Dynamic Loading of Road Pavements

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ABSTRACT

A heavy goods vehicle was driven over an experimental road of known longitudinal profile in which were installed gauges to measure transient stresses and strains generated by the passage of the vehicle. Simultaneous measurements of applied wheel load and strain in the pavement permitted an investigation of the effects of vehicle dynamics and pavement profile on dynamic loading, and hence pavement performance.

INTRODUCTION

The load applied to the surface of a road by a tyre of a vehicle travelling over it is the sum of the static load carried by the tyre, as would be measured by a weighbridge with the vehicle at rest, and a continuously varying dynamic load. This dynamic load, which is the result of the vehicle responding to the longitudinal unevenness of the road, causes local increases in the loading of the road pavement that are influenced by the profile of the road, the speed of the vehicle, the mass of the vehicle and the design of its suspension. Measurements of the dynamic loads applied to roads by heavy goods vehicles have been measured on a number of occasions, recent examples being by Sweatman (1983), by Ervin, Nisonger, Sayers, Gillespie and Fancher (1983) and by Dickerson and Mace (1981). A more general review of the effect of the suspension characteristics of heavy vehicles on road damage has been provided by Magnusson, Carlsson and Ohlsen (1984). No attempt appears to have been made to date to correlate measured dynamic loadings with stresses or strains measured simultaneously in the road pavement, which would make possible a quantitative assessment of the effect of dynamic loading on pavement life, and there are at present considerable uncertainties about the amount of additional pavement damage that is caused by dynamic loading.

The work described in this report attempts to link the dynamic loads applied to a road pavement by a heavy goods vehicle to stresses and strains in the pavement, so that the possible effects of the dynamic loads on pavement life can be analysed.

DESIGN OF THE EXPERIMENT

The experiment was planned to use a 4-axle articulated heavy goods vehicle, instrumented to measure instantaneous changes in load applied to the road by the tyres of the semi-trailer. This vehicle was to be run over a short stretch of road pavement on the research track at TRRL, that had been instrumented to measure stress and strain in the pavement at the same time as the loads applied to the pavement were being measured. It was found that the unevenness of the test road, although built to good standards of longitudinal profile, excited sufficient vertical motion of the vehicle to produce substantial dynamic loading. It was also found that the distribution of the quasi-static load between the axles of the vehicle was affected by the long-wavelength profile of the test road, and additional instrumentation was then added to enable the instantaneous load on each of the four axles to be measured simultaneously.

TEST PAVEMENT CONSTRUCTION AND INSTRUMENTATION

The instrumented pavement comprised 50 mm of rolled asphalt wearing course and two 75 mm layers of dense bitumen macadam roadbase material on a 300 mm thick well-graded granite sub-base. The subgrade was a heavy clay of CBR 3 per cent. Gauges of the type described by Potter (1972) were installed at a depth of 150 mm in the subgrade to measure the transient vertical component of stress. Resistance foil gauges were installed at the underside of the roadbase to measure the longitudinal and transverse horizontal components of strain in the bituminous layers. Finally wire loops, forming part of a system to indicate the lateral position of a vehicle, described by Halliday (1977), were installed at the interface of the upper bituminous layers.

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The gauges were arranged in four groups, with 3 m separation between groups, along lines taken by both the nearside and offside wheels of the loading vehicle as shown in Figure 1. Two further lines of 4 gauges were installed 180 mm distant from each side of the line of trafficking of the offside wheel line. Their purpose was limited to indicating variations in lateral position of the vehicle as it passed over the pavement but because of gauge failures on the trafficking line during pavement construction, two of the position indicating gauges, 40 and 354 in Figure 1, were used for measurement purposes.

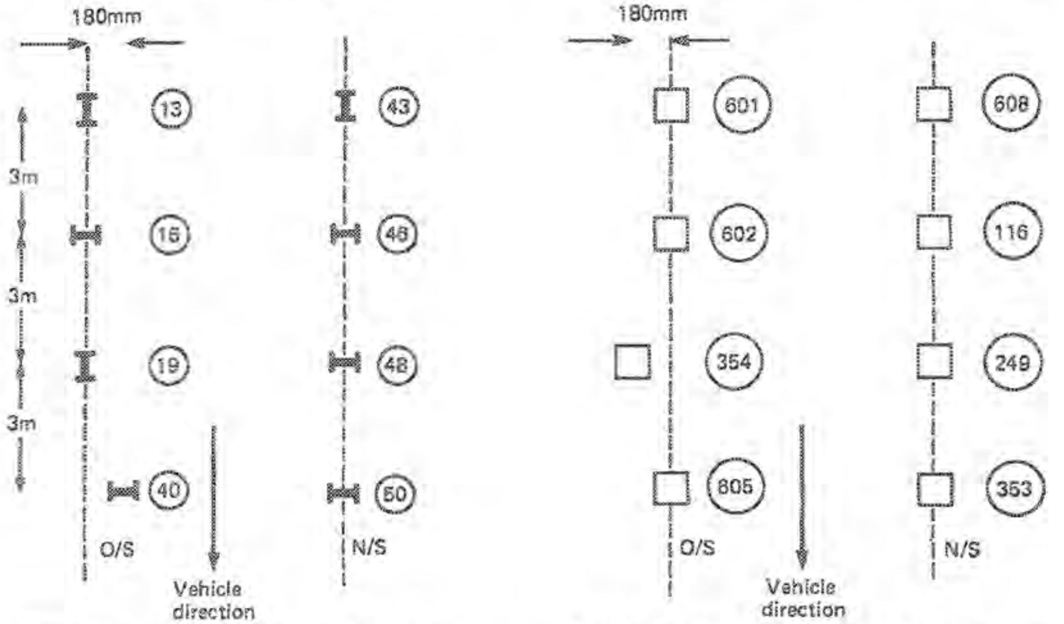
During construction of the pavement it was intended that the longitudinal profile of the finished pavement would be free of local variations that might cause unwanted dynamic components of loading. To this end, coated chippings were not applied to the wearing course.

THE TEST VEHICLE

The test vehicle was a 4-axle articulated heavy goods vehicle consisting of a Leyland Marathon 2-axle tractor towing a Crane-Fruehauf flat-bed semi-trailer, Type PSK 44 EN F2. The tractor suspension consisted of multileaf steel springs with dampers, and was standard for the vehicle. The wooden decked, steel framed, semi-trailer was 12.3 m long and was supported by two axles spaced 2 metres apart, each of which was fitted with either four 11.00 x 22.5 radial ply or 11.00 x 20 crossply tyres. The trailer suspension had monoleaf tapered steel springs interconnected by balance beams. The axles were retained longitudinally by radius rods. The trailer axles could be fitted with telescopic shock absorbers (dampers) manufactured by Armstrong Patents Co Ltd (Type N67) and recommended by Crane Fruehauf Ltd. The vehicle is shown driving over the test pavement in Figure 2, which also shows details of the trailer suspension.

The trailer was equipped with a load rack above its axles in which steel plates could be secured. This enabled the trailer to be operated at a bogie load of 18 tonnes (4.5 tonnes per axle end). The pressure in the tyres of the trailer was maintained constant by continuously supplying air to the tyres of the trailer through a regulating valve.

