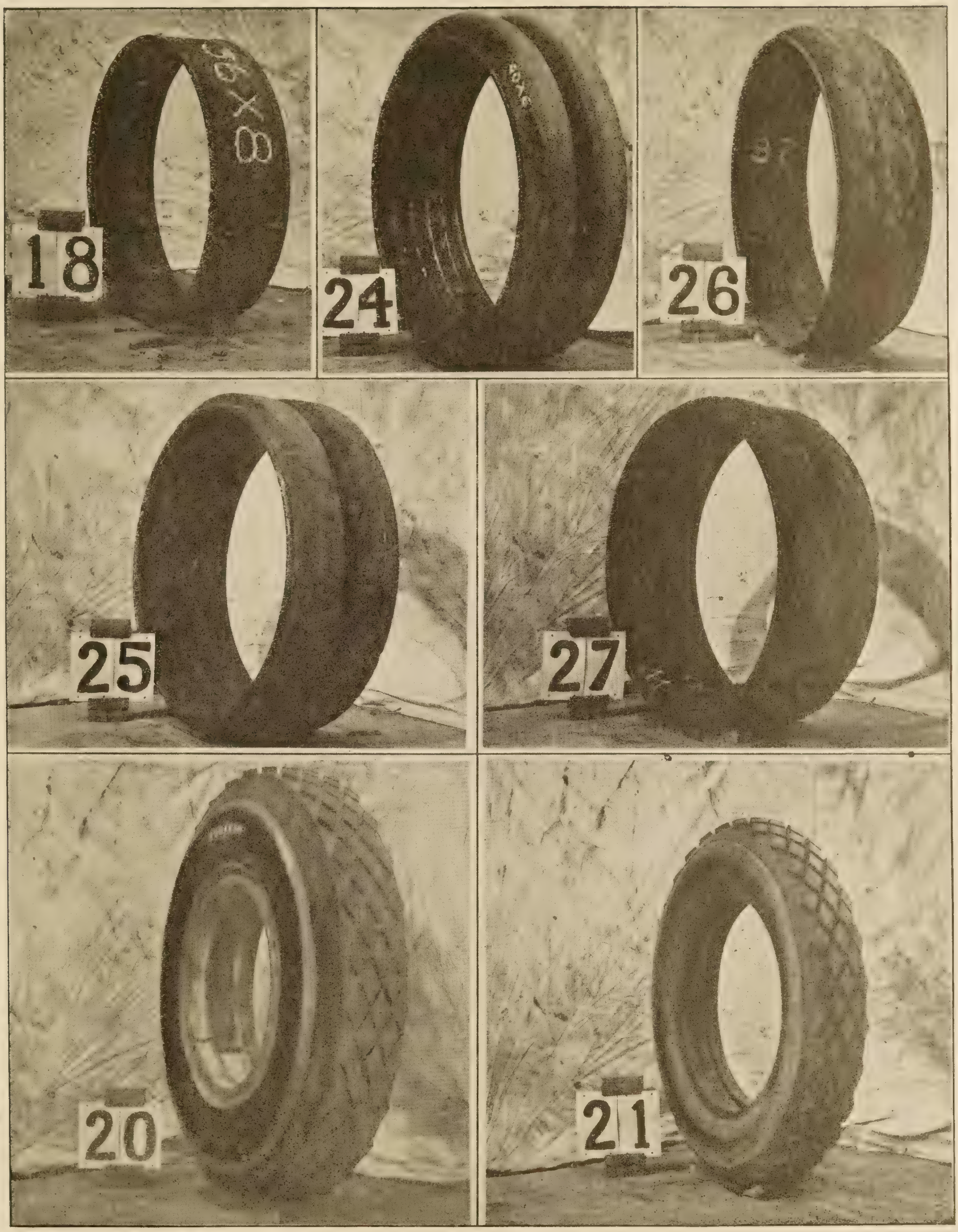


FIG. 6.—STATIC LOAD VS. DEFORMATION OF RUBBER TIRE.



TYPES OF TIRES USED IN THE EXPERIMENT.

again. The wheel and the body are then acting as a unit and are falling freely under the influence of gravity only. They have a downward velocity due only to the height of fall, the final velocity v being given by the equation

$$v=\sqrt{2gh} \quad \ldots \ldots \ldots \ldots \ldots \quad (2)$$

The actual performance of the truck in motion over a road surface is not such as to cause it to be in flight at such a height nor for a sufficient length of time to permit the vibration of a wheel under the influence of the spring to die out, so that there is no relative movement

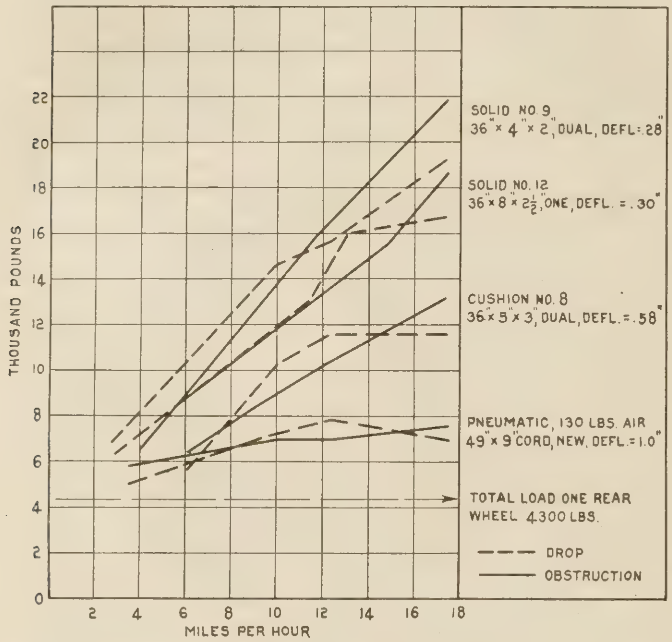


FIG. 7.—COMPARISON OF TIRES (TRUCK, 2-ton A.; LOAD, 2 TONS; (UNSPRUNG WEIGHT), mg., 1,000 LBS.).

between the wheel and body. If, therefore, a truck wheel be suddenly released from its road support and drops to a lower surface it does so under the combined influence of gravity and spring pressure. The spring pressure is a maximum at the beginning of the drop and a minimum at the end. In the case of a direct drop from one level surface to another, the initial spring pressure is equal to the load carried, and the final spring pressure depends upon the stiffness of the spring and the amount it has opened. Spring deflections usually vary directly with the load, and range in value up to 6 or 8 inches. The stiffness varies for different truck springs from 1,000 pounds to 3,000 pounds per inch of deflection. See figure 3. Irregularities and falling distances in road surfaces are usually less than 2 inches, most of them being under 1 inch. It will therefore be seen that the usual drop or action of a wheel is always within the range of influence of the spring. The fact should also be realized that the motion of the body or sprung weight of the truck is not appreciable until some time after the disturbing event has occurred.

In a simple way we may consider the truck wheel as a single mass acted upon by gravity and by a spring pressure, then the velocity at the end of the fall is

$$v=\sqrt{2gh}+at \quad \ldots \ldots \ldots \ldots \quad (3)$$

(g is 32.2, the acceleration of gravity; h is the height of fall in feet; t is the time of fall in seconds; and, a is the acceleration due to spring pressure).

That is, as shown by equation (3), the velocity attained under the combined action of gravity and spring pressure is equal to the velocity attained under free fall plus a velocity which is a function of the acceleration due to spring pressure. This acceleration is not constant, since the force producing it is not constant; its value depends upon a complex integral equation.

Solution of equation (3) shows that the vertical velocity of the truck wheel falling or acting within the influence of the spring pressure is very much greater than when falling free from a considerable height. While we are not concerned directly with the value of the velocity, it is a factor which enters into the determination of the final deceleration.

The final force of the blow is dependent upon how quickly the mass is brought to rest. Since acceleration is dependent upon the rate of change of velocity from the instant of touching the road surface to the instant when the mass is finally at rest, it is readily seen that the shorter the time and distance over which this change takes place the greater will be the force. This, also, applies when the mass starts from rest, or zero, and is changed to some maximum value as the wheel rises vertically over a wave or obstruction.

The rate of change, that is, the acceleration or deceleration, is determined by the time necessary to change the velocity from one value to another. In the cases with which we are now concerned, either the final or initial velocity is always zero. Therefore, if the time required to change the vertical velocity of a wheel to zero can be determined, we may obtain the acceleration by dividing the initial velocity by this time. This time interval, however, is very difficult to determine in any way except by means of some autographic recording device.

EFFECT OF TIRES.

The time element in the rate of change of velocity varies with the distance over which the change takes place. If a vertically moving wheel with a steel tire strikes a hard rigid road surface it is brought to rest in a very small vertical distance, and consequently in a very small time; therefore, the deceleration value will be large, producing a large impact force. If the wheel carries a solid rubber tire it will be brought to rest in a somewhat greater distance and time, and the result will be a smaller deceleration value and less impact. The greater the tire deflection, or cushioning effect, the less will be the impact value. This is as should be expected, and the fact is very clearly shown in the experimental results.

OTHER DESTRUCTIVE EFFECTS OF TRUCKS.

Because of the large amount of power and tractive effort a large shearing force is applied by the two rear wheels to the road surface. In the case of hard surfaced roads this has no particular destructive effect. But in the case of loose surfaced roads, such as gravel, sand clay, and waterbound macadam, tractive forces may be very destructive. However, this may not be any greater in the case of trucks than it is for pleasure cars running at high speeds.

Trucks, which under load have a total weight of 20,000 pounds, may have in most types of construction a single rear wheel load of 7,000 to 8,000 pounds. This as a simple static load is often sufficient to break through some roads.

While an impact is the most severe and the most frequent of the forces produced by a truck passing over an imperfect road surface, there is another effect of increased road pressure which should be understood. When a truck passes over a road surface, even if at such a speed as to produce little or no actual wheel impact, the irregularities and waves in the road cause the body to oscillate up and down. This oscillation is not a simple vibration, but is rather complex with respect to its amplitude and period. On each downward oscillation of the body, the springs are compressed to a greater amount than that due to the static or dead load. This greater spring deflection produces a correspondingly greater pressure on the road surface. As an example, considering the effect at one rear wheel: A truck is carrying on the rear spring, 8,000 pounds; the unsprung weight is 1,500 pounds; the spring deflection under its load is 4 inches; the oscillation causes the load in falling to deflect the spring an additional 4 inches, which from observation is entirely reasonable; then we have—

	Pounds.
Actual load	8,000
Addition load from 4 inches additional spring deflection	8,000
Unsprung weight	1,500
Total oscillation effect, at one rear wheel	17,500

This could be further added to by wheel impact. Combinations of impact and oscillations very often occur at the same instant; then the oscillation effect would be added to the impact effect. Suppose at this same instant an impact force of 10,000 pounds had occurred, then the total road pressure would be 17,500 + 10,000 = 27,500 pounds at one rear wheel.

The additional road pressure due to the oscillation of the body is only very slightly affected by the kind and condition of the tire. This is because we are dealing with the sprung weight and the spring is cushioning this weight far more than is the tire; it is not in the nature of an impact but only similar to a suddenly applied load.

EFFECT OF THE UNSPRUNG WEIGHT.

In order to consider the effect of the unsprung weight on the value of the impact produced by a truck on the road surface, it must be realized that a truck wheel can not be isolated from the influence of the truck spring, either in its upward or downward movement. The effect of the unsprung weight can not be said to bear a definite fixed ratio to the effect of the load carried by the truck.

In the *downward* movement of the unsprung weight, in flight free from the road surface, its velocity at any

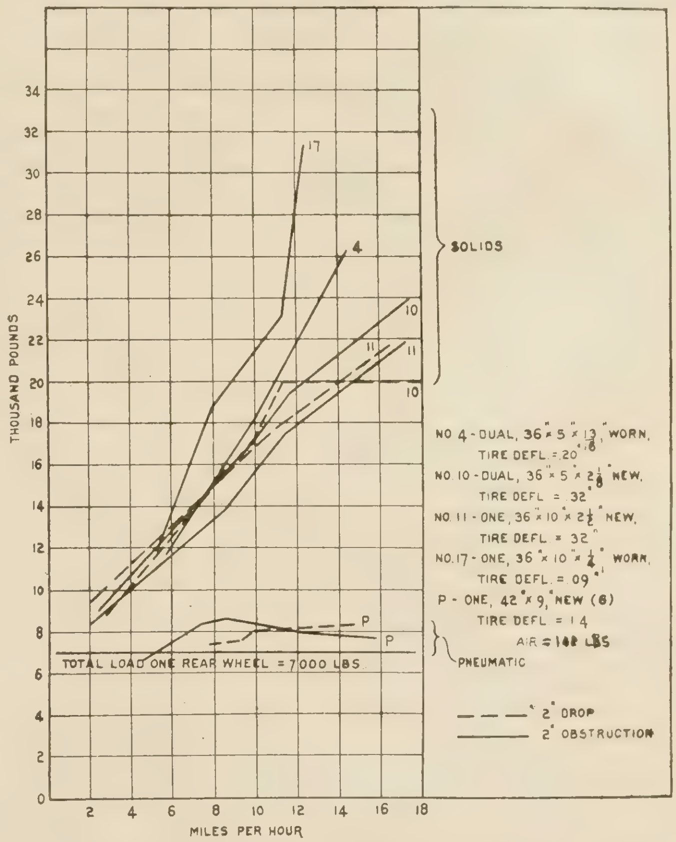


FIG. 8.—COMPARISON OF TIRES (TRUCK 3½-TON P; LOAD, 4½ TONS (UNSPRUNG WEIGHT), MG., 1,300 LBS.).

given time depends upon the ratio of the spring pressure (including gravity) and the unsprung weight. These two factors can not be separated, because of the influence of the inertia of the unsprung weight. With the same spring pressure a higher velocity will be imparted to a light unsprung weight than to a heavy unsprung weight; also, for any given unsprung weight the greater the spring pressure the greater will be the downward velocity. But when the final value of the force of impact is considered then the factor of unsprung weight enters a second time. For having obtained the deceleration value, as a function of the unsprung weight, spring pressure, and the time required to change the velocity to zero, then the impact force is the product of this value multiplied by the unsprung weight. Therefore, the greater the spring pressure with a given unsprung weight the greater will be the force of impact. Also, with any given spring and loading condition, the greater the unsprung weight the greater will be the impact.

In the *upward* movement of the wheel as a result of striking an obstruction or irregularity, the initial vertical

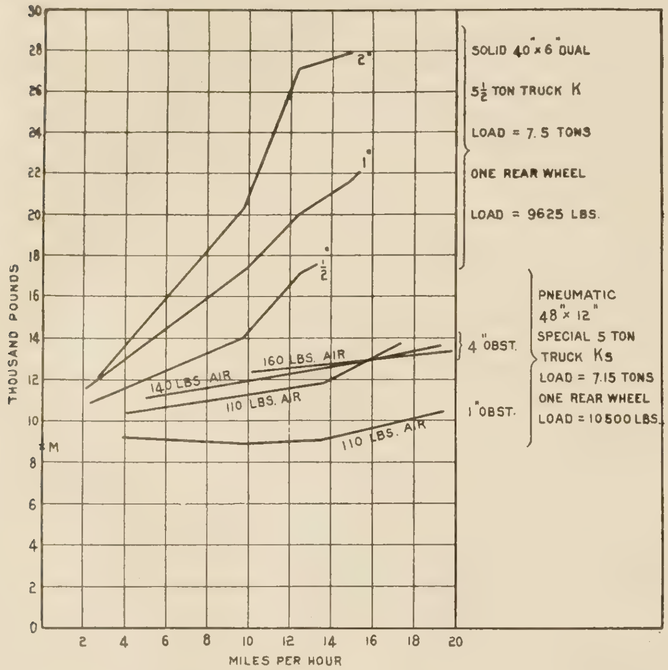


FIG. 9.—COMPARISON OF SOLID AND PNEUMATIC TIRES (TWO TRUCKS APPROXIMATELY THE SAME).

velocity is zero; its maximum velocity and acceleration are dependent upon tire deflection, the slope of the approach, and the horizontal speed of the truck. The value of the force in this case, equals the mass of the unsprung weight multiplied by the vertical acceleration, plus the spring pressure during impact. When the wheel starts downward again if it has left the road surface, the spring pressure acts to increase the impact as explained in the preceding paragraph. It should also be understood that the less the deflection of the tire the greater will be the vertical movement and acceleration; while a soft cushion or a pneumatic tire may so deform or deflect as to absorb more of the vertical movement and thus reduce the acceleration.

The effect on the truck body of the upward movement of the unsprung weight is dependent upon the vertical velocity and acceleration, the spring stiffness, and the load carried. As the weight moves upward it does work by compressing the spring and lifting the body. If very stiff the spring transmits to the body a large part of the force as an impact; resulting in a series of severe vibrations. The amount of energy delivered to the spring may be minimized in any particular truck by reducing the vertical velocity and acceleration, which is most certainly accomplished by slower truck speeds, or by using pueumatic instead of solid tires. All impacts are very much reduced by using good solid tires which have at least a 2-inch thickness of rubber at the tread, instead of old or badly worn tires which have less than 1 inch of rubber thickness. In the design of the truck any reduction of the unsprung weight, or distribution of it to two rear axles instead of one will tend to reduce the upward force against the spring.

EXPERIMENTAL RESULTS.

For the purposes of the tests which have been made a special runway of concrete was constructed, as shown in figure 4. This runway is so designed that the height of the head of the plunger B is flush with the road surface. The "obstruction" tests are made at this place by bolting to the plunger head a strip of hardwood 4 inches wide and 16 inches long, using thicknesses of $\frac{1}{4}$ in., $\frac{1}{2}$ in., $\frac{3}{4}$ in., 1 in., 2 in., 3 in., and in the case of pneumatic tires, 4 inches.

The "drop" tests are made at the drop-off edge E, the plunger beyond and in the lower pit being so placed that the plunger head A may be elevated to give "drop" distances varying from 0 to 3 inches. The plunger may also be moved away from the edge E any distance to receive the blow of the wheel as it jumps varying distances depending upon the speed of the truck. A $\frac{1}{2}$-inch copper cylinder, heretofore mentioned, is placed under each plunger as shown. By this preparation it is easy to secure the data from both types of tests during one run or passage of the truck.

The impact of only the left rear wheel is measured. A bridge is placed over each plunger head to protect it from the front wheel. As this wheel passes, the bridge is jerked out leaving the plunger head clear to receive the impact of the rear wheel. In the case of the obstruction test, the right wheels (front and rear) do not strike the obstruction. But in the case of the drop test both right and left wheels are caused to drop the same amount.

Truck speeds are determined with a stop watch by noting the time to pass two points which are 30 feet apart. These speed determinations are accurate to a maximum variation of 10 per cent, but from the fact that the results may be influenced more than this amount of variation by the action of the front wheel, this error in speed determination is considered of little consequence.

The indications given by the measurements of the copper cylinders may have a maximum variation of about 5 per cent. This is due to slight variations in the annealing of the copper, to errors in measurement, and to variations in obtaining the equivalent value from the static-load curve.

It has been briefly mentioned above that the introduction of a copper cylinder as a means for measuring the impact also introduces a cushioning effect which in turn serves to reduce the impact value. A few experiments have been conducted to determine approximately what this cushioning effect may be. Copper cylinders of different diameters all one-half inch in height were used to receive the impact of a constant weight falling the same height in each case. This was also repeated by changing the height of fall. Autographic space-time curves were also taken of these same impacts, without using a copper cylinder. The intermediate sizes of copper cylinders were used to obtain an idea of the progressive variation due to different cushioning effects. Results of these trials are plotted in figure 5. It will be seen that for values of 1-inch drop the1/2-inch copper cylinder indications should be increased 42 per cent and for a 2-inch drop the increase should be 45.6 per cent. By applying such corrections as this for the different heights of drop it is possible to get an idea of the more correct value of the impact force.

