SUPER-SINGLE VERSUS DUAL TYRES

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The problem of dual tyres vs wide base tyres

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1. Introduction

As a vehicle moves on the road, the weight of the vehicle is passed to the road by tyres. This load causes vertical stresses to the bituminous layers and further to unbound layers and subgrade. Because of the great difference between the elastic moduli of the bituminous or cement treated layers and the underlying unbound base course the horizontal stresses at the bottom of the bituminous layers become critical to pavement life. Also vertical stresses on the subgrade are critical (figure 1). In certain cases also the strain and stresses in other parts of the pavement structure shall be considered.

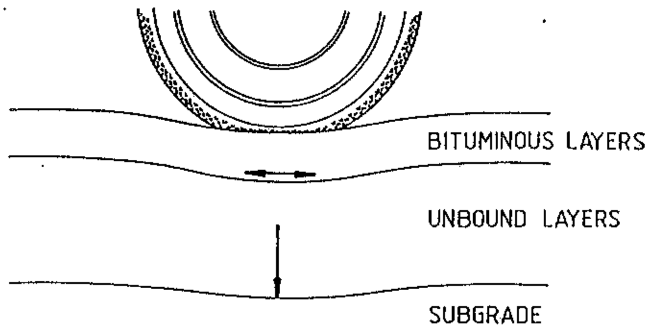

Figure 1. The basic behaviour of a pavement under moving axle load; the critical strains and stresses.

If the number and the magnitude of the tensile strains at the bottom of the bituminous layers (strains are usually easier to handle in pavement engineering than stresses) exceeds the fatigue life of the bituminous material, the pavement will crack forming usually alligator shaped cracks.

If the repeated stresses to the subgrade are higher than its fatigue strength the whole pavement will rut. Cracks may be formed, too.

The bituminous layers are viscoelastic by nature which means that their stiffness especially at warm temperatures may be low and vehicle tyres may cause plastic deformation. It can be seen often as dual ruts.

Fatigue cracking is more typical for countries with lower axle loads and less dense heavy vehicle traffic like USA, Finland and other Nordic Countries and New Zealand and less a problem in countries like Germany and France because they often have thicker bituminous layers.

The increased traffic and heavier vehicles cause much more distress to roads nowadays than earlier. The regulations of weights and dimensions have become more important especially since there is substantial pressure from the transport industry to allow even heavier and bigger vehicles. The recent developments of tyres, axles and suspensions are very important from the point-of-view of the road engineers. Most of the new developments seem to increase distress to the pavements. New regulations often come only after some technical development or even may in some cases hinder the development. The technical basis for regulations has often been very vague. One reason is that the regulations require special knowledge somewhere between the expertness of mechanical engineers and civil engineers.

Perhaps the most important technical changes in vehicles, which are important for roads are:
- tridem axles,
- tandem axles with different tyres and loads on axles,
- radial tyres,
- increased tyre pressures,
- wide base tyres instead of dual tyres,
- smaller tyres carrying, however, the same load,
- new suspensions, especially air suspensions.

In order to study the effects of different tyres, axles and suspensions, four different approaches can be used:
- full size road tests,
- measurements of stresses and strains in pavements (response measurements),
- theoretical (mechanistical) calculations of stresses and strains in pavements,
- measurements of dynamic axle loads in the vehicle.

In the first approach the road is damaged by repeated loads. If moving trucks are used as loads, the test is very expensive like the AASHO Road Test. The linear or circular test tracks like CAPTIF at Christchurch are very important in pavement research but have certain limitations for this purpose. Road tests give the only real and reliable results and the results received by other means should be compared to actual road tests.

The mechanistical calculations by multilayer or finite element computer programs are inexpensive and easy but because the basic assumptions of the behaviour of tyres and pavements must be simplified, the results may be erroneous.

The stresses and strains in the pavement due to a passing vehicle can be measured (response measurements). The results are turned into equivalency factors using appropriate failure criteria. Because the equivalency factors are compared to each other, their exact validity is not very important. The results may reveal, for instance, the behaviour of different tyres and uneven distribution of the load within tandem axles or dual tyres, which is seldom taken into account in mechanistical calculations. The results are clear and easily explained, which is important because of the economical and political pressure groups.

In the approaches above, the road is even or it is assumed to be even. The effect of suspensions is mostly neglected. The effect of suspensions can be studied measuring the dynamic axle loads in the vehicle. Pavement studies are more difficult but now the use of circular tests tracks are considered for this purpose.

