The Effect of Different Trucks on Road Pavements

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BACKGROUND

During the last few years the technical development of trucks has been considerable. Besides single and tandem axles, tridem axles are also in use. The spacings of tandem axles vary, there are single and twin tires in the same tandem axle, double front axles, the load of a tandem axle is not always divided evenly on both axles, instead of twin tires super-single (wide base) tires can be used as well as smaller wheel sizes. Tire pressures seem to increase in many countries, new types of suspensions are used, especially the use of air suspensions is increasing. It is likely that most new solutions cause more distress to the road pavements than the traditional axles or tires.

In order to keep the distress to the road network reasonable, the road and traffic officials (or governments) set the rules, what are the maximum axle loads for each kind of axle, tires etc. The basic knowledge of the effect of different axles and tires dates from the AASHO Road Test of the early sixties and is not totally relevant any more. Because of the economical and political pressure groups, the governmental road officials have difficulties setting the rules for different trucks. For instance the Confederation of the Finnish Industries had a research study done this year concerning the benefits of increased road funds to the national economy (it included operating, time, accident and logistic costs). The main result was that one markka used for roads earns two point two markka to the national economy. It also included a recommendation of increasing the axle loads from 10 to 13 tons (from 22 to 29 kips) and the total weight from 48 to 60 tons (from 105 to 132 kips). The discussion continues.

For the economic calculations and the setting of rules, the effect of different axles, etc. must be known. Four different approaches can be used:

- full size road tests,
- theoretical calculations using multilayer or finite element computer programs,
- measurements of stresses and strains in road pavements caused by different axles, etc.,
- measurements of the dynamic forces 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. The most famous and complete is the AASHO Road Test in 1957 - 1961 from which the basic formulae of the influence of different axle loads and the equivalency of the single and the tandem axles come. The circular or linear test tracks have only limited use for this purpose. Road tests give the only real and reliable results and the results received by other means should be compared to those.

The theoretical calculations by multilayer or finite element computer programs are relatively cheap and easy but because the basic assumptions of the behaviour of the tires and the pavements must be simplified, the results may be unreliable and should be verified. However, the scope of the results received by other means can be extrapolated with theoretical calculations.

The stresses and strains in the road pavement due to passing vehicles can be measured. The results may reveal for instance the behaviour of different tires and uneven distribution of the load of tandem axles, which are seldom taken into account in theoretical calculations. The results are clear and easily understandable, which is important because of the economical and political pressure groups. The measurements are turned into equivalency factors using different failure criteria. Because the equivalency factors are compared to each other, their exact validity is not very important.

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In all four approaches, the road is even or assumed to be even. The influence of suspensions or tires is mostly neglected. That influence can be measured in a vehicle driving on an ordinary road or passing an artificial bump. The stresses and strains in the road pavement can also be simultaneously measured.

Because of the new technical solutions used in trucks and the vague knowledge of the effects of different axle configurations, tires and suspensions, the Road and Traffic Laboratory of the Technical Research Centre of Finland (VTT) have made measurements at the Virttaa test field since 1983. The study continues and includes also theoretical calculations.

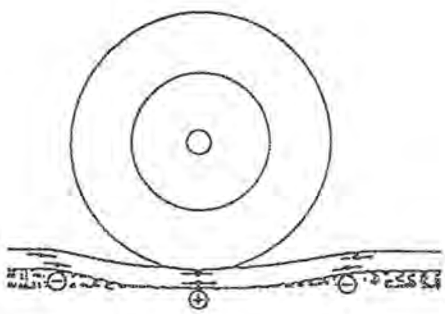
MEASUREMENTS

The critical points of the asphalt pavements are:

- horizontal tensile stresses at the bottom of the asphaltic layers,
- vertical stresses on the subgrade,
- plastic deformations of asphaltic layers.

When a wheel moves on the road, the asphalt pavement bends (Figure 1).Under the wheel there is a tensile stress at the bottom of the asphalt surfacing and a compressive stress at the surface. The tensile stress is critical for the pavement.

The pavement must reduce the stress due to the axle load small enough on the subgrade so that there will be no detrimental permanent deformations of the whole pavement structure.



Compressive (-) and tensile (+) stresses under a wheel load. Deformations not to a scale

FIGURE 1

The stiffness of an asphalt pavement is highly dependent on the temperature. At warm temperatures asphalt surfacings soften and tires may cause plastic deformations (permanent deformation) which is often seen as twin tire rutting, asphalt concrete "flows" from below the tire aside.