The semi-trailer was instrumented to measure continuously the instantaneous vertical load on each of the four axle ends. This used the instrumentation system developed by Dickerson and Mace (1981) which was initially installed on a 2-axle rigid vehicle. At each axle-end, an optical contactless sensor is used to measure the deflections of the tyres. These deflections were interpreted as forces, using the measurements of tyre stiffness reported by Ramshaw (1985). In addition,



Plan of base strain gauges and identity numbers

Plan of subgrade stress gauges and identity numbers

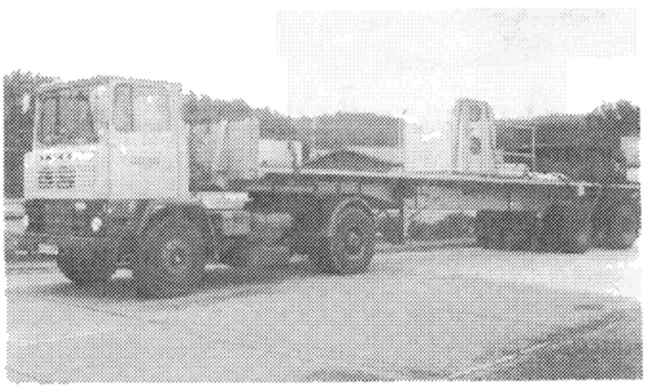
Instrumentation layout in experimental pavement

FIGURE 1

at each axle-end a transducer was fitted to measure the vertical movement of the suspension. The values of the tyre deflections and spring movements were recorded each time the vehicle had travelled 152 mm, each measurement being the average of a number of values during the preceding interval. The transducer recording these intervals also enabled the road speed to be measured.

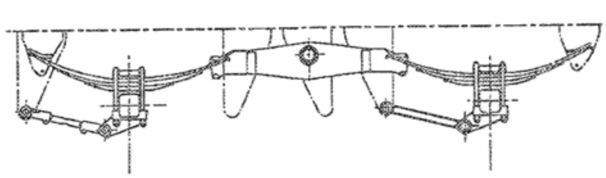
To measure the longitudinal position of the vehicle within 5 cm the vehicle was equipped with a sideways-facing infra-red beam that was reflected from posts installed beside the track. Intermediate positions between posts were determined from the distance transducer. A probe coil, excited by 10 kHz square waves, was mounted under the front axle of the trailer bogie to measure the lateral position of the vehicle by inductive interaction with the fixed loops already installed in the road.

After the experiment had started it was decided to add an additional set of instrumentation to measure the load carried by each of the four axles of the vehicle. This consisted of strain gauges fixed to the axles between the springs to measure the bending moment in the axle due to vertical loads at the wheels. Although no attempt was made to correct for the inertia of the unsprung mass, the strain gauges gave results for the axle loads that agreed well with those measured using the optical contactless sensors.



Test vehicle on test pavement

FIGURE 2a



Trailer tandem axle suspension

FIGURE 2b

DYNAMIC LOADING TESTS

The investigation of dynamic loading effects began with a series of tests to determine the degree of dynamic loading on the test pavement. Further tests established the response of the pavement to those dynamic loads.

DYNAMIC LOADS ON TEST PAVEMENT

Tests were carried out with the vehicle in both a 4-axle configuration and, with the trailer rear axle road wheels removed, a 3-axle configuration. When operated with three axles, the load compensating mechanism was rendered inoperative and, in order to maintain a 9 tonne loading on the single trailer axle, the mass carried was reduced. With four axles tests were conducted both with and without shock absorbers fitted to the trailer axles.

Initially the vehicle made a number of passes in one direction along the test pavement at speeds in the range 8 to 64 km/h, dynamic load measurements being taken on each pass.

Figure 3 shows axle load measurements for the rear axle of the 3-axle vehicle from which it is clear that on a non-textured pavement surface laid to good longitudinal profile standards, the trailer oscillated vertically at a frequency of approximately 3 Hz. The frequency of oscillation was independent of vehicle speed. Over the range 8 to 32 km/h amplitude increased rapidly with increasing speed, but at speeds greater than 32 km/h there was no discernible variation with speed.

The positions along the pavement at which the maximum and minimum loads occurred remained constant for each pass of the vehicle when travelling at a constant speed of 32 km/h as illustrated in Figure 4. This suggests that the dominant input forces bringing about the dynamic loading were a result of pavement surface irregularities. As Figure 3 shows, the distance between successive peak loadings is proportional to vehicle speed, and substantial variations in speed change the position along the pavement at which the maximum and minimum loads occur.

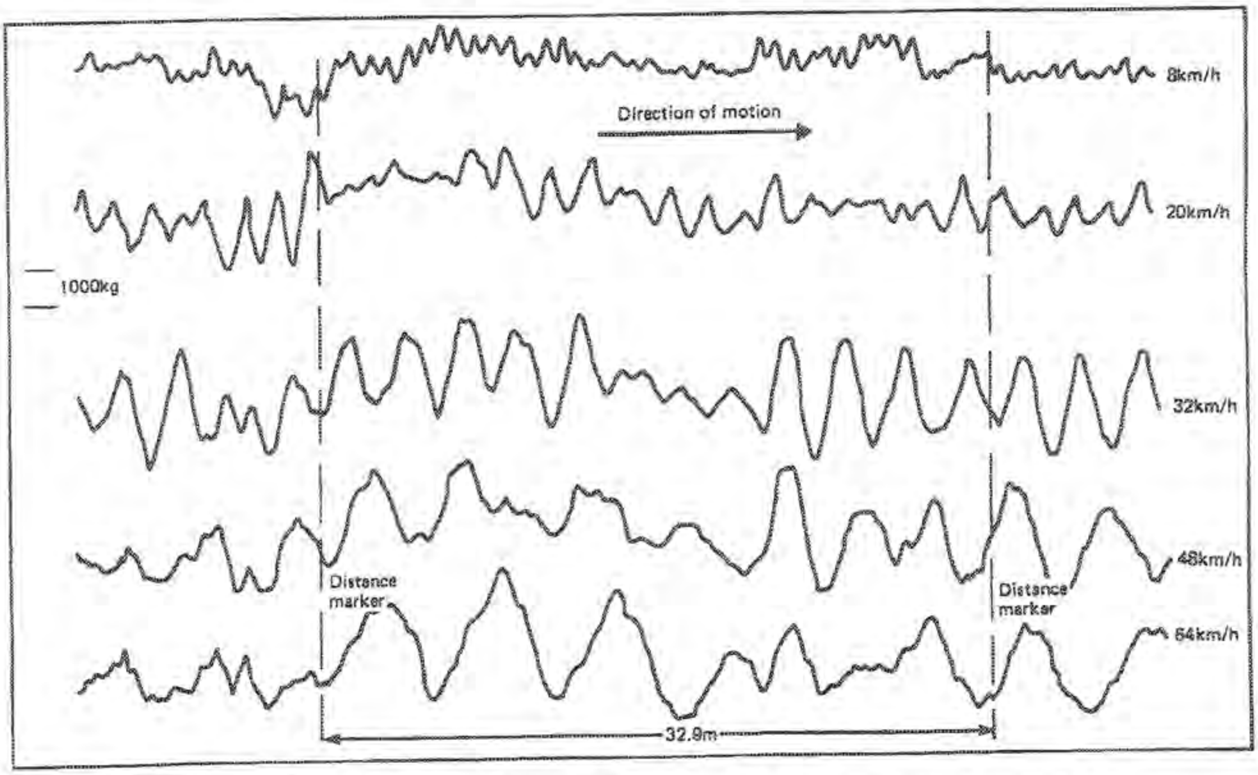
Typical load variations of ±15% of the total static wheel load of the trailer were recorded with twin trailer axles, increasing to ±25% with the single axle. The maximum load variation observed was about ±40% of the static wheel load. More generally, the results show that the oscillatory motions of both the front and rear trailer axles remain in phase, although their amplitudes differ. Similarly, the oscillatory motions at each end of both trailer axles remain in phase and are generally of similar amplitude, suggesting that no significant roll component was being generated in the trailer by the test pavement.