2. VTT research concerning dual tyres vs super singles

The Road and Traffic Laboratory of the Technical Research Centre of Finland (VTT) started to make comparisons of different tyres, axles etc at the Virttaa test field in mid-1980s /1-2/. The test field is a three kilometre long, 40 meter wide part of a highway that is used as a temporary airfield by the Finnish Air Force. Any truck or vehicle combination can easily attain the maximum legal speed of 80 kms per hour and drive back on the other side. VTT has had there several heavily instrumented test sections.

The Virttaa test field has been used for
- developing pavement design,
- the measurements of the response of different vehicles (loads, axles, tyres, suspensions etc.).

VTT made measurements concerning the effects of tyre types and tyre pressures in 1984 and 1985. A more systematic research program was realized in 1987. The project included the comparisons of two dual tyres and three wide base tyres. All together, 51 combinations were measured.

The following tyres were used:

1. 12R22.5 dual tyres,
2. 265/70R19.5 dual tyres,
3. 445/65R22.5 wide base tyres,
4. 385/65R22.5 wide base tyres,
5. 350/75R22.5 wide base tyres.

The markings are inconsistent. The letter R means radial tyre, the figure after it means the diameter of the rim or the inner diameter of the tyre in inches. The first figure is the width of the tyre in inches (type 1) or in millimetres (types 2-5). In the past the height and width of a tyre has usually been about the same (the aspect ratio is 100 percent) but nowadays the tyres may be flatter. The height is 65 - 75 percent of the width in types 2 to 5 (the percentage is the number after the slash).

The tyres are typical, but not necessarily those most used in Finland, because the number was limited and enough variety in dimensions was needed. All are radial tyres. Tyres 1 and 3 can carry 11...12 tons (the legal axle load limit for single axles in Finland is 10 tons) and tyres 2, 4 and 5 can carry 8...8.5 tons (the legal limit for tandem axles is 16 or 18 tons). The diameter of the type 2 is 20 percent less than type 1 and that kind of tyres is used in order to have more height for the load or to have the trailer platform lower.

For technical reasons all the tyres were measured with three axle loads, in most cases 10 tons or the nominal maximum and 20 percent more and 20 percent less.

For each load three different tyre pressures were used. The tyre pressure that is recommended by the tyre manufacturer for that tyre and that load was taken as the base (optimal tyre pressure), and other tyre pressures were in most cases 20 percent more and 20 percent less. The tyre pressures varied from 480 to 1080 kPa, most common for optimal loads were 700... 850 kPa.

The basic results have been published earlier /3-7/. This presentation will handle them briefly and will concentrate more on later handling of data and more recent research.

The results are based on horizontal strain measurements on the bottom of the bituminous layers and vertical stress measurements on the subgrade and in unbound layers. In our standard set up ten strain gauges and six pressure cells are attached to amplifiers, to a/d units and further to a microcomputer.

A typical signal of a passing vehicle combination (six axles) is presented in figure 2 (directly from a computer display). The computer measures the peak values, which are shown on the right. The transverse position of the right side tyres is measured and shown in relation to the gauge line in the lower right hand corner. In figure 2 the front tyre is outside the line, the right edge of the left dual tyres of the tandem axles goes over the line, the front left dual tyre of the trailer goes over the line almost in the middle and the left tyres of the trailer tandem axles are exactly in the middle. Note too, the vehicle runs like a dog slightly sideways.

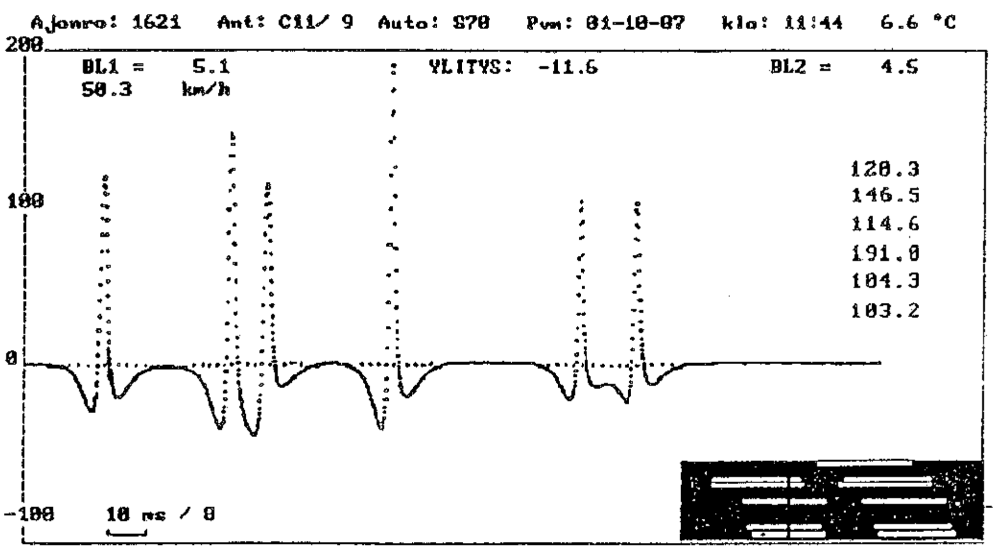

Figure 2. Typical signal from a strain gauge.