The impact values shown on the charts as ordinates are the actual static indications from the 1/2-inch copper cylinder as measured immediately after the test. This is known as the static equivalent, and is plotted as such in all of the charts without corrections of any kind. It is realized that these values are only comparative and are not actual impact values. To arrive at a more nearly actual impact indication, or maximum force value, it will be necessary to correct these static equivalent values by increasing each by the cushioning factor as indicated in figure 5 and multiplying by some factor to allow for the fact that the copper cylinder measures the average impact and not the maximum. The value of this last factor may be from 1.5 to 2, depending upon the equation of the stress-strain diagram. No corrections of this kind have been made in any of the data or charts presented in this paper.

Because of the nature of these experiments no great accuracy has been attempted, and for practical results it is not considered that a high degree of accuracy is necessary. The forces with which we are dealing are very large, and 5 to 10 per cent variation is not considered to be of much importance. To have insisted upon a high degree of accuracy would have delayed the experiments and possibly discouraged further investigation by others.

These tests are planned to show the influence of only the important factors upon the value of the impact force. Not all possible factors are considered, only those having a definite and direct influence and which are more or less easily controlled in the operation of a motor truck, or which may be controlled in the design and equipment.

The speed of the truck is considered to be one of the most important factors. It is the factor which is most spoken of in connection with the operation of a truck, and the one factor against which there are aimed more traffic rules and laws than any other. The determination of its effect upon the value of the impact force is very important. For this reason speed values, in miles per hour, have been made the independent variable in most of the tests.

Trucks of different weights and capacities have been used in the tests. A full tabulation of the weights

TABLE I.—*Showing size, weights, and loadings of trucks.*

Truck.	Rated capacity.	Empty weight.			Unsprung weight.		Distribution of load (cargo only).				Total sprung weight on 1 rear wheel, cargo and truck.	Spring deflection for total sprung weight.	Total load on road from 1 rear wheel.
		Total.	Front.	Rear.	2 rear.	1 rear.	Total tons.	Front axle.	Rear axle.	Per cent load on rear axle.			
	Tons.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*		*Pounds.*	*Pounds.*		*Pounds.*		*Pounds.*
W	1½	6,320	2,250	4,070	2,030	1,065	0	0	0	0	970	....	2,035
W	1½	6,320	2,250	4,070	2,030	1,065	1½	200	2,880	90	2,410	....	3,475
W	1½	6,320	2,250	4,070	2,030	1,065	2¼	280	4,410	98	3,175	....	4,240
A	2	7,800	3,300	4,500	2,000	1,000	0	0	0	0	1,250	1.02	2,250
A	2	7,800	3,300	4,500	2,000	1,000	2	−100	4,100	102.5	3,300	2.70	4,300
A	2	7,800	3,300	4,500	2,000	1,000	3	400	5,600	93.5	3,900	3.19	4,900
A	5	9,850	3,900	5,950	3,900	1,950	0	0	0	0	1,050	.38	3,000
A	5	9,850	3,900	5,950	3,900	1,950	5	50	9,950	100	5,950	2.12	7,900
A	5	9,850	3,900	5,950	3,900	1,950	7½	0	15,150	100	8,650	3.09	10,600
P	3–3½	9,500	3,800	5,700	3,400	1,700	0	0	0	0	1,150	.48	2,850
P	3–3½	9,500	3,800	5,700	3,400	1,700	2½	400	4,600	92	3,450	1.44	5,150
P	3–3½	9,500	3,800	5,700	3,400	1,700	4½	700	8,300	92	5,300	2.25	7,000
B	3	11,370	4,520	6,850	3,675	1,837	0	0	0	0	1,588	.74	3,425
B	3	11,370	4,520	6,850	3,675	1,837	3.6	580	6,620	92	4,900	2.62	6,735
B	3	11,370	4,520	6,850	3,675	1,837	5	980	9,020	90	6,100	3.63	7,935
Ka	5½	11,800	5,300	6,500	2,000	1,000	0	0	0	0	2,250	1.12	3,250
Ka	5½	11,800	5,300	6,500	2,000	1,000	5	540	9,620	95	7,060	3.73	8,060
Ka	5½	11,800	5,300	6,500	2,000	1,000	7¾	900	14,650	94	9,575	5.12	10,575
Kc	7½	13,600	5,240	8,380	3,000	1,500	0	0	0	0	2,695	1.08	4,195
Kc	7½	13,600	5,240	8,380	3,000	1,500	3⅓	310	6,940	104	6,200	2.70	7,700
Kc	7½	13,600	5,240	8,380	3,000	1,500	8½	360	16,720	97.5	11,000	4.78	12,500
Ks	5	13,600	5,860	7,740	2,260	1,130	0	0	0	0	2,740	....	3,870
Ks	5	13,600	5,860	7,740	2,260	1,130	6.4	1,050	10,680	92	8,080	....	9,215
Ks	5	13,600	5,860	7,740	2,260	1,130	7.15	1,020	13,280	93	9,380	....	10,510
Kb	5½	9,800	4,900	4,900	2,600	1,300	0	0	0	0	1,600	.53	2,900
Kb	5½	9,800	4,900	4,900	2,600	1,300	5	650	9,350	93.5	5,800	1.93	7,100
Kb	5½	9,800	4,900	4,900	2,600	1,300	7½	650	14,350	95.6	8,800	2.93	10,100
G	5	12,700	....	....	3,000	1,500	5	....	....	....	[1] 7,980	1.75	[1] 9,480
G	....	....	....	....	[2] 3,000	[1] 1,500	7½	....	....	....	[1] 10,280	2.62	[1] 11,775

[1] Two wheels.

[2] Four wheels.

TABLE II.—*Data referring to the graphical charts.*

Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
1	F	1	1	1,175	375	7	Solid	0.11	......	1.63	Drop-stationary.
2	F	1	1	1,175	375	7	do	.11	......	1.63	Obstruction.
3	F	1	1	1,175	375	......	Cushion	.33	......	1.63	Do.
4	W	1½	0	970	1,065	5	Solid	.13	......	......	Drop.
5	W	1½	1½	2,410	1,065	5	do	.15	......	......	Do.
6	W	1½	2¼	3,175	1,065	5	do	.23	......	......	Do.
7	W	1½	0	970	1,065	5	do	.13	......	......	Obstruction.
8	W	1½	1½	2,410	1,065	5	do	.15	......	......	Do.
9	W	1½	2¼	3,175	1,065	5	do	.23	......	......	Do.
10	A	2	3	3,900	1,000	22	Pneumatic	1.05	E	3.19	Drop.
11	A	2	2	3,300	1,000	22	do	.95	E	2.70	Do.
12	A	2	3	3,900	1,000	22	do	1.05	E	3.19	Obstruction.
13	A	2	2	3,300	1,000	22	do	.95	E	2.70	Do.
14	A	2	2	3,300	1,000	21	do	1.05	E	2.70	Drop.
15	A	2	3	3,900	1,000	21	do	1.15	E	3.19	Do.
16	A	2	2	3,300	1,000	21	do	1.05	E	2.70	Obstruction.
17	A	2	3	3,900	1,000	21	do	1.15	E	2.70	Do.
18	A	2	3	3,900	1,000	22	do	1.05	E	3.19	Drop.
19	A	2	3	3,900	1,000	22	do	1.05	E	3.19	Obstruction.
20	A	2	0	1,250	1,000	8	Cushion	.39	E	1.02	Drop.
21	A	2	2	3,300	1,000	8	do	.57	E	2.70	Do.
22	A	2	3	3,900	1,000	8	do	.62	E	3.19	Do.
23	A	2	2	3,300	1,000	8	do	.57	E	2.70	Obstruction.
24	A	2	3	3,900	1,000	8	do	.62	E	3.19	Do.
25	A	2	2	3,300	1,000	9	Solid	.27	E	2.70	Drop.
26	A	2	3	3,900	1,000	9	do	.30	E	3.19	Do.
27	A	2	2	3,300	1,000	9	do	.27	E	2.70	Obstruction.
28	A	2	3	3,900	1,000	9	do	.30	E	3.19	Do.
29	A	2	3	3,900	1,000	12	do	.32	E	3.19	Do.
30	A	2	2	3,300	1,000	12	do	.30	E	2.70	Do.
31	A	2	2	3,300	1,000	12	do	.30	E	2.70	Drop.
32	P	3–3½	2½	3,450	1,700	......	Pneumatic	1.18	D	1.44	Do.
33	P	3–3½	4½	5,300	1,700	......	do	1.40	D	2.20	Do.
34	P	3–3½	0	1,150	1,700	4	Solid	.12	D	.48	Do.
35	P	3–3½	2½	3,450	1,700	4	do	.17	D	1.44	Do.
36	P	3–3½	4½	5,300	1,700	4	do	.20	D	2.20	Do.
37	P	3–3½	2½	3,450	1,700	10	do	.26	D	1.44	Do.
38	P	3–3½	4½	5,300	1,700	10	do	.32	D	2.20	Do.
39	P	3–3½	0	1,150	1,700	10	do	.18	D	.48	Do.
40	P	3–3½	2½	3,450	1,700	10	do	.26	D	1.44	Do.
41	P	3–3½	4½	5,300	1,700	10	do	.32	D	2.20	Do.
42	P	3–3½	0	1,150	1,700	10	do	.18	D	.48	Obstruction.
43	P	3–3½	2½	3,450	1,700	10	do	.26	D	1.44	Do.
44	P	3–3½	4½	5,300	1,700	10	do	.32	D	2.20	Do.
45	P	3–3½	0	1,150	1,700	11	do	.17	D	.48	Drop.
46	P	3–3½	2½	3,450	1,700	11	do	.26	D	1.44	Do.
47	P	3–3½	4½	5,300	1,700	11	do	.32	D	2.20	Do.
48	P	3–3½	0	1,150	1,700	11	do	.17	D	.48	Obstruction.
49	P	3–3½	2½	3,450	1,700	11	do	.26	D	1.44	Do.
50	P	3–3½	4½	5,300	1,700	11	do	.32	D	2.20	Do.
51	P	3–3½	0	1,150	1,700	17	do	.05	D	.48	Drop.
52	P	3–3½	2½	3,450	1,700	17	do	.08	D	1.44	Do.
53	P	3–3½	4½	5,300	1,700	17	do	.09	D	2.20	Do.
54	P	3–3½	0	1,150	1,700	17	do	.05	D	.48	Obstruction.
55	P	3–3½	2½	3,450	1,700	17	do	.08	D	1.44	Do.
56	P	3–3½	4½	5,300	1,700	17	do	.09	D	2.20	Do.
57	P	3–3½	0	1,150	1,700	18	do	.05	D	.48	Do.
58	P	3–3½	0	1,150	1,700	18	do	.05	D	.48	Drop.
59	B	3	0	1,388	1,837	......	do	......	A	.74	Do.
60	B	3	3.6	4,700	1,837	......	do	......	A	2.62	Do.
61	B	3	5	5,900	1,837	......	do	......	A	3.62	Do.
62	B	3	0	1,388	1,837	......	do	......	A	.74	Obstruction.
63	B	3	3.6	4,700	1,837	......	do	......	A	2.62	Do.
64	B	3	5	5,900	1,837	......	do	......	A	3.62	Do.
65	A	5	5	5,950	1,950	13	do	.15	F	2.12	Drop.
66	A	5	7½	8,650	1,950	13	do	.18	F	3.09	Do.
67	A	5	5	5,950	1,950	13	do	.15	F	2.12	Obstruction.
68	A	5	7½	8,650	1,950	13	do	.18	F	3.09	Do.
69	A	5	0	1,050	1,950	14	do	.13	F	.38	Drop.
70	A	5	5	5,950	1,950	14	do	.26	F	2.12	Do.
71	A	5	7½	8,650	1,950	14	do	.31	F	3.09	Do.
72	A	5	0	1,050	1,950	14	do	.13	F	.38	Obstruction
73	A	5	5	5,950	1,950	14	do	.26	F	2.12	Do.
74	A	5	7½	8,650	1,950	14	do	.31	F	3.09	Do.
75	A	5	0	1,050	1,950	15	do	.19	F	.38	Drop.
76	A	5	5	5,950	1,950	15	do	.38	F	2.12	Do.
77	A	5	7½	8,650	1,950	15	do	.45	F	3.09	Do.
78	A	5	0	1,050	1,950	15	do	.19	F	.38	Obstruction.
79	A	5	5	5,950	1,950	15	do	.38	F	2.12	Do.
80	A	5	7½	8,650	1,950	15	do	.45	F	3.09	Do.
81	A	5	0	1,050	1,950	24	do	.18	F	.38	Drop.
82	A	5	5	5,950	1,950	24	do	.36	F	2.12	Do.
83	A	5	7½	8,650	1,950	24	do	.43	F	3.09	Do.
84	A	5	0	1,050	1,950	24	do	.18	F	.38	Obstruction.
85	A	5	5	5,950	1,950	24	do	.36	F	2.12	Do.
86	A	5	7½	8,650	1,950	24	do	.43	F	3.09	Do.
87	A	5	0	1,050	1,950	25	do	.08	F	.38	Drop.
88	A	5	5	5,950	1,950	25	do	.16	F	2.12	Do.
89	A	5	7½	8,650	1,950	25	do	.19	F	3.09	Do.
90	A	5	4.8	5,150	1,950	25	do	.15	F	1.84	Do.
91	A	5	6.7	8,150	1,950	25	do	.18	F	2.90	Do.
92	A	5	0	1,050	1,950	25	do	.08	F	.38	Obstruction.
93	A	5	5	5,950	1,950	25	do	.16	F	2.12	Do.
94	A	5	7½	8,650	1,950	25	do	.19	F	3.09	Do.
95	A	5	4.8	5,150	1,950	25	do	.15	F	1.84	Do.
96	A	5	6.7	8,150	1,950	25	do	.18	F	2.90	Do.
97	Ka	5½	5	7,060	1,000	2	do	.23	B	3.73	Iron obstruction.
98	Ka	5½	5	7,060	1,000	2	do	.23	B	3.73	Drop.
99	Ka	5½	7¾	9,575	1,000	2	do	.28	B	5.12	Do.

TABLE II.—*Data referring to the graphical chart*—Continued.

Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires.			Springs.		Type of test.
						No.	Kind.	Deformation due to wheel load.	No.	Deflection due to sprung weight.	
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
100	Ka	5½	0	2,250	1,000	2	Solid	0.15	B	1.12	Obstruction.
101	Ka	5½	5	7,060	1,000	2	do	.23	B	3.73	Do.
102	Ka	5½	7¾	9,575	1,000	2	do	.28	B	5.12	Do.
103	Kb	5½	0	1,600	1,300	16	do	.15	G	.53	Drop.
104	Kb	5½	5	5,800	1,300	16	do	.28	G	1.93	Do.
105	Kb	5½	7½	8,800	1,300	16	do	.35	G	2.93	Do.
106	Kb	5½	0	1,600	1,300	16	do	.15	G	.53	Obstruction.
107	Kb	5½	5	5,800	1,300	16	do	.28	G	1.93	Do.
108	Kb	5½	7½	8,800	1,300	16	do	.35	G	2.93	Do.
109	Kb	5½	0	1,600	1,300	24	do	.18	G	.53	Drop.
110	Kb	5½	5	5,800	1,300	24	do	.33	G	1.93	Do.
111	Kb	5½	7½	8,800	1,300	24	do	.42	G	2.93	Do.
112	Kb	5½	0	1,600	1,300	24	do	.18	G	.53	Obstruction.
113	Kb	5½	5	5,800	1,300	24	do	.35	G	1.93	Do.
114	Kb	5½	7½	8,800	1,300	24	do	.42	G	2.93	Do.
115	Kb	5½	0	1,600	1,300	25	do	.08	G	.53	Drop.
116	Kb	5½	5	5,800	1,300	25	do	.15	G	1.93	Do.
117	Kb	5½	7½	8,800	1,300	25	do	.18	G	2.93	Do.
118	Kb	5½	0	1,600	1,300	25	do	.08	G	.53	Obstruction.
119	Kb	5½	5	5,800	1,300	25	do	.15	G	1.93	Do.
120	Kb	5½	7½	8,800	1,300	25	do	.18	G	2.93	Do.
121	Kc	7½	0	2,700	1,500	1	do	.30	C	1.08	Drop.
122	Kc	7½	3⅓	6,200	1,500	1	do	.48	C	2.70	Do.
123	Kc	7½	8½	11,000	1,500	1	do	.60	C	4.78	Do.
124	Kc	7½	0	2,700	1,500	1	do	.30	C	1.08	Obstruction.
125	Kc	7½	3⅓	6,200	1,500	1	do	.48	C	2.70	Do.
126	Kc	7½	8½	11,000	1,500	1	do	.60	C	4.78	Do.
127	Ks	5	0	2,740	1,130		Pneumatic				Do.
128	Ks	5	6.4	8,080	1,130		do				Do.
129	Ks	5	7.15	9,380	1,130		do				Do.
130	G	5	5	[1] 7,980	[1] 1,500		do			1.75	Drop.
131	G	5	7½	[1] 10,280	[1] 1,500		do			2.62	Do.
132	G	5	5	[1] 7,980	[1] 1,500		do			1.75	Obstruction.
133	G	5	7½	[1] 10,280	[1] 1,500		do			2.62	Do.

and equipment of the trucks used is shown in Table I. Some of these trucks have comparatively heavy unsprung parts and some have light unsprung parts. The effect of this factor was especially studied in the tests upon two trucks of the same capacity under different loadings and speeds, each truck being equipped with the same set of tires.

Tire equipment was considered to be a very important factor. As far as possible, each truck was tested, at different speeds and loadings, with several kinds and conditions of tires.

To get a definite idea of the effect of the height of fall, or of the height of an obstruction or irregularity in a road surface, this factor was used as one of the variables in most of the tests.

The experimental results obtained during the conduct of these tests are plotted in Charts Nos. 1 to 133, inclusive. The data as plotted on these charts represent the average of two or three trials, and in the case of wide variation from the supposed position of the point on the curve additional trials were made. In several cases the plotted points on these curves seem to be more or less out of position to give uniform or relative results, but from successive trials and observations during the test it was noted that certain oscillations set up by the front wheel striking the obstruction are sufficient to very materially change the impact of the rear wheel.

The index to these charts is given by corresponding numbers at the bottom of each page, and the data for all charts are repeated in Table II. The points on the vertical axis of each curve marked Mg and mg are respectively the values of the sprung weight and of the unsprung weight. This is shown on each chart for the purpose of comparing the impact values with the load values.

No attempt will be made to explain all the variations which may be noticed on the charts. The data are presented complete for the purpose of affording an opportunity to make such extended study as any one may desire.

The results presented in Charts Nos. 130 to 133, inclusive, are for a very special truck constructed with two rear axles, making what may be called a six-wheel truck. This truck was equipped with pneumatic tires; and power was applied to each of the four rear wheels. This construction serves to distribute the weights to four wheels at the rear of the truck instead of two wheels as in the ordinary truck. The impact results, as shown on these charts represent the combined impacts received from the two left rear wheels. It should be noticed in this particular case that the impact is practically constant for speeds between 10 and 25 miles per hour and that the impact value was less than the total load on two rear wheels.

Charts Nos. 127 to 129, inclusive, show the variation of the impact due to different air pressures in pneumatic tires.

Spring dimensions and characteristics are shown in figure 3, and Table III. It should be noticed that the "load-deflection" curve in each case is practically a straight line. These data should aid in a further study of the impact results.

TABLE III.—*Showing spring characteristics of the various trucks used in the tests. (See Figure 3.)*

Curve.	Truck.	A	B	D	Number of leaves.	Width.	Stiffness.
	Tons.	*Inches.*	*Inches.*	*Inches.*		*Inches.*	*Pounds per inch.*
A	3 B	57½	6½	....	17	4	1,625
B	5½ Ka	52	6½	7¼	17	4	2,000
C	7½ Kc	50½	6¾	7	17	4	2,300
D	3 P	45⅛	5¼	7	12	3	2,400
E	2 A	52⅞	4½	7	12	3	1,230
F	5 A	47⅜	6½	8	16	3	2,800
G	5½ Kb	52	6¼	6½	17	4	3,000

Tire dimensions and deformations are shown in figure 6. For each tire a curve is shown which gives the deflection or deformation under different loads.