The effect of fitting shock absorbers was tested by driving the 4-axle vehicle over low profile ramps (25 mm height) fixed to the road surface. Figure 5 shows that, as expected, the shock absorbers had no effect on the frequency of oscillation. It was more surprising that the shock absorbers had little effect on the amplitude of oscillations. Figures 3 and 5 together show that, provided the load per axle is maintained constant, the frequency of oscillation at a given speed is the same for the semi-trailer, regardless of whether it is fitted with one or two axles.

The records of load obtained from the contactless sensors were compared with axle-to-chassis height variations measured with a potentiometer attached between these two points. Figure 6 presents the results of this comparison and shows that no significant 3 Hz component was present in the axle-to-chassis height measurements. Hence it would appear that the forces generated when running on a smooth surface were almost wholly absorbed in the tyres, and the suspension system was not actuated. This is supported by the observation that shock absorbers had only a small effect on the amplitude of the dynamic component of load. The observed oscillation was mainly therefore the result of the chassis and unsprung mass bouncing on the tyres at a frequency of 3 Hz.

Further analysis of the results of these tests suggested that other forces were modifying the shape and amplitude of the dynamic pavement-induced forces. These could include tyre/rim eccentricities or tyre/rim out-of-balance, pavement profile variations because of deviation of the vehicle from the specified line, or localised speed fluctuations, all of which may vary from pass to pass. These were not however sufficient to disturb the general repeatability of the dynamic loading component, and altered the load peaks by typically 10% of the peak to peak load variations.

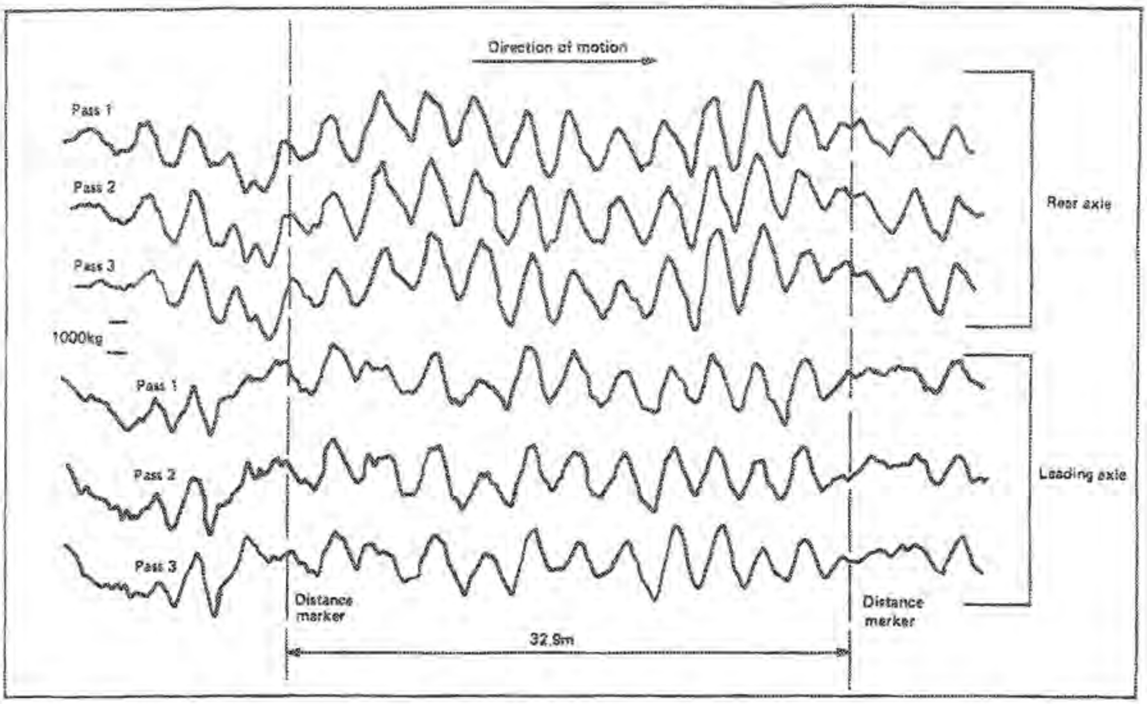
The average level of loading after smoothing out the 3 Hz component still showed a significant variation as the vehicle passed along the pavement.



Measured wheel load variations for rear axle of 3-axle articulated vehicle

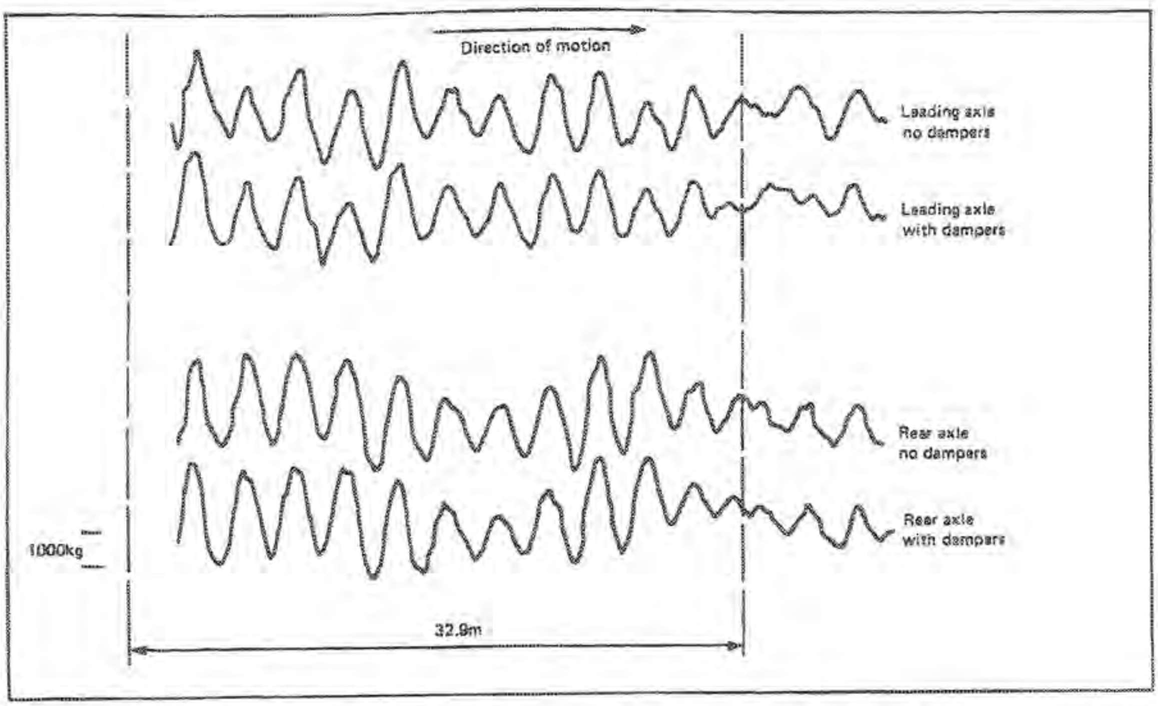
(9 tonne static weight, cross-ply tyres, no damper fitted)

FIGURE 3



Measured wheel load variations at 32 km/h on each of a dandem pair of 4 axle articulated vehicle (9 tonne per axle static weight, cross-ply tyres, damper fitted)

FIGURE 4



Measured wheel load variations at 32 km/h on each of a tandum pair of 4 axle articulated vehicle (9 tonne per axle static weight, cross-ply tyres)

FIGURE 5

VEHICLE CHARACTERISTICS

The results of the trials described in the previous section of this paper suggest that although dynamic components of loading are largely induced by pavement surface irregularities, some input forces may arise from the vehicle itself. In order to isolate these input forces, tests were carried out with the vehicle on a 3 m diameter dynamometer drum. For the purposes of this experiment, the drum acted as a 'flat' road, with no surface irregularities. The eccentricity of the drum was measured and found to be 0.5 mm.