The peak values of the first axle of the trailer are presented as a function of the transverse position in figure 3 (directly from a computer display). The vehicle is the same as in figure 2. After the shape in figure 3 is well defined, the peak value is determined by hand using the "mouse" of the computer.

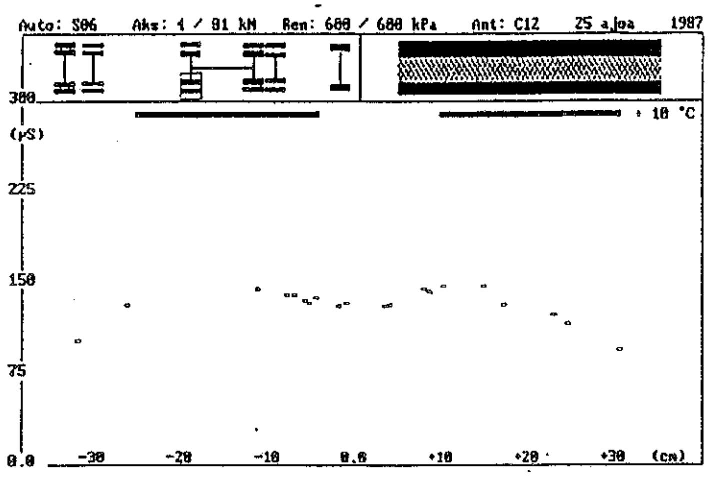

Figure 3. An example of strains as a function of the transverse position.

The strain or stress values are turned into an equivalent number of axle passes using appropriate failure (fatigue) criteria (the exponent of the "fourth power law" is in this case). Equivalent numbers are compared to that of a standard (reference) axle (a carrying ten ton single axle with dual tyres 12R22.5, the tyre pressure 700 kPa). That value is called the equivalency factor and describes the damaging power or the aggressiveness of the axle. If it is 2 for example, the pavement will last only half as long as it would with a standard axle. Because the equivalency factors are compared to each other, the exact validity of the failure criterion is not very important.

3. Results

The main results are shown in figures 4 and 5 as equivalencies as a function of axle loads. It can be seen from that the traditional dual tyre 12R22,5 causes the least stress on the pavement (least aggressive). The next best is the smaller dual tyre 265/70R19,5. The wide base tyres are also more aggressive than dual tyres. Within wide base tyres wider tyres are less aggressive than narrower tyres.

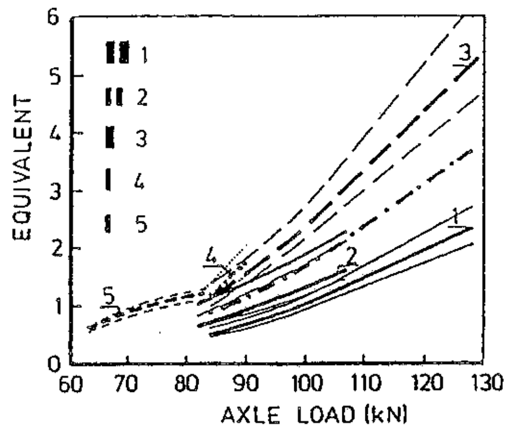

Figure 4. Equivalencies as a function of the axle load (80 mm AC).

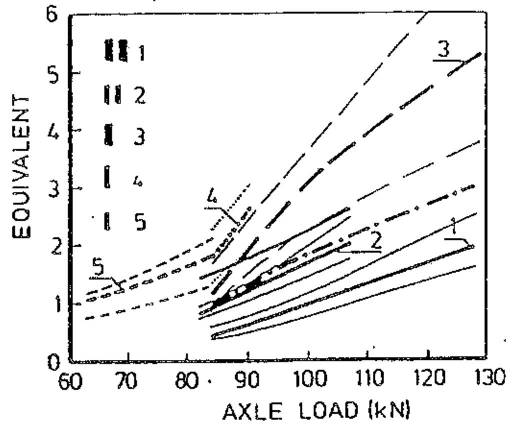

Figure 5. Equivalencies as a function of the axle load (150 mm AC).

