

# The effect of wide-based tyres on pavements

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The recent development of tyres, axles and suspensions is very important from the point-of-view of the road engineers. Most of the new development seems to increase distress to the pavements. Wide base tyres replace often dual tyres. The comparison of their effects on pavements is not simple; different approaches have been used in this study.

## 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 (Fig. 1). In certain cases also the strains and stresses in other parts of the pavement structure shall be considered.

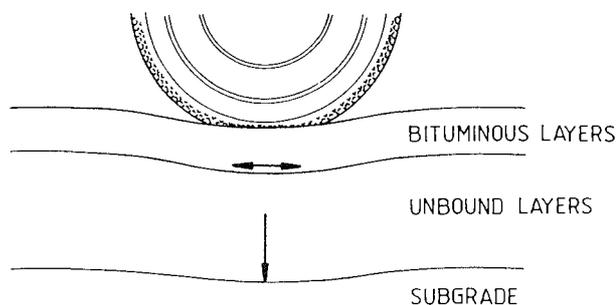


Fig. 1. The basic behaviour of a pavement under moving axle load; the critical strains and stresses.

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.

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 (mechanistic) 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 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 mechanistic 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 the uneven distribution of the load within tandem axles or dual tyres, which is seldom taken into account in mechanistic 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.

#### VTT APPROACH TO THE PROBLEM OF DUAL TYRES VS WIDE BASE TYRES

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 metre 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 Fig. 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 Fig. 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.

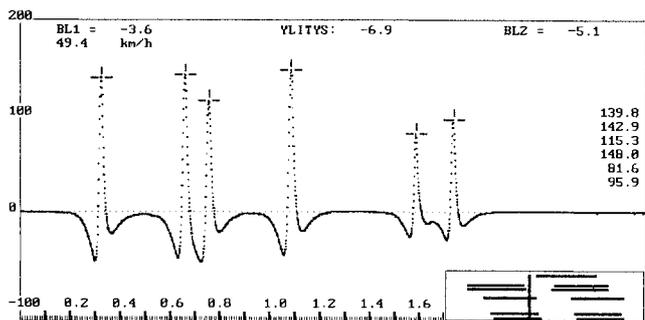


Fig. 2. Typical signal from a strain gauge.

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

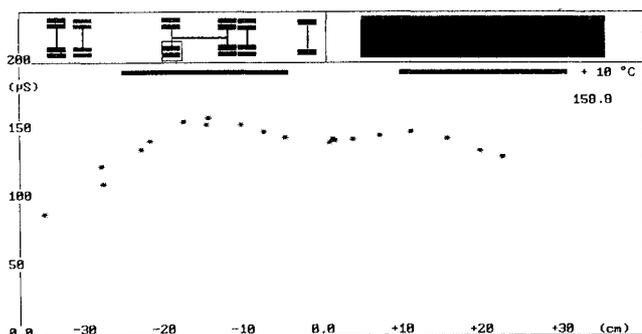


Fig. 3. An example of strains as a function of the transverse position.

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 4.2). 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.

RESULTS

The main results are shown in Fig. 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.

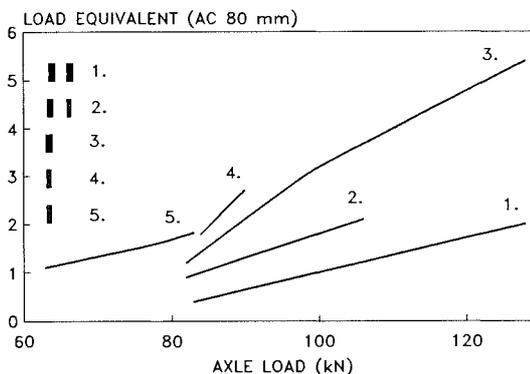


Fig. 4. Equivalencies as a function of the axle load (80 mm AC).

The wide base tyres are relatively more

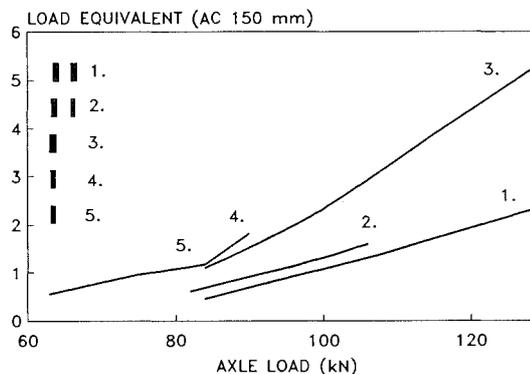


Fig. 5. Equivalencies as a function of the axle load (150 mm AC).