In the tests, the rearmost road wheels of the trailer axle were removed, together with the shock absorbers fitted to the remaining axle. The compensating mechanism was rendered inoperative and the load on the trailer axle was adjusted to 9 tonnes. The tractor was attached and parked with the handbrake on while the road wheels of the trailer axle were driven at speeds corresponding to road speeds of up to 65 km/h. Visible oscillations of the trailer indicated the action of vertical input forces. At speeds where the oscillation could be discerned its frequency was approximately 3 Hz, and reached maximum amplitude at 36 km/h, the speed for which the wheel rotational period is 1/3 second. At other speeds the amplitude varied as would be expected if the 3 Hz oscillations were being excited by an out-of-balance mass on the wheel. At 36 km/h, the amplitude of the oscillation was ±25 per cent of the static axle load, while at 32 and 40 km/h it was only ±5 per cent.

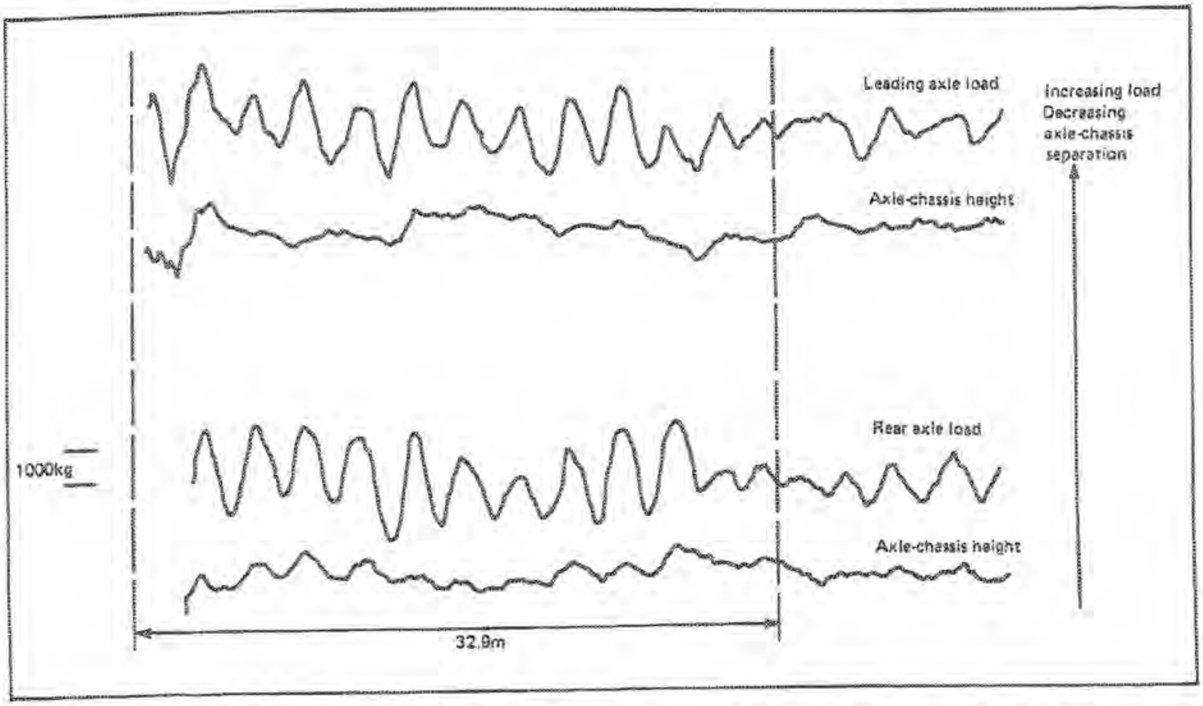
Measurements of axle and body movements during the tests described above showed that most of the body movement was accounted for by tyre deflection and that less than 10% was due to movement of the vehicle suspension system.

The results of these experiments provide the basis on which dynamic load measurements can be related to simultaneous measurements of stress and strain in a road pavement.

MEASUREMENTS OF DYNAMIC LOAD AND PAVEMENT STRESS AND STRAIN

The response of the pavement to the changing dynamic loads indicated by the contactless sensors was related to the stress and strain levels generated at fixed positions within the pavement.

The interpretation of these results is best understood by considering the expected effects in the absence of dynamic loading. Thus, as the test vehicle passes over the pavement with no dynamic loading, it would be expected that stress and strain levels indicated by a pair of gauges in the nearside



Measured wqheel load and axle-chassis height variations at 32 km/h on each of a tandem pair of 4 axle articulated vehicle (9 tonne per axle static weight, dampers fitted)

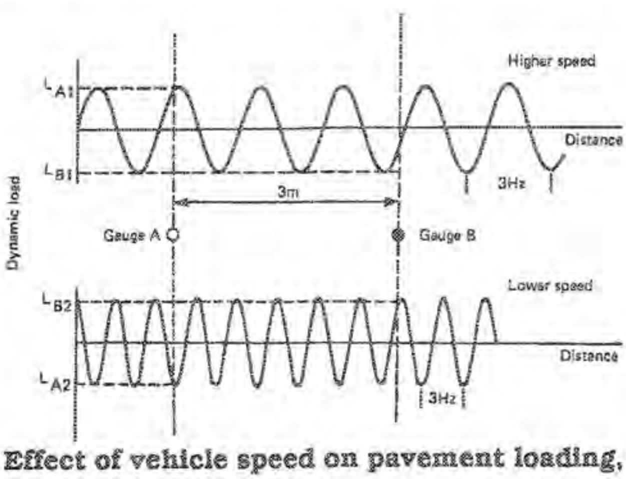
FIGURE 6

and offside wheelpaths would be similar and would respond similarly to changes in vehicle speed. Furthermore, all gauges over which the vehicle passed should indicate similar levels of stress or strain, and both should decrease as the vehicle speed increases because of the visco-elastic nature of the bituminous pavement layers.

In the presence of dynamic loading, however, the stress and strain levels respond less predictably to changes in vehicle speed. As the wavelength of the 3 Hz load oscillations changes with vehicle speed fixed points on the pavement would be subjected to loads that would vary with speed, as shown in Figure 7. Clearly, the pavement response depends on the location of a particular gauge and Figure 7 illustrates that at some locations (Gauge A) an increase in speed produces an increase in strain rather than the decrease that would be expected as a result of the viscoelastic nature of bituminous materials. Note that neither Gauge A nor Gauge B gives an absolute measure of strain. Increases in stress and strain arising as a result of increasing speed can therefore be assumed to be the effects of dynamic loading.