The Road and Traffic Laboratory of the Technical Research Centre (VTT) has developed gages for the measurements of stresses in asphalt pavements, originally for pavement design purposes, but by now they have mostly been used for comparing the effects of different trucks.

Instead of the horizontal stress at the bottom of the asphaltic layers the corresponding strain is measured, not only because of gage techniques but also because of the easier interpretations of the results.

The measurement of strains at the bottom of the asphaltic layers is easy in principle, attach a commercially available strain gage under the surfacing. If it is laid before paving, it must tolerate compacting and temperatures up to 150°C (300°F). If it is reinforced, it may be too stiff to follow the movements of the pavement especially at warmer temperatures. We considered for pavement design purposes that there is no reinforcing. We selected an approach, where a core sample is drilled from a pavement, a specially high-yield strain gage (well protected) is glued under the core sample and glued with a very thin layer of glue (less than 1 mm) to a hole in the test pavement. The OECD Road Transport Program Scientific Expert Group I2 (Full Size Pavement Tests) organized a common comparative strain measurement test at Nardo in Southern Italy in 1984. Nine teams from eight countries of three continents participated in the test. Our system proved to be successful.

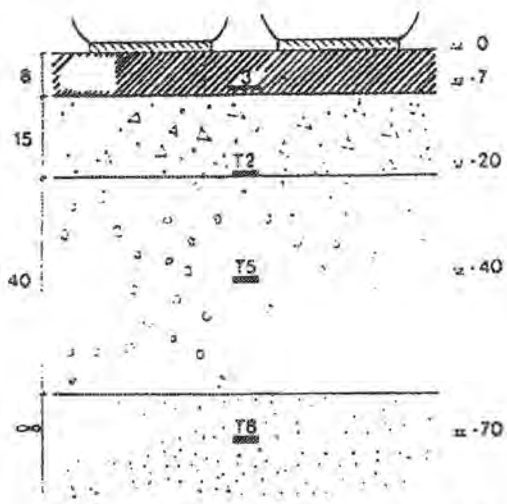
The vertical pressure in the subgrade and also in the unbound layers (gravel or sand) was measured by pressure cells which were first bought and later on made by ourselves in order to have as proper sensitivity and rigidity as possible for each situation.

It is very likely that our strain gages used in asphalt pavements are also suitable for the measurement of plastic deformations of the asphaltic layers. So far only a few measurements have been made. It is likely that only the axle load and tire pressure have influence on plastic deformations and from the point of view of this study these measurements were of minor importance but will be made, however later on.

The test field of Virttaa is on a 3 km (2 miles) long even part of a highway, which can be used as a temporary airfield even for jets. The test section was constructed in the road but outside the carriageway so that all the construction work was easy to do. All the trucks and truck combinations can easily attain the legal speed limit 80 km/h (50 mph) and rive back on the other side, circulating time is 5-6 minutes.

The first test section was constructed in 1983 having 80 mm (3 in) thick asphalt layer, 150 mm (6 in) crushed gravel, 400 mm (16 in) gravel on a fine sand subgrade. In 1985 two new test sections were added having asphalt layers of 50 mm (2 in) and 150 mm (6 in). The pressure cells are at three different depths (-200 mm, -400 mm and -700 mm, 8 in, 16 in and 28 in), always at least three at the same level in order to control their performance. The structure with gages is shown in Figure 2.

A typical signal from a strain gage at the bottom of an asphalt layer is presented in Figure 3 and from a pressure cell in Figure 4. In both cases the signals are caused by a truck with tandem axle, the transversal position of the truck to the gage line is shown at the upper corners of the figures. The signals were first registered by a very fast UV-recorder and measured by hand which was a huge task, in 1984 about 50,000 peaks. From 1985 on, a microcomputer was used, first an IBM PC, which was all too slow and now a Compaq, which stores the signals simultaneously from 16 gages, calculates the peak values, displays them as a function of the transversal position of the wheel, either with or without temperature correction, all that within a few seconds.