The wide base tyres are relatively more aggressive on thin bituminous pavements than on thick pavements. All the tyre types seem to have relatively the same sensitivity for the change of relative axle loads. For instance 20 percent overload doubles the aggressiveness. Results are presented more in detail in other papers /3-7/.

4. Special problems in the comparison of the effects of dual and wide base tyres

4.1 Uneven load distribution in dual tyres

A special difficulty in the comparison of wide base and dual tyres is that the load in dual tyres is usually assumed to be divided evenly on both tyres. That is very seldom true and less load is allowed for a tyre in dual tyres than if the same tyre is a single tyre. The uneven load distribution between dual tyres may be due to:

- tyres have not worn similarly; for instance, one is older than the other,
- the manufacturer or the brand is not the same,
- the tyre may be new or retreaded,
- there is more or less fatigue in the carcass,
- different tyre pressures,
- different tyre temperatures and, due to that, different tyre pressures,
- uneven road (ruts, crown),
- the camber angle or the bending of the axle.

This effect of uneven load distribution has not been taken into account in any research project earlier. It was simulated in a series of measurements where one tyre had a tyre pressure 500 kPa and the other 1000 kPa. The values are arbitrary and give only some estimate of the effect of uneven distribution.

The effect of tyre pressures and uneven axle loads is presented in figure 6 (reference dual tyre 12R22.5). The simulation increased the equivalencies by 60 percent.

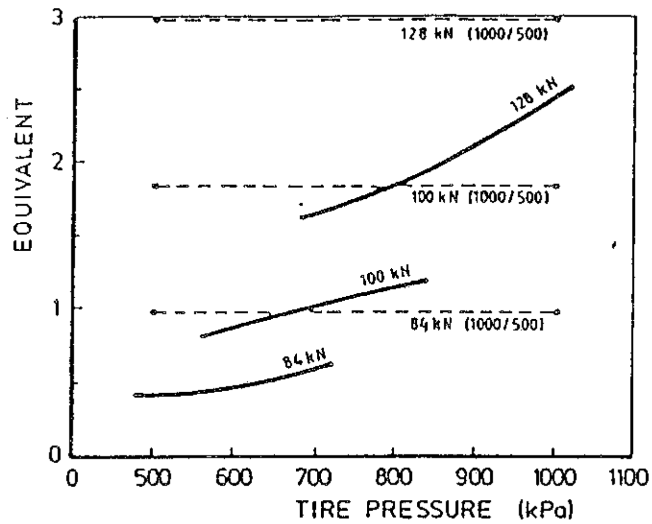

Figure 6. Equivalencies as a function of tyre pressure, (reference dual tyre 12R22.5). Simulation of uneven load by tyre pressures 500 to 1000 kPa.

4.2 The results taking account the transverse wander

All the preceding results were based on the highest values from the strain/transverse position figure. The shapes from wide base tyres and dual tyres are, however, different (Figure 7). Vehicles do not drive like trains but there is always some lateral wander. That is why the peak values do not come to the same transverse spot but are divided to a certain area.

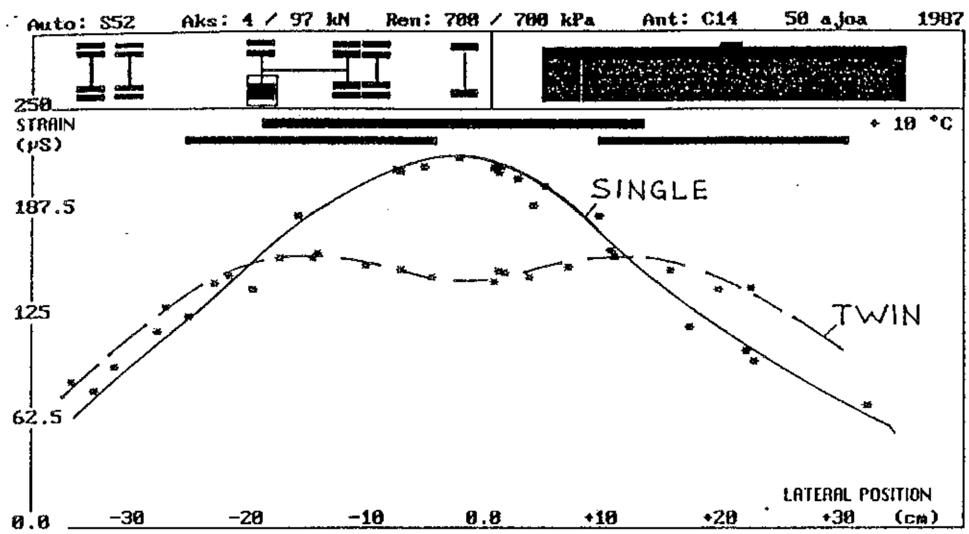

Figure 7. The strain shape because of single and dual tyre.