To eliminate the effects of interaction between closely coupled axles the trials were conducted with the vehicle in 3-axle configuration. Shock absorbers were not fitted to the single trailer axle.

Stresses in the subgrade were measured using the pairs of gauges, shown in Figure 1. Gauges forming a pair, numbers 601 and 608, for example, were positioned directly opposite each other in the nearside and offside wheelpaths, and were located longitudinally at 3m intervals. Of the eight gauges measuring strain at the bottom of the roadbase, six were positioned directly above stress gauges.



Effect of vehicle speed on pavement loading, at a fixed frequency

FIGURE 7

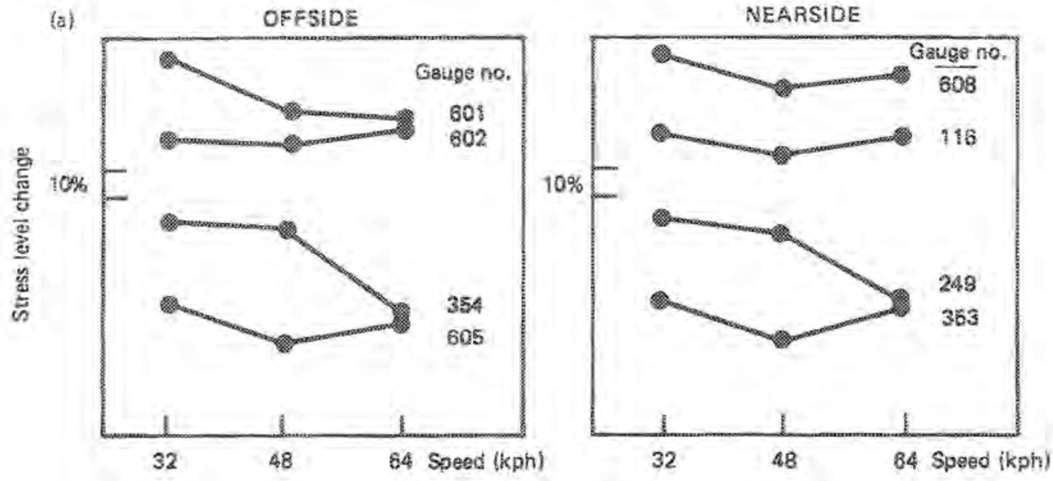
Three separate trials were conducted. In each, vehicle passes were made in the same direction at speeds of 32, 48 and 64 km/h: for the first trial 5 passes of the vehicle were made, in Trials 2 and 3 six passes were made. In Trials 1 and 2 the vertical components of subgrade stress were measured and compared for repeatability. In Trial 3 horizontal strains at the bottom of the roadbase were measured and compared with the response of the subgrade stress gauges.

In order to assess the degree to which the pavement is affected by dynamic loads, the mean levels of stress or strain in the pavement for the five or six passes at a given speed were calculated. When plotted against vehicle speed, as in Figure 8, pronounced and repeatable differences are apparent in the response of stress and strain gauge pairs to vehicle speed. Note that the absolute level of stress or strain is not shown. The vertical separation between results from pairs of gauges is used as an aid to observing the effects. While some gauges show stress and strain decreasing with increasing vehicle speed, as would be expected if dynamic loading had no effect, others show an increase with increasing vehicle speed. The observation of increases in stress or strain with speed confirms the presence of a repeatable dynamic load component and the measurements suggest that at the speeds investigated there may be stress or strain increases of up to 20 per cent compared with the static axle weight.

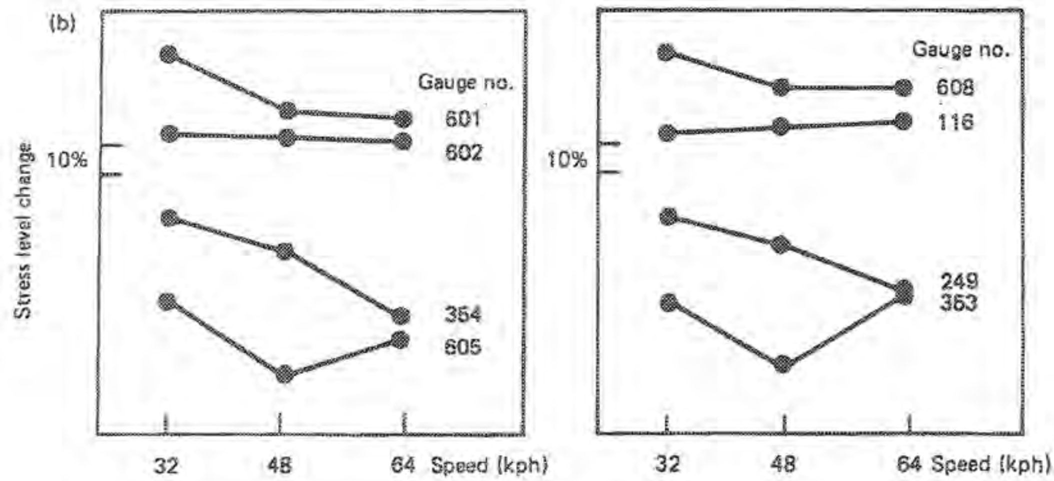
The results of Trials 1 and 2 are presented in more detail in Figure 9 which shows, for consecutive passes of the test vehicle, the individual stress level (relative to the level measured for the first pass of the vehicle over the first gauge). These are compared with the simultaneous load changes measured by the contactless sensor, presented as a difference between static and measured load. The strong similarity between load changes and stress changes between successive passes is further evidence of a close correlation between pavement response and the dynamic load induced as the vehicle passes over the pavement. For an individual gauge, the variation over the six passes at a given speed may be the result of variations in lateral position or vehicle speed.

STUDIES OF LONG WAVELENGTH DYNAMIC LOAD COMPONENT

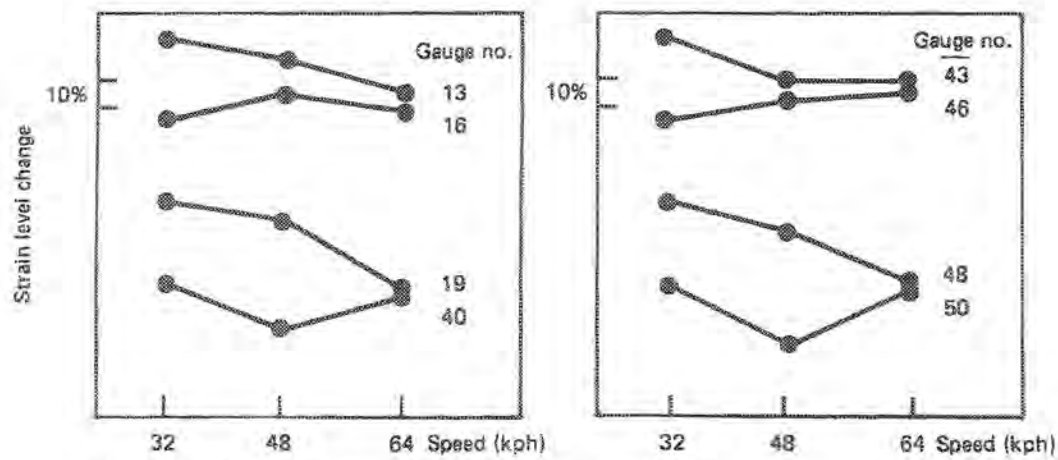
It was noted earlier that after smoothing out the 3 Hz component, loads indicated by the contactless sensors still had a long wavelength dynamic component and could differ significantly between the