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.

The axle loads that correspond to equivalent value 1.0 have been taken from Fig. 4 and 5 and are presented in Fig. 6. The tyre pressures are optimal. It shows that for instance small wide base tyres of 60 kN axle loads have the same aggressivity as ordinary dual tyres of 100 kN axle load on thin pavement.

A vertical line has drawn on the same way in order to have equivalent values that correspond the same axle load 84 kN (Fig. 7). The axle load 84 kN has been selected because it is the only load which has been used on all the tyre types. The same kind of comparisons can be made for the whole area of Fig. 4 and 5, but interpolation and extrapolation are needed, which may give misleading results.

The equivalencies of all tyre types as a function of tyre pressure have been drawn in Fig. 8 (the axle load is 84 kN). It can be seen from

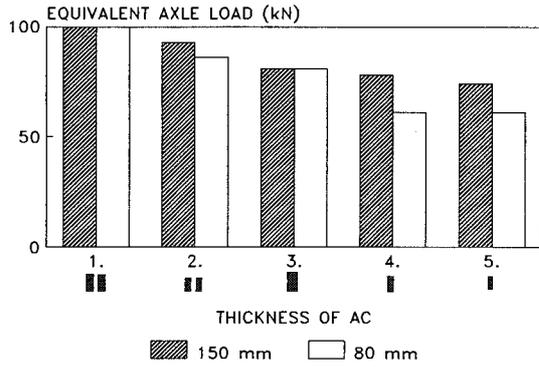


Fig. 6. Equivalent axle loads for tyre types.

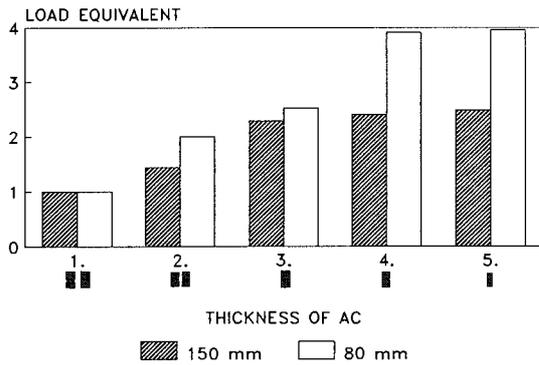


Fig. 7. Load equivalents for tyre types (axle load 84 kN).

Fig. 8 that there is no optimal tyre pressure from the point-of-view of the pavement, which is contrary to the opinions of some tyre manufacturers, but the equivalencies increase with tyre pressure.

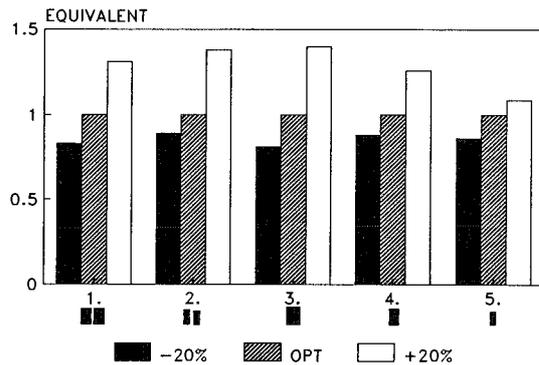


Fig. 8. The effect of tyre inflation pressure.

The results can be developed further to equivalencies for vehicle combinations, which are perhaps easier to understand. Trucks, trailers and semitrailers have been equipped with different tyre combinations and corresponding loading equivalencies for 80 mm bituminous layers are presented in Figs 9 and 10.