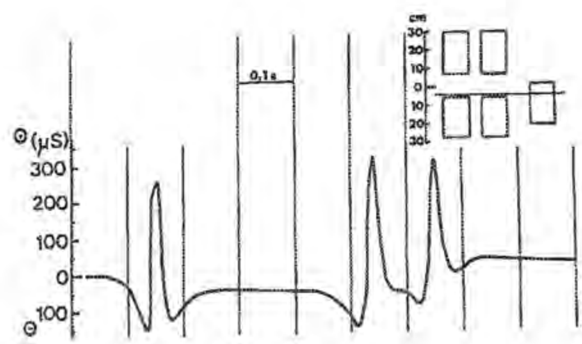


Cross section of a test structure. T2, T5 and T8 are pressure cells, 3 is a strain gage. This measures in centimeters

FIGURE 2

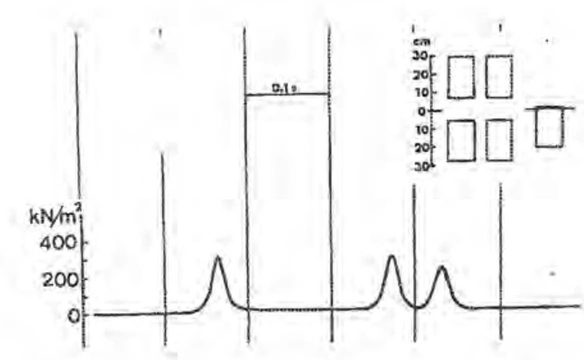
It proved to be very important to be able to measure the transversal position of the wheel passing at the speed of 80 km/h with an accuracy of about 10 mm. After studying different sophisticated possibilities we concluded to a very simple method, a thin layer of moist sand, where the imprint of the tire can be seen. A computer output of the stress versus the transversal position is shown as an example in Figure 5. The peak value of the curve is taken as the characteristic stress or strain value caused by the wheel.

The stiffness modulus of the asphalt pavement is temperature dependent and it is very necessary to make temperature corrections to the stress and strain values. In order to keep them as small as possible, most measurements were made in Sep-



Typical signal from a strain gage

FIGURE 3



Typical signal from a pressure cell

FIGURE 4

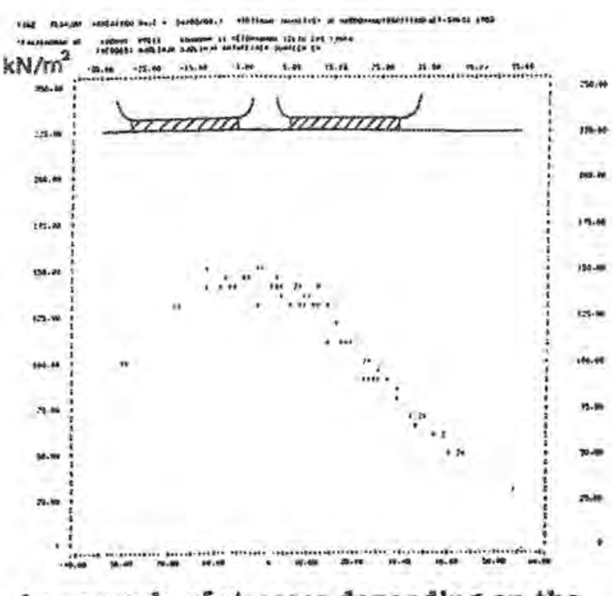
tember and October, when the daily temperature variations are small. Those temperatures are also close to the weighted mean temperatures of the asphalt pavements in Finland.

TRUCKS COMPARED IN 1983 AND 1984

In order to compare the effect of different axle configurations, tires, etc. we tried to select trucks which would include most types used in Finland. The trucks included in the measurements of 1983 are shown in Figure 6 and those of 1984 in Figure 7. Because the handling of the 1984 data took more than a year, it was not possible to renew in 1985 those measurements, whose results were doubtful. That is why in 1985 the emphasis was in the pavement design problems and in the measurements of the dynamic effects due to unevenness of the road (a pilot study).

The 1983 measurements can be taken as a pilot study and this paper will concentrate on the 1984 measurements.

The legal limit in Finland for a single axle is 100kN (10 metric tons, 22 kips) and a tandem axle 160 kN (15 tons, 35 kips). The legal limit for a tridem is 180 - 220 kN (18-22 tons, 39 - 48 kips) depending on the spacing of the axles. The limit for the total weight is 48 tons (106 kips).



An example of stresses depending on the transversal position of a wheel

FIGURE 5

The trucks and truck combinations, which were used in 1984, are presented in Figure 7.