Trial 1: Change in subgrade stress level at different speeds



Trial 2: Repeat of trial 1



Trial 3: Change in strain level in the sub-base at different speeds

Subgrade stress and strain in the roadbase

FIGURE 8

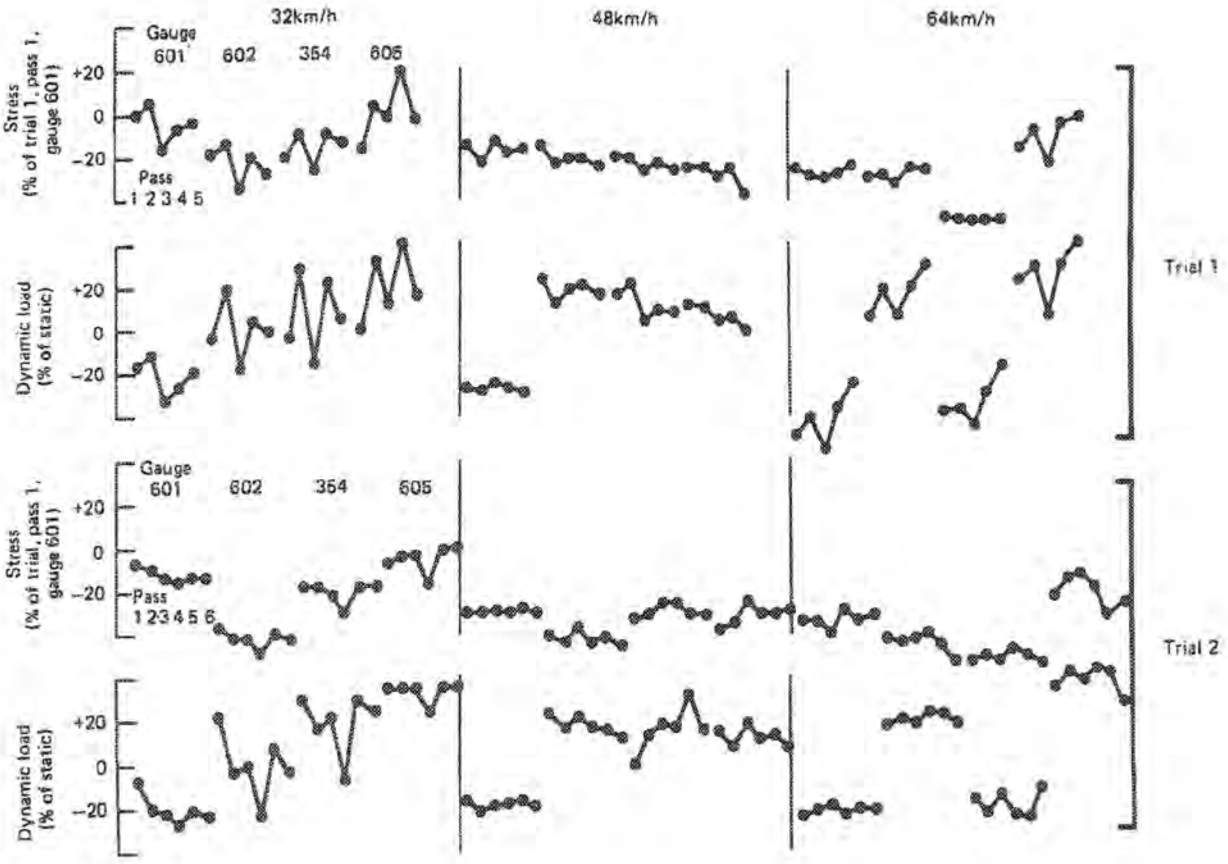
two trailer axles of the loading vehicle. Figure 10 shows recorded axle load variations which indicate that, under the conditions encountered in these experiments, the amplitude of this long wavelength component is comparable with that of the 3 Hz oscillation. Further studies were therefore conducted to establish the source and significance of this variation.

A detailed comparison of simultaneous measurements indicated that underloads on the forward trailer axle of up to 40 per cent were associated with rear axle overloads of 15 per cent, suggesting that the remaining 25 per cent of load carried by the trailer axle is transferred to the tractor.

The long wavelength component is present on the load measurements for each pass along the test pavement. Its amplitude and position along the pavement are repeatable and independent of vehicle speed over the range of 2 to 64 km/h.

In passing over a length of pavement an articulated vehicle is subject to a longitudinal profile which may bring about changes in the angular location of the loading platform with respect to the horizontal. Using the measurements of longitudinal profile in the wheel tracks, shown in Figure 11, the 3rd-axle-to-chassis height variations introduced as a result of differences in absolute height between tractor axles and trailer rear axle, were computed along the test pavement. These, together with simultaneous mean load measurements are shown in Figure 12. The two sets of measurements behave similarly, suggesting that the long wavelength component may be attributed to longitudinal profile effects.

To substantiate this, tests were conducted with the front trailer wheels removed and the compensator rendered inoperative. Although it was anticipated that this would result in a constant load on the rear trailer axle, load variations were still



Relative changes in subgrade stress and axle load for several passes of an articulated vehicle, at 3 different speeds over 4 separate gauges

FIGURE 9

observed, but there was a 50 per cent reduction in their amplitude.

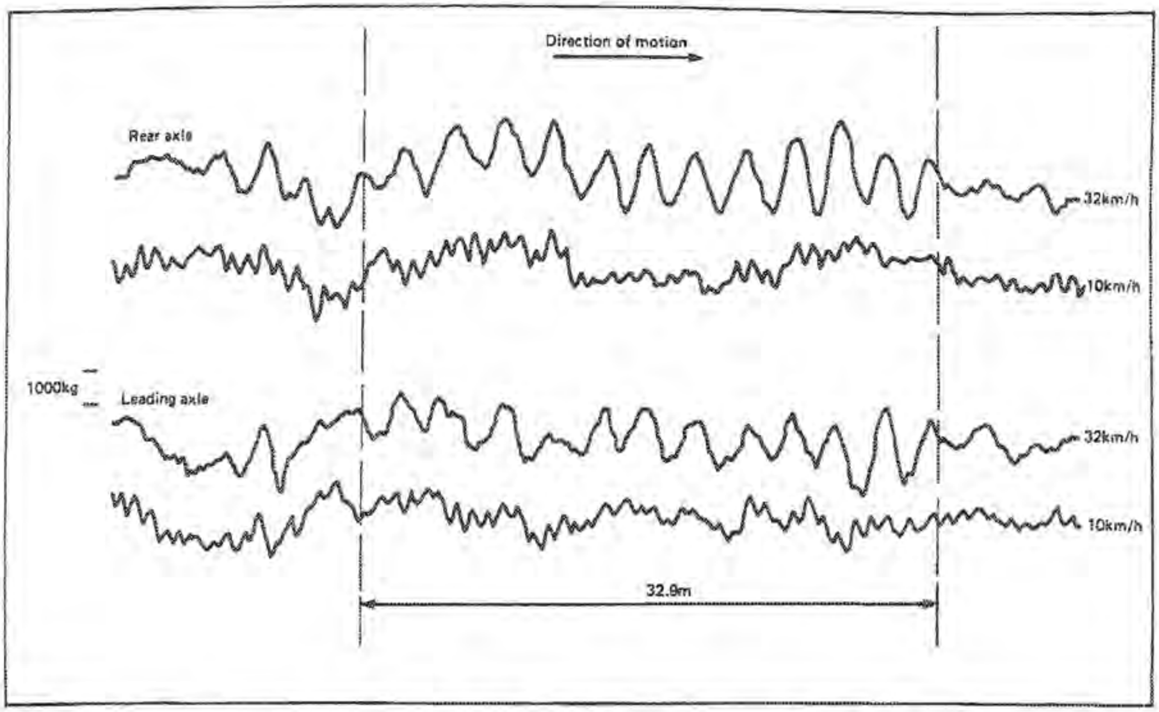
MEASUREMENT OF AXLE LOAD USING STRAIN GAUGES