The results from the research project were "revisited". The wander effect was taken into account superposing the strain/transverse position figure and the lateral wander figure. As no good Finnish data for wander were available Danish measurements were used (Figure 8).

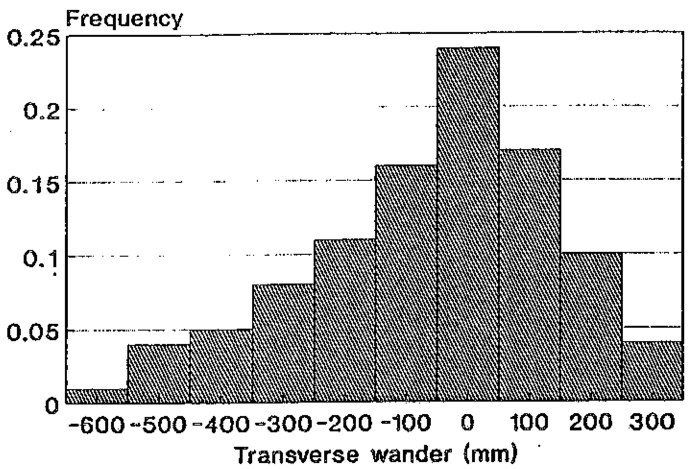

Figure 8. Frequency vs. the transverse wander of vehicle.

Because the strains from wide base tyres are much more peaked than the peak values due to dual tyres they are divided on wider area. Thus as the wander is taken into account the "multiplying" the wander and strain distributions.

Only some combinations were calculated. The main results are presented in Figure 9 and Table 1. The values in Table 1 present, how many more passes the pavement can take before the failure, if the wander effect is taken into account. The values are from 1.43 to 2.64. The mean value for wide base tyres is 2.25 and for dual tyres 1.56. Thus the values of wide base tyres received from peak values should be multiplied by 1.4 if the wander effect is taken into account and the difference between wide base tyres and dual tyres will be consequently smaller.

Table 1. The effect of wander on equivalents.

Tire code	Axle load	Equivalents	
	(kN)	Thin pavement	Thick pavement
445/65R22.5	81 97 126	2.21 2.26 1.99	2.14 2.09 1.94
385/65R22.5	29 81 87	2.64 2.26 2.30	2.39 2.22 2.10
350/75R22.5	60 70 81	2.53 2.54 2.24	2.23 2.25 2.18
12R22.5 twin	81 97 125	1.47 1.50 1.58	1.50 1.38 1.67
265/70R19.5 twin	29 79 104	2.13 1.50 1.54	1.58 1.48 1.43

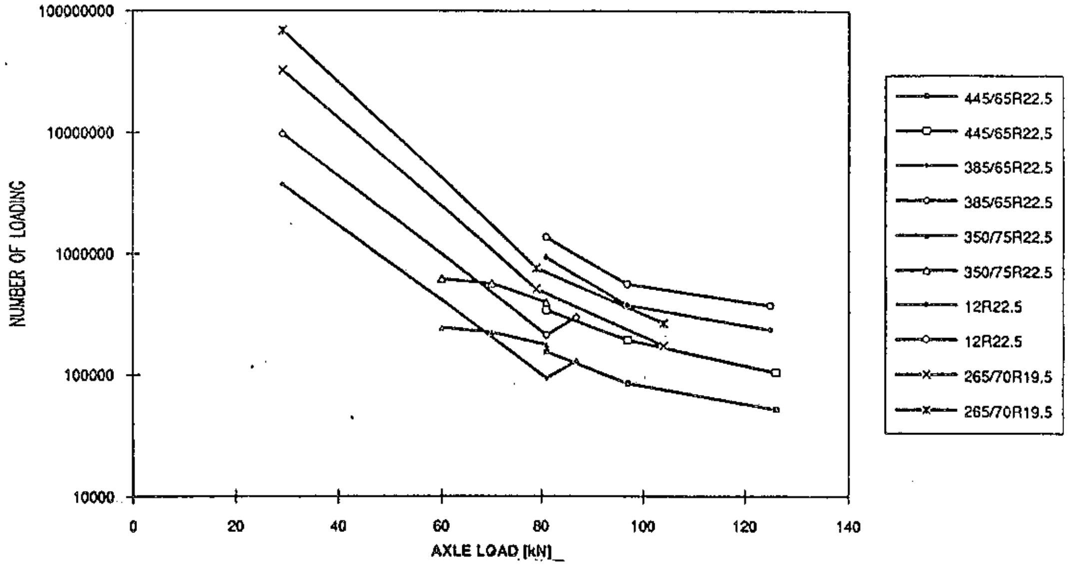

Figure 9. Number of loading vs. axle load of different tyres (80 mm AC).