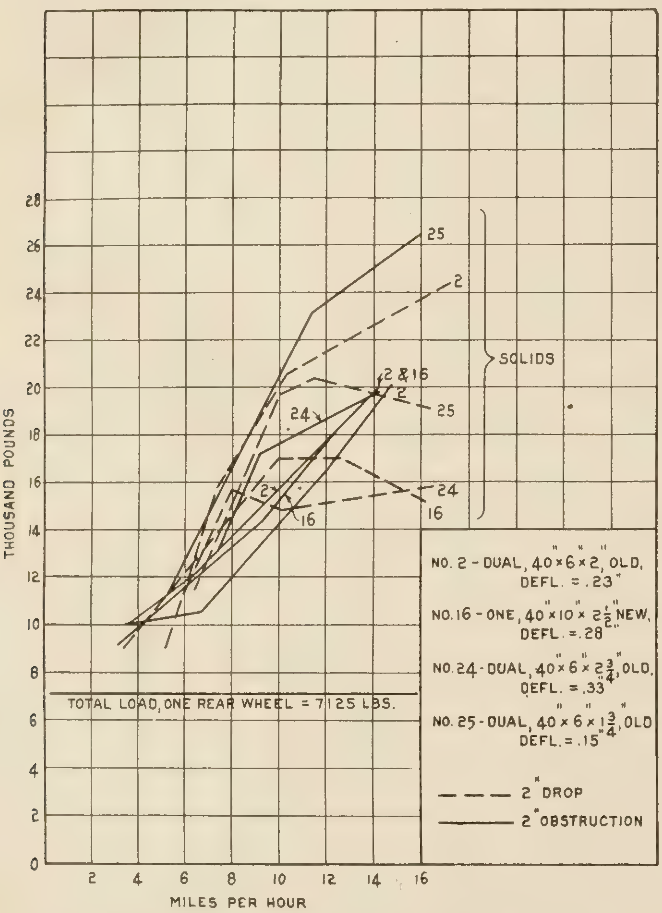


FIG. 10.—COMPARISON OF TIRES (TRUCK 5-TON K; LOAD, 5 TONS; (UNSPRUNG WEIGHT), mg., 1,300 LBS.).

No attempt is made to take into account the variation in rubber composition, except as is shown by the deformation.

After securing and studying results as shown in Charts Nos. 1 to 133, inclusive, many interesting and important comparisons present themselves. No attempts will be made at this time to analyze all possible comparisons between the results shown on the charts. A few of the important features and indications are shown in figures 7 to 12, inclusive.

Figure 7 shows an important comparison of the effect of the tire equipment upon the value of the impact. The truck used in this comparison was of 2-ton capacity, carrying a 2-ton load. Four different tires were used and a complete series of tests was run with each, using in each case the speed as the independent variable. The comparison is shown with both the drop and the obstruction test. To draw attention to the obstruction test only, it is noticed that the impact value (the ordinate) shows a considerable change with only a slight change in the tire deflection. The impact value, with all conditions the same except the tire, is the greatest for the solid rubber tires and the smallest for the pneumatic tire, the cushion tire giving an intermediate value. At low speed the difference is not so great. At a speed of 17½ miles per hour the pneumatic tire gives an impact value of only 1.75 times the rear wheel pressure on the road surface, the cushion tire over three times, and the solids 4.3 to 5.1 times. In this particular case, the cushion tire gives an impact value of 63 per cent of the solid tire average, and the pneumatic only 36 per cent. It should also be noticed that for the pneumatic tire the impact value increases only very slightly with the increase of speed.

Figure 8 shows also a comparison of the effect of tire equipment. The truck used in this case was of 3½-ton capacity, loaded with 4½ tons, the unsprung weight being equal to 1,300 pounds. The total load at one rear wheel was 7,000 pounds. Here, it should be noticed that with pneumatic tire equipment the impact force was only 15 per cent greater than the actual wheel load. The four different solid tires which were used in this series show very clearly the effect of the condition of the tire. Tire No. 17 gave some very high impact values even at 12 miles per hour. This tire was badly worn, having a thickness of only one-fourth inch above the rim. The other solid tires gave impact values somewhat in proportion to their deflection or condition. The results as shown by tires Nos. 10 and 11 indicate the usual impact values that may be expected with good solid tire equipment, while the results shown by the use of tires Nos. 4 and 17 show the increase or extreme values that may be expected from the same truck when the tires are in a badly worn condition.

Figure 9 is also a comparison between the effects of solid and pneumatic tires. The truck used in this case was of 5½-ton capacity, loaded with 7½ tons. This figure is intended to show the very great cushioning effect of pneumatic tires in comparison with solid tires. In this case a 4-inch obstruction was used during the test with the pneumatic tires, and the resulting effect was very much less than when using a solid tire on ½-inch, or 1-inch, or 2-inch obstruction. The figure also shows the effect of the air pressure in the pneumatic tires upon the value of the impact force.

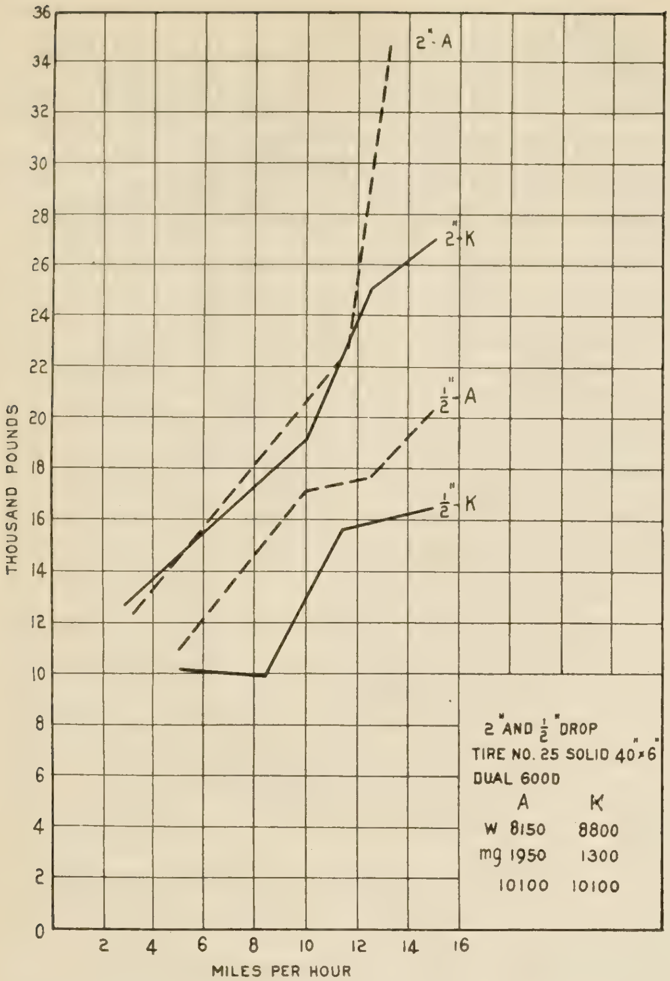


FIG. 11.—COMPARISON OF TRUCKS VS. SPEED.

Figure 10 shows also a comparison of tires. This shows that in general the magnitude of the impact force is dependent upon the condition and deflection of the tire. It shows, as did figure 8, the wide variation in impact values that may be expected from the same truck equipped with tires of different conditions.

Figure 11 shows a comparison between trucks. Two 5½-ton trucks were used in this case and each was loaded so that the total rear wheel load was the same in each case. Truck A had an unsprung weight of 1,950 pounds and truck K had an unsprung weight of 1,300 pounds. Both trucks were equipped with the same set of tires. The purpose of this comparison is to show the effect of unsprung weight upon the impact value. It is very clear that the truck having the lighter unsprung weight produced the smaller impact values under the conditions of this test.

Figure 12. The purpose of this chart is to show the possible impact values which may be obtained by using trucks of different capacities. It is clear that the light truck, W, if run at a sufficient speed, may give impact values as high as a heavy truck, when run at the ordinary truck speeds of 8 to 10 miles per hour. These impact values were all obtained from a 2-inch obstruction. This figure shows that it can not be said that a heavy truck always gives the highest impact values, without stating several qualifying conditions, especially the condition of speed and of tire equipment. This statement refers to impacts only. It should be noted in particular that a light truck running at high speed will produce large impacts only occasionally and never very heavy load pressures; while a heavy truck will produce in addition to impacts a continuous heavy pressure on the road surface.

SUMMARY OF INDICATIONS.

The results presented here must not be considered as final. The investigation has not been completed, and will continue under different conditions for some time.

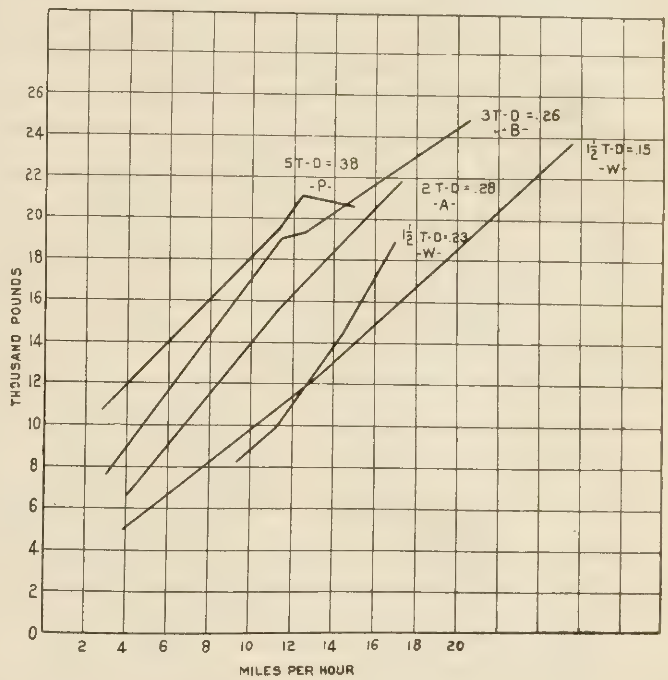


FIG. 12.—COMPARISON OF TRUCKS. (TIRE DEFLECTIONS INDICATED. ALL 2-INCH OBSTRUCTIONS).

It is not the intention in this paper to state final conclusions or to deduce final laws and comparisons. It is, however, thought desirable to state briefly some of the indications toward which these results may point.

The impact value depends very largely upon the tire equipment. The condition of the tire—that is, whether it is new or badly worn—determines the amount of cushioning effect it may offer. The deflection of the tire depends upon its depth and quality, and any condition of the tire which adds to its deflection will, of course, serve to reduce the impact. The actual shape and construction of the tire seem to have considerable influence upon its cushioning effect. No account, however, has been taken of the power-consuming factor of any particular type or shape of tire.

So far as they have been tested, cushion tires seem to offer a decided advantage in reducing the impact. In

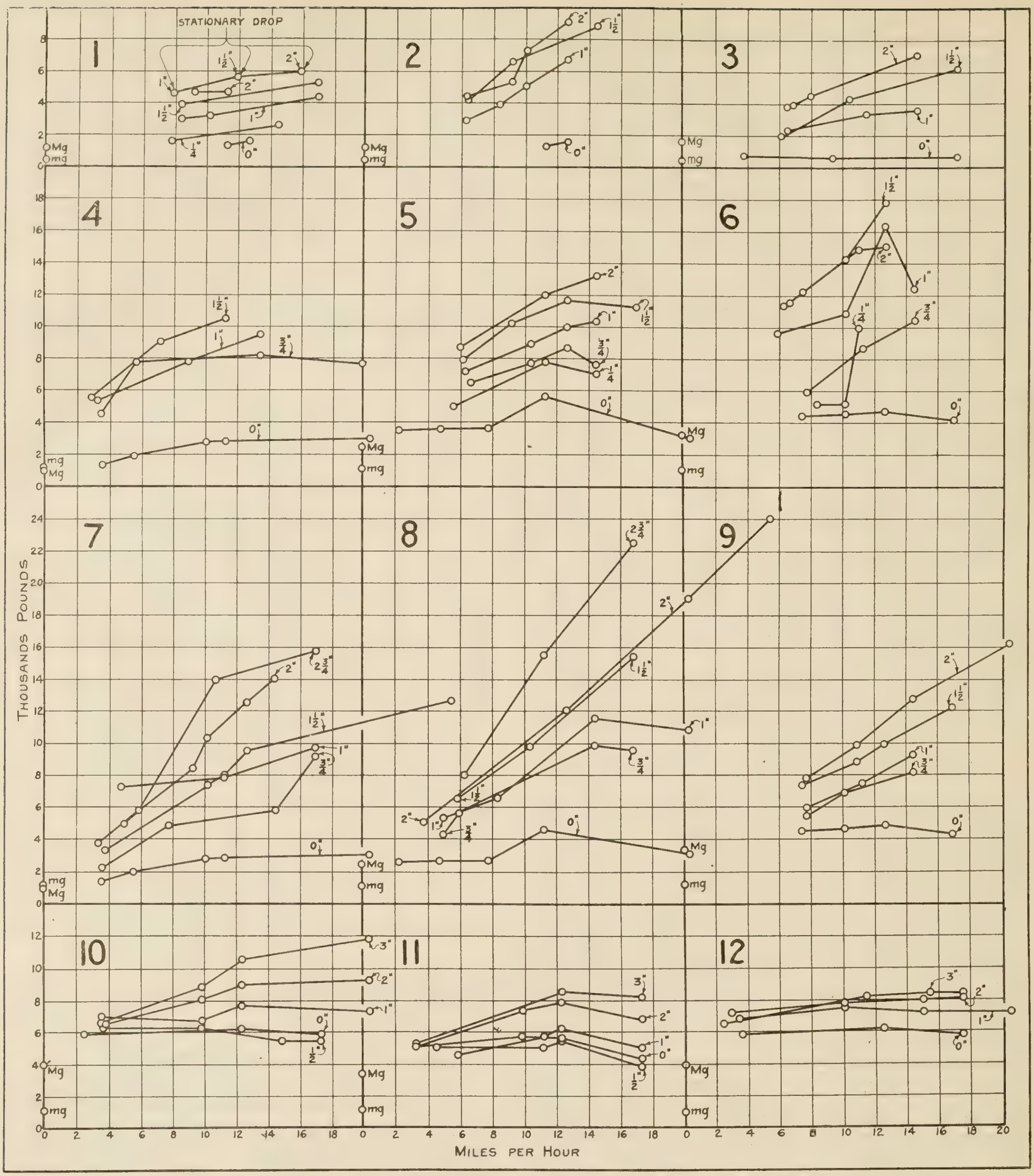


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
1	F	1	1	1,175	375	7	Solid	0.11		1.63	Drop-stationary.
2	F	1	1	1,175	375	7	....do	.11		1.63	Obstruction.
3	F	1	1	1,175	375		Cushion	.33		1.63	Do.
4	W	1½	0	970	1,065	5	Solid	.13			Drop.
5	W	1½	1½	2,410	1,065	5	....do	.15			Do.
6	W	1½	2¼	3,175	1,065	5	....do	.23			Do.
7	W	1½	0	970	1,065	5	....do	.13			Obstruction.
8	W	1½	1½	2,410	1,065	5	....do	.15			Do.
9	W	1½	2¼	3,175	1,065	5	....do	.23			Do.
10	A	2	3	3,900	1,000	22	Pneumatic	1.05	E	3.19	Drop.
11	A	2	2	3,300	1,000	22	....do	.95	E	2.70	Do.
12	A	2	3	3,900	1,000	22	....do	1.05	E	3.19	Obstruction.

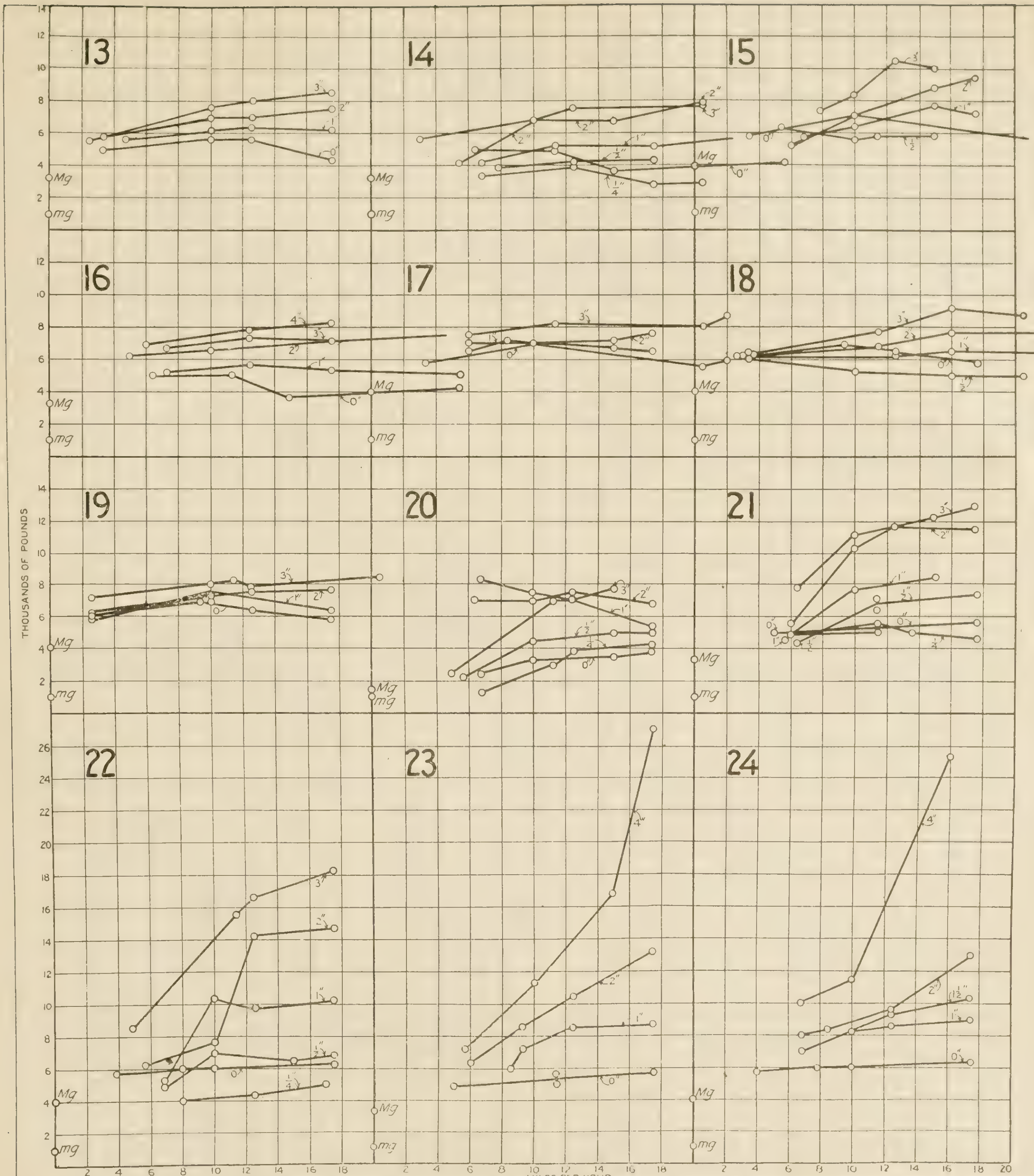


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
13	A	2	2	3,300	1,000	22	Pneumatic	0.95	E	2.70	Obstruction
14	A	2	2	3,300	1,000	21	....do	1.05	E	2.70	Drop.
15	A	2	3	3,900	1,000	21	....do	1.15	E	3.19	Do.
16	A	2	2	3,300	1,000	21	....do	1.05	E	2.70	Obstruction
17	A	2	3	3,900	1,000	21	....do	1.15	E	2.70	Do.
18	A	2	3	3,900	1,000	22	....do	1.05	E	3.19	Drop.
19	A	2	3	3,900	1,000	22	....do	1.05	E	3.19	Obstruction
20	A	2	0	1,250	1,000	8	Cushion	.39	E	1.02	Drop.
21	A	2	2	3,300	1,000	8	....do	.57	E	2.70	Do.
22	A	2	3	3,900	1,000	8	....do	.62	E	3.19	Do.
23	A	2	2	3,300	1,000	8	....do	.57	E	2.70	Obstruction
24	A	2	3	3,900	1,000	8	....do	.62	E	3.19	Do.