Load transfer between individual axles on the vehicle was further investigated by bonding pairs of resistance strain gauges to each axle. Drive axle gauges on each side of the differential casing were separated by approximately 0.5 m but the remaining gauge pairs were positioned together at the top centre of the axles. The outputs from the gauges were displayed on a multi-channel UV recorder against a single time base. The relationship between strain in each axle and load was determined using an accurate low-speed dynamic weighbridge: the relationship was linear over the range of loads investigated.

Trials on the test pavement were conducted with the articulated vehicle in 4-axle and 3-axle configurations with trailer axle loads of both 9 tonnes and 5.5 tonnes, at creep speed and 32 km/h, and with cross-ply and radial-ply tyres. In all cases there was very good agreement between the strain gauges and the contactless sensor, as shown in Figure 13.

In 4-axle configuration the long wavelength component of load was evident and repeatable on the strain gauge signals at both the test speeds. Along the length of the test pavement a maximum load reduction of 2.4 tonnes on the forward trailer axle was accompanied by an increase of 1.7 tonnes on the rear trailer axle and 0.3 tonnes on the tractor drive axle. In 3-axle configuration there was no measurable load variation on the trailer axle.

While this evidence supports the possibility of load transfer between tandem axles as first indicated by the contactless sensors it suggests lower magnitudes of load transfer. The difference is thought to be due to simultaneous lifting and rotation of the contactless sensors as the vehicle is driven over the test pavement. After allowing for this the similarities between the load variations indicated by the strain gauges and contactless sensors suggest that the slowly varying component of dynamic load is a result of load transfer between axles caused by long wavelength features in the longitudinal profile of the road. It is a phenomenon which should be minimised if the load equalising mechanism is operating efficiently. In the present tests, this mechanism was properly maintained and in good working order, but nevertheless failed to perform satisfactorily as a load equaliser.



Measured wheel load variations on each of a tandem part of 4 axle articulated vehicle (9 tonne per axle static weight, cross-ply tyres, dampers fitted)

FIGURE 10

EFFECT OF VEHICLE VARIABLES ON SHORT WAVELENGTH DYNAMIC COMPONENT OF LOADING

The generally good agreement between the strain gauge and contactless sensor methods of measurement shown in Figure 13 allowed the simpler strain gauge system to be used in an investigation of the effect of selected vehicle variables on the short-wavelength components of dynamic load described earlier.

The effects of axle load and tyre type on the amplitude and frequency of the short wavelength component of dynamic load were investigated with the vehicle in 4-axle configuration, and cross-ply tyres fitted to each trailer axle. Trials on the test pavement were conducted at 32 km/h, and at two different trailer axle loads. Radial-ply tyres were then fitted to the trailer axles and the trials repeated.

With a 9 tonne load on each trailer axle and four cross-ply tyres per axle the trailer axles oscillated in phase on the tyres at a frequency of 3.5 Hz. The tractor drive axle, carrying a 6.5 tonne load on 4 radial-ply tyres, also oscillated at 3.5 Hz but generally in anti-phase to the trailer axles. The tractor steering axle carrying a 5 tonne load on two radial-ply tyres, oscillated at 2.5 Hz.

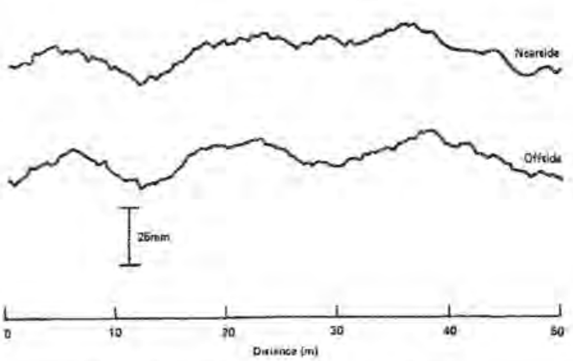
Reducing the trailer axle load to 5.5 tonnes per axle caused a reduction of approximately 40 per cent in the amplitude of the dynamic component of load and an increase in its frequency from 3.5 to 4.25 Hz. The tractor drive and steering axles, carrying similar loads to those previously mentioned continued to oscillate at 3.5 Hz and 2.5 Hz respectively.

Restoring the trailer axle load to 9 tonnes and fitting radial-ply tyres caused a reduction in frequency of oscillation on the tyres to a little over 3 Hz. There was some reduction in the amplitude of the dynamic component when compared with that produced by the same load carried on cross-ply tyres. With the 5.5 tonne axle load the introduction of radial-ply tyres caused a similar reduction in the frequency of oscillation, from 4.25 Hz to 3.75 Hz, but no significant change in the amplitude of the dynamic component.

EFFECTS ON PAVEMENT PERFORMANCE

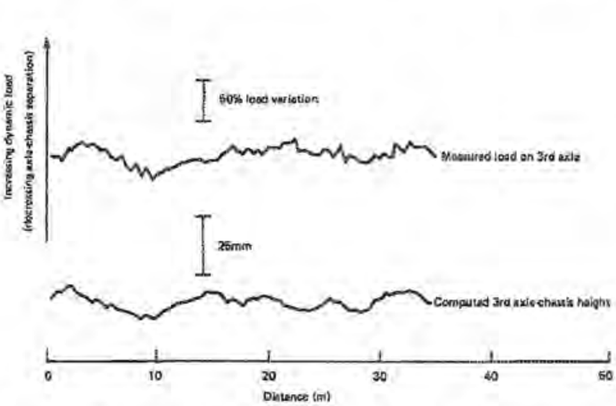
The results of the tests described in this paper show that when passing over a pavement laid to good standards of longitudinal profile, an articulated heavy goods vehicle experiences sufficient input forces to produce appreciable dynamic loading effects on the pavement. The input forces are a result of variations in pavement surface profile, and it is this profile, together with vehicle mass, speed and suspension characteristics, that determine the positions at which peak overloads occur.