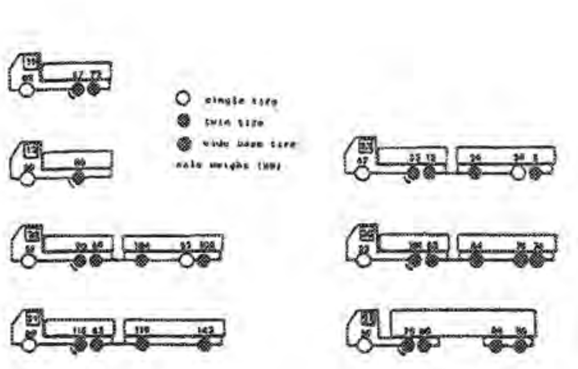
The front wheels were about the same in all the trucks (A-N).

The use of the second front axles have been increasing but not any more, their use may even be decreasing (A and C).

Single driving axles were in D and E. Other trucks had tandem axles, either both of them driving axles (I and K) or in most cases only one axle of the tandem axle was driving (A,B,C,F,G,L,M,N). If only one of the tandem axles is driving, the axle load of a tandem axle is not evenly divided, but usually about 55 percent is on the driving axle. The second axle can be lifted, if the truck is not fully loaded (lift-up axle).

A very special case is the mixed tandem axle in type L, where the front tandem axle has an ordinary single wheel and the rear tandem axle has twin wheels. The legal limit for this kind of tandem axle is the same 160 kN, the first axle 60 kN and the second one 100 kN. The single wheel axle is not usually made by the truck manufacturer but added later on by the companies specialized for that work. As far as is known, this kind of extra axle is a Finnish and Swedish specialty, but the export to Central-European countries has begun. The extra axle can be lifted up, when the truck is not fully loaded.

The same kind of extra axles are used with ordinary tandem axles in order to have a tridem axle e.g. in the trailer type L.



Different trucks and truck combinations used in 1983

FIGURE 6

All the tires were radial ply tires (not bias tires). Special wide base (super single) tires were used instead of ordinary twin tires in types B, G and L. The tire pressures were usually 800 kPa (115 psi), in one case (B) also 700 and 900 kPa (100 and 130 psi) were used.

No special attention was paid to different suspensions when the trucks were selected for the study. Air suspensions were in types L and M.

All the trucks were loaded to maximum axle loads and also to 10 - 20 percent over and underload in order to find out the effect of the load.

The effect of driving forces on the pavement was studied, driving two trucks (K and N) first normally and then the clutch detached.

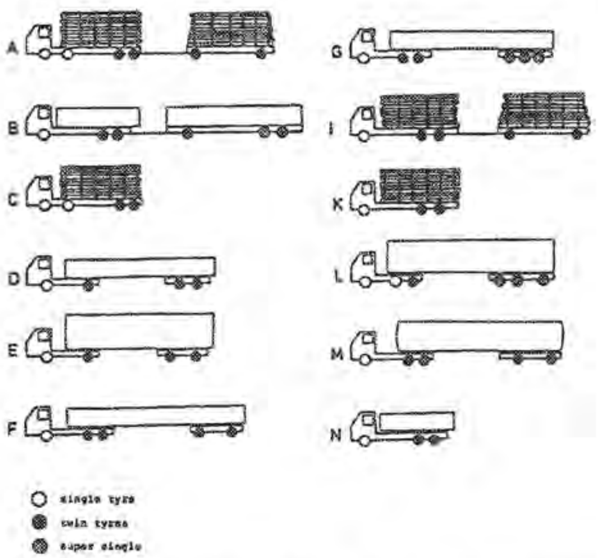
The driving speed was in theory 80 km/h, in reality usually 72-76 km/h.

RESULTS

The maximum value of curve fitted to the transversal position/strain (stress) figure (see Figure 5) was taken as a characteristic value. First analyses were made by drawing strain or stress as a function of axle loads but another approach was found to be more practical. Based on the characteristic strain or stress values the cumulative number of equivalent axle loads was calculated. That number is in principle the fatigue life of that pavement, that is to say the number of equivalent loads that deteriorates the pavement. The fatigue curves, which were used in making the Shell Pavement Design Manual, were utilized in this study. The basic concept is generally approved and widely used in pavement design.