The calculations above take only into account the separate wheels but not the total vehicle or vehicle combination. The following wheels do not drive the same path and thus the lateral wander effect complicates. Some patterns of vehicles and vehicle combinations used by VTT is presented in Figure 10. Only the right-hand side of the vehicle is drawn in the figure, note also the very different scales. The wheels are not following each other but especially the transverse position of the front tyre is different from others. The phenomena will be even more complicated as the vehicles run like a dog, not exactly straight but slightly sideways. That depends further to certain degree on the crossfall of the road. Thus it would be important not to calculate only the effect of different axles but the effect of total vehicle or vehicle combination. That has not been made by now but will be made later.

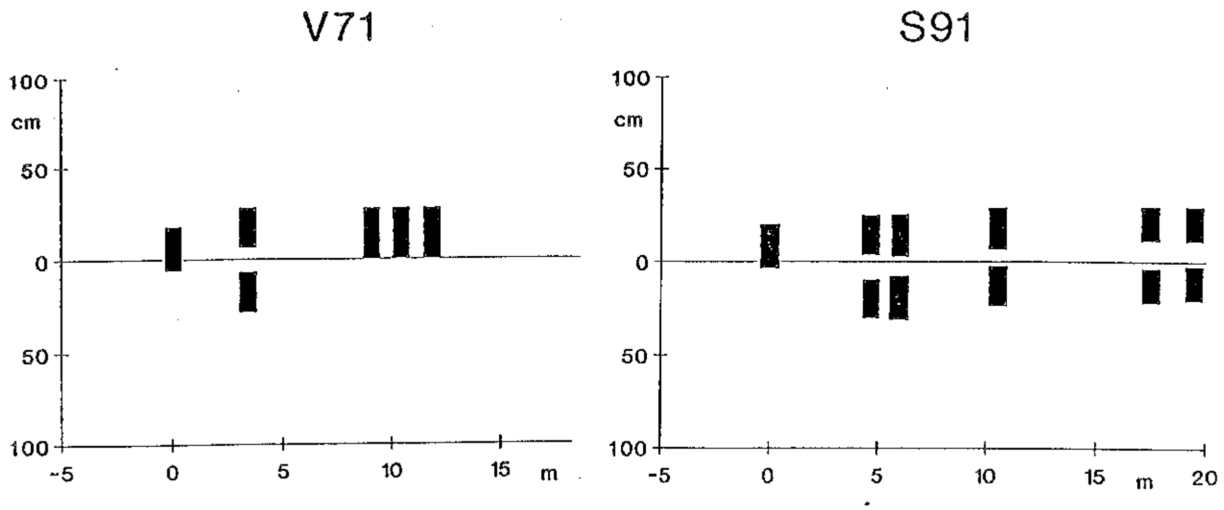

Figure 10. Patterns of vehicles.

4.3 The effects of the viscoelastic properties of pavement materials

The VTT system of strain measurement consists of strain gauges glued to six inch core samples. The gauges act as an integral part of the bituminous layer. The gauges have no elastic part and thus plastic deformation and relaxation can also be followed /8-9/.

A typical shape of a longitudinal strain at the bottom of the bituminous layers is presented in Figure 2 (the description of the figure is given in chapter 2). There is always compression first (negative values), then tension and subsequently compression. After the pass of an axle the strain level will be always about zero (no permanent deformation). In tandem axles there is always compression between the axles. Note also the difference in peak values of the tandem axle of the truck, due to the uneven load distribution on the axles.

The shape of the signal is not symmetric but relaxation can be found because of the viscoelastic nature of bituminous materials. The strain value is highly dependent on the temperature. The thickness of the bituminous layer also has a considerable impact on the strains.

The basic shape of the signal from transverse gauges is presented in Figure 11. There is no compression but only tension, and the tension decreases slowly to zero (relaxation). Because the temperature in this case is only 25 °C the relaxation is reasonably fast.