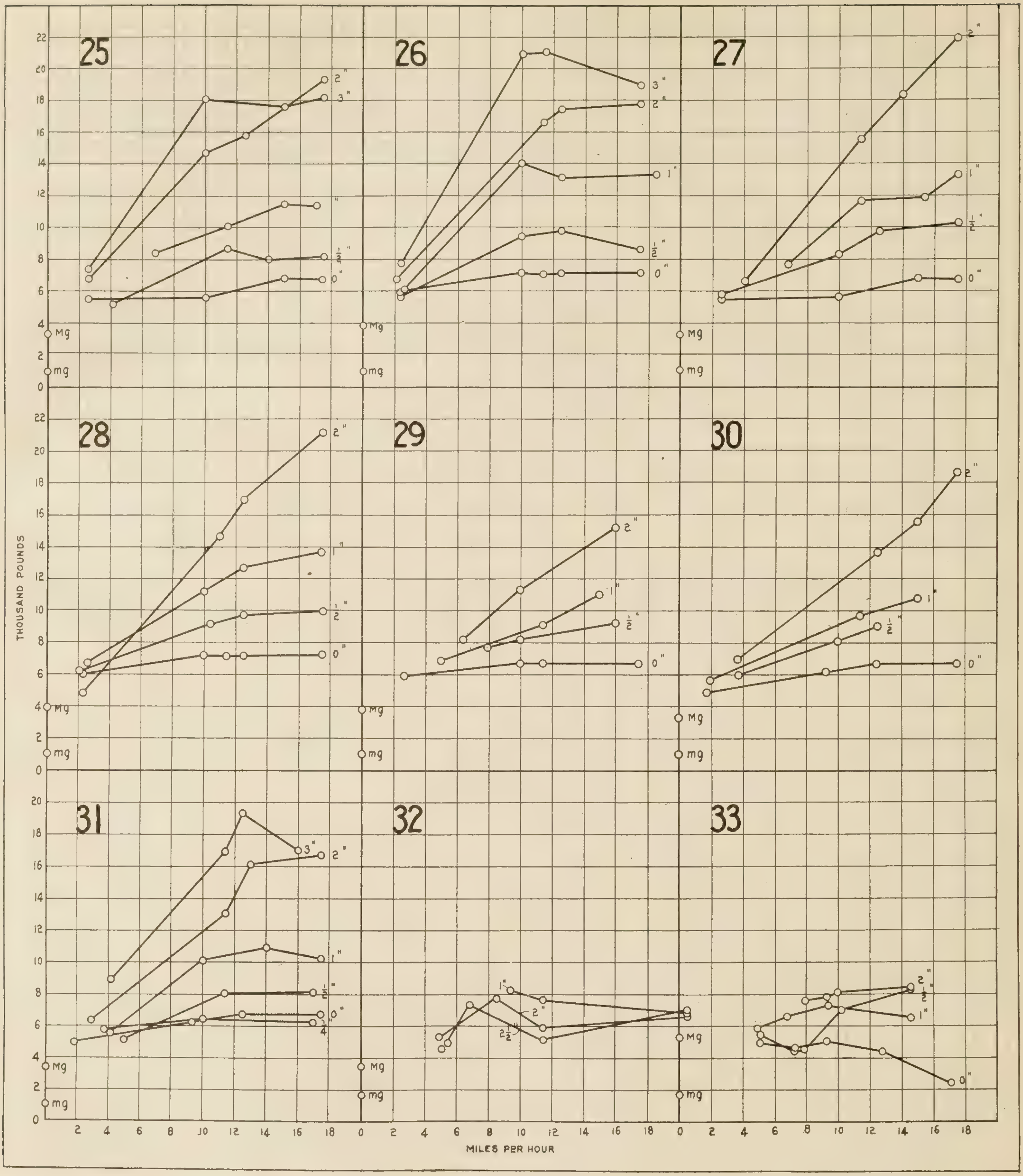


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
25	A	2	2	3,300	1,000	9	Solid	0.27	E	2.70	Drop.
26	A	2	3	3,900	1,000	9	do	.30	E	3.19	Do.
27	A	2	2	3,300	1,000	9	do	.27	E	2.70	Obstruction.
28	A	2	3	3,900	1,000	9	do	.30	E	3.19	Do.
29	A	2	3	3,900	1,000	12	do	.32	E	3.19	Do.
30	A	2	2	3,300	1,000	12	do	.30	E	2.70	Do.
31	A	2	2	3,300	1,000	12	do	.30	E	2.70	Drop.
32	P	3–3½	2½	3,450	1,700		Pneumatic	1.18	D	1.44	Do.
33	P	3–3½	4½	5,300	1,700		do	1.40	D	2.20	Do.

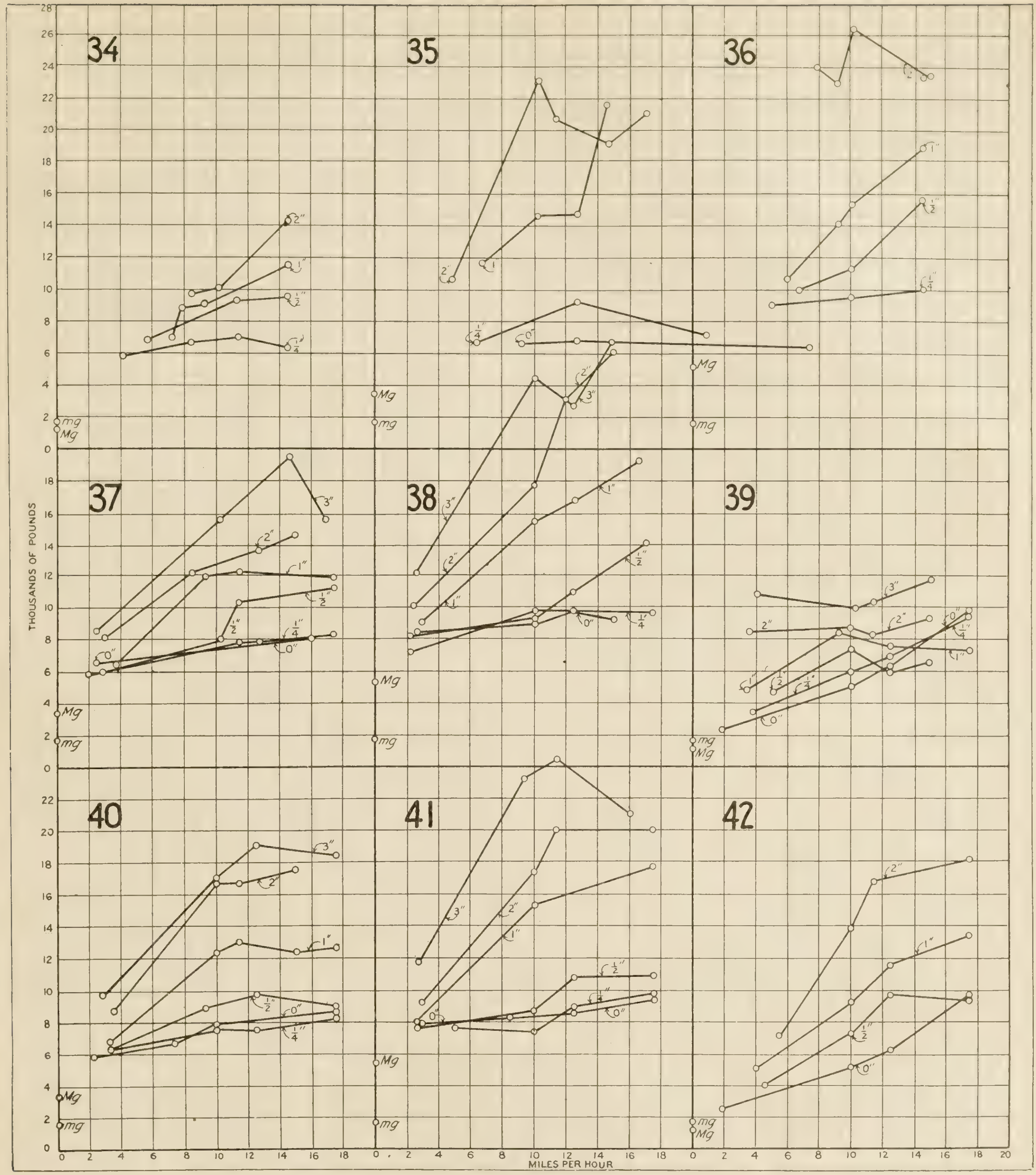


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires.			Springs.		Type of test
						No.	Kind.	Deformation due to wheel load.	No.	Deflection due to sprung weight.	
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
34	P	3–3½	0	1,150	1,700	4	Solid	0.12	D	0.48	Drop.
35	P	3–3½	2½	3,450	1,700	4	....do	.17	D	1.44	Do.
36	P	3–3½	4½	5,300	1,700	4	....do	.20	D	2.20	Do.
37	P	3–3½	2½	3,450	1,700	10	....do	.26	D	1.44	Do.
38	P	3–3½	4½	5,300	1,700	10	....do	.32	D	2.20	Do.
39	P	3–3½	0	1,150	1,700	10	....do	.18	D	.48	Do.
40	P	3–3½	2½	3,450	1,700	10	....do	.26	D	1.44	Do.
41	P	3–3½	4½	5,300	1,700	10	....do	.32	D	2.20	Do.
42	P	3–3½	0	1,150	1,700	10	....do	.18	D	.48	Obstruction.

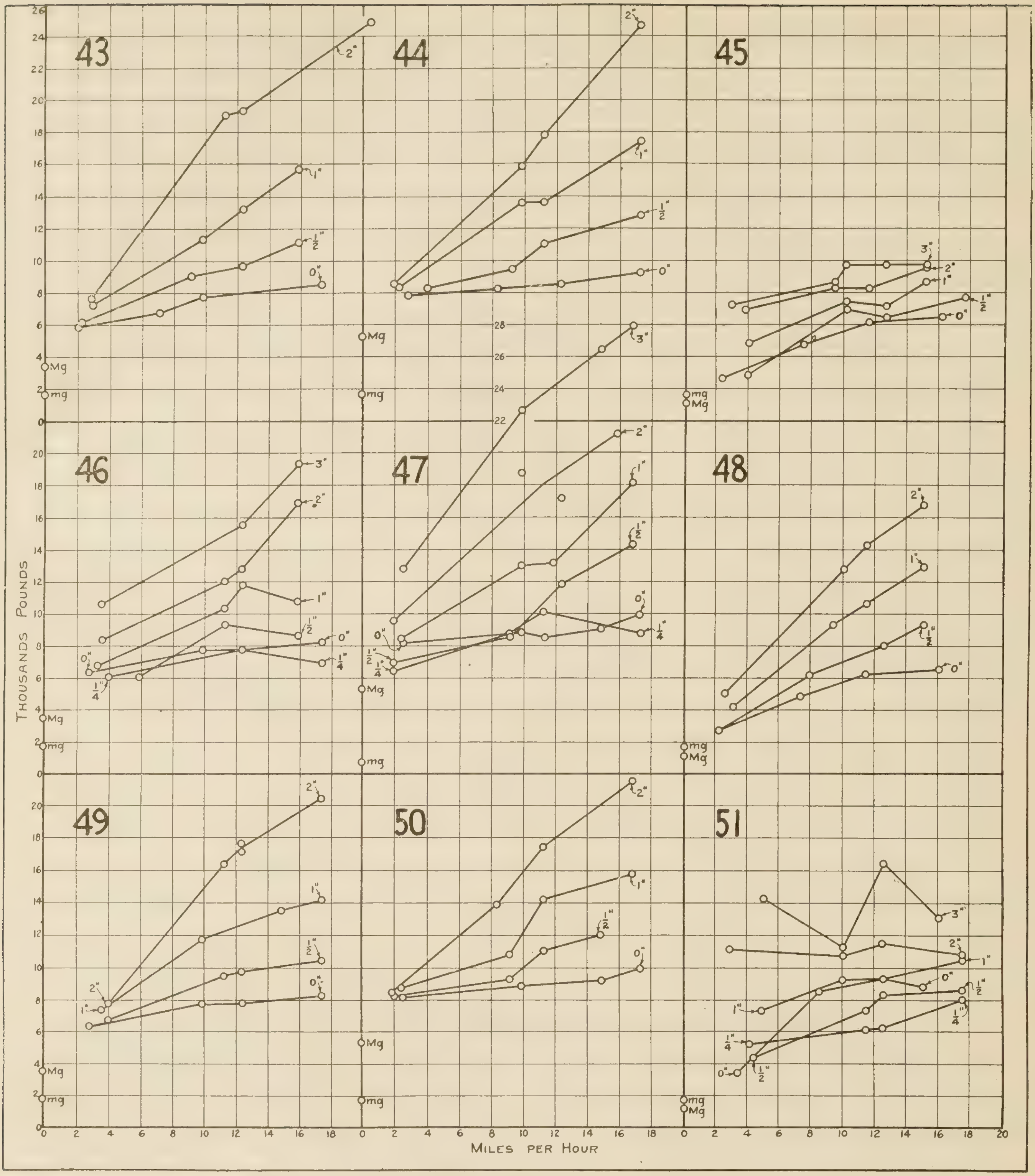


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
43	P	3-3½	2½	3,450	1,700	10	Solid	0.26	D	1.44	Obstruction.
44	P	3-3½	4½	5,300	1,700	10	do	.32	D	2.20	Do.
45	P	3-3½	0	1,150	1,700	11	do	.17	D	.48	Drop.
46	P	3-3½	2½	3,450	1,700	11	do	.26	D	1.44	Do.
47	P	3-3½	4½	5,300	1,700	11	do	.32	D	2.20	Do.
48	P	3-3½	0	1,150	1,700	11	do	.17	D	.48	Obstruction.
49	P	3-3½	2½	3,450	1,700	11	do	.26	D	1.44	Do.
50	P	3-3½	4½	5,300	1,700	11	do	.32	D	2.20	Do.
51	P	3-3½	0	1,150	1,700	17	do	.05	D	.48	Drop.

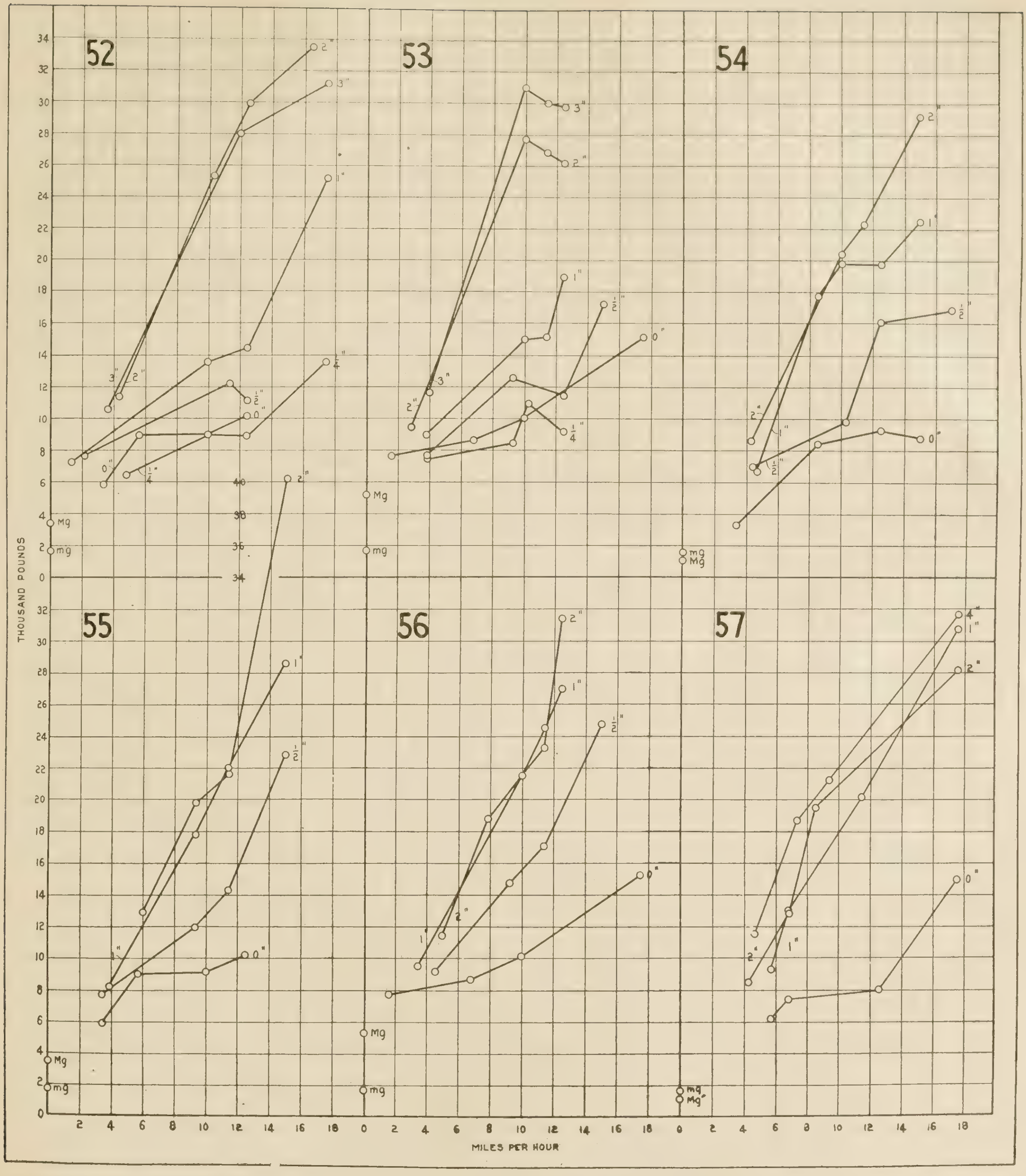


Chart No.	Truck.	Capacity	Load.	Sprung weight on 1 rear wheel (Mg).	Unsprung weight on 1 rear wheel (mg).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
52	P	3-3½	2½	3,450	1,700	17	Solid	0.08	D	1.44	Drop.
53	P	3-3½	4½	5,300	1,700	17	do.	.09	D	2.20	Do.
54	P	3-3½	0	1,150	1,700	17	do.	.05	D	.48	Obstruction.
55	P	3-3½	2½	3,450	1,700	17	do.	.08	D	1.44	Do.
56	P	3-3½	4½	5,300	1,700	17	do.	.09	D	2.20	Do.
57	P	3-3½	0	1,150	1,700	18	do.	.05	D	.48	Do.