On the test vehicle, the dominant response was a vertical oscillation at about 3 Hz involving the trailer bouncing on its tyres. The response was very lightly damped and was excited by normal variation in road profile. If the road was perfectly smooth then the 3 Hz oscillation could be excited by eccentricities in the tyres and wheels, but the degree of repetition from one pass to the next shows that the effect of eccentricity was small compared with those due to longitudinal road profile. The oscillatory forces on the trailer springs caused very little movement of the suspension,



Longitudinal surface profile of experimental pavement

FIGURE 11



Computed 3rd axle-chassis height variations compared with measured dynamic loads

FIGURE 12

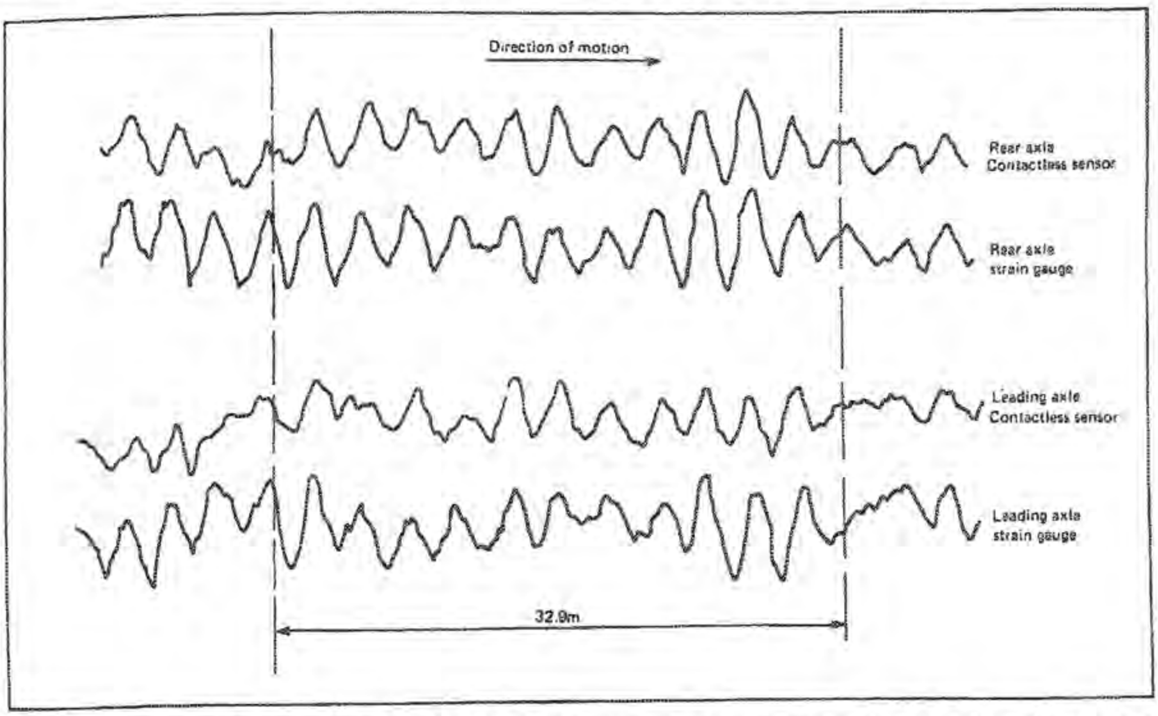
probably because of the stiffness of the springs and the friction at the spring ends.

The amplitude of the dominant response at about 3 Hz is dependent on vehicle speed, axle load and tyre type; its exact frequency is dependent on axle load and tyre type. On a pavement in service, vehicle speeds may vary over a relatively narrow range and axle loads will vary over a much wider range. These variations will probably ensure that for a pavement in service over- and under-loads will be evenly distributed over the length of the pavement. However, the position of the overloads will tend to be repeated for similar vehicles running at or near their maximum plated weight and at the same speed, and it is these vehicles which contribute most to pavement damage. Any significant localised variations in the longitudinal profile, as might occur for example at sites of over- or under-filled trenching, or where the longitudinal profile is very uneven, will induce large dynamic overloads.

A semi-trailer with steel leaf springs and an inadequate compensating mechanism will suffer load transfer between axles when the pitch angle of the trailer is affected by longer wavelength changes in road profile. In passing over a length of pavement, therefore, these vehicles will probably introduce over-loads at similar positions on the pavement. These will occur at the same point regardless of vehicle speed.

It is clear that some points on a road in service could experience repeated overloads due to the action of vehicles of similar type and loading while other points experience repeated under-loads. Moreover, these increased dynamic loads were transmitted into the test pavement where they appeared as increased horizontal strains at the underside of the roadbase, and increased vertical stresses in the soil. On the comparatively smooth pavement tested, strains at the underside of the roadbase and vertical stresses in the soil exceeded the nominal level expected on a perfectly smooth road by up to 20 per cent.

The mechanisms by which pavements deteriorate by fatigue cracking and by deformation are complex and behavioural models used in design methods for road pavements are not necessarily adequate for the more demanding task of assessing the consequences of dynamic loading. However, levels of strain and stress in the road can be related to some aspects of deterioration and some broad indication can be given of the consequences to pavement life of increased dynamic loading. Thus, a dense bituminous pavement that might deteriorate primarily by fatigue cracking could be subject to a tensile strain level of, say, 100



Comparison of contactless sensor and axle strain gauge measurements, 4 axle articulated vehicle (9 tonne per axle, 32 km/h, cross-ply tyres)

FIGURE 13

microstrain under a nominal static wheel load; the expected life to the onset of fatigue cracking would be approximately 4.2 x 10 cycles of loading. A 20 per cent increase in strain level would reduce the life to about 2.0 x 10 cycles. The corresponding increase in the level of subgrade stress would also increase deterioration in that layer. However, many road pavements deteriorate to failure by deformation of the whole road structure; such behaviour is affected by other factors in addition to peak loading, and notional estimates of additional damage from overloads are not readily made. The substantial reduction in fatigue life quoted above represents an extreme condition because heavy vehicle traffic using the road will comprise a variety of vehicle types having different types of suspension carrying a range of loads, but probably at similar speeds. On newly constructed roads of good longitudinal profile the differing suspension characteristics of vehicles travelling at similar speeds will probably subject local areas of the pavement, rather than particular points, to successive over-loads, as a result of small differences in the frequency of the dynamic loading. As the profile deteriorates, the magnitude of the dynamic component will increase and areas subjected to early over-loads may be propagated in the direction of traffic flow. Severe local deterioration in profile may induce other modes of dynamic loading brought about by movements in the suspension system rather than tyre oscillations. Although these will be more effectively damped than tyre oscillations, they will probably be much greater in amplitude and will induce high transient strains in the pavement.

CONCLUSIONS

From the tests described in this paper the following conclusions may be drawn:

1. Dynamic loading of the test pavement was brought about by the vehicle bouncing on its trailer tyres, at a frequency of 3 Hz. This was a lightly damped movement excited by small variations in longitudinal profile such as might be expected on a high speed principal road built to normal United Kingdom standards.

2. On a good longitudinal profile, dynamic loads up to 15 per cent of the nominal static axle load were recorded for tandem axles. For a single axle trailer the dynamic component was 25 per cent.

3. These variations in loading were accompanied by measured variations in stress and strain in the pavement of up to 20 per cent of that expected for the nominal static load. It was calculated that the consequence of the increased strain at the bottom of the roadbase could be to reduce the life of particular areas of some pavements by up to 50 per cent.

4. An additional component of dynamic loading, was induced by long wavelength variations in pavement profile and caused an increase of 19 per cent in the rear trailer axle load on a smooth pavement. This was attributable to the inadequacy of the mechanism for sharing load between the two axles of the semi-trailer.

5. These results were obtained from one vehicle operating over one pavement. Further measurements on a range of vehicle/suspension types would be needed before conclusions of more general applicability could be drawn.

ACKNOWLEDGEMENTS

The work described in this paper forms part of the programme of the Transport and Road Research Laboratory and the paper is published by permission of the Director. The instrumentation system on the articulated vehicle was maintained and operated during the tests by Mr B Broad, whose contribution to this study is gratefully acknowledged.

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