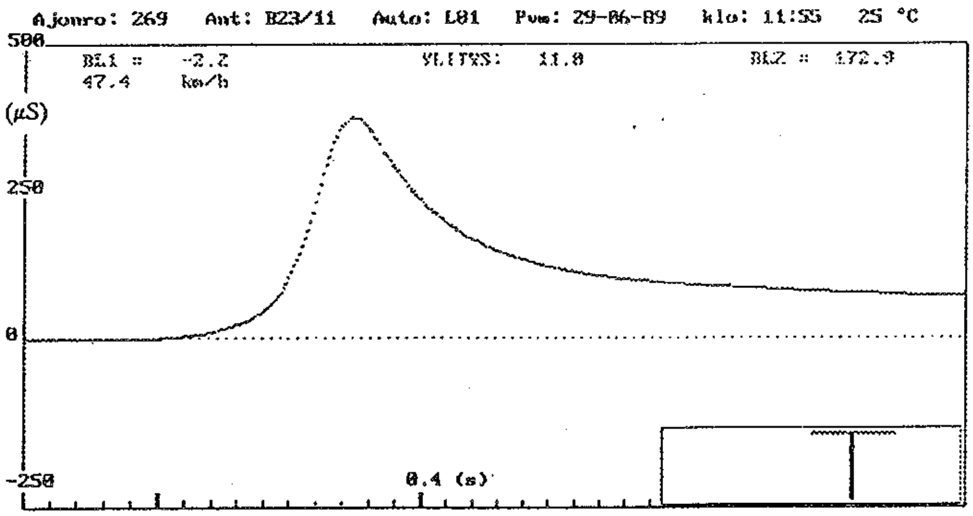

Figure 11. Typical signal from a transverse strain gauge.

If the following axle comes before the complete relaxation, the tension will accumulate and for instance after five axle passes it may be double that of the first axle (Figure 12). The accumulation is stronger at higher temperatures (39.6 °C). The tension is about 30 % of the highest tension values after one minute

(N.B., the time scale changes after 1.5 seconds from the beginning of the measurements).

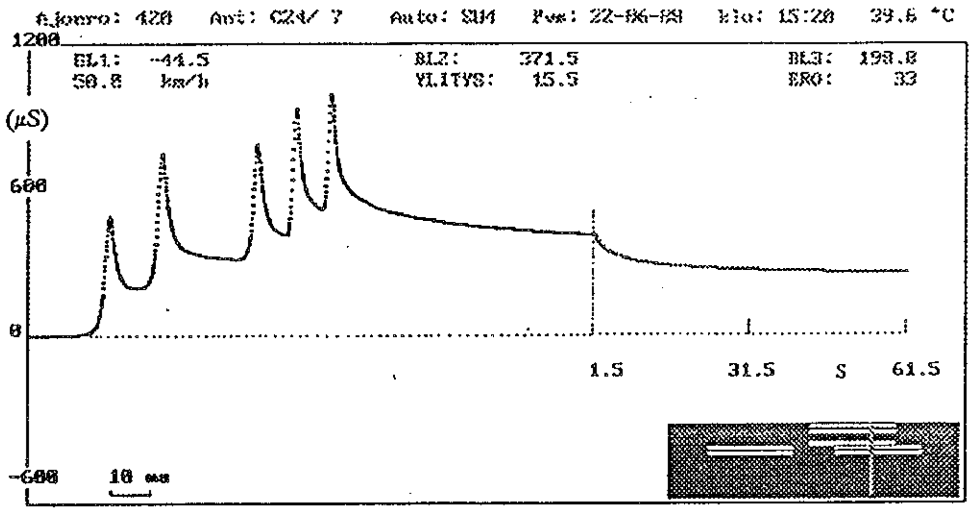

Figure 12. Accumulating transverse strains.

The shapes of the signal from longitudinal gauges are similar even the tyre does not pass over the gauge. The transverse gauges are very sensitive to the transverse position of the passing truck. Thus the cumulative value may be complicated, as in Figure 13 where the front axle passes over the gauge and the gauge remains between the dual tyres. The front axle causes tension which relaxes about 60 % before the tandem axle causes compression. The final "result" is compression which relaxes slowly.