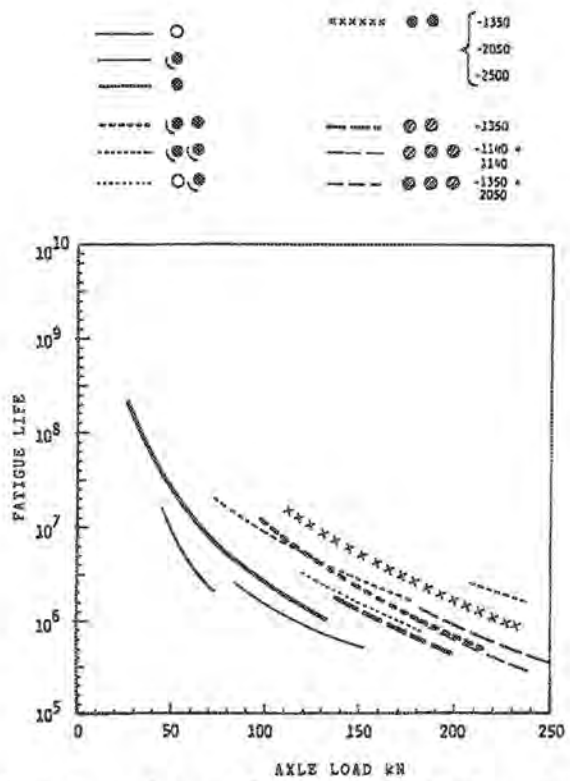
The main results of the study are shown in Figures 8 - 11. The load on the single, tandem or tridem axle is on the abscissa and the fatigue life expressed in cumulative standard axles on the ordinate. The nearer the curve is to the origin, the more detrimental the corresponding axle type is to the pavement. The length of the curves expresses the axle loads used in this study.

Figure 8 is based on the horizontal strain measurements made at the bottom of the asphalt courses. The front axle is the most detrimental, a driving single axle is slightly better, and a carrying axle is the most advantageous of the single axles. A tandem axle with super single tires is clearly more detrimental than an ordinary carrying tandem axle. The spacings of tandem axles had no influence.



Different trucks and truck combinations used in 1984

FIGURE 7

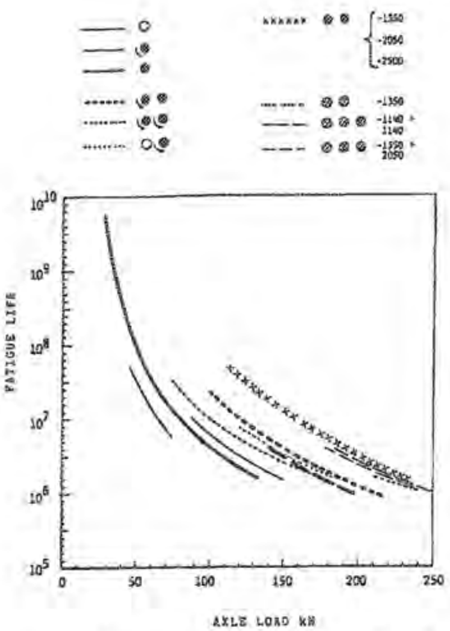


The comparisons of different axles based on the horizontal strains in the asphalt concrete

FIGURE 8

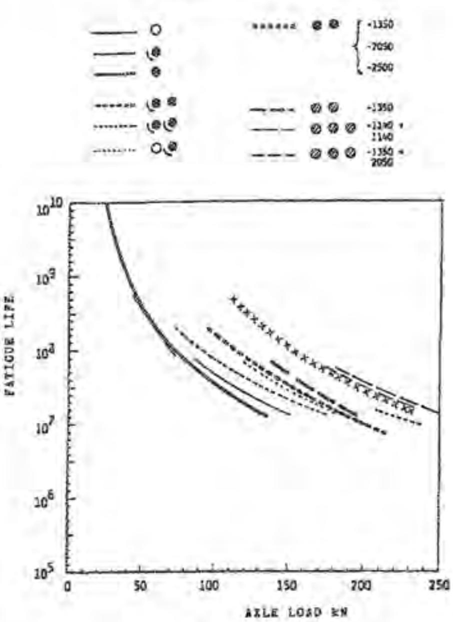
The mixed tandem axle is the most detrimental of the driving axles. A tandem axle with both axles driving was the most advantageous.

The tridem axles has super single tires. They were about as detrimental as tandem axles though they had one more axle. In the case of the longest spacing (L) the axle loads were uneven, which has also some influence on the results.



The comparisons of different axles based on the vertical stresses in the base course

FIGURE 9