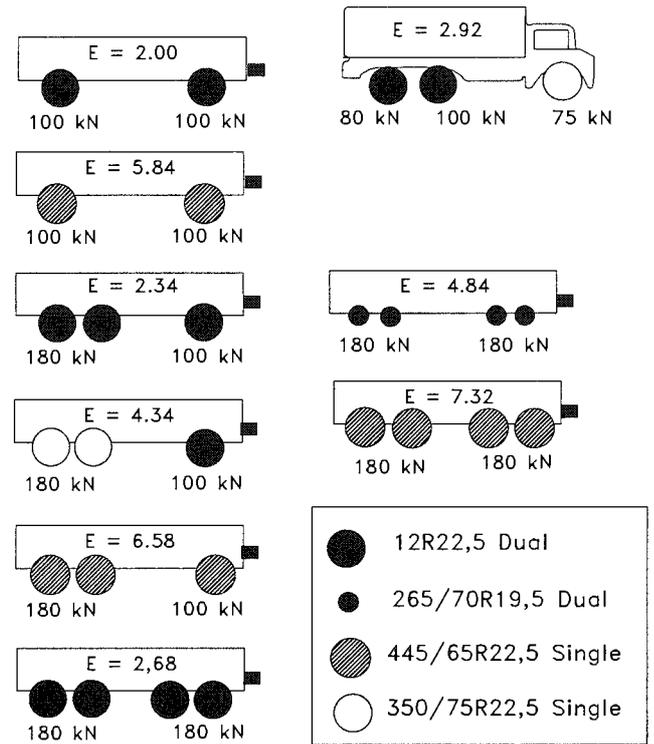


Fig. 9. Loading equivalents for trucks and trailers.

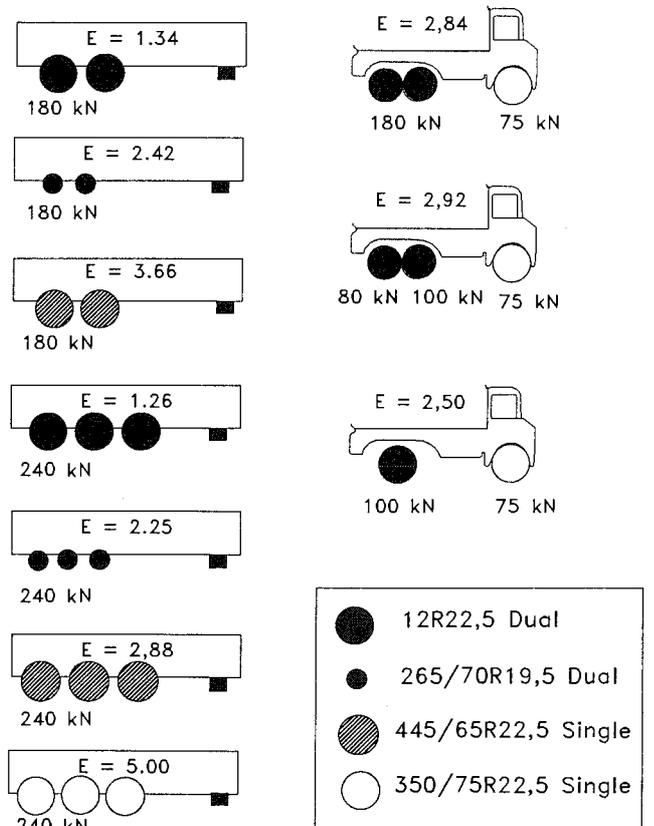


Fig. 10. Loading equivalents for trucks and semitrailers.

**SPECIAL PROBLEMS IN THE COMPARISON OF THE EFFECTS OF DUAL AND WIDE BASE TYRES**

**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. In this study it was simulated in a series of measurements where in dual tyres 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 Fig. 11 (reference dual tyre 12R22.5). The simulation increased the equivalencies by 60 percent.

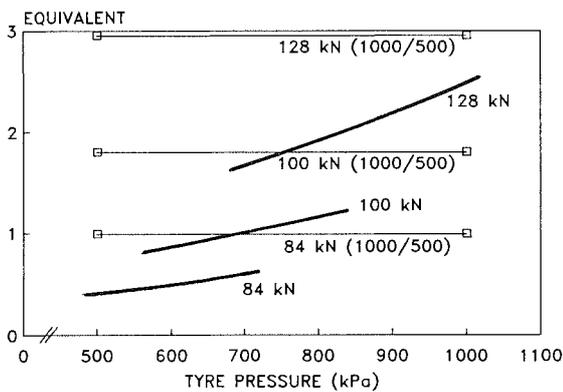


Fig. 11. Equivalencies as a function of tyre pressure, (reference dual tyre 12R22.5). Simulation of uneven load by tyre pressures 500 to 1000 kPa.

**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 (Fig. 12). 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.