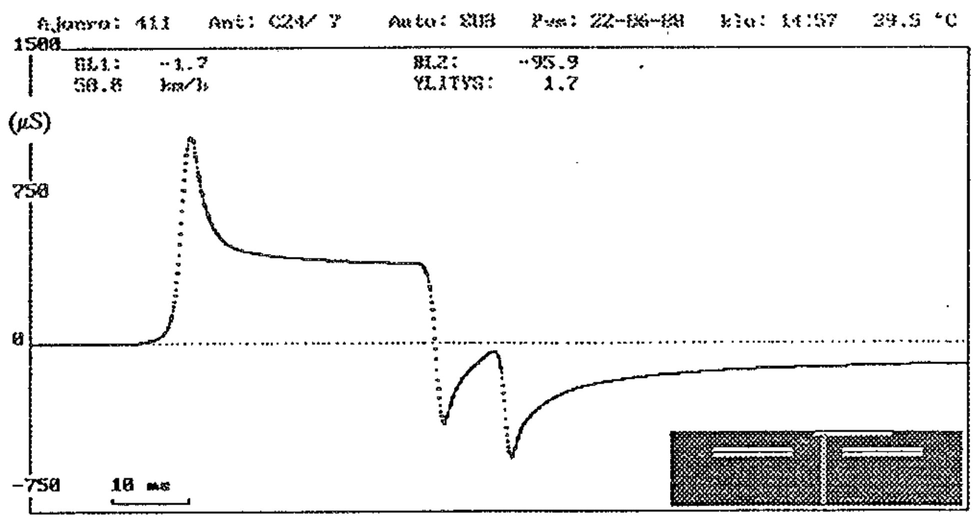

Figure 13. Cumulating transverse strains, tandem axles not passing over the gauge.

The strains from transverse gauges are usually 1.1 to 1.5 times greater than those from longitudinal gauges. If the temperature is higher the figure seems to be greater.

The load equivalencies based on longitudinal and transverse strains are different and should be handled separately. The transverse strains cannot be handled axle by axle but as a whole vehicle combination (a truck and a trailer). Because of the sensitivity of the strains in pavements due to transverse position the necessary number of passes for reliable results is high especially because measurements must be made at different temperatures. That is why a simulation computer program was developed and the simulation seems to work reasonably well.

The temperature of pavement was in the preceding examples relatively high and the special behaviour of the transverse strains is much more pronounced than in lower temperatures. It shall also be noted that bituminous pavements are designed according to the temperature range prevailing in each country and the temperatures in these figures may correspond much higher temperatures for instance in New Zealand.

All the fatigue tests have been made either with sinusoidal load or pulse load which more or less simulate longitudinal strains. Thus there is no practical evidence on the fatigue due to transverse strains, especially if the strain is accumulating. Direct analogies from other materials like metals cannot be applied because bituminous materials are viscoelastic by nature and self-healing occurs between the loadings. The combination of longitudinal and transverse strains may be very complicated.

5. Conclusions

The problem of dual tyres vs super singles is a very complicated issue because the behaviour of a bituminous pavement is very complex. A pavement consists of a viscoelastic bituminous material which lies on unbound layers, crushed rock, gravel or sand. Their mechanical properties are stress dependent. The contact pressure distribution between the tyre and pavement depends on the type of the tyre and also on the speed, load and tyre inflation pressure. The strains in bituminous pavements are not similar in transverse and longitudinal directions, the preceding axle pass may have effect on the strains due to the following (pavement has a memory) and the transverse position and wander of the tyres has its effects.

However, the following conclusions can be drawn:

Wide base tyres are more aggressive than dual tyres by a factor of 2.3 - 4.0 in ideal conditions for dual tyres. The load is very seldom evenly distributed on both dual tyres. The uneven load was simulated by tyre pressures. Despite this, wide base tyres were more aggressive by a factor of 1.2 - 1.9 if they were compared to the most common dual tyre. Within wide base tyres there are differences, by a factor up to 1.6 and within wide base tyres wider tyres are less aggressive.

All the differences are greater if bituminous layers are thinner and weaker if they are stronger. The values above are for pavements with 80 mm - 150 mm thick bituminous layers. More detailed conclusions are presented in references 3-5.

All the preceding results were based on the highest values from the strain/transverse figure. The shapes from wide base tyres and dual tyres are different. Vehicles do not drive like trains but there is always some lateral wander. Because the strains from wide base tyres are much more peaked than the peak values due to dual tyres they are divided on wider area. If the wander effect is taken into account the values of wide base tyres received from peak values should be divided by 1.4. Thus the difference between wide base tyres and dual tyres will be smaller than in earlier studies.

The load equivalencies based on longitudinal and transverse strains are different because of the viscoelastic properties of the bituminous materials and should be handled separately. The transverse strains cannot be handled axle by axle but as a whole vehicle combination (a truck and a trailer). If the first cracks are longitudinal, transverse strains are more important and vice versa. The relation of transverse and longitudinal strains depends also on the temperature and the type of the pavement.

6. References

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