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COMMISSIONER OF HIGHWAYS

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
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MEMO TO: A. O. Neiser
Assistant State Highway Engineer

The attached report, "Dynamics of Sprung Loads on Pavements," resulted from a need for reliable impact factors for use in the structural design of pavements. For some years, it has been customary to use 1.2 times the static wheel load for designing portland cement concrete pavements. We, along with other investigators, have questioned this value, and have actually used higher values for some specific conditions. Impact factors for specific situations are listed on page 33 of the report. The three roads classed as smooth averaged 1.25, while the rough road gave a value of 1.35. Depressions at culverts and bridge approaches gave average values of 1.58 and 1.49 respectively. It appears that pavement design impact factors of 1.20 are too low and should be in the order of 1.33 to 1.50.

Respectfully submitted,

A handwritten signature in cursive script that reads "W. B. Drake".

W. B. Drake
Director of Research

WBD:dl

Enc.

cc: Research Committee Members
Bureau of Public Roads (3)

Commonwealth of Kentucky
Department of Highways

DYNAMICS OF SPRUNG LOADS ON PAVEMENTS

by

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and
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Highway Materials Research Laboratory
Lexington, Kentucky
January, 1962

INTRODUCTION

Considering a highway pavement as being a designed structure in the same sense that buildings and bridges are designed, there are certain limits of loads and stresses which it can safely withstand without collapsing or failing. From this point of view, one can readily appreciate the necessity for imposing legal load limits upon cargo haulers and the necessity for enforcement of these limits as is presently done through the use of "weigh stations". The "dead-weight" or "static force" acting on a structure alludes to a special case of dynamics which deals with particles and masses undergoing no acceleration and consequently one in which the Newtonian forces are constant. In this sense, a truck moving over a perfectly smooth, horizontal roadway will exert a downward force thereon which is equal to its static or "weighed" load; but, if the surface is uneven or rough, the forces arising from the upward and downward motion of the truck will be alternately greater and less than the static load; and the resulting difference between the static or weighed load of the truck and the instantaneous force on the pavement is accountable by and equal to the inertial force of the truck, e.g. $F_d = Wa_d/g$.*

* With respect to a non-inertial frame of reference, F_d is the apparent force and a_d is the acceleration of the particle in the reference frame. The Newtonian force is: $F = F_d + Wa_o/g$; where a_o is the acceleration

The dynamic components of loading represent only one aspect in the general problem of designing pavements to carry heavy cargo trucks. It is of interest to pavement designers to know the distribution of contact pressures under tires, the arrangement of wheels under the load, the deflection profile of the pavement and the pressures developed under the pavement. Even if it were possible to obtain accurate measurements of stresses and strains on and under pavements due to moving, heavy trucks, it would still be desirable to make independent, simultaneous measurements of the actual forces exerted by the moving truck and to equate them to the measured responses of various pavement systems. Such analyses could readily lead to refinements in existing theories and design criteria.

of the non-inertial system with respect to the inertial frame. It follows that $F = Wa_0/g + Wa_d/g$ and that Wa_0/g represents the static force, F_s , of the truck with which the discussion above is concerned. It follows also that $F = F_s + Wa_d/g$ and that $F = F_s + F_d$. However, it is of particular importance to the problem to show the equation in the following forms:

$$F = W(a_0/g + a_d/g) = W \left(\frac{a_0 + a_d}{g} \right)$$

Since a_0 alludes to gravity, $a_0/g = 1$; hence:

$$F = W (1 + a_d/g).$$

We have, then, on the one hand, an equation based on an inertial frame of reference and, on the other hand, one based upon a non-inertial frame of reference. From a practical point of view, they differ only in the way that the acceleration parameters are handled and more particularly in the method of measurement. For instance, if $a_0 + a_d/g$ is measured directly in g's, $F = W \times g$'s; whereas, if a_d/g is measured (in g's), $F = W + W \times g$'s.

While it seems appropriate above to mention briefly the more encompassing significance of measuring dynamic forces, the scope of this study is necessarily limited to an investigation of a specific method of measuring and monitoring the inertial forces in a particular loaded truck. For this reason, it seems equally appropriate merely to invite attention to references 1 through 12 where ample discussions of theories and pavement design criteria may be found.

Heretofore, a number of methods have been used in attempts to measure the so-called "impact" forces of vehicles on pavements. These may be readily classified into two categories, as follows: 1) methods by which some remote-reading, load- or pressure sensing device is placed on or in the pavement, and 2) methods by which the sensing devices are mounted in and carried by the vehicle. Of those in the latter category, it seems that almost every conceivable type of measurement, excluding the one with which this study is concerned, has been made at one time or another. For this reason, a brief review of previous investigations of this nature is presented.

The earliest method of measurement, other than static weighing by means of truck scales, consisted of placing a tube or hose filled with water across the pavement and measuring remotely the hydraulic pressure while the wheels were poised on the tube. The ratio between this static pressure and the pressure obtained as the truck wheels were

moved at some speed across the tube might be interpreted as an impact factor or shock coefficient. There are obvious objections to this type of procedure inasmuch as the mere presence of the tube introduces an obstacle on the pavement and inasmuch as the inertia of the water itself makes the method impractical for measurements at high vehicle speeds. Of course, a series or blanket of parallel tubes and recording gauges might be installed in such a way as to minimize the obstacle effects and to obtain a more-or-less continuous record of pressures over a short length of pavement. It would be difficult, however, to design and construct a system of this type without introducing other extraneous influences such as damping or stiffness. This method would have the particular disadvantage of being a permanent or semi-permanent installation and would therefore be better suited to weighing vehicles in motion than to measuring the impacts of a particular vehicle passing over various kinds of road surfaces. From this standpoint, it is obvious that the type of information sought in the present study would be more adequately provided by sensing devices and instruments carried by the vehicle.

In addition, various kinds of platforms supported on pressure cells and various kinds of electro-mechanical transducers have been placed in the pavement to measure loads, strains, and vertical deflections. These have consisted of miniature L.V.D. T's and of bonded SR-4-type strain gauges. Of course, the most primitive approach to

the measurement of pavement deflections is through the use of the Benkelman Beam, and this method is limited strictly to static measurements. In order to avoid confusion as to the specific purposes of these different kinds of measurement, a fuller explanation of each follows:

1. A platform supported on sensing devices may be considered to be a weighing scale if the entire force of a wheel, axle, or vehicle bears thereon.
2. A rod or free piston projecting through the pavement to the surface and supported upon hydraulic or electrical sensing devices may be considered to be a pressure gauge if the area of the probe at the surface is small with respect to the area of the tire imprint.
3. The deflection of a pavement may be considered to be the difference between the elevation of a point on the pavement surface before loading and the elevation of the same point under a given load (point at the center of the loaded area).
4. Miniature L.V.D.T.'s, i.e. linear, variable, differential transformers, are essentially displacement sensing devices consisting of an excited coil and a magnetic core. Either the core or coil is fixed to the deflecting element and the other is fixed to a non-deflecting element. For example, if a rigid plate is buried deep in the ground beneath a pavement and a rod is set thereon so as to project up

to some point in the pavement -- the rod being frictionless, as a free piston and acting as or supporting the magnetic core - the relative movement of the coil attached to the pavement and with respect to the core would be measured electrically. Although such devices have probably been used to measure the static and dynamic deflections of pavements, it is rather obvious that such installations would be quite expensive and there is reason to suspect that the presence of the hole through which the probe rod acts may interfere with the otherwise normal reactions of the pavement system.

5. SR-4-type strain sensing elements bonded to a Hookean member may, by calibration, constitute a pressure sensing device or a weighing scale. If properly bonded to some element of the pavement itself, e.g. the bottom of a concrete pavement, these gauges could be used to measure strains in the bottom fibers.

6. The Benkelman Beam consists of a teeter or fulcrum and beam, one end of which probes the surface of the pavement near the center of loading. The fulcrum is presumably positioned at a sufficient distance away to be outside the deflection area; and the deflection is measured at the remote end of the beam. This method of measurement is tedious inasmuch as the probe must be set on the pavement and the wheel of the truck carefully brought to that position. It is understood, of course, that deflections may be measured as the wheel approaches and is removed from the test site.

Referring again to the second category of tests wherein sensing devices are mounted on the vehicle, it is likewise apparent that various kinds of gauges may be used to measure the deflection of the load-springs and, by proper calibration thereof, to monitor spring forces. Of course, truck springs do not exhibit simple Hookean response; and, for this reason, it is more desirable to monitor the responses of some load-bearing element having a linear relationship between the force thereon and the measured response. Although, the possibilities of finding a more favorable load-detecting point in the supporting members seem rather limited, it is of interest to review the methods that have been investigated:

1. Tire Pressures. The simple theory of pneumatic tires suggests that the inflation pressure remains essentially constant and that only the area of the tire contacting the pavement varies. However, the deflection of the tire may be viewed also as the chord of a circle cutting off a segment which when resolved across the width of the tire, describes a slight reduction in volume. Similarly, viewing a cross-section through the tire, the flattening and the attendant bulging of the sidewalls would also account for a slight change in volume and consequently produce a slight change in inflation pressure.

In 1957, the Bureau of Public Roads reported (13) rather good correlation between tire pressures and load, as measured by an electronic, plat-form-type, weighing scales. However, there were indications

that the variations in the tire pressure of a moving truck would not normally exceed ± 5 psi; and it was suggested that a more sensitive transducer might be used to measure only the differential pressure between the tire and an exterior balancing pressure equal to the static inflation pressure of the tire. One may surmise that such a method would be directly applicable to single-tired wheels; whereas dual-tired, multi-wheel arrangements would involve either simultaneous recordings from each tire individually or a manifold pressure system whereby all of the tires on each axle might be averaged on a single recording channel.

2. Tire Side-Wall Bulge. In the study reported by the Bureau of Public Roads, the interior tire of a standard, dual-tired, single-axle truck was removed; and roller-tipped, spring-type probes emanating from the axle and having SR-4-type gauges bonded thereto were used to record the bulge in the side-walls of the single tire directly above the center of its flattened portion. This method of measurement did not provide a sufficiently favorable correlation and is considered here to be more seriously limited in application than the pressure measurements. This method of measurement appears to have been proposed originally by Endres and Bombard (14).

3. Axle-Housing Strain. Also in the Bureau of Public Roads study, SR-4-type strain detectors were mounted on the rear axle housing -- the housing acting as a cantilevered beam. The axle-

housing strains were calibrated by positioning the rear wheels on a platform scale and incrementally increasing the cargo load. For these tests, too, the inner tire of the dual-tired wheel was removed; and it is obvious that the method would be impractical in dual-tire applications inasmuch as a slight unevenness of the pavement could affect the distribution of the load between the tires and produce a corresponding shift in the length of the lever arm.

The primary purpose of the Bureau's study was to evaluate the reliability of an electronic platform scale in the pavement in detecting axle loads of trucks moving at normal or slightly reduced speeds. The ultimate objective of "weighing vehicles in motion" is to develop a weighing system which will accurately detect the "static" weight of axles. In order to accomplish this, it is more-or-less imperative that the roadway approaching the weighing platform be perfectly smooth and that the platform be equally as rigid and as smooth as the pavement. Even so, it is likely that extraneous dynamic influences will persist and that some averaging or damping of these components will eventually need to be provided.

In summary to the foregoing discussions, it should be apparent that the underlying purpose in the present study is to measure and analyze the dynamic components of forces acting on pavements; and, whereas these same force components are plaguing and troublesome

from the standpoint of weighing vehicles in motion, they are of considerable importance in pavement design and performance. At least one design criterion (15) suggests that assumed or weighed static loads be increased by 1.2 (an impact factor) to obtain the equivalent active load on the pavement, and another (16) suggests 1.25. The literature is not clear as to the origin of these factors; and, even though values in this order of magnitude have been rather widely adopted, it was the obscure origin of these factors that provided the original incentive for the present study.

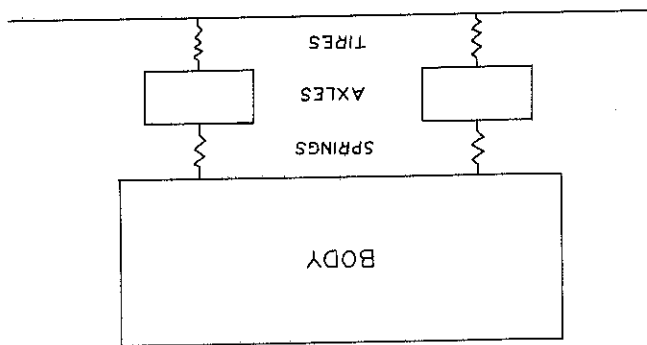
Concurrently with the original conception of this study and the experimental work described herein, the Cornell Aeronautical Laboratory published a preliminary report (17) on an elaborately conceived research endeavor sponsored by the Bureau of Public Roads and in which the stated objectives are: 1) the analysis of basic road-loading mechanics, 2) development of complete vehicle equations, 3) the development of road equations of motion, and 4) the application of system equations. The preliminary report further stated that the development of a satisfactory mathematical model of the vehicle had been accomplished. The model, when subjected to various stylized road inputs on an analog computer produced characteristic steady-state response. The second and third phases of the proposed work include provisions for experimental verification, and it is to be hoped that the fulfillment of these objectives will soon be forthcoming.

Whereas the Cornell studies seem to embody many and far more comprehensive approaches to the general problem, the methods of measurement and analysis used in this study are thought to be somewhat original in their application to the specific problem. The method of measurement consisted of mounting accelerometers on both the cargo and the under-carriage of a heavy truck and of recording these accelerations for a number of different roadway conditions and truck speeds. This method of measurement was selected in an attempt to circumvent the obvious troublesome features of the other methods described. As will be shown subsequently, the acceleration parameter is particularly amenable to the analysis of the forces with which the study is concerned.

Elementary Theory

A truck consists essentially of four wheels carrying a cargo box on intervening springs. The characteristics of a truck and the factors which enter into the determination of impact values are the sprung weight, the unsprung weight, the spring characteristics, the kind and condition of the tires, the horizontal speed of the truck, and the irregularities in the surface over which the wheels pass. Hence, there are three distinct masses: the body, the front axle, and the rear axle; and there are eight distinct springs: the four springs proper and the four tires (see Fig. 1). A body free in space has six

Fig. 1: Mechanical Model of a Truck.



degrees of freedom: it can bob up and down, sway back and forth, move forward and backward; and moreover, it can have three rotations which are known technically as:

1. Rolling about a longitudinal axis.
2. Pitching about a lateral axis.
3. Yawing or nosing about a vertical axis.

Since a truck has three such bodies, it really has 18 degrees of freedom; however, a good many of those are rather unimportant. For example, a sidewise motion of any axle, with the chassis fixed in space, is hardly possible on account of the great lateral stiffness both of the springs and of the tires. It is recognized, too, that the maximum impact will occur at the rear axle; and, of the many forces produced by the dynamic action of a motor truck, it is assumed that the maximum impact will be the force acting vertically upon the road surface.

The instantaneous force exerted in any direction by a mass may be expressed in terms of its weight, W , times a/g , where a is the acceleration in the considered direction and where g is the gravitational constant. Then:

$$F = W \times a/g = W \times g's$$

A sprung load, illustrated by Fig. 2, would likewise be attended by forces equal to:

$$F = Wa/g = kd$$

where:

k = spring constant for springs that are linear
 d = deformation of the spring.

In actuality, the problem of impact in loaded trucks may be analyzed by the use of a model as shown in Fig. 3. Displacements arising from irregularities in the profile of the roadway are transmitted through the suspending system to the masses M_1 and M_2 and, therefore, increase or decrease the force, F , on the pavement. For instance, if the system is compressed in the direction shown by x_1 and x_2 , the force on the pavement can be found by writing the equations of dynamic equilibrium.

$$M_2 \ddot{x}_2 + k_2 (x_2 - x_1) = 0$$

$$M_1 \ddot{x}_1 + k_1 x_1 + k_2 (x_2 - x_1) = 0$$

$$F_d = k_1 x_1$$

where:

$$F_d = \text{dynamic force.}$$

Solving the above equations for $M_2 \ddot{x}_2$ and $k_1 x_1$:

$$k_1 x_1 = M_1 \ddot{x}_1 + k_2 (x_2 - x_1)$$

$$M_2 \ddot{x}_2 = k_2 (x_2 - x_1)$$

Therefore:

$$F_d = M_1 \ddot{x}_1 + M_2 \ddot{x}_2$$

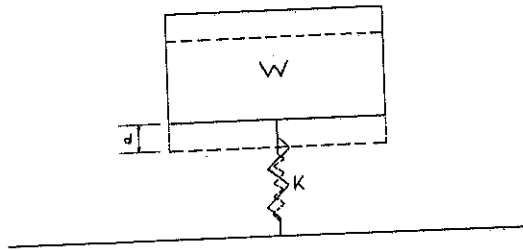


Fig. 2: Simplified Mechanical Model of a Sprung Load.

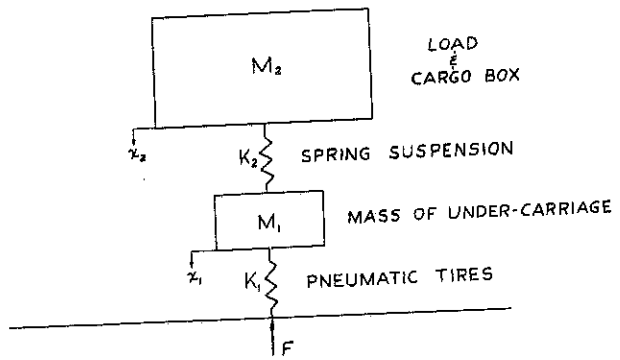


Fig. 3: Simplified Model of a Loaded Truck.

the apparent natural frequency (25 cps). However, these high acceleration amplitudes do not seem to produce a proportionately larger effect upon the cargo accelerations -- in fact the effects on the cargo accelerations seem to be somewhat higher in frequency. As a possible explanation of this obvious contradiction of logic, it is suggested that the axle was either forced to vibrate in a higher mode which the accelerometer did not faithfully record or else the Fourier expansion (19) of the 2.25-cps cargo accelerations contains terms which are close to the natural flexural frequency of the axle, in which case there would result a high magnification ratio and much higher amplitudes. The latter possibility seems to be the more plausible one because it more adequately explains the slight lowering of the axle frequency in those instances.

If the foregoing interpretation is correct, the dynamic force of the under-carriage can not be expressed as the product of its mass and apparent acceleration because the apparent accelerations are not equivalent to the true accelerations of a concentrated mass in series with the springs and cargo as depicted in the model system.

In view of the complicating factors described, an alternative method of analysis is proposed wherein the accelerations of the cargo are assumed to represent approximately the accelerations of the gross mass of the system and wherein the effective spring modulus corresponding to the 2.25-cps frequency is assumed to have the value of

Maximum Cargo Accelerations Developed at Test Sites

Although the accelerations experienced by the cargo throughout each test event are portrayed by the respective charts, the maximum values attendant to each event are tabulated below and according to the type of situation represented:

Bridge Approaches (Figs. 9, 10, 11 & 12)	1.47	1.52	1.45	1.50	1.49 Avg.
R. R. Crossings (Figs. 13, 14 & 15)	1.60	1.92	1.60		1.71 Avg.
Rough Roads (Fig. 16)					1.35
Settlement (Culverts) (Figs. 18, 19 & 20)	1.55	1.40	1.80		1.58 Avg.
Smooth Roads (Figs. 16, 21 & 22)	1.30	1.20	1.25		1.25 Avg.
Six-Inch Precipice (Fig. 23)					1.72
Two-Inch Obstacle (Fig. 24)					1.50

Significantly, the average maximum values given in the right-hand column above and representing selected extremes in roadway conditions are seen to range between 1.25 and 1.71. Since the lower value represents some rather ideal pavement conditions, there arises a somewhat distressing possibility that pavement imperfections, however slight they may be, and perhaps vibrations originating within the

truck itself have an accumulative effect which tends to cause the cargo to vibrate in its most natural mode and that the accelerations resulting therefrom might not be directly related to the magnitude of pavement imperfection -- but rather to the frequency of occurrence. This complicating aspect of the problem merits further discussion.

The truck in this instance was traveling at 40 mph or 58 ft. per sec.; its steady state frequency is 2.25 cps. The equivalent wavelength is thus: $\lambda = 1/f \times 58 \text{ ft. per sec.} = .444 \times 58 \approx 25.7 \text{ ft.}$ Pavement imperfections re-occurring at or close to this interval or even at some multiple of this interval would contribute accumulatively to the amplitude of vibration until equilibrium is established between the force of the disturbance and the damping force in the system. Clearly, this hypothetical condition would be one of harmonic resonance -- a condition which would be just as likely to occur through numerous possible combinations of vehicle speeds and recurrence intervals of the pavement imperfection. Prof. Quinn (19) more aptly described this phenomena, thus:

"The effect of vehicle speed is seen to be significant in the special situation in which a section of highway considered 'smooth' produces a higher mean squared force than a section considered 'rough'."

and thus:

"For highway profiles exhibiting well-defined periodicity a Fourier series analysis can be made. Such an analysis describes the highway profile in terms of a fundamental wave length... and integer multiples thereof. Wave lengths existing in the highway that are not integer multiples the fundamental can not be identified...

"Other highway profiles...do not display a well-defined profile and therefore do not lend themselves to this type of analysis. In these cases it is convenient to assume that the highway elevations are random and to apply a statistical analysis commonly used in dealing with random phenomena."

To characterize the random function, Prof. Quinn uses the power spectrum which he defines as the Fourier transform of the autocovariance.

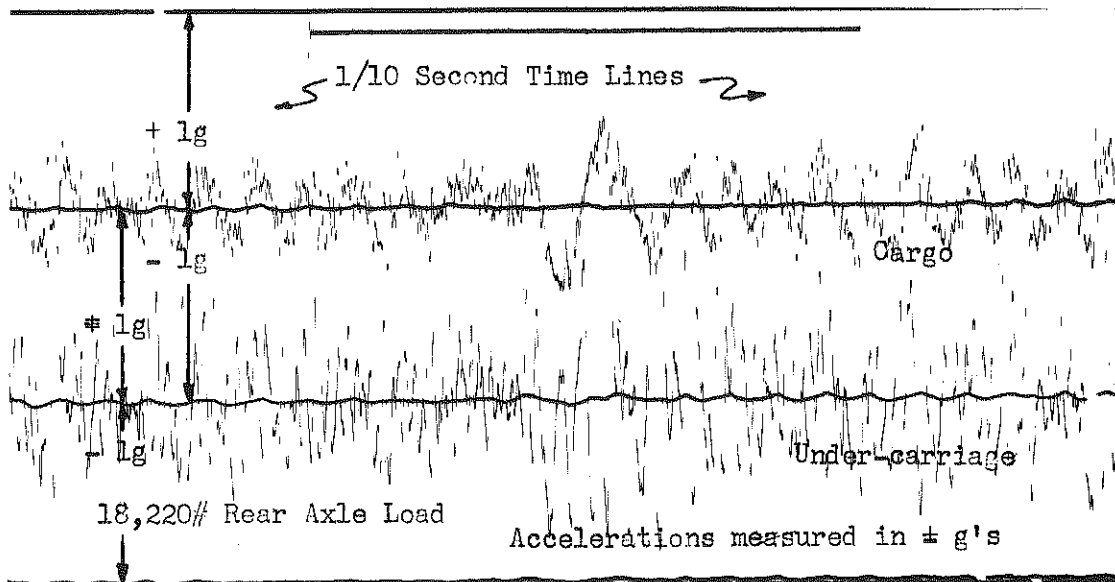
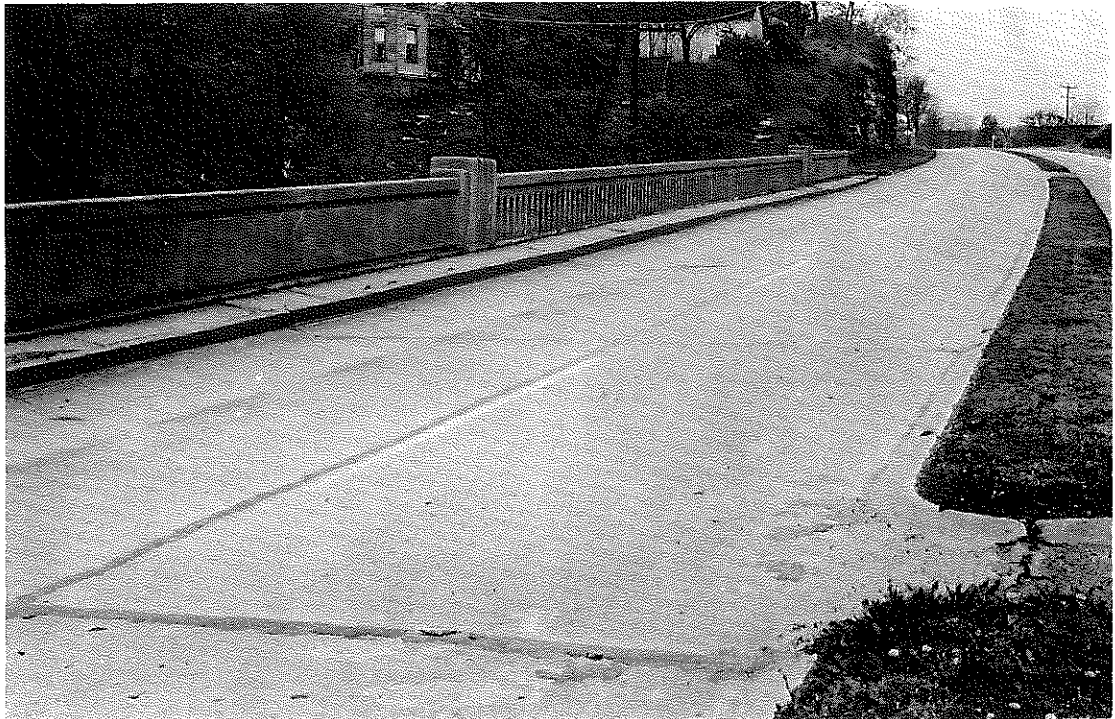


Fig. 9. Photograph of South Elkhorn Creek Bridge on US 60 and Corresponding Oscillographic Record of Accelerations.

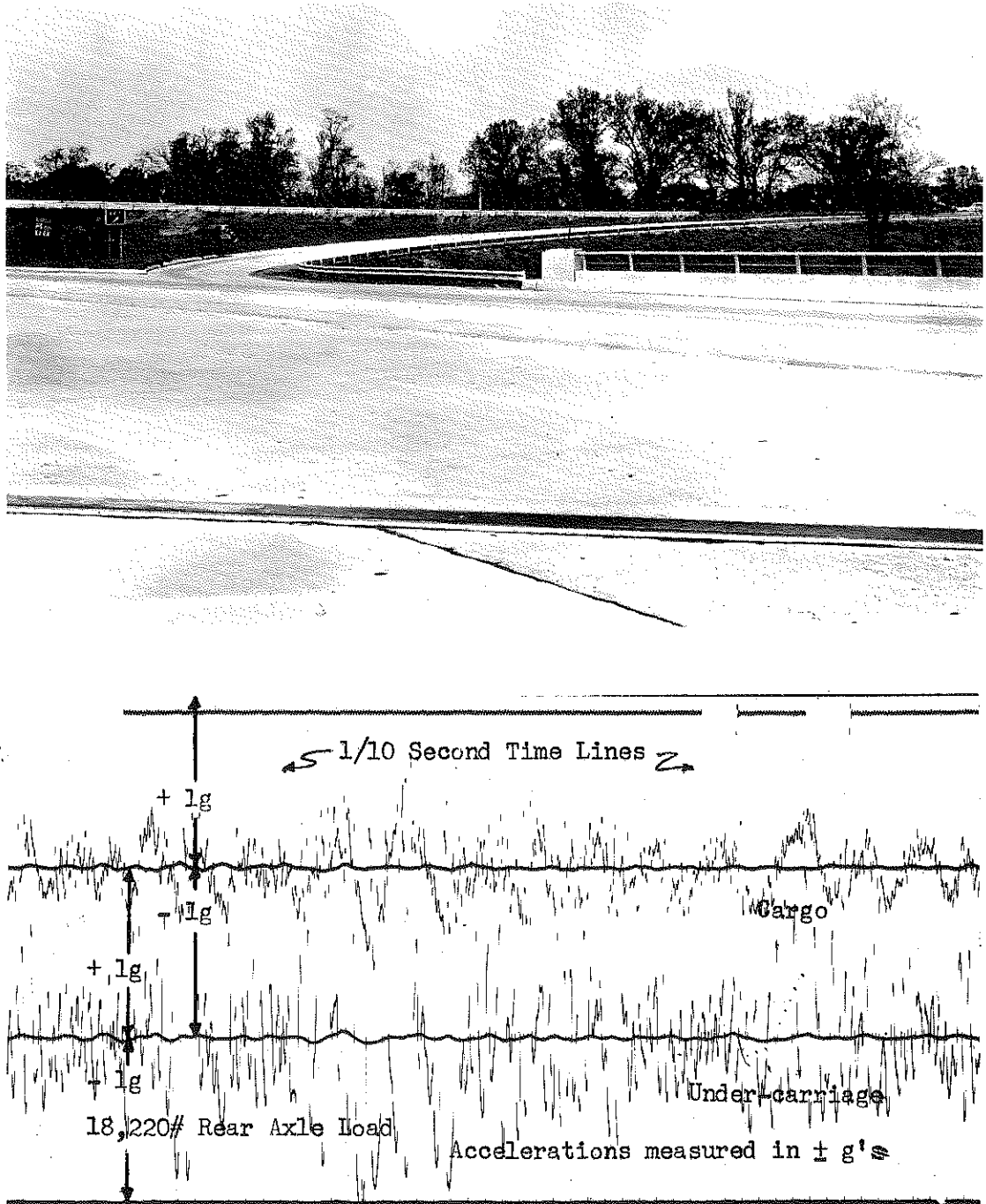


Fig. 10. Railroad Over-pass, US 60, and Accelerations Recorded in Eastbound Lane.

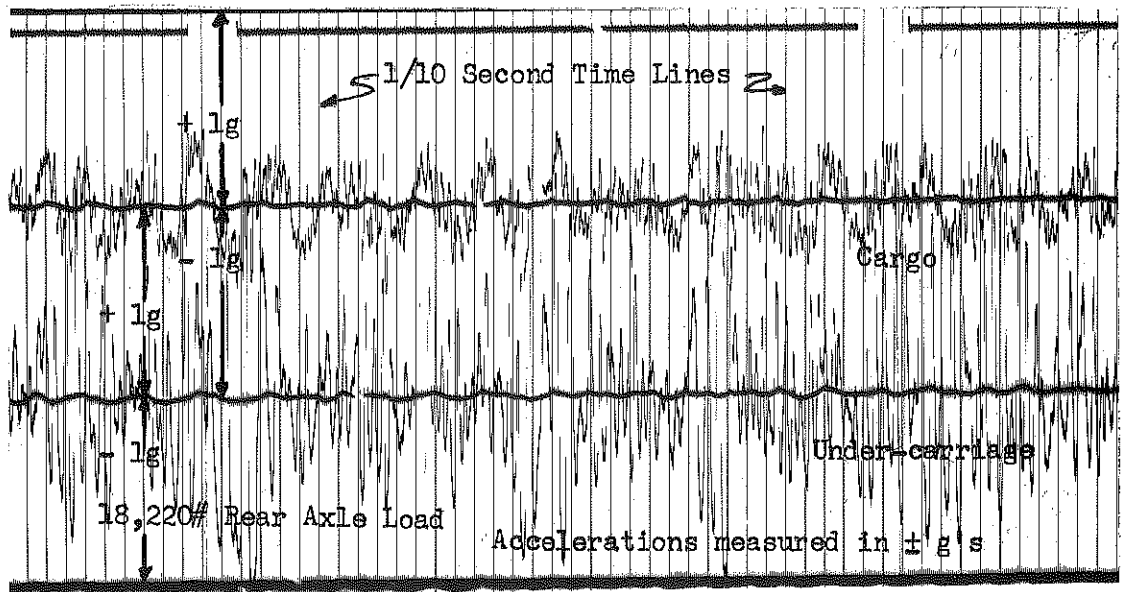


Fig. 11. South Elkhorn Creek Bridge, US 421, Accelerations Recorded in Southbound Lane.

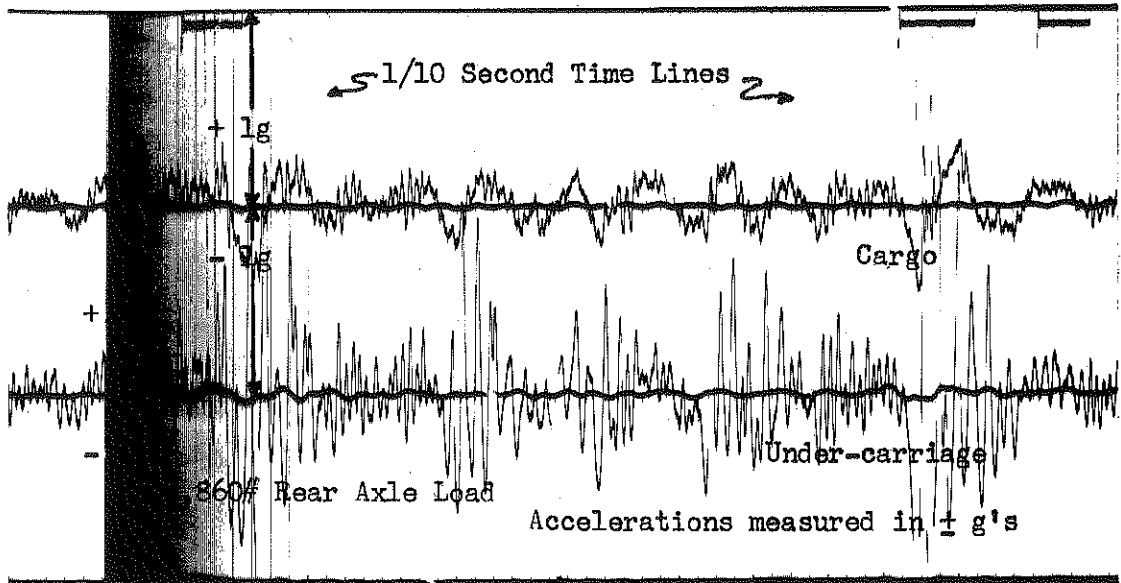


Fig. 12. Railroad Over-pass on New Circle Road, Lexington, Kentucky, and Accelerations Recorded on Southbound Lane.

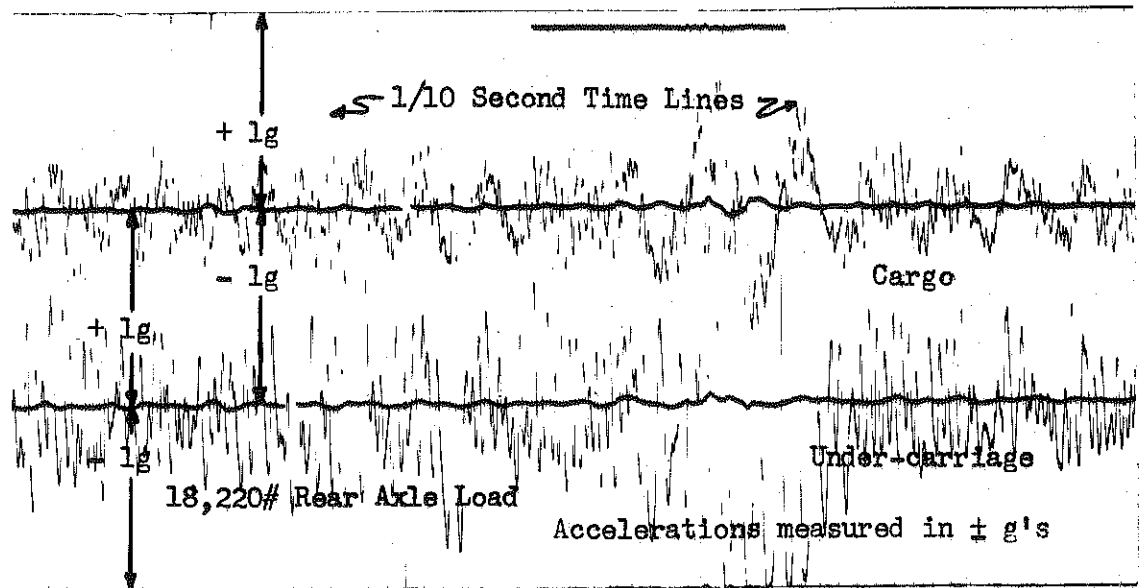
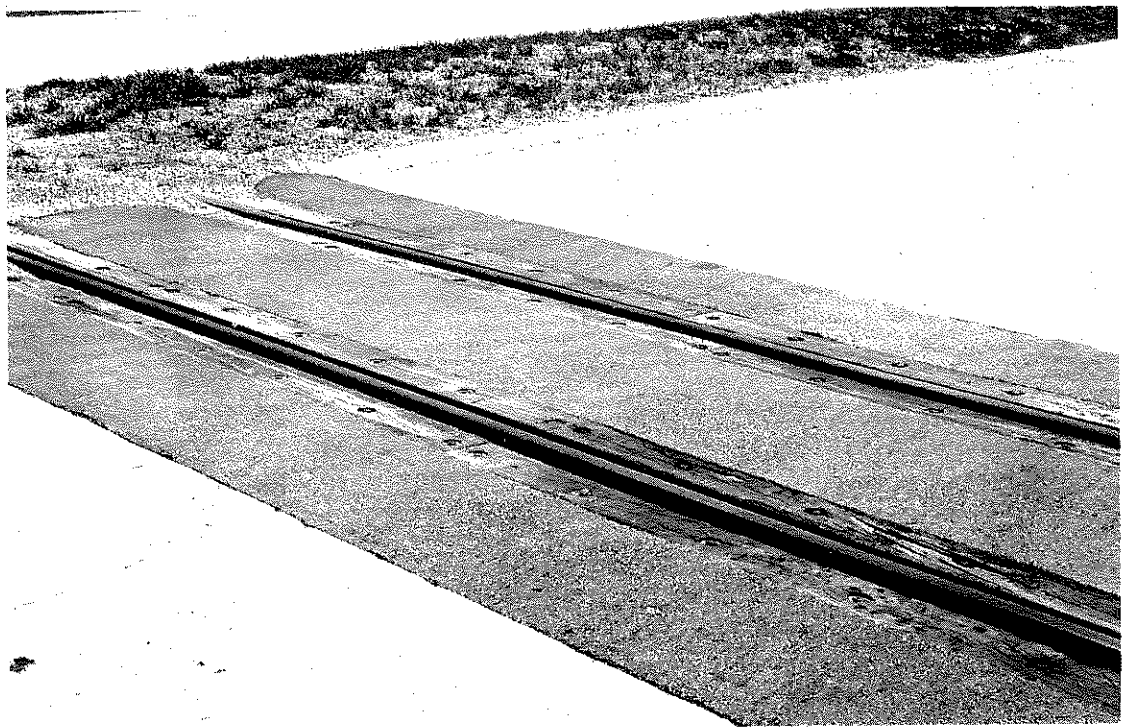


Fig. 13. Railroad Crossing, US 60, Versailles By-Pass, and Accelerations Recorded in Eastbound Lane.

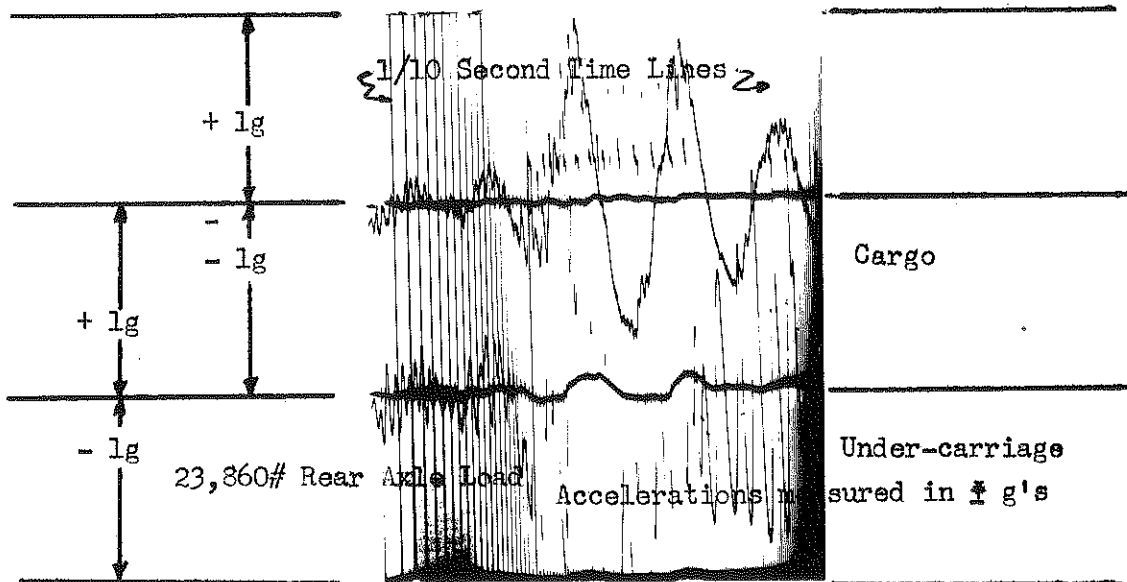
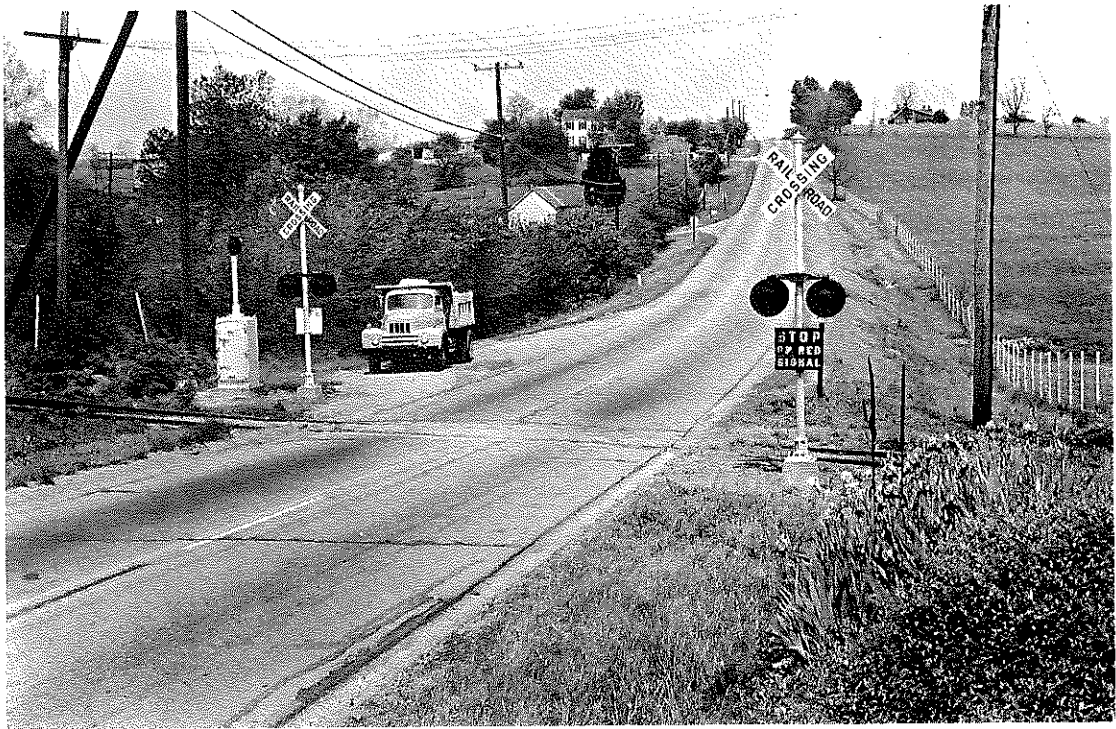


Fig. 14. Railroad Crossing, US 421, Leestown Road, and Accelerations Recorded in Southbound Lane.

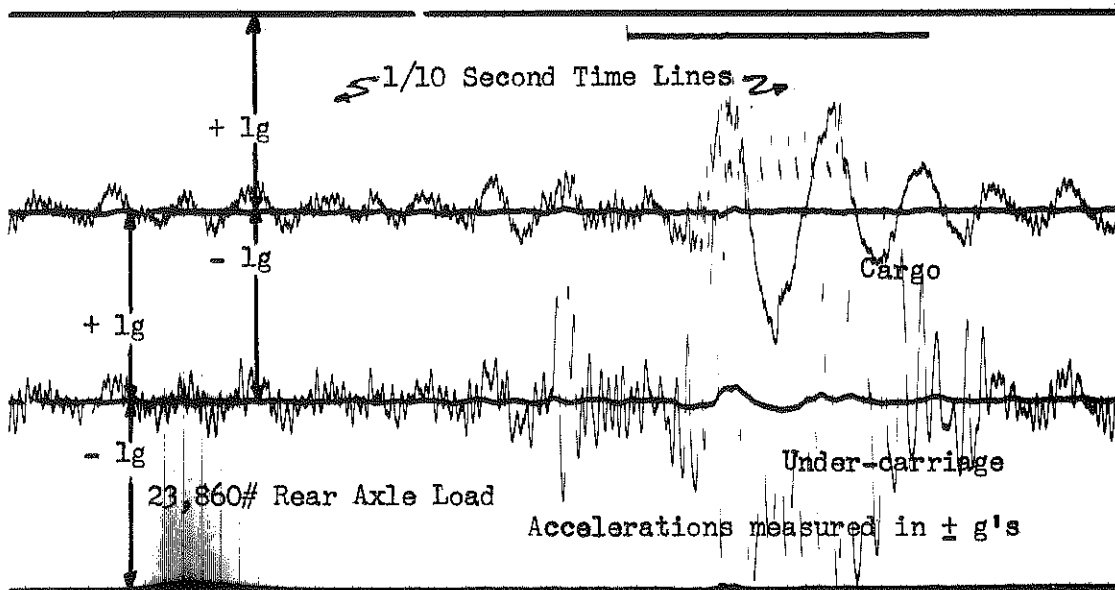
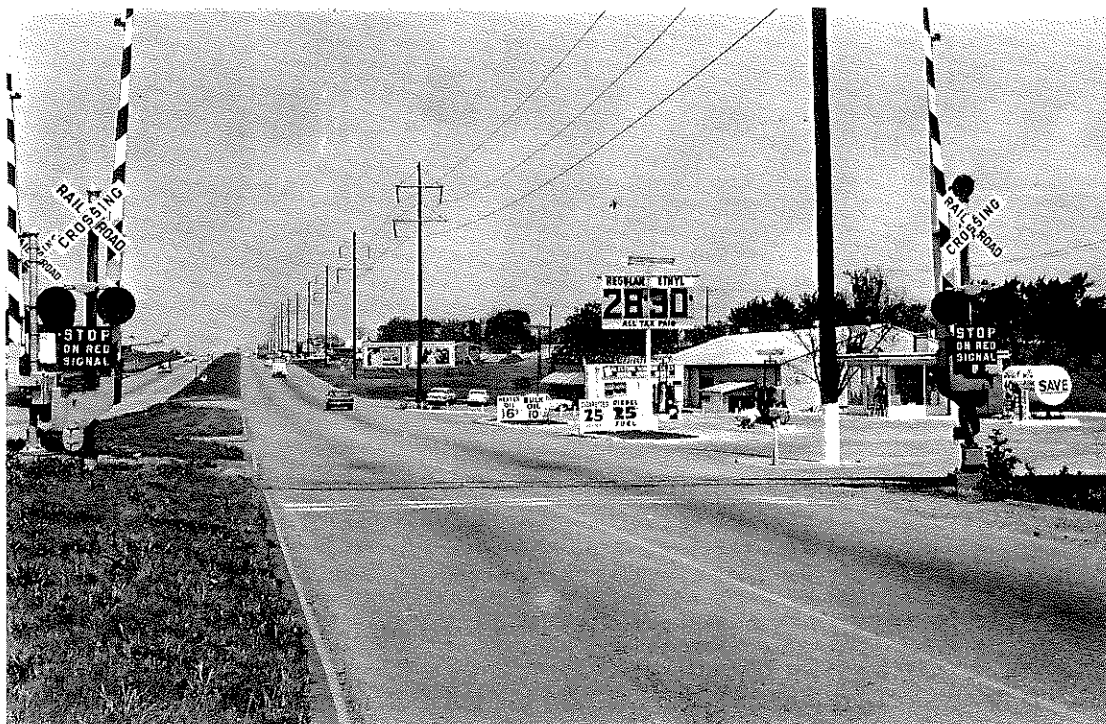


Fig. 15. Railroad Crossing, New Circle Road, Lexington, Kentucky, and Accelerations Recorded in North-bound Lane.

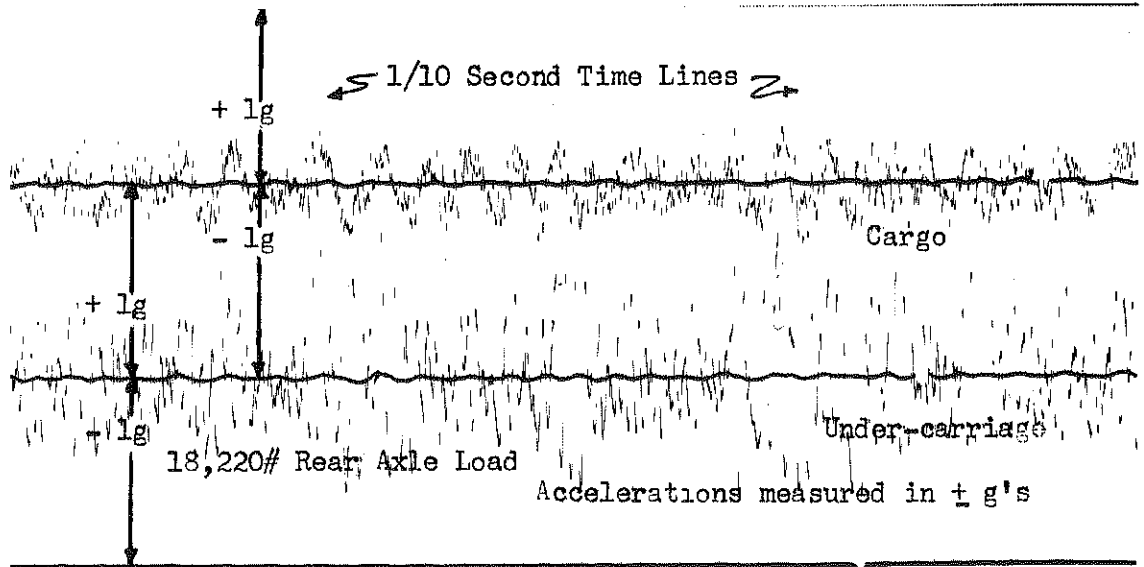
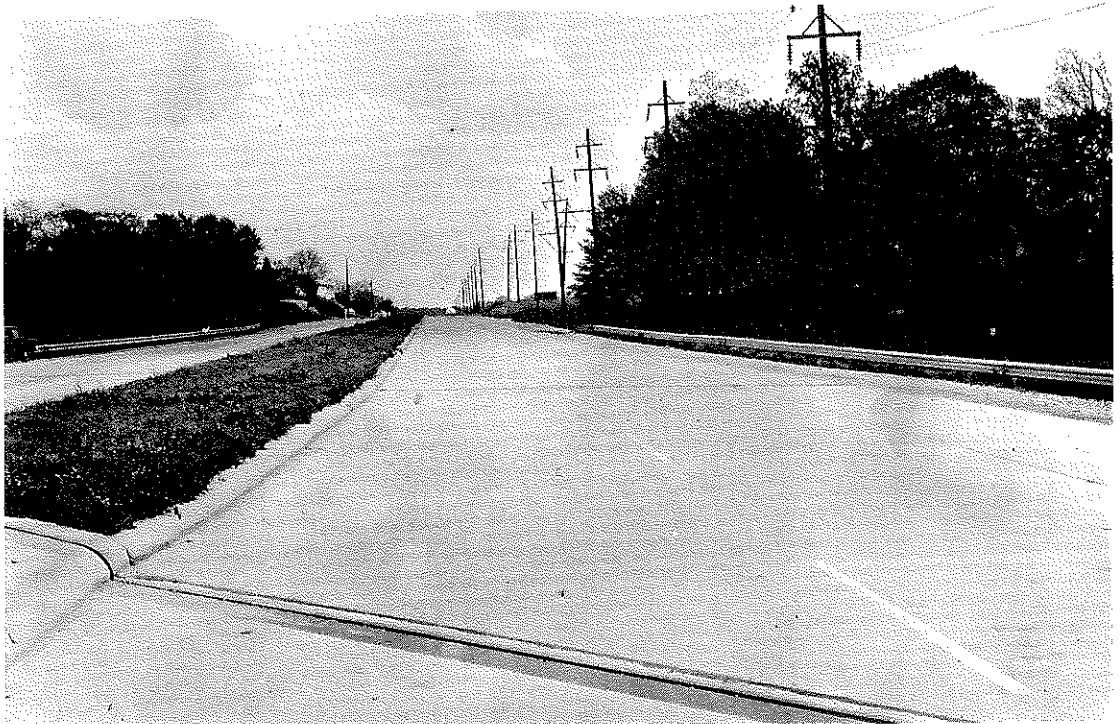


Fig. 16. Smooth Section, US 60, and Accelerations Recorded in Eastbound Lane.

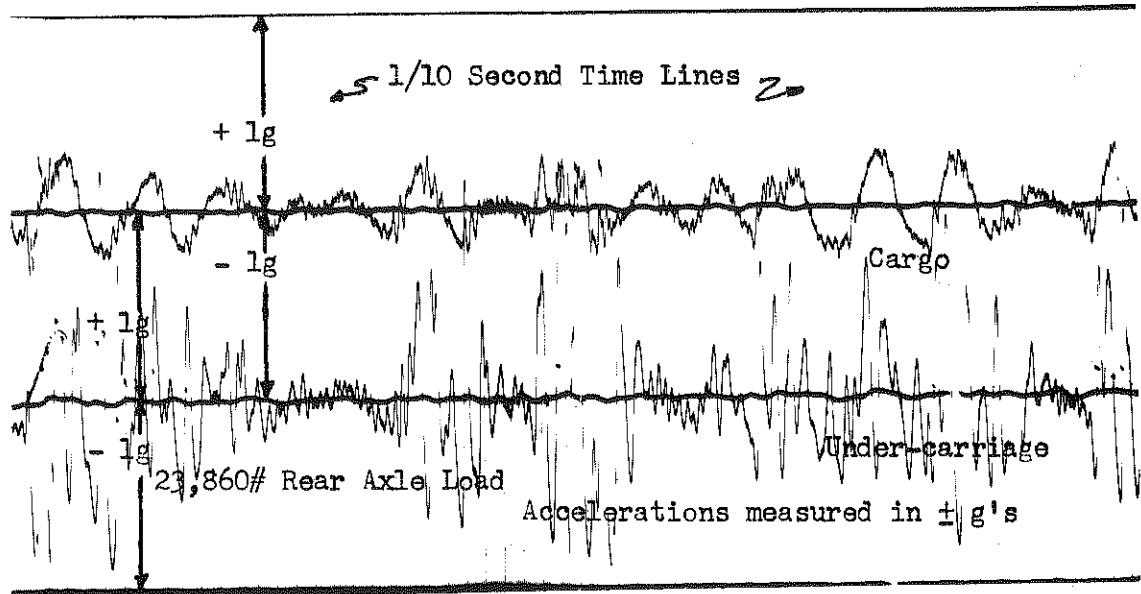


Fig. 17. Rough Section, US 421, and Accelerations Recorded in Southbound Lane.

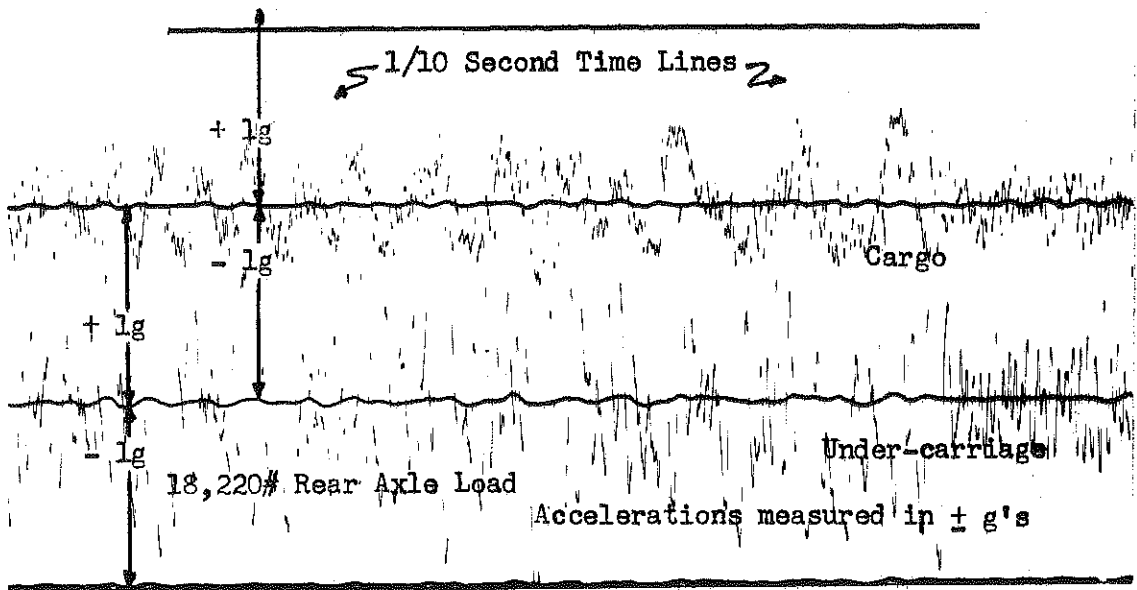


Fig. 18. Culvert Depression, US 60, and Accelerations Recorded in Westbound Lane.

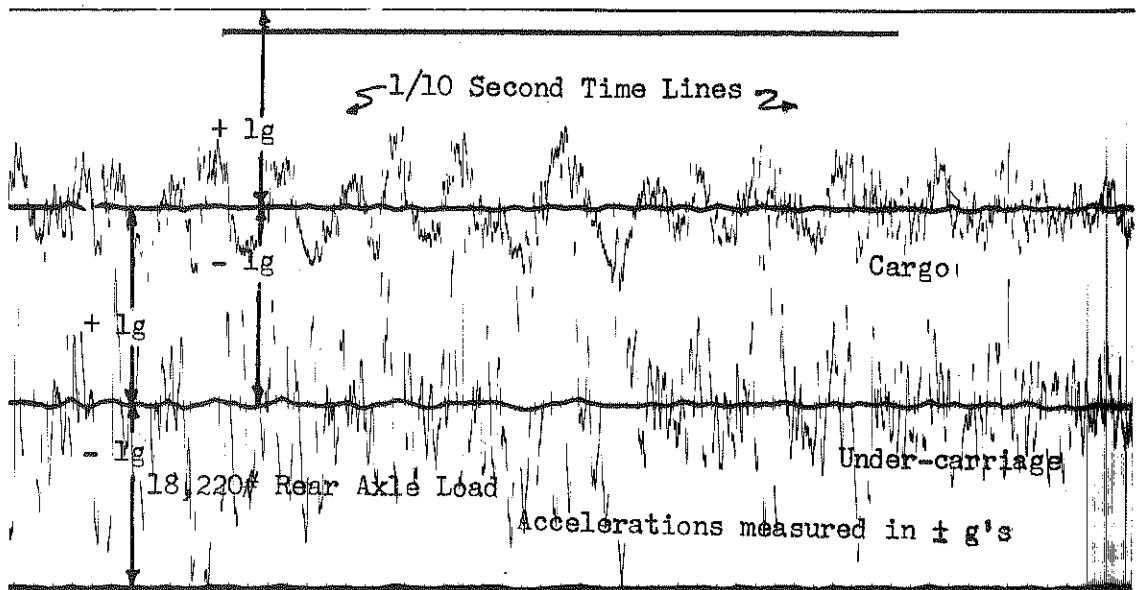


Fig. 19. Culvert Depression, US 60, and Accelerations Recorded in Eastbound Lane.

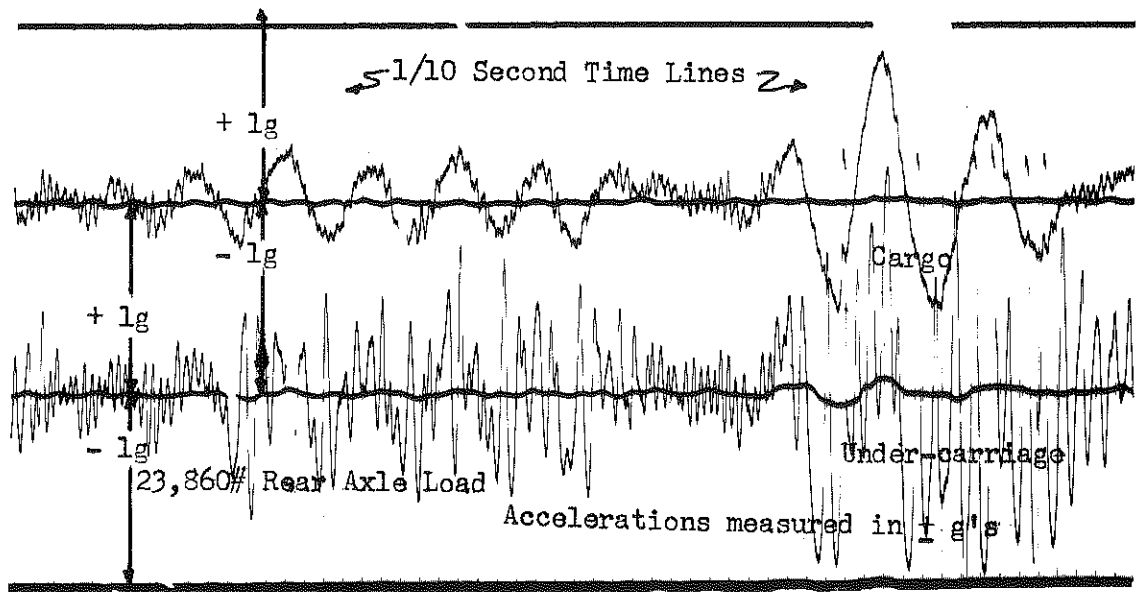
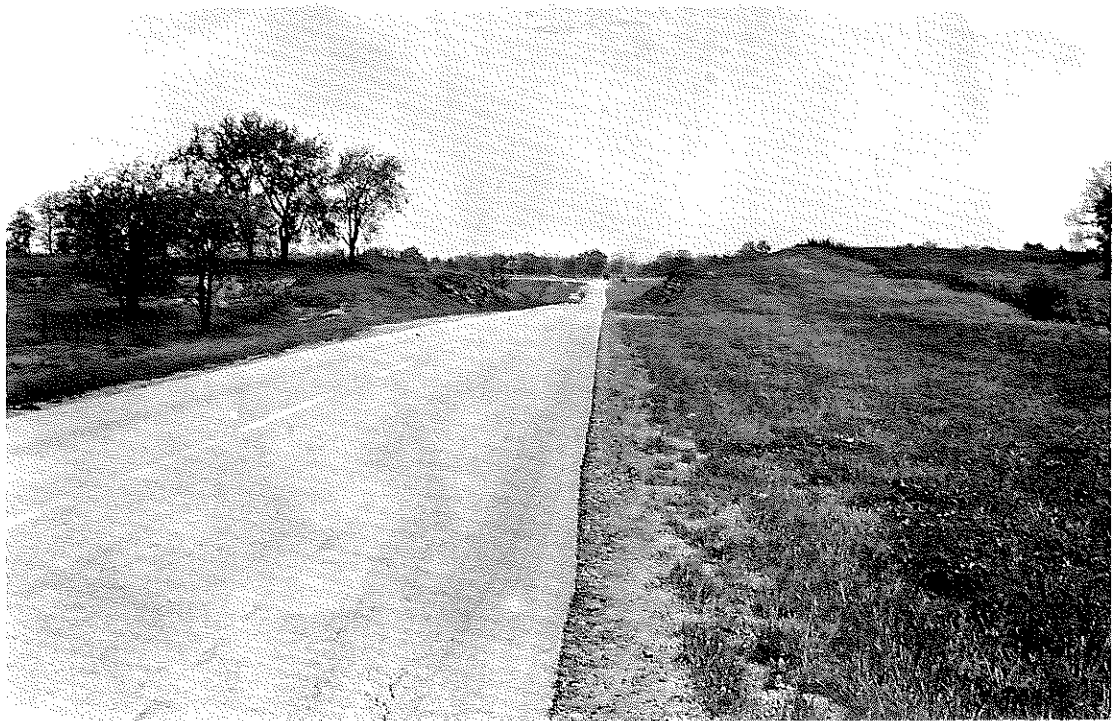


Fig. 20. Culvert Depression, New Circle Road, Lexington, Kentucky, and Accelerations Recorded in Southbound Lane.

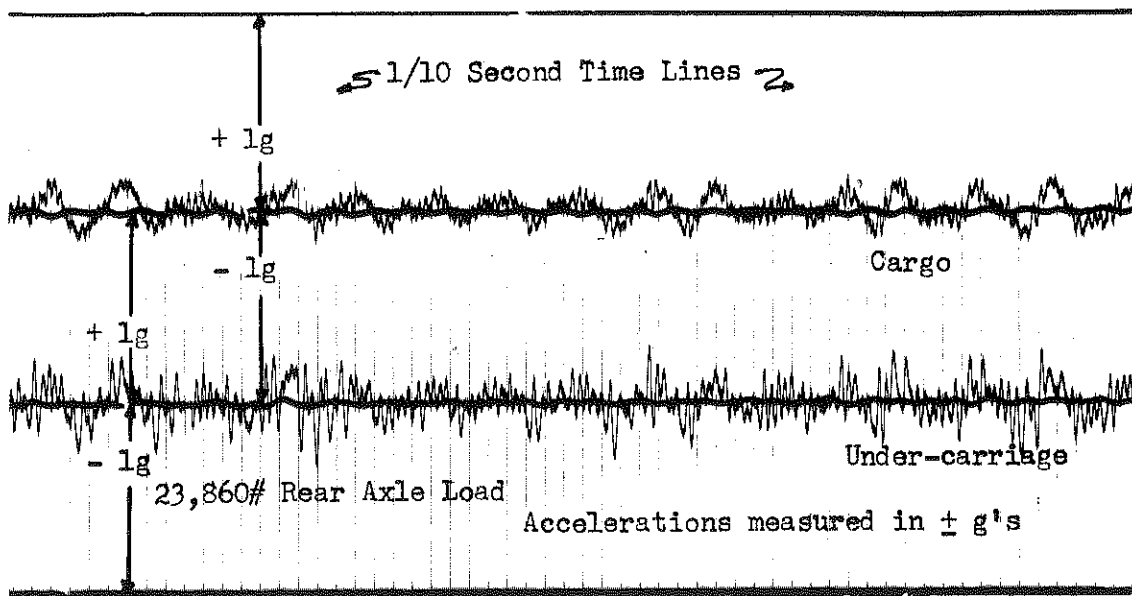


Fig. 21. Accelerations Recorded Traversing a Smooth Section of New Circle Road, Lexington, Kentucky.

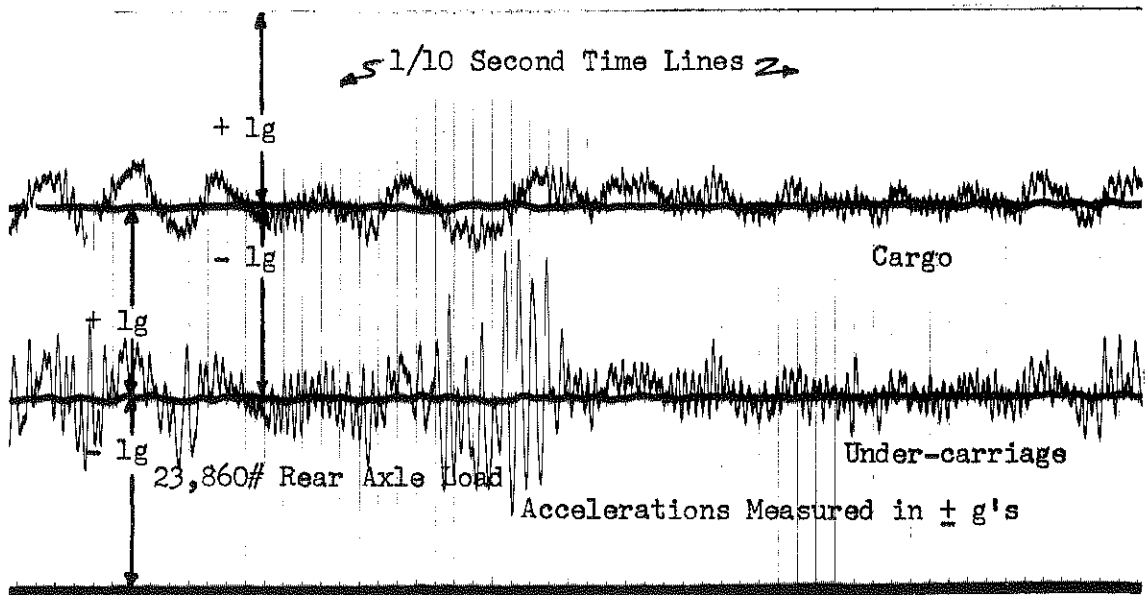


Fig. 22. Accelerations Recorded Traversing a Smooth Section of
Tates Creek Road, Lexington, Kentucky.

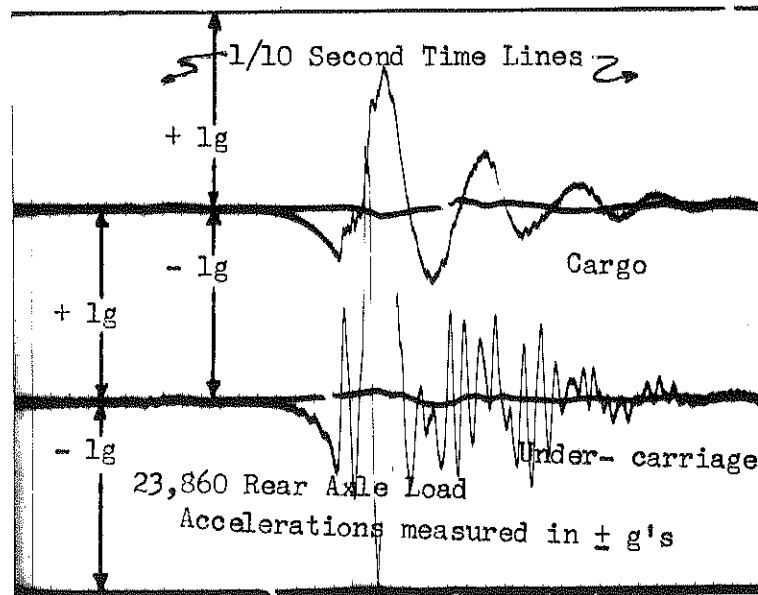


Fig. 23. Accelerations Recorded by Dropping the Rear Axle from a Height of 6 Inches.

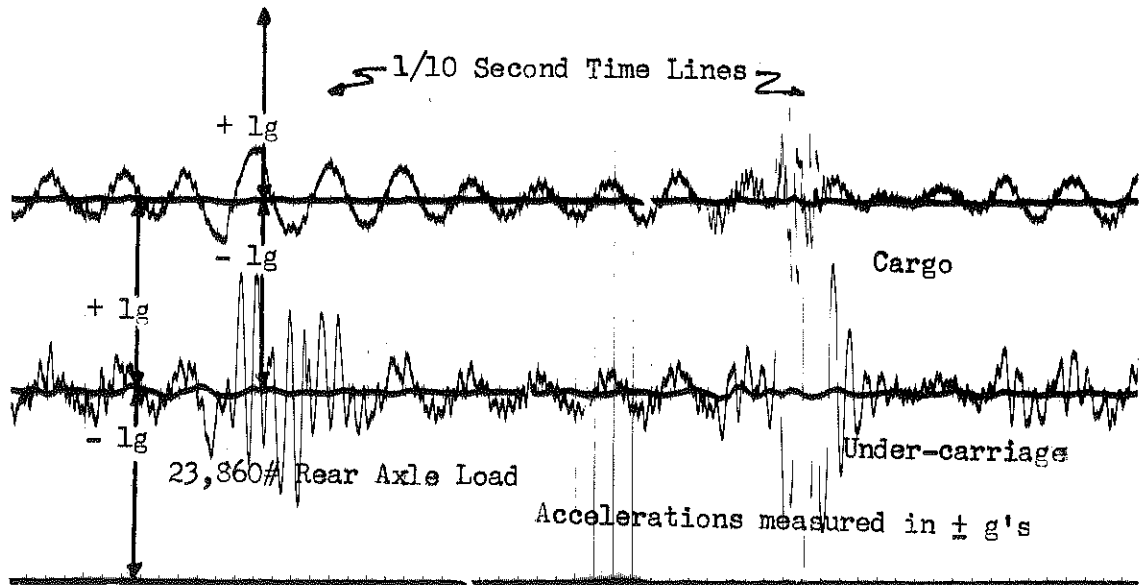


Fig. 24. Accelerations Recorded by Passing Over a 2-Inch Board.

SUMMARY AND DISCUSSIONS

The foregoing study represents an exploratory investigation of a problem in highway engineering dealing with the dynamics and impact loads of heavy cargo vehicles upon pavements; and although the analyses are modestly presented and are not at all exhaustive in their scope, the data obtained and the interpretations offered therefrom should, indeed, challenge others to seek a fuller understanding of the problem. It must be recognized, of course, that an "impact factor" can not be single-valued except in the sense that it may describe a statistical mean or mode. One must recognize, also, that impact forces are inherently manifestations of the roughness profile of the pavement and of the response characteristics of the vehicle, neither of which have been exhaustively analyzed in this study. The experiences gained here indicate, however, that more detailed studies into these particular aspects of the problem would not be futile.

Anyone would certainly expect a truck to experience rather large g-forces while surmounting large obstacles or precipices in the roadway profile. However, this study attributes considerable importance to profile-waviness, harmonic to the basic cargo frequency and speed of travel. Probably the most significant observation provided is the persistence of cargo accelerations in the order of ± 0.2 g's even on apparently smooth pavements -- undoubtedly arising from random

disturbances within the vehicle as well as from random pavement imperfections, however slight they may be. This, in fact, suggests rather strongly that truck loads on new, smooth pavements are equivalent to the weighed load compensable by an impact factor of 1.2. Paradoxically speaking, it seems doubtful that this condition could be alleviated to a significant degree by more precise planning of the pavement surface unless shock-absorbers (damping devices) were fixed somehow in the tires and load-springs.

As a pavement ages and as the profile becomes pervaded with bumps and ruts, the impact forces become progressively higher -- a compounding effect -- and eventually the conditions of the pavement is declared to be intolerable. The interim condition of the pavement obviously lies between the aforementioned extremes: one represented by an impact factor of 1.2 and the other represented by a factor adjudged to be higher than 1.2. Whereas a number of selected conditions in the realm of extremes were illustrated in this study, they must be considered more-or-less as singular excursions because, fortunately, roadways are not composed continuously of dips, settled bridge-approaches, railroad crossings, etc. Although those extremes are of interest in a different way, they would not be likely to contribute significantly to a statistical evaluation of the average g-force representing a pavement in its terminal condition. Since, this study

offers no particular basis for judgement in regard to terminal conditions, it is hopefully suggested that further studies of this nature include a specific investigation in that particular area.

Future investigators are likewise invited to explore the possibility of relating interim and terminal impact factors to Serviceability Index (20) as developed recently in conjunction with the AASHO test road and to the more specific methods of expressing profile and roughness parameters now in use (18), (19), and (21).

It is foreseen that a thorough analysis of the mechanical system of a truck and of the response of a given truck to various frequencies and magnitudes of pavement imperfections will involve either or both the Fourier series analyses and power spectrum analyses and that such analyses would require electronic computations. However, this observation is not intended as a deterrent to those who might wish to pursue investigations of impact forces on an empirical and statistical basis.

Many possible variations in testing conditions that might have been of some correlative interest come readily to mind. For instance, it would have been of interest to have compared the effects of different cargo loads and of various tire pressures in each of the given circumstances and perhaps to have exhibited in each case an oscillographic record made with the truck unloaded. However, the principal interests in the present study was in the development of a practical method of obtaining recordings of these dynamic forces and in exploring the effects of loads in the region of legal limits and over-loads.

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