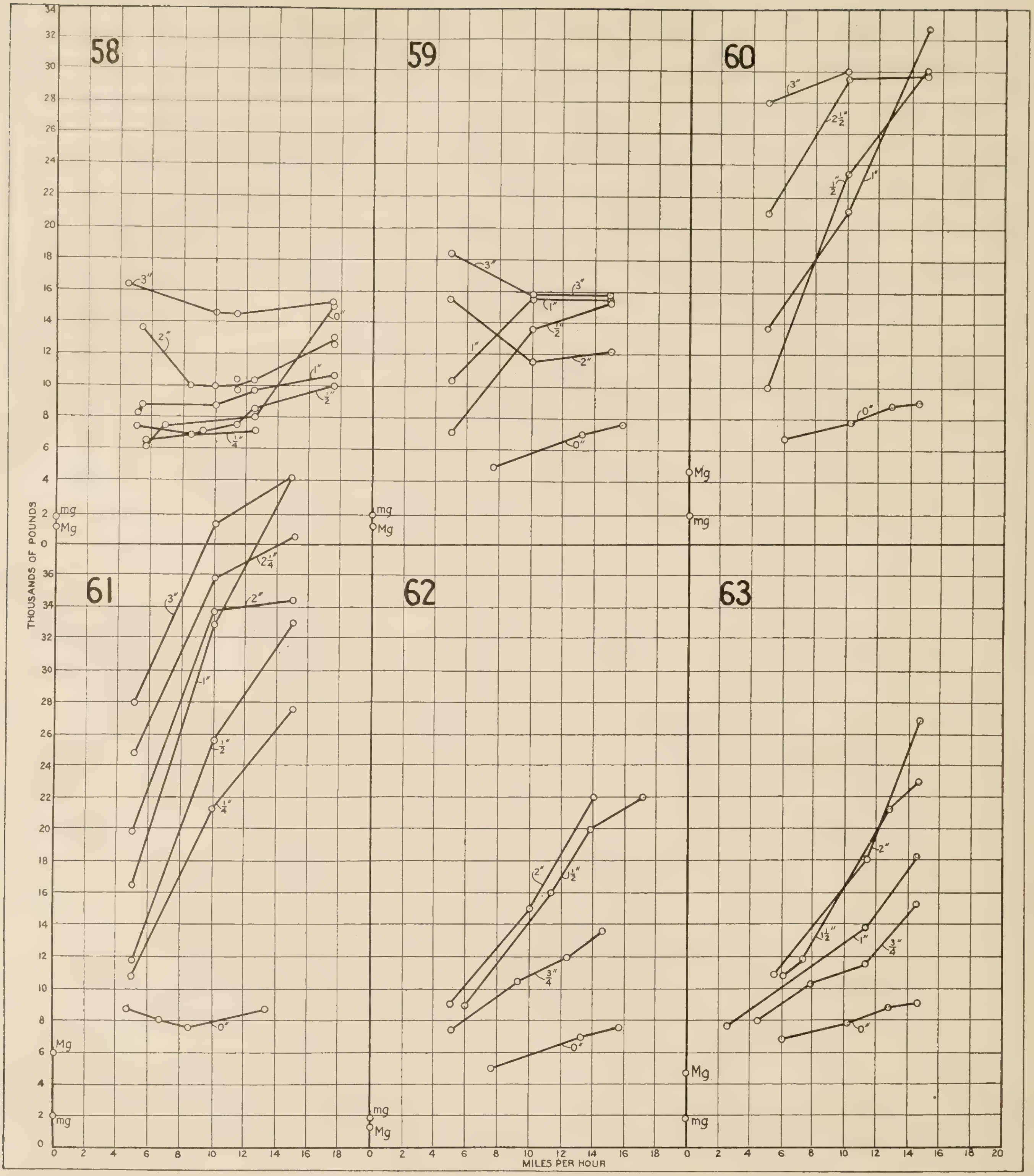


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
58	P	3–3½	0	1,150	1,700	18	Solid	0.05	D	0.48	Drop.
59	B	3	0	1,388	1,837		do		A	.74	Do.
60	B	3	3.6	4,700	1,837		do		A	2.62	Do.
61	B	3	5	5,900	1,837		do		A	3.62	Do.
62	B	3	0	1,383	1,837		do		A	.74	Obstruction.
63	B	3	3.6	4,700	1,837		do		A	2.62	Do.

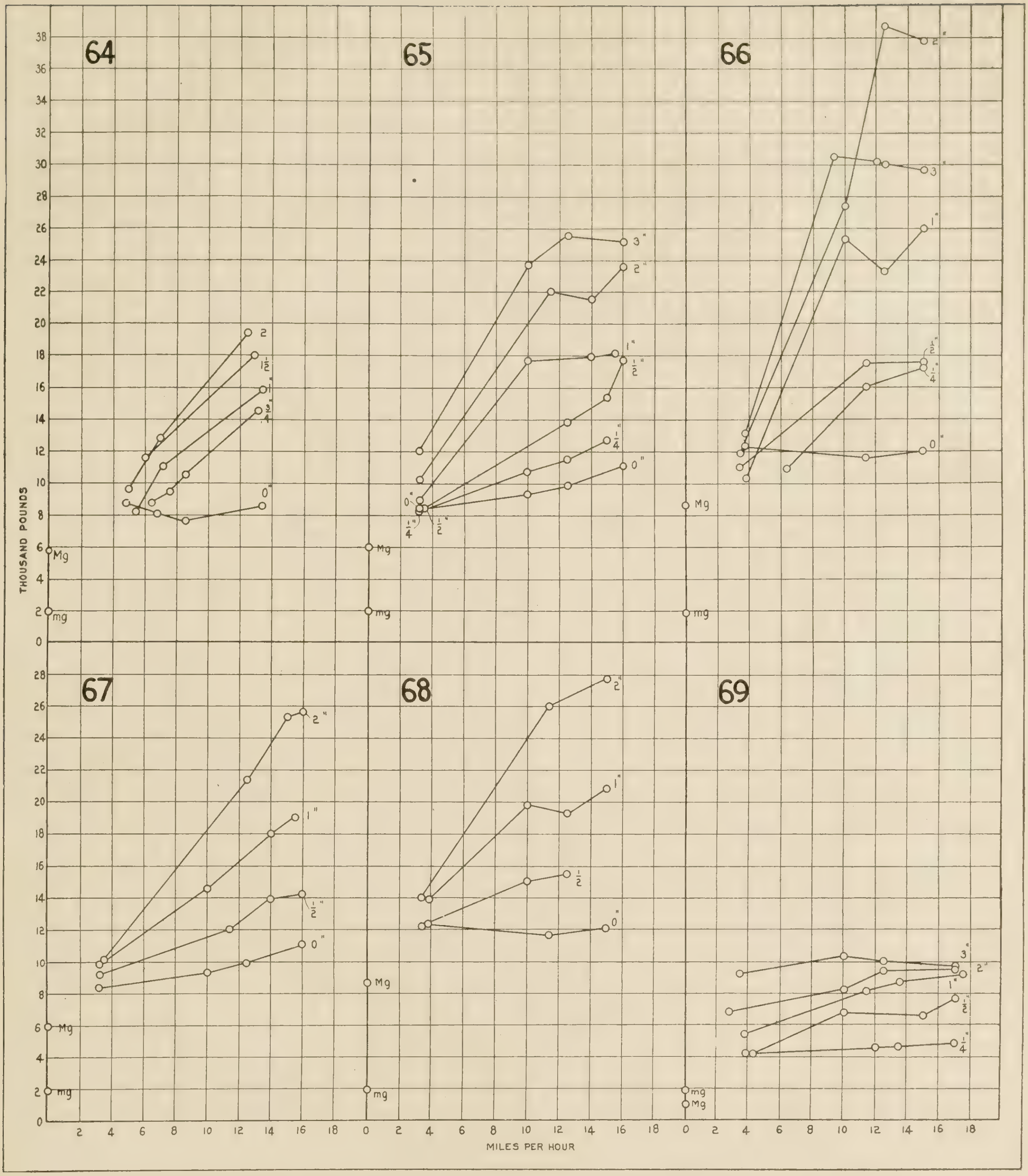


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (Mg).	Unsprung weight on 1 rear wheel (mg).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
64	B	3	5	5,900	1,837		Solid		A	3.62	Obstruction.
65	A	5	5	6,950	1,950	13	do	0.15	F	2.12	Drop.
66	A	5	7½	8,650	1,950	13	do	.18	F	3.09	Do.
67	A	5	5	5,950	1,950	13	do	.15	F	2.12	Obstruction.
68	A	5	7½	8,650	1,950	13	do	.18	F	3.09	Do.
69	A	5	0	1,050	1,950	14	do	.13	F	.38	Drop.

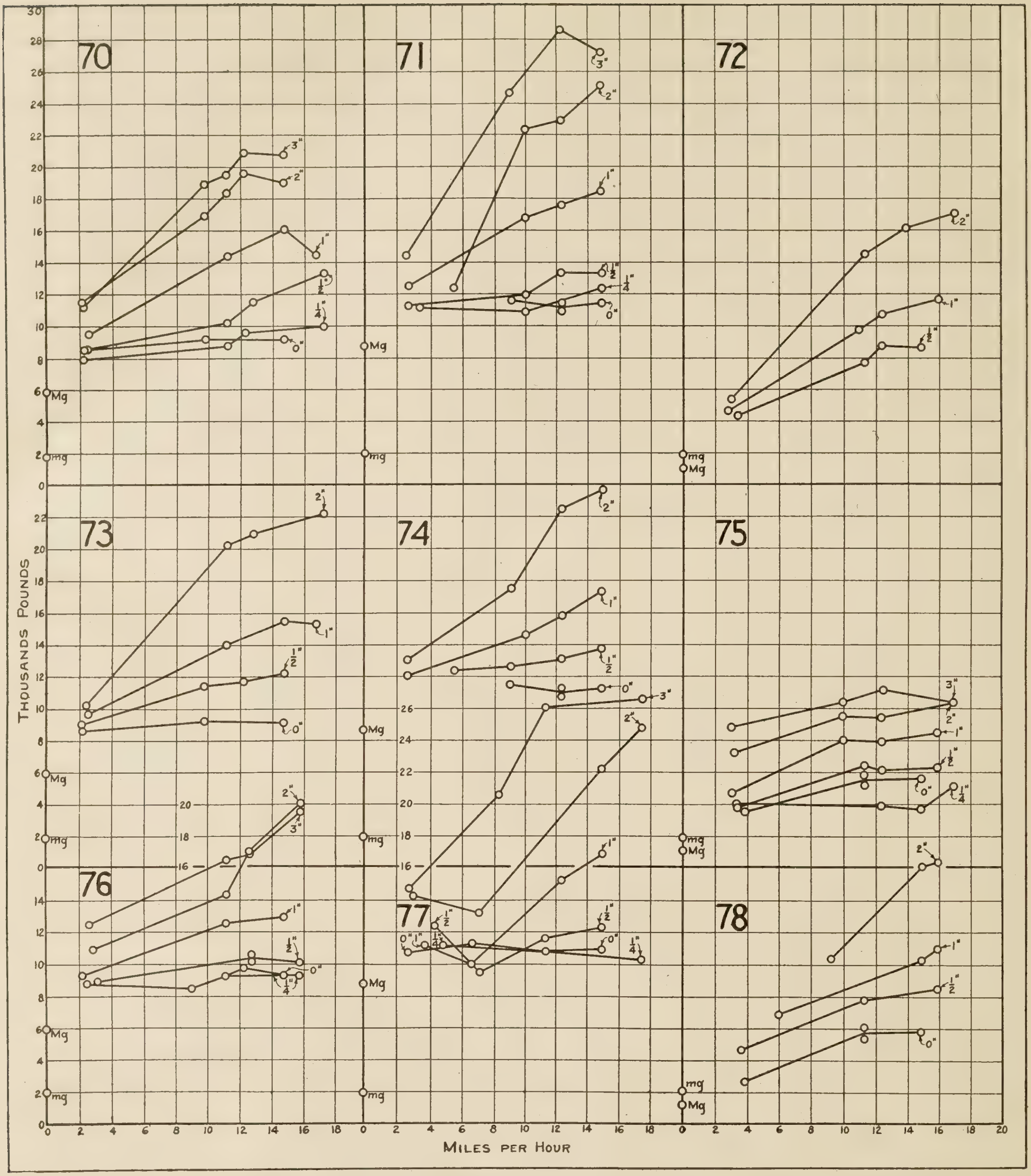


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires.			Springs.		Type of test.
						No.	Kind.	Deformation due to wheel load.	No.	Deflection due to sprung weight.	
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
70	A	5	5	5,950	1,950	14	Solid	0.26	F	2.12	Drop.
71	A	5	7½	8,650	1,950	14	....do	.31	F	3.09	Do.
72	A	5	0	1,050	1,950	14	....do	.13	F	.38	Obstruction.
73	A	5	5	5,950	1,950	14	....do	.26	F	2.12	Do.
74	A	5	7½	8,650	1,950	14	....do	.31	F	3.09	Do.
75	A	5	0	1,050	1,950	15	....do	.19	F	.38	Drop.
76	A	5	5	5,950	1,950	15	....do	.38	F	2.12	Do.
77	A	5	7½	8,650	1,950	15	....do	.45	F	3.09	Do.
78	A	5	0	1,050	1,950	15	....do	.19	F	38	Obstruction.

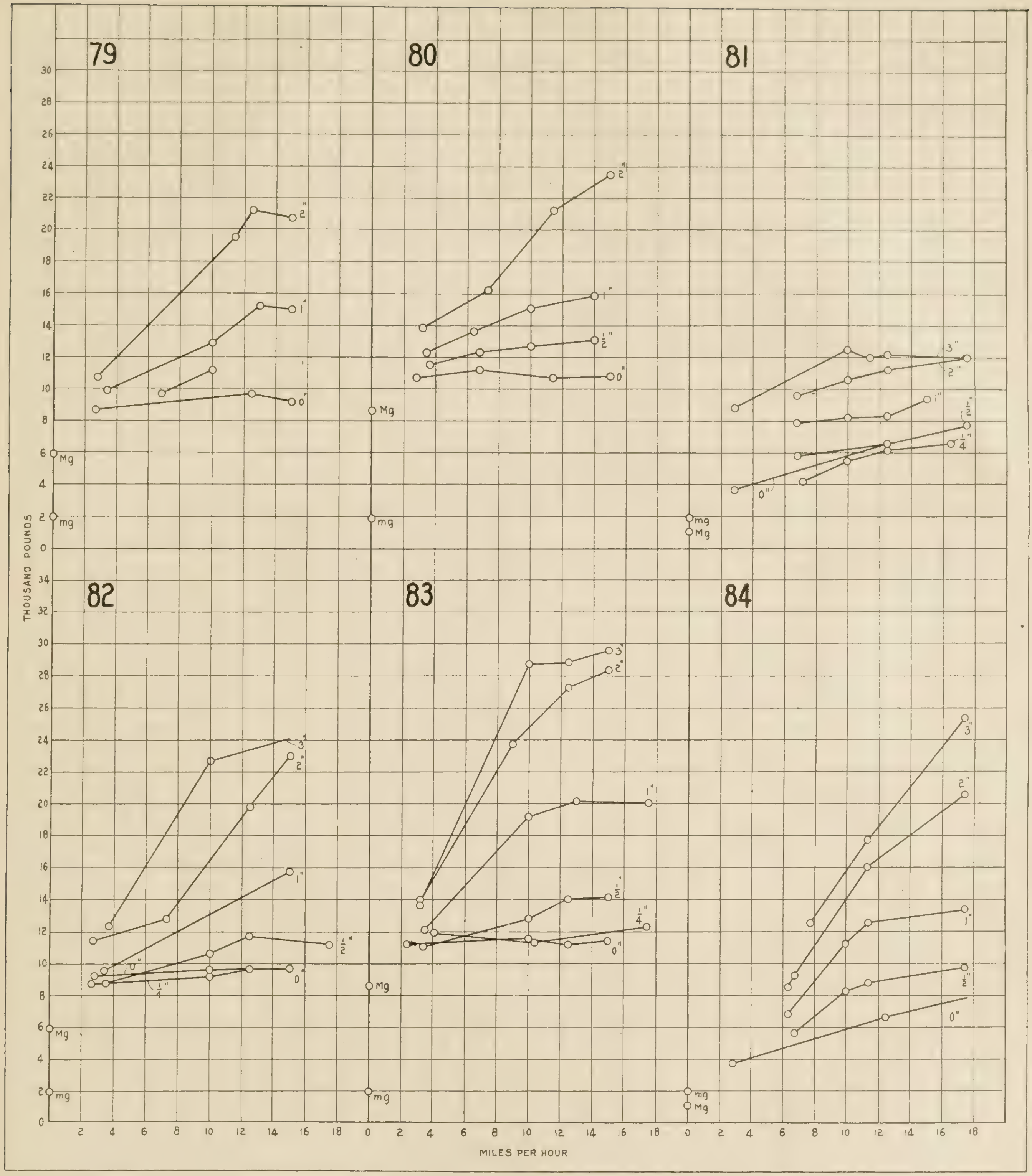


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires.			Springs.		Type of test.
						No.	Kind.	Deformation due to wheel load.	No.	Deflection due to sprung weight.	
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
79	A	5	5	5,950	1,950	15	Solid	0.38	F	2.12	Obstruction.
80	A	5	7½	8,650	1,950	15	do	.45	F	3.09	Do.
81	A	5	0	1,050	1,950	24	do	.18	F	.38	Drop.
82	A	5	5	5,950	1,950	24	do	.36	F	2.12	Do.
83	A	5	7½	8,650	1,950	24	do	.43	F	3.09	Do.
84	A	5	0	1,050	1,950	24	do	.18	F	.38	Obstruction.

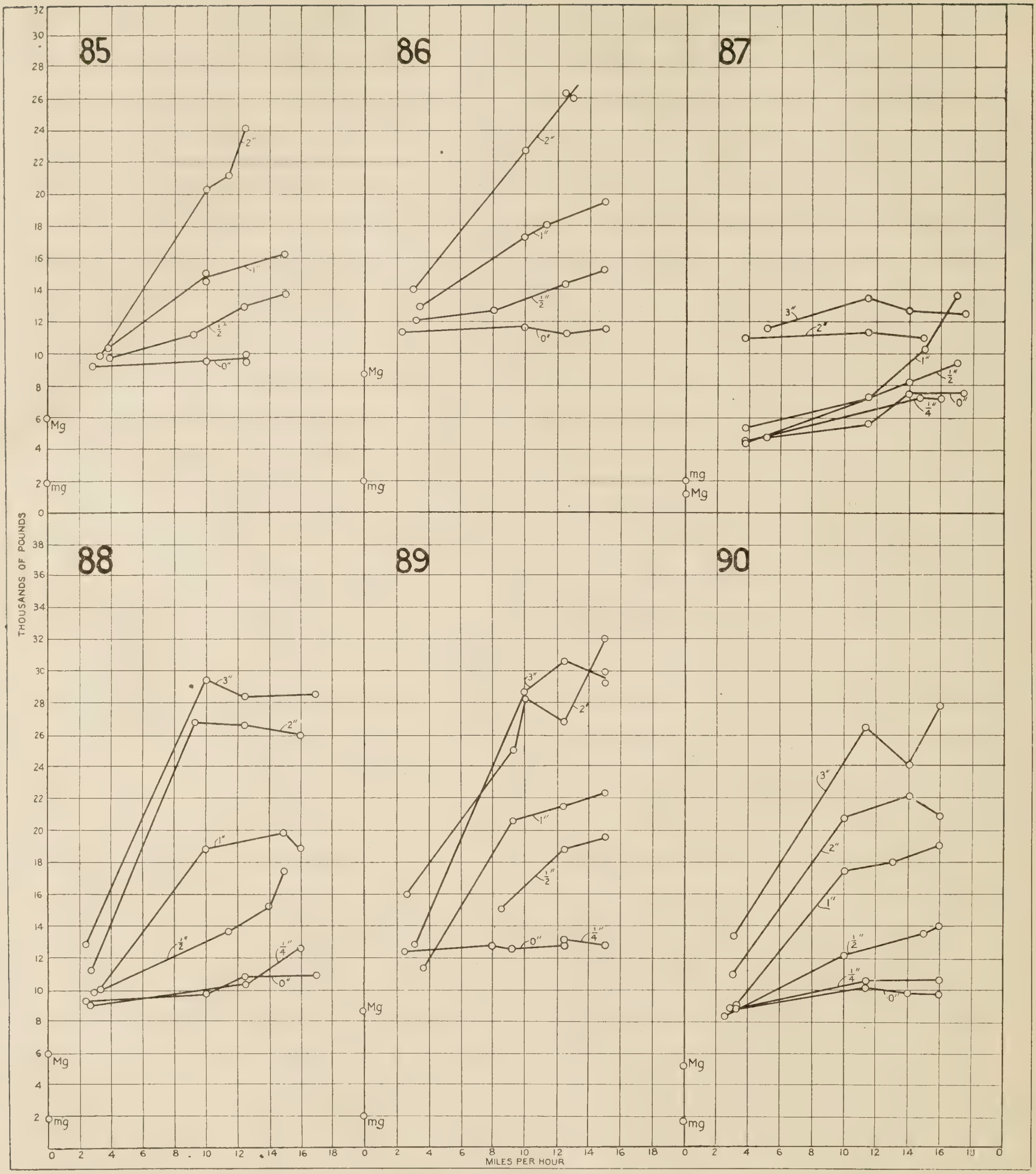


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires.			Springs.		Type of test.
						No.	Kind.	Deformation due to wheel load.	No.	Deflection due to sprung weight.	
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
85	A	5	5	5,950	1,950	24	Solid	0.36	F	2.12	Obstruction.
86	A	5	7½	8,650	1,950	24	....do	.43	F	3.09	Do.
87	A	5	0	1,050	1,950	25	....do	.08	F	.38	Drop.
88	A	5	5	5,950	1,950	25	....do	.16	F	2.12	Do.
89	A	5	7½	8,650	1,950	25	....do	.19	F	3.09	Do.
90	A	5	4.8	5,150	1,950	25	....do	.15	F	1.84	Do.

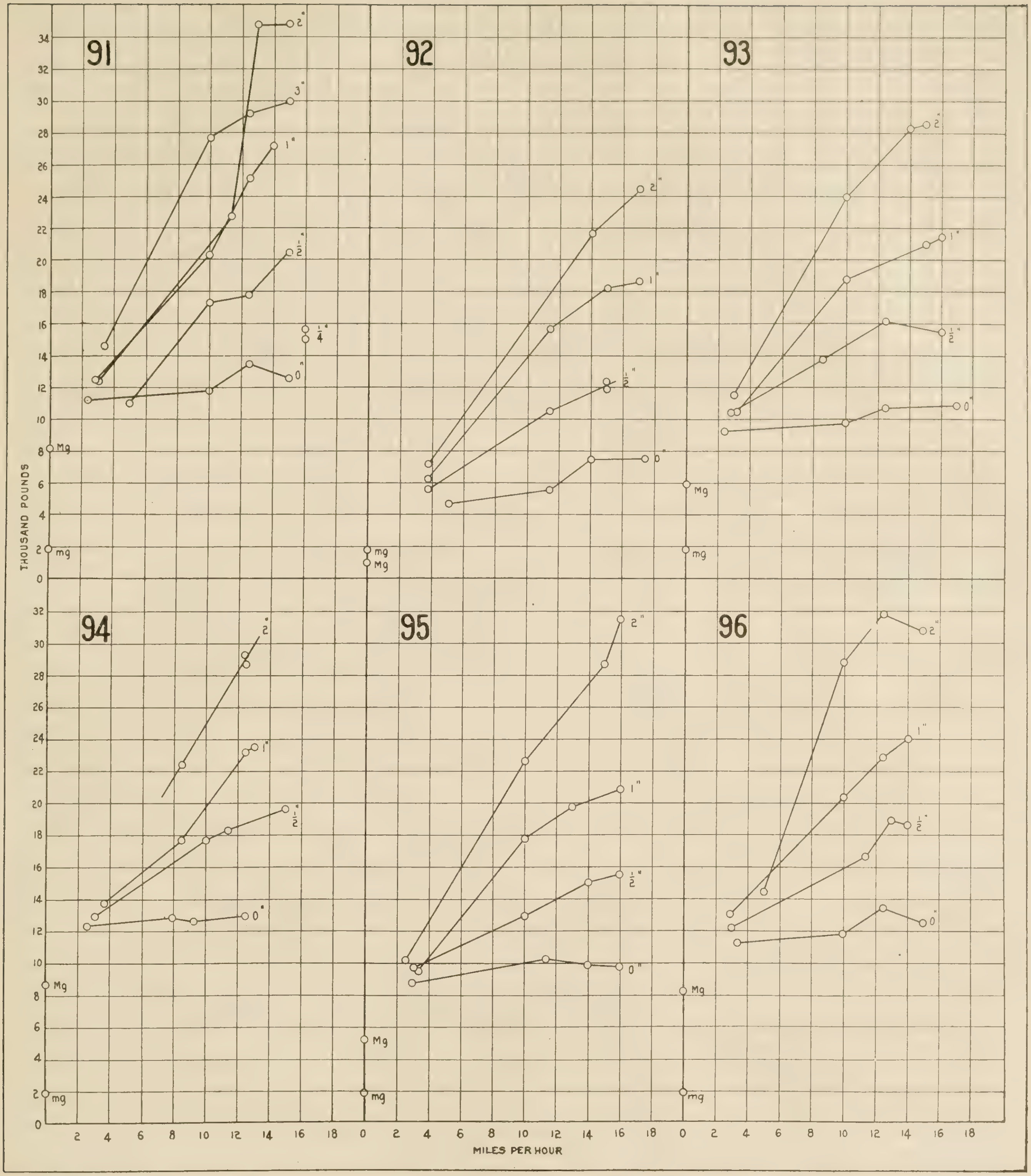


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires.			Springs.		Type of test.
						No.	Kind.	Deformation due to wheel load.	No.	Deflection due to sprung weight.	
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
91	A	5	6.7	8,150	1,950	25	Solid	0.18	F	2.90	Drop.
92	A	5	0	1,050	1,950	25	...do	.08	F	.38	Obstruction.
93	A	5	5	5,950	1,950	25	...do	.16	F	2.12	Do.
94	A	5	7½	8,650	1,950	25	...do	.19	F	3.09	Do.
95	A	5	4.8	5,150	1,950	25	...do	.15	F	1.84	Do.
96	A	5	6.7	8,150	1,950	25	...do	.18	F	2.90	Do.

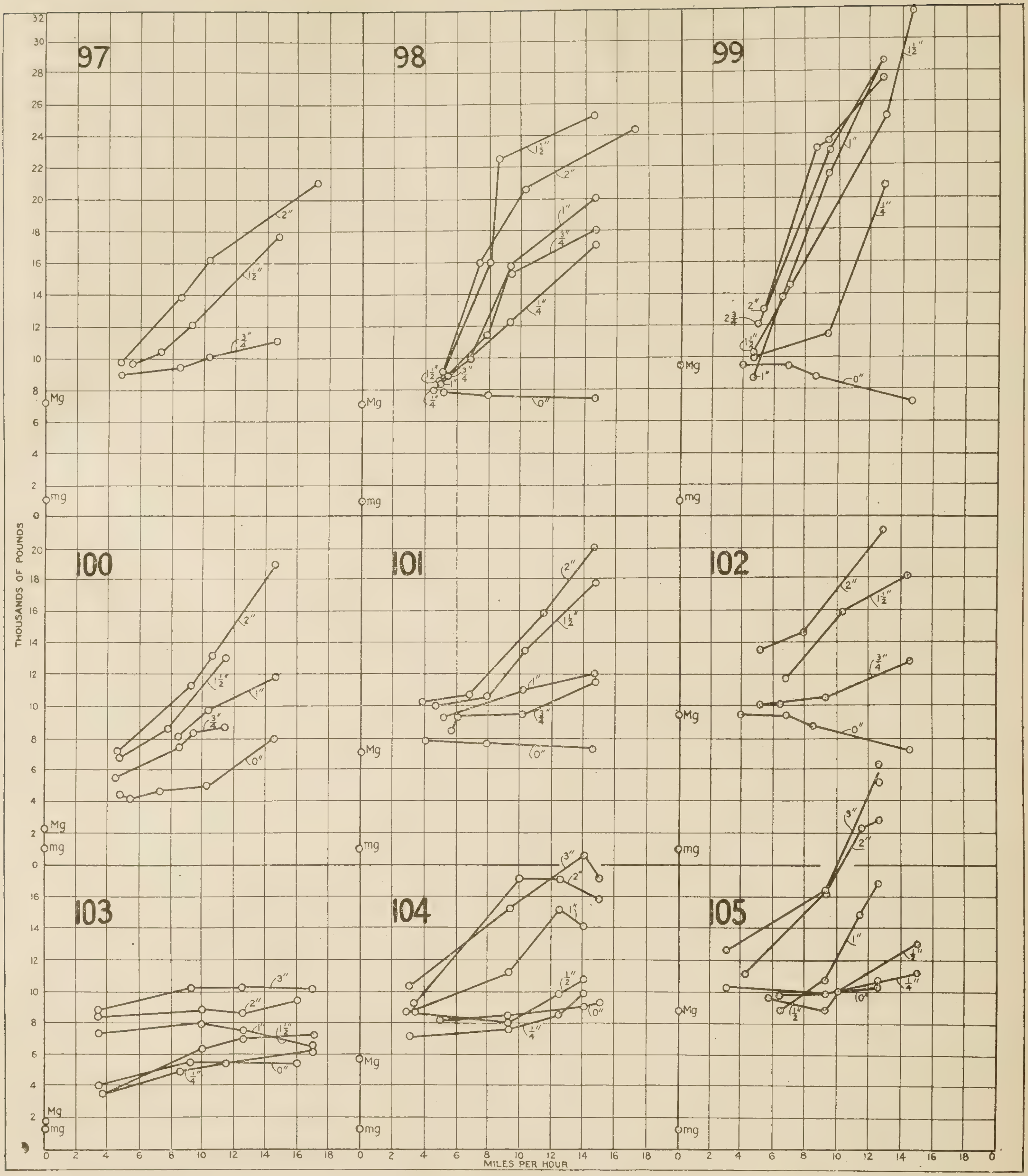


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires.			Springs.		Type of test.
						No.	Kind.	Deformation due to wheel load.	No.	Deflection due to sprung weight.	
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
97	Ka	5½	5	7,060	1,000	2	Solid	0.23	B	3.73	Iron obstruction.
98	Ka	5½	5	7,060	1,000	2	do	.23	B	3.73	Drop.
99	Ka	5½	7¾	9,575	1,000	2	do	.28	B	5.12	Do.
100	Ka	5½	0	2,250	1,000	2	do	.15	B	1.12	Obstruction.
101	Ka	5½	5	7,060	1,000	2	do	.23	B	3.73	Do.
102	Ka	5½	7¾	9,575	1,000	2	do	.28	B	5.12	Do.
103	Kb	5½	0	1,600	1,300	16	do	.15	G	.53	Drop.
104	Kb	5½	5	5,800	1,300	16	do	.28	G	1.93	Do.
105	Kb	5½	7½	8,800	1,300	16	do	.35	G	2.93	Do.

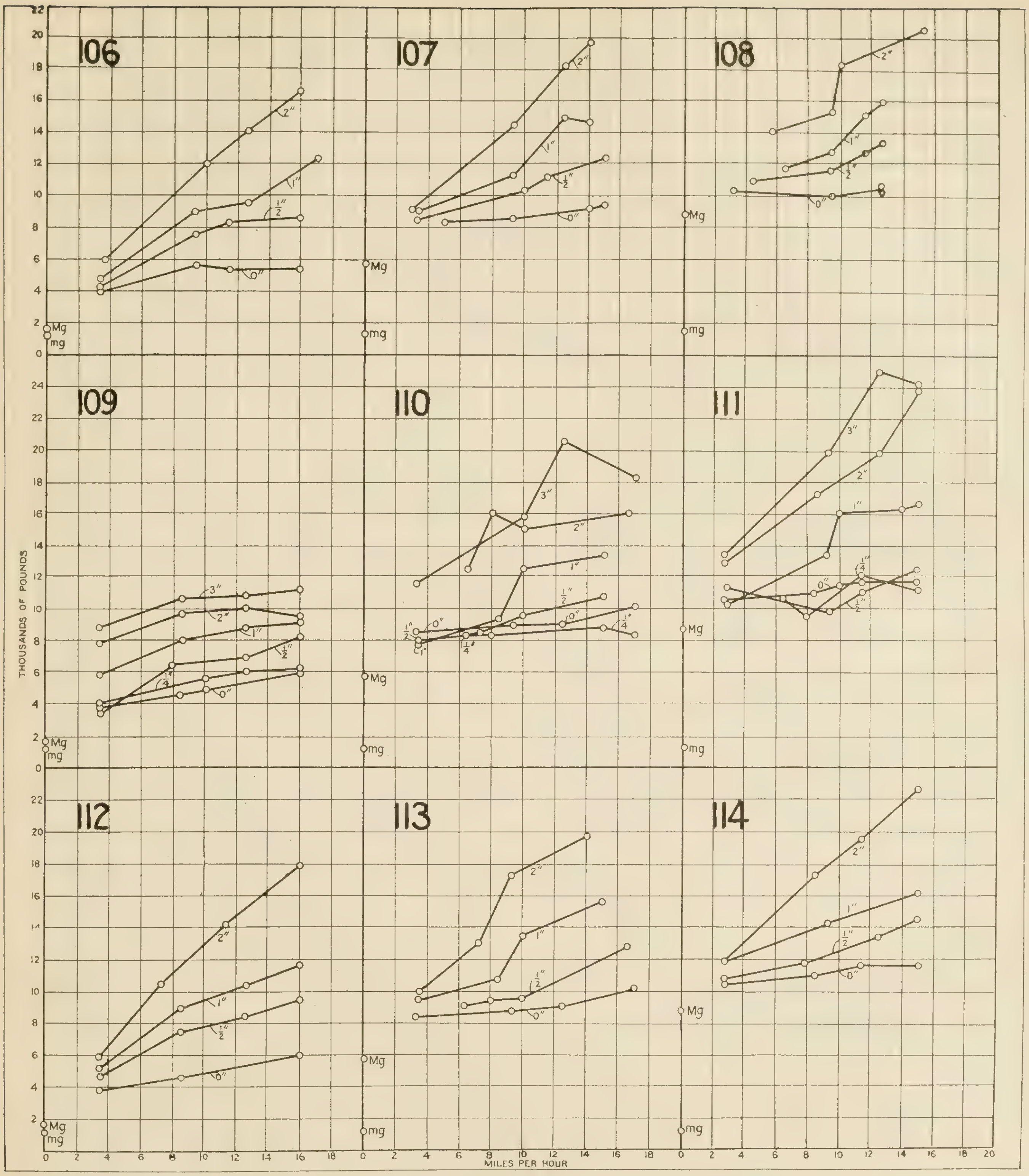


Chart No.	Truck.	Capacity	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
106	Kb	5½	0	1,600	1,300	16	Solid	0.15	G	0.53	Obstruction.
107	Kb	5½	5	5,800	1,300	16	....do	.28	G	1.93	Do.
108	Kb	5½	7½	8,800	1,300	16	....do	.35	G	2.93	Do.
109	Kb	5½	0	1,600	1,300	24	....do	.18	G	.53	Drop.
110	Kb	5½	5	5,800	1,300	24	....do	.33	G	1.93	Do.
111	Kb	5½	7½	8,800	1,300	24	....do	.42	G	2.93	Do.
112	Kb	5½	0	1,600	1,300	24	....do	.18	G	.53	Obstruction.
113	Kb	5½	5	5,800	1,300	24	....do	.35	G	1.93	Do.
114	Kb	5½	7½	8,800	1,300	24	....do	.42	G	2.93	Do.

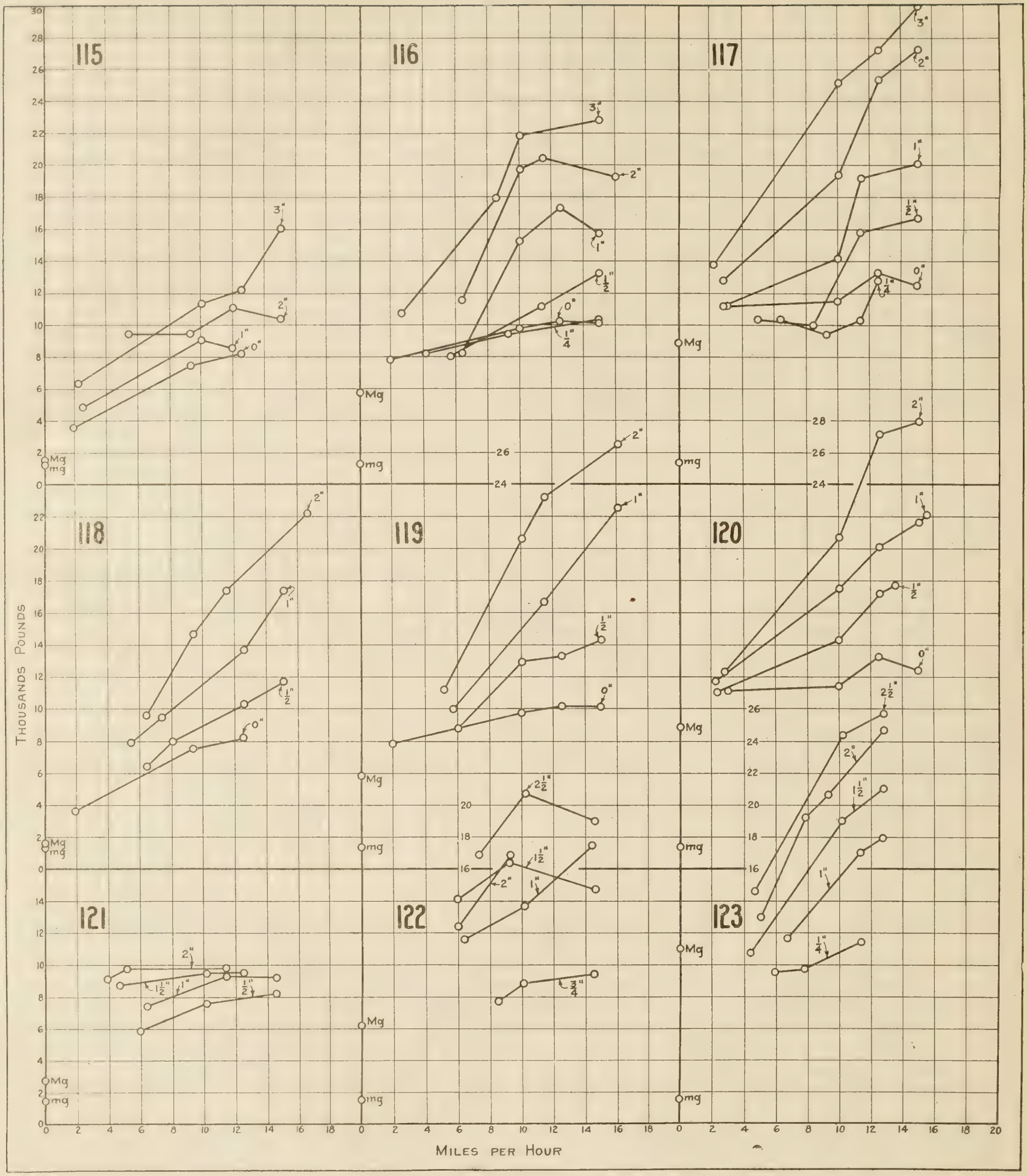


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
115	Kb	5½	0	1,600	1,300	25	Solid	0.08	G	0.53	Drop.
116	Kb	5½	5	5,800	1,300	25	...do	.15	G	1.93	Do.
117	Kb	5½	7½	8,800	1,300	25	...do	.18	G	2.93	Do.
118	Kb	5½	0	1,600	1,300	25	...do	.08	G	.53	Obstruction.
119	Kb	5½	5	5,800	1,300	25	...do	.15	G	1.93	Do.
120	Kb	5½	7½	8,800	1,300	25	...do	.18	G	2.93	Do.
121	Kc	7½	0	2,700	1,500	1	...do	.30	C	1.08	Drop.
122	Kc	7½	3I	6,200	1,500	1	...do	.48	C	2.70	Do.
123	Kc	7½	8½	11,000	1,500	1	...do	.60	C	4.78	Do.

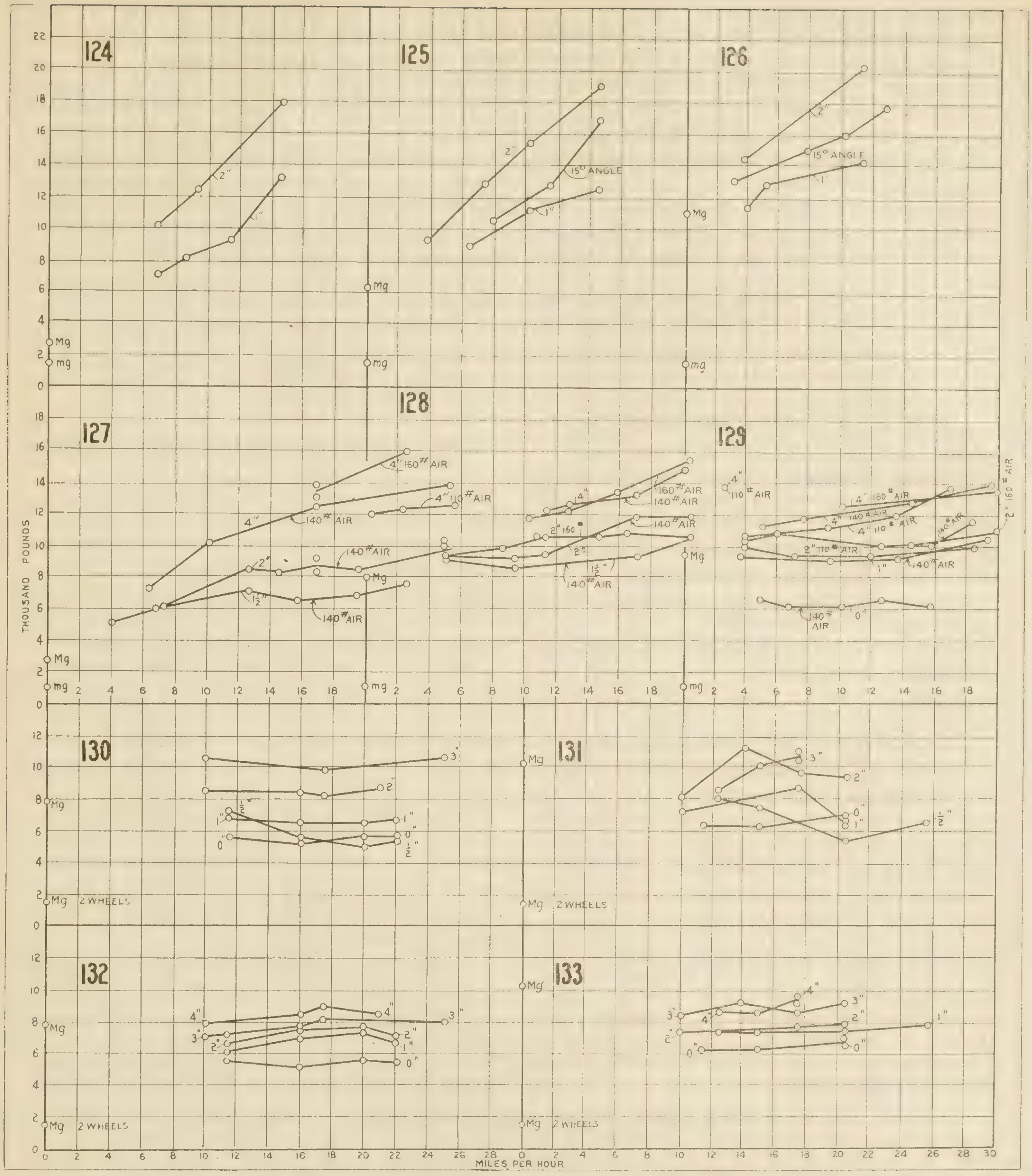


Chart No.	Truck.	Capacity.	Load.	Sprung weight on 1 rear wheel (*Mg*).	Unsprung weight on 1 rear wheel (*mg*).	Tires. No.	Tires. Kind.	Tires. Deformation due to wheel load.	Springs. No.	Springs. Deflection due to sprung weight.	Type of test.
		Tons.	*Tons.*	*Pounds.*	*Pounds.*						
124	Kc	7½	0	2,700	1,500	1	Solid	0.30	C	1.08	Obstruction.
125	Kc	7½	3½	6,200	1,500	1	do	.48	C	2.70	Do.
126	Kc	7½	8½	11,000	1,500	1	do	.60	C	4.78	Do.
127	Ks	5	0	2,740	1,130		Pneumatic				Do.
128	Ks	5	6.4	8,080	1,130		do				Do.
129	Ks	5	7.15	9,380	1,130		do				Do.
130	G	5	5	[1] 7,980	[1] 1,500		do			1.75	Drop.
131	G	5	7½	[1] 10,280	[1] 1,500		do			2.62	Do.
132	G	5	5	[1] 7,980	[1] 1,500		do			1.75	Obstruction.
133	G	5	7½	[1] 10,280	[1] 1,500		do			2.62	Do.

this connection it should be stated that the name "cushion" on a tire does not necessarily make it such a tire. Some definitions and deflection requirements should be adopted for the classification of tires. Certainly a tire which does not have at least a deflection value of 40 per cent to 50 per cent of the deflection of a pneumatic tire under the same capacity load should not be classed as a cushion tire.

Pneumatic tires, as might be expected, show a very great influence in reducing impact values, and the impact produced with such equipment seems to increase only very slightly with the speed.

Considering the effect only upon the impact, the width of the tires, or the load per inch of tire width has very little controlling influence. The deflection of the tire is the main factor and this is controlled only slightly by its width. A decrease in tire width increases the load per square inch of tire, which in turn causes a slightly greater tire deflection. This, then, should tend to slightly decrease the impact. It will thus be seen that a large tire width does not tend to decrease the impact, but rather to increase it. It is a fact that a very wide but thin solid tire will give much higher impact forces than a narrow thick one. In so far as the unit load on the road surface is concerned, this must be considered from an entirely different viewpoint.

The speed of the truck has an important influence upon the value of the impact force, but it is a somewhat complex relation. It is not a simple arithmetical ratio, nor can it be expressed simply as a certain power of the speed ratio. When striking an obstruction or irregularity, the curve showing the impact values in relation to speed is approximately a straight line. But the equation of this curve depends upon the characteristics of the truck, the height of the obstruction, and the deflection of the tire, as well as the speed. For approximate comparisons it may be stated that the impact increases with the increase of speed:

10 to 100 per cent for solid tires;
10 to 75 per cent for cushion tires;
and 0 to 10 per cent for pneumatic tires.

An average of any of these limiting percentages must not be used, as the performance of any truck is too variable, and the relation of the other controlling factors can not be predicted.

When dropping from one level to another the speed affects the impact value somewhat according to the percentage variations, given in the preceding paragraph, up to the point of a critical speed of 9 to 12 miles per hour. Beyond the point of critical speed at which the wheel falls freely there should be no increase in impact value.

Although heavy unsprung weights may give higher impact values than lighter unsprung weights, it can not be said that this is the major controlling factor. With all other conditions remaining constant this may be true. But other controlling factors, such as tire equipment, spring stiffness, load carried, and speed, may have a greater influence and overcome any difference due to the unsprung weights.

It is easily possible to so operate a light-weight truck under certain load and speed conditions that it will produce as high impact values as a heavy truck under certain conditions. Much remains to be learned, however, as to the relative destructive effects of light-weight, fast-running vehicles, and slow-moving heavy trucks.

The impact values as shown on the accompanying charts may be as high as 7 times the load at one rear wheel for a solid tire over a 1-inch obstruction at 16 miles per hour; an average value being about 4 times. For pneumatic tires the maximum impact value is probably not more than one and three-fourths times the load at one rear wheel, and an average value is not more than 25 per cent.

REPORT ON CALIFORNIA HIGHWAYS READY.

The report of the Bureau of Public Roads on the study of the California highway system made by the bureau has been completed and will be published by the California Commission about March 30.

The report, which was transmitted to the State Commission by Secretary of Agriculture, E. T. Meredith on February 18, covers the work done at the request of the California Highway Commission and Highway Engineer since July 8, 1920. The field studies and the preparation of the report were carried forward under the immediate direction of Dr. L. I. Hewes and T. Warren Allen, general inspectors of the Bureau of Public Roads.

The published report will contain about 58,000 words and numerous tables, together with 11 appendices. It is profusely illustrated with photographs and 115 maps and diagrams. Bound in cloth it will make a valuable addition to highway engineering libraries.

It is the most comprehensive study of the results obtained through the development of a State highway system that has yet been undertaken. The work follows two principal lines; one that includes those questions that are engineering in character, and the other those that are economic in character.

For the purpose of the study, the principal operation was to classify all the pavement laid. This classification covered 1,262 miles from which a complete record of all concrete pavement for each one-tenth mile resulted, and is supported by 7,500 consecutive photographs filed in the bureau.

An abstract of the report will be published in the April issue of Public Roads.

Acknowledgment is made to Mr. J. T. Pauls for his painstaking and thorough effort in conducting the field tests, and for his aid in preparing and plotting the charts; and to Mr. C. A. Hogentogler for helping to secure and analyze the data. This investigation is done under the general direction of Mr. Thos. H. MacDonald, Chief of the Bureau of Public Roads, and Mr. A. T. Goldbeck, Engineer of Tests.

FEDERAL AID ALLOWANCES.

PROJECT STATEMENTS APPROVED IN JANUARY, 1921.

State.	Project No.	County.	Length.	Type of construction.	Project statements approved.	Estimated cost.	Federal aid.
			Miles.				
Arizona	25	Prima and Santa Cruz		Bridges	Jan. 15	$52,000.74	$26,000.37
	27	Santa Cruz	14.500	Gravel	do.	114,603.50	57,301.75
	41	Maricopa	[1] 6.473	Concrete	Jan. 7	[1] 200,000.24	100,000.12
Arkansas	32	Hempstead	[3] 3.940	Gravel	Jan. 18	[3] 29,647.04	[1] 19,000.00
	39	Grant	[1] 14.300	do	Jan. 25	[1] 52,090.50	[1] 15,000.00
	74	Searcy		Bridge	Jan. 27	[1] 34,650.00	[1] 15,600.00
	110	Chicot	[1] 2.000	Concrete	Jan. 26	[1] 37,041.98	[1] 4,200.00
Colorado	30	Jefferson	.977	do	Jan. 6	68,999.99	19,540.00
	51	Cheyenne	[3] 4.334	Gravel	Jan. 21	[3] 27,865.54	[3] 13,932.77
	54	Chaffee	5.099	Earth	Jan. 28	110,775.50	55,387.75
	85	Larimer	1.295	Concrete	Jan. 6	57,963.95	25,900.00
	88	Boulder	1.316	do	Jan. 21	57,975.70	26,320.00
	89	Adams	4.413	do	Jan. 6	175,983.50	87,991.75
	122	Sedgwick	8.500	Gravel	Jan. 22	68,202.75	34,101.37
	125	Gunnison	2.819	Earth and gravel	Jan. 26	88,810.26	44,405.13
	126	Montezuma	2.992	Gravel	Jan. 21	39,314.55	19,657.27
Connecticut	7	New London	4.250	Bituminous macadam	Jan. 6	189,456.30	85,000.00
Georgia	13	Muscogee		Bridge	Aug. 2	[1] 59,950.00	[1] 29,975.00
	27	Polk	[1] 14.700	Top soil	do.	[1] 41,184.00	[1] 20,000.00
	37	Dekalb	[1] 5.500	Concrete	do.	[1] 134,778.38	[1] 45,591.04
	72	Gwinnett	[1] 10.000	do	do.	[1] 51,154.71	[1] 25,577.35
	188	Randolph	[3] 6.500	Sand-clay	Jan. 15	[3] 45,884.08	[3] 7,500.00
	189	Hart	4.000	do	Jan. 4	26,793.80	13,396.90
	195	Glynn and McIntosh	4.830	Shell	Jan. 6	195,647.58	90,000.00
	194	Fayette	2.270	Topsoil	Jan. 26	15,102.82	7,551.41
	209	Tift		Bridges	do.	36,300.00	18,150.00
	217	Barton	2.000	Gravel	Jan. 17	22,000.00	11,000.00
	213	Worth	4.340	Earth and hard surface	Jan. 26	176,180.53	25,000.00
	216	Columbia	4.000	Sand-clay	do.	28,585.37	14,000.00
Indiana	16	Vanderburg, Warrick, Spencer, Dubois, Orange, Lawrence.		Earth, brick, concrete, or bituminous concrete.	Jan. 21	[2] 2,115,596.26	[2] 1,057,798.13
	27	Noble	14.500	Brick, concrete, or bituminous	Jan. 15	636,900.00	318,450.00
Kansas	50	Bourbon, Crawford	[1] .521	Bituminous macadam	Jan. 14	16,182.52	7,815.00
	73	Cherokee	13.340	Gravel	Jan. 28	378,840.00	103,800.00
Louisiana	51	St. Charles	[1] 6.230	Sand-clay, gravel	do.	[1] 62,531.15	[1] 31,265.57
	57	Grant and La Salle		Bridges	Jan. 24	[1] 16,991.15	[1] 8,495.57
	83	Caldwell	14.900	Gravel	do.	195,749.84	88,000.00
Maryland	48	Harford	3.040	Concrete	Jan. 22	120,973.60	60,486.80
Massachusetts	45	Hampden	2.325	Bituminous macadam	Jan. 4	79,761.00	39,880.50
	49	Plymouth	2.108	do	Jan. 22	50,923.40	25,461.70
	50	Worcester	1.763	Bituminous concrete	do.	71,520.46	35,260.00
	51	do	4.498	Bituminous macadam	Jan. 24	276,511.73	89,960.00
	52	do	3.208	Concrete	Jan. 21	178,774.75	64,160.00
	53	do	3.068	Bituminous macadam	Jan. 28	153,741.50	61,360.00
	54	do	3.591	do	Jan. 24	197,692.00	71,820.00
Michigan	57	Kent	17.320	Concrete or bituminous concrete	Jan. 28	778,442.50	346,400.00
Minnesota	118	Carver	[3] 12.480	Gravel	Jan. 7	[3] 45,005.62	[3] 3,699.02
Mississippi	19	Montgomery	[1] 9.110	do	Jan. 27	[1] 30,573.84	[1] 15,000.00
	29	Union	[2] 12.670	Gravel or slag	Jan. 28	[2] 87,403.25	[2] 15,796.63
	49	Coahoma	[1] 10.680	Concrete	Jan. 12	[1] 320,485.44	[1] 100,000.00
	103	Leake	14.100	Earth	Jan. 28	99,772.75	49,886.37
	111	Madison	14.000	do	do.	58,300.00	29,150.00
Montana	150	Sanders		Bridge	Jan. 26	96,992.50	48,496.25
New Mexico	61	Bernalillo	[3] .400	Concrete	do.	[3] 19,151.00	[3] 9,575.50
	63	Curry	12.000	Caliche	Jan. 22	92,803.70	46,401.85
	65	Ris Arriba		Bridge	Jan. 28	48,836.15	24,418.07
North Dakota	115	Adams	3.000	Earth	Jan. 14	13,860.00	6,930.00
Ohio	70	Allen	[1] 4.430	Bituminous macadam	Jan. 7	[1] 123,000.00	[1] 43,600.00
	124	Auglaize	[1] 5.306	Concrete	do.	[1] 220,000.00	[1] 72,000.00
Oklahoma	49	Pittsburg		Bridge	Jan. 15	40,000.00	20,000.00
Oregon	50	Benton	7.960	Concrete	Jan. 22	247,929.00	123,964.50
South Carolina	60	Beaufort		Bridge	Jan. 27	[1] 207,900.00	[1] 103,950.00
Texas	58	Navarro	[1] 11.540	Macadam	Jan. 31	[1] 133,102.20	[1] 66,551.10
	230	Denton	5.430	Gravel	Jan. 17	58,791.81	25,000.00
	232	Comanche	8.000	do	Jan. 6	126,297.69	31,574.42
Utah	10	Uintah	22.620	do	Jan. 12	413,002.04	206,501.02
West Virginia	110	Wyoming	4.000	Earth	Jan. 22	94,076.00	47,038.00

[1] Withdrawn or canceled.
[2] Revised statement. Amounts given are decreases from those in original statement.
[3] Revised statement. Amounts given are increases over those in the original statement.

PROJECT AGREEMENTS EXECUTED IN JANUARY, 1921.

State.	Project No.	County.	Length.	Type of construction.	Project agreement signed.	Estimated cost.	Federal aid.
			Miles.				
Arizona	6A	Apache	3.000	Gravel	Jan. 21	$30,607.83	$15,303.91
	15D	Graham	5.026	do	do.	64,088.55	32,044.27
	31	Maricopa		Bridge	Jan. 18	78.895.85	39,447.92
	38	Cochise	26.370	Gravel	Jan. 21	160,603.52	80,301.76
	39	Mohave	23.000	Gravel and earth	Jan. 18	177,430.35	88,715.17
Arkansas	55	Priarie	3.830	Gravel, surface treated	Jan. 31	55,277.78	21,400.00
	63	White	11.010	do	Jan. 26	96,854.72	36,300.00
Colorado	59	Bent		Gravel	Jan. 5	[3] 31,153.52	[3] 15,576.76
	123	Eagle and Garfield		Earth	Jan. 7	[3] 51,509.37	[3] 25,754.69
Delaware	2	Sussex		Concrete	Jan. 24		[4] 162,674.82

Footnotes on page 39.

PROJECT AGREEMENTS EXECUTED IN JANUARY, 1921—Continued.

State.	Project No.	County.	Length.	Type of construction.	Project agreements signed.	Estimated cost.	Federal aid.
			Miles.				
Georgia	3	Brooks		Bituminous macadam	Jan. 26	[4]$137,468.70	[4]$34,320.00
	76	Wheeler		Sand-clay	Jan. 21	[3]21,006.23	[3]9,088.31
	117	Gwinnett	[3]0.193	Topsoil	...do...	[3]90,929.48	[3]51,005.42
	141	Macon		Sand-clay	...do...	[3]1,424.01	[3]712.00
	154A	Wayne	3.250	Topsoil	...do...	16,254.46	8,127.23
	162	Gwinnett	6.120	...do	...do...	79,216.35	39,608.17
	164	Macon		Bridge	...do...	28,975.30	12,513.08
	178	Murray	6.670	Topsoil	...do...	78,822.84	39,411.42
	181	Dekalb	1.913	Bituminous macadam	...do...	69,122.91	5,000.00
	199	Quitman	5.000	Sand-clay	...do...	30,454.21	15,227.10
	202	Wilcox	1.130	Gravel	...do...	21,764.60	10,882.30
Illinois	1-23	Lee	0.807	Concrete	Jan. 4	27,928.49	13,964.24
	1-M	Kane	0.487	Concrete and brick	...do...	22,752.95	9,740.00
	2-M	Iroquois	0.698	Concrete	...do...	27,006.52	13,503.26
	9-W	Fayette	1.894	Earth and four bridges	Jan. 27	210,241.28	52,560.32
	11-S	Vermilion		Bridge	Jan. 4	27,858.61	13,929.30
	14-9, 10, 11	Jackson and Union	13.299	Earth	Jan. 17	247,202.80	61,800.69
	15-5	Williamson	3.763	...do	Jan. 27	122,556.18	30,639.04
	17-1, 2	Adams	14.392	...do	Jan. 4	213,378.29	53,344.57
Indiana	16-EF	Spencer and Dubois	16.996	Earth and brick, concrete or bituminous concrete.	Jan. 19	237,258.06	118,629.02
Iowa	83ABCD	Union	14.503	Earth	Jan. 27	111,494.84	16,900.00
	91BCD	Wayne	10.950	...do	...do...	79,604.41	39,000.00
	122	Decatur	9.929	...do	...do...	76,051.91	31,800.00
Kansas	41	Saline		...do	Jan. 6	[2]278,627.27	[2]63,000.00
	45	...do		...do	...do...	[2]393,639.05	[2]84,180.00
	50	Bourbon	[1].520	Bituminous macadam	Jan. 14	[1]16,208.58	[1]7,800.00
	52	Wyandotte and Leavenworth	7.968	Concrete	Jan. 31	494,033.15	119,520.00
	62	Morris	6.809	Bituminous macadam	Jan. 25	341,773.43	97,000.00
	65	Allen	2.003	Concrete	Jan. 26	96,248.24	30,045.00
	69	Saline and Ottawa	1.989	Earth	Jan. 16	22,476.85	5,967.00
	71	Cherokee	3.073	Concrete	Jan. 24	283,220.74	46,095.00
Louisiana	65	St. Martin	4.950	Gravel	Jan. 14	76,972.44	38,486.22
Maryland	7-D	Baltimore	.146	Waterbound macadam	Jan. 12	9,565.71	2,920.00
	40	...do	2.410	Sheet asphalt	Jan. 5	98,445.38	48,200.00
	42	Anne Arundel	2.120	Concrete	...do...	82,508.80	41,254.40
	43	Prince Georges	0.504	Sheet asphalt	...do...	21,298.75	10,000.00
Michigan	1AB	Oceana and Muskegon	9.942	Concrete	Jan. 26	379,933.79	189,966.89
	26	Antrim	7.839	Gravel	Jan. 15	119,167.33	59,583.66
	33CD	Alcona	7.837	...do	Jan. 21	128,607.21	64,303.60
Minnesota	1	Pine		...do	Jan. 19	[5]52,490.14	[5]26,245.07
	17	Carlton		...do	Jan. 7	[5]3,851.95	[5]1,925.97
	22	Dakota	17.035	Earth	Jan. 12	217,115.81	108,557.90
	31	Kandiyohi		Concrete	Jan. 24	[4]19,185.40	[4]23,425.14
	40AB	Meeker		Gravel	Jan. 25	[3]8,560.12	[3]6,288.88
	45	Nobles	18.960	...do	Jan. 5	155,346.95	65,000.00
	74	Sibley	9.700	...do	Jan. 25	73,871.16	36,935.58
	114	Sherburne	[3]1.297	Concrete	...do...	[3]48,462.52	[3]24,231.22
	140	Cass	12.430	Gravel	Jan. 10	95,634.15	25,000.00
	153A	Blue Earth	6.914	...do	Jan. 5	92,771.74	46,000.00
	162	Beltrami	12.120	...do	Jan. 12	76,072.31	15,000.00
	176	Itasca		...do	Jan. 24	[3]3,583.25	[3]14,656.24
	188	Freeborn	4.955	...do	Jan. 20	44,992.87	3,000.00
	195	Lac qui Parle	8.010	...do	Jan. 5	21,019.50	10,000.00
Mississippi	30	Lauderdale	[4]1.000	...do	Jan. 20	[4]7,272.16	[4]3,636.08
	42	Pike	9.739	...do	Jan. 29	100,062.46	50,031.23
	49	Coahoma	[1]10.660	Concrete	Jan. 12	[1]319,877.77	[1]100,000.00
Missouri	62	Macon		Gravel	Dec. 21	[3]41,386.34	[3]20,693.17
	84	Jasper	6.470	Concrete	...do...	231,072.51	115,536.25
	121A	Barry	4.880	Gravel	...do...	60,341.33	30,170.66
	122	Pettis		Bituminous macadam	...do...	[3]8,853.46	[3]4,426.73
	150AB	Greene	31.330	Gravel	...do...	243,676.35	121,838.17
Montana	9A	Madison		...do	Jan. 4	[4]41,793.58	[4]20,896.79
	15	Rosebud	[3]0.784	...do	Jan. 20	[3]27,220.22	[3]13,610.11
	94	Meagher		Earth	Jan. 4	[3]28,164.33	[3]14,082.17
	108A	Musselshell	11.323	...do	...do...	74,834.73	37,417.36
	136	Teton	13.240	Gravel	Jan. 3	84,428.64	42,214.32
Nevada	34	Churchill	8.290	Gravel	Dec. 28	121,148.80	60,574.40
New Mexico	13A	Valencia		Gravel and sand-clay	Jan. 17	[4]3,495.14	[4]1,747.57
	44	Hidalgo	8.000	Gravel	Jan. 22	48,959.70	24,479.85
New York	22	Broome		Bituminous macadam	Jan. 27	[3]7,500.00	[3]2,625.00
	69	Delaware		Reinforced concrete	Jan. 10	[3]75,300.00	[3]26,355.00
North Carolina	26	Davidson	[2]4.462	Topsoil	Jan. 31	[2]7,906.63	[2]2,524.98
	33	Montgomery	[2]7.064	...do	...do...	[2]6,975.69	
	55B	Mecklenburg	4.590	Bituminous macadam	...do...	188,445.18	91,800.00
	59	Columbus		Sand-clay	Jan. 22	[3]18,407.62	[3]9,203.81
	66	Haywood	6.177	Topsoil	Jan. 4	85,413.95	42,706.97
	70A	Jackson	4.832	Gravel	Jan. 7	136,743.31	68,371.65
	91	Surry		Topsoil	Jan. 22	[4]13,581.37	[4]6,790.69
	96	Yancey	2.946	Gravel	...do...	82,653.12	41,326.56
	99	Chatham		Topsoil	...do...	[3]32,448.15	[3]16,224.07
	100AB	Avery	14.001	Waterbound macadam	...do...	267,013.28	133,506.63
	125A	Alleghany	4.985	...do	...do...	153,899.13	76,949.56
Ohio	89	Madison	2.421	Bituminous macadam	Jan. 24	81,200.00	25,000.00
	96	Paulding		Bituminous macadam, Kentucky rock asphalt.	Jan. 4	[3]29,200.00	[3]20,400.00
	151	Clermont	3.548	Water-bound macadam	Jan. 15	104,600.00	39,320.00
	175	Hocking	5.351	Bituminous macadam	...do...	220,000.00	82,000.00
Oklahoma	18	Muskogee		Gravel	Jan. 26	[3]170,496.17	[3]85,248.08
Oregon	4	Wheeler		...do	Jan. 4	[3]78,207.80	[3]39,103.90
	12	Yamhill		Waterbound macadam	...do...		[3]5,000.00
	17	Malheur		Earth	...do...	[3]4,089.25	[3]2,044.62
	24	Gilliam		Gravel	...do...	[3]151,151.00	[3]75,575.50
	25	Sherman		...do	...do...	[3]129,051.45	[3]64,525.73
	35	Wasco		...do	...do...	[3]45,760.00	[3]22,880.00
	44	Gilliam	9.210	...do	...do...	51,040.00	25,520.00
Pennsylvania	85	Dauphin and Perry	7.908	Reinforced concrete	Jan. 21	507,518.80	158,160.00
	91	Lancaster	5.412	...do	Jan. 28	339,171.92	108,240.00
	92	Delaware	2.838	Concrete	...do...	170,167.08	56,760.00
	94	Northumberland	3.053	Reinforced concrete	...do...	139,790.97	61,060.00
	95	Lycoming	5.570	...do	...do...	441,291.75	111,400.00
Rhode Island	11	Providence	5.000	Bituminous concrete	Jan. 19	248,660.28	100,000.00

Footnotes on page 39.

PROJECT AGREEMENTS EXECUTED IN JANUARY, 1921—Continued.

State.	Project No.	County.	Length.	Type of construction.	Project agreements signed.	Estimated cost.	Federal aid.
			Miles.				
South Carolina	13	Chester and Union		Bridge	Jan. 15	$80,264.78	$35,001.45
	28	Orangeburg		Concrete and sand-clay	Jan. 19	[2] 4,749.35	
	44	Clarendon	7.830	Sand-clay	Jan. 11	79,843.61	39,921.80
	96	Anderson	8.414	Topsoil	Jan. 21	112,801.52	56,400.76
Texas	42	Tarrant	[3] 3.327	Gravel, bituminous top	Jan. 28	[3] 118,941.15	[3] 59,470.57
	61	Wichita		Concrete	Jan. 10	[4] 29,923.41	[4] 50,000.03
	73	Guadalupe		Rock asphalt	Jan. 15	[4] 44,097.16	[4] 22,048.50
	88B	Cass	10.990	Gravel	Jan. 26	126,741.98	35,000.00
	128C	Montague	3.920	Gravel and sand-clay	Jan. 12	49,964.98	22,500.00
	142	Harrison		Gravel, surface treatment	Jan. 25		[5] 15,532.19
	158	Hemphill	13.440	Sand-clay	Jan. 10	82,747.61	40,000.00
	166	Atacosa	13.500	Gravel, bituminous top	Jan. 15	301,356.09	142,866.61
	176	Runnels	5.760	Gravel	Jan. 25	40,248.54	20,124.27
Utah	19C	Piute		Bridge	Jan. 17	19,181.49	9,590.74
Vermont	17	Windsor		Bridge	Jan. 19	17,095.65	8,547.82
	20	Washington		do	Jan. 22	33,765.98	16,882.99
Virginia	91	King George	9.250	Gravel	Jan. 31	80,878.20	40,439.10
	106	Southampton	0.980	Concrete	Dec. 28	64,034.50	19,600.00
Washington	41	Thurston		Gravel	Jan. 3	[3] 24,879.80	[3] 12,001.97
	44	Clarke		Concrete	Dec. 20		[3] 8,500.00
	78	Skamania	1.240	Gravel	Jan. 3	42,014.83	21,000.00
	79	Lincoln	2.010	Earth	Jan. 25	48,163.28	24,000.00
	80	Benton	1.613	Gravel	Jan. 3	24,700.61	12,000.00
Wisconsin	12	Dane		Waterbound macadam	Jan. 11	[3] 18,437.23	[3] 11,691.39
	13	Clark		Gravel	Jan. 17		[1] 3,380.52
	22	Jefferson and Dodge		do	Jan. 13		[3] 6,000.00
	45	Ashland		Earth	do	[3] 4,656.55	[3] 1,552.18
	82	Vernon		Bituminous macadam	Jan. 7	[3] 36,073.65	[3] 19,361.42
	105	Monroe	3.760	Shale	Jan. 26	38,088.34	10,481.31
	125	Taylor	4.500	Gravel	Jan. 18	48,551.05	21,116.17
	126	St. Croix	2.730	Concrete	Jan. 4	99,701.23	40,542.91
	134	Juneau	5.280	Topsoil	Jan. 18	44,608.63	16,493.52
	137	Lafayette	1.540	Earth and concrete	Jan. 13	42,962.00	16,481.00
	139	Brown		Concrete	Jan. 11		[3] 1,474.07
	140	Iowa	8.180	Earth	do	121,520.09	50,000.00
	165	Vilas	9.510	do	Jan. 26	67,392.75	25,000.00
	176	Sauk	1.310	Gravel	Jan. 7	21,876.25	8,938.12
	177	do	3.620	do	do	52,442.69	24,000.00
Wyoming	19	Natrona		Concrete	Jan. 25	[3] 120,981.47	[3] 48,541.27

[1] Canceled.
[2] Modified agreement. Amounts given are decreases from those in the original agreements.
[3] Modified agreement. Amounts given are increases over those in the original agreements.
[4] Modified agreement. Amounts given are increases. Second revision.
[5] Modified agreement. Amounts given are increases. Third revision.

CONSTRUCTION AND MAINTENANCE IN ILLINOIS.

A total of 341 miles of durable hard surfaced roads was built by the State of Illinois during 1920. According to the State highway department this is a greater mileage of high type construction than has been built in any previous year by any State, and more than any other State built during 1920 except Pennsylvania which completed 410 miles.

The mileage completed during 1920 is distributed as follows:

	Miles.
Lincoln Highway	51
Dixie Highway	46
National Old Trails Road	69
Chicago-East St. Louis Road	113
Chicago-Waukegan Road	9
State-aid Work	53
	341

There are still uncompleted contracts on the above roads approximately as follows:

	Miles.
Lincoln Highway	12
Dixie Highway	20
National Old Trails Road	48
Chicago-East St. Louis Road	71
Chicago-Waukegan Road	11
State-Aid Work	28
	190

In addition contracts were awarded in 1920 for 134.95 miles of grading and 81 bridges on the bond issue system, the total cost of which will be about $3,427,000. Of these contracts 56.77 miles grading and 30 bridges have been completed.

According to a recent bulletin issued by the State highway department the effort put forth by the department and the contractors would easily have built double the mileage if conditions had been favorable. At the beginning of the season there were approximately 100 paving machines on hand waiting for materials to be delivered to them. On account of the car shortage and restrictive rulings of the Interstate Commerce Commission not more than 53 of these machines were in use at any one time during the season, and the average was considerably under that number.

The department warmly commends the contractors for their earnest efforts to conform strictly to the specifications and to produce roads of good quality despite the unfavorable conditions with which they had to contend. In many instances the increased cost of labor and materials caused by the car shortage meant the absorption of all their profits and in some cases even a direct loss.

MAINTENANCE COSTS.

The cost of maintaining the hard surfaced roads of the State in 1919 is shown in the table on this page. The table shows separately the cost of maintaining the surfaces and the shoulders and ditches and the combined maintenance cost for the whole roadway. The 1920 costs have not yet been tabulated. In some instances they will exceed the 1919 figures because of the higher costs of material and labor and the necessity for repairing breaks in all types of pavement due to excessive loading.

In interpreting the table of maintenance costs the department says:

"It should be understood that a one-year record of the maintenance cost of any particular type of construction is not necessarily a measure of the economic service value of that type. This is true because of the fact that certain types of road, such as bituminous macadam, may require but very little maintenance expenditure during one season, and the following season it may be necessary to give the road a surface treatment at a very considerable cost in order to preserve its integrity. This is not only true for the type of road mentioned, but is more or less true for all types. Further, if a certain type of pavement designed for, and used by, light traffic is suddenly called upon to bear heavy motor truck traffic, the pavement may be utterly destroyed so that it has to be replaced by an entirely different type to resist the altered traffic. The reconstruction is not ordinarily classed as maintenance but as new construction. This, of course, may lead to a misconception of the service rendered by a given type of pavement. Moreover, if but a small mileage of a given type of pavement is under maintenance, an unusually large expenditure on one section may cause the average for that type of pavement for one year to appear abnormally high. On the other hand, the location of the roads of a given type may be such that the total mileage of that type is subjected to unusually light traffic, and the maintenance cost, therefore, may appear abnormally low. These things must be kept in mind in connection with the table of costs presented."

LOCATING THE BOND ISSUE ROUTES.

During the past two years the greater part of the bond issue system of roads has been definitely located. This is a work that has consumed a large part of the time of the department, both in making reconnaissance surveys and in hearings held prior to determining upon locations.

The realization of the great value of the roads to communities and to farm residents has brought about very bitter contests over road locations in many places in the State, and in some instances has caused keen disappointment to the unsuccessful contestants. The department, in all cases, has rendered its decision only after the most thorough engineering study and careful consideration of all factors involved.

ROAD EXPERIMENT PLANNED FOR 1921.

In order to provide a basis for the solution of the questions of road strength which have been brought up by the motor truck, the department has entered upon the construction of a test road, in cooperation with the Bureau of Public Roads. The road will be completed early in the summer of 1921, and the tests will be made immediately following its completion. It is believed that the results obtained will give a very definite idea of the value of the different types and thicknesses of pavement for carrying truck loads, and also what limits shall be applied to the weight of vehicles which are permitted to use the roads.

Maintenance costs, Illinois roads, 1919 (all widths from 10 to 18 feet included).

Type.	Miles.	Wearing surface.		Upkeep of roadsides, etc.		Total maintenance.	
		Cost.	Average cost per mile.	Cost.	Average cost per mile.	Cost.	Average cost per mile.
Brick	86.90	$3,704.13	$42.63	$6,618.57	$76.16	$10,322.70	$118.79
Portland cement concrete	366.15	19,793.42	54.05	35,081.94	95.81	54,875.36	149.86
Bituminous concrete	19.43	4,745.94	244.75	230.77	11.88	4,976.71	256.13
Bituminous macadam	24.02	6,101.43	254.01	1,769.61	73.67	7,871.04	327.68
Waterbound macadam	26.95	8,070.32	299.45	952.73	35.35	9,023.05	334.80
Gravel	42.36	5,474.68	129.24	1,090.19	25.74	6,564.87	154.98
Oiled earth	133.50	8,460.51	63.37	2,820.33	21.13	11,280.84	84.50
Earth	280.75	21,529.11	76.69	4,382.56	15.61	25,911.67	92.30
Total	980.06	77,879.54	....	52,946.70	....	130,826.24	....

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS.

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets, nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

REPORTS.

*Report of the Director of the Office of Public Roads for 1916. 5c.
*Report of the Director of the Office of Public Roads for 1917. 5c.
Report of the Director of the Bureau of Public Roads for 1918.
Report of the Chief of the Bureau of Public Roads for 1919.

DEPARTMENT BULLETINS.

Dept. Bul. *105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913. 5c.
*136. Highway Bonds. 25c.
220. Road Models.
*230. Oil Mixed Portland Cement Concrete. 10c.
*249. Portland Cement Concrete Pavements for Country Roads. 15c.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
314. Methods for the Examination of Bituminous Road Materials.
347. Methods for the Determination of the Physical Properties of Road-Building Rock.
*348. Relation of Mineral Composition and Rock Structure to the Physical Properties of Road Materials. 10c.
*370. The Results of Physical Tests of Road-Building Rock. 15c.
*373. Brick Roads. 15c.
386. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
*389. Public Road Mileage and Revenues in the Central, Mountain, and Pacific States, 1914. 15c.
390. Public Road Mileage in the United States, 1914. A summary.
*393. Economic Surveys of County Highway Improvement. 35c.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
414. Convict Labor for Road Work.
*463. Earth, Sand-Clay, and Gravel Roads. 15c.
532. The Expansion and Contraction of Concrete and Concrete Roads.
*537. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
555. Standard Forms for Specifications, Tests, Reports, and Methods of Sampling for Road Materials.
583. Reports on Experimental Convict Road Camp, Fulton County, Ga.
586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916.
*660. Highway Cost Keeping. 10c.
670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691. Typical Specifications for Bituminous Road Materials. 15c.
704. Typical Specifications for Nonbituminous Road Materials.
*724. Drainage Methods and Foundations for County Roads. 20c.

Public Roads, Vol. I, No. 11. Tests of Road-Building Rock in 1918.
*Public Roads, Vol. II, No. 23. Tests of Road-Building Rock in 1919. 15c.

DEPARTMENT CIRCULAR.

No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS.

F. B. *338. Macadam Roads. 5c.
505. Benefits of Improved Roads.
597. The Road Drag.

SEPARATE REPRINTS FROM THE YEARBOOK.

Y. B. Sep. 727. Design of Public Roads.
739. Federal Aid to Highways, 1917.

OFFICE OF PUBLIC ROADS BULLETINS.

Bul. *45. Data for Use in Designing Culverts and Short-Span Bridges. (1913.) 15c.

OFFICE OF PUBLIC ROADS CIRCULARS.

Cir. *89. Progress Report of Experiments with Dust Preventatives, 1907. 5c.
*90. Progress Report of Experiments in Dust Prevention, Road Preservation, and Road Construction, 1908. 5c.
*92. Progress Report of Experiments in Dust Prevention and Road Preservation, 1909. 5c.
*94. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1910. 5c.
*99. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1912. 5c.

OFFICE OF THE SECRETARY CIRCULARS.

Sec. Cir. 49. Motor Vehicle Registrations and Revenues, 1914.
*52. State Highway Mileage and Expenditures to January 1, 1915. 5c.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*65. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Aid Road Act. 5c.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
74. State Highway Mileage and Expenditures for the Calendar Year 1916.
*77. Experimental Roads in the Vicinity of Washington, D. C. 5c.

Public Roads Vol. I, No. 1. Automobile Registrations, Licenses, and Revenues in the United States. 1917.
Vol. I, No. 3. State Highway Mileage and Expenditures in the United States, 1917.
*Vol. I, No. 11. Automobile Registrations, Licenses, and Revenues in the United States, 1918. 15c.
Vol. II, No. 15. State Highway Mileage and Expenditures in theUnited States in 1918. 15c.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH.

Vol. 5, No. 17, D- 2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cement.
Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 20, D- 4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D- 6. A New Penetration needle for Use in Testing Bituminous Materials.
Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced Concrete Slabs Under Concentrated Loading.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.
Vol. 17, No. 4, D-16. Ultra-Microscopic Examination of Disperse Colloids Present in Bituminous Road Materials.

---

* Department supply exhausted.