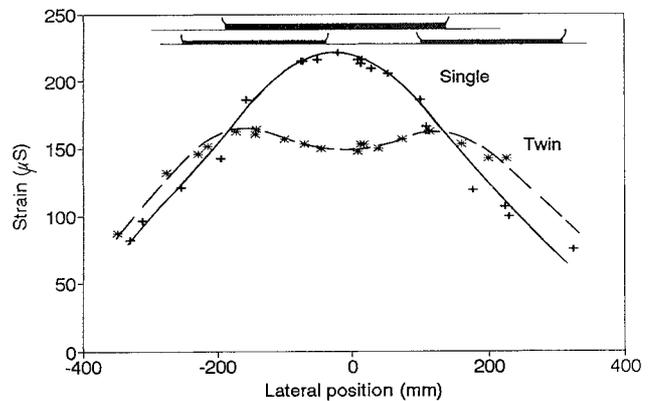


Fig. 12. The strain shape because of single and dual tyre.

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 (Fig. 13).

Because the strains from wide base tyres are much more peaked than the peak values due

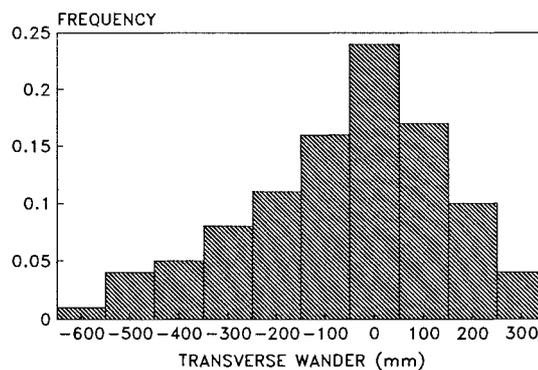


Fig. 13. Frequency vs. the transverse wander of vehicle.

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

A simpler approach was made. If the lateral wander is assumed to be divided evenly on one meter, it simulates in a simple way an ideal situation. Those results are presented in Fig. 14 as a function of the lateral wander: (1) no wander, (2) normally distributed wander, (3) evenly distributed wander. It makes the difference of equivalencies of dual tyres and wide base tyres smaller than approaches before.

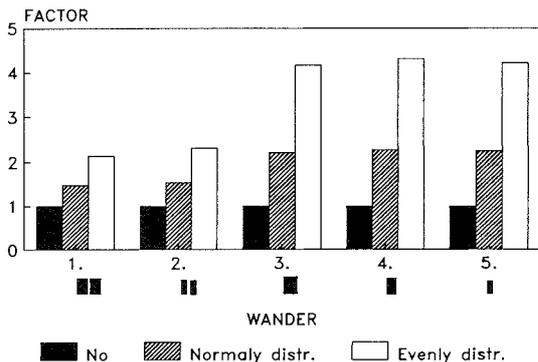


Fig. 14. The effect of different lateral wander assumptions.

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 Fig. 15. 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.

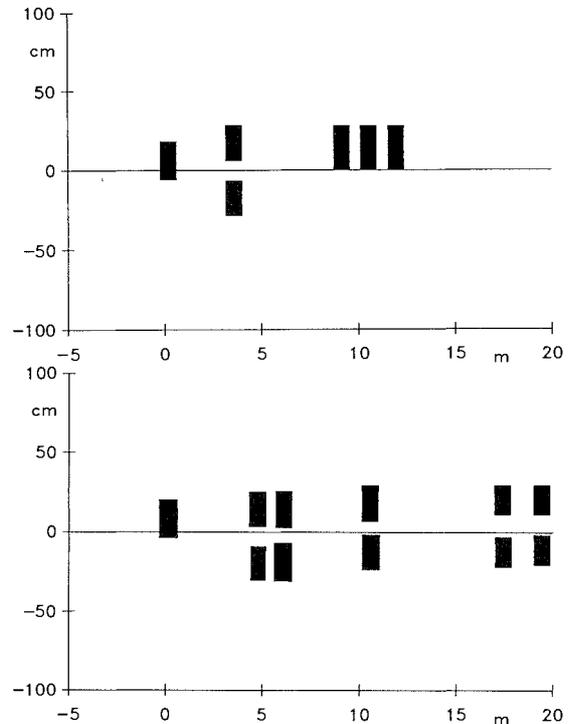


Fig. 15. Patterns of vehicles.

CONCLUSIONS

The problem of dual tyres vs wide base tyres 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. For example a six tons axle with the smallest wide base tyres has the same aggressiveness as the ten tons axle with normal 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.

As the tyre inflation pressure increases, the aggressiveness increases; there is no optimum. An increase of 20 percent increases the aggressiveness by a factor 1.1 - 1.4 times.

All the differences are greater if bituminous layers are thinner and weaker if they are stronger. 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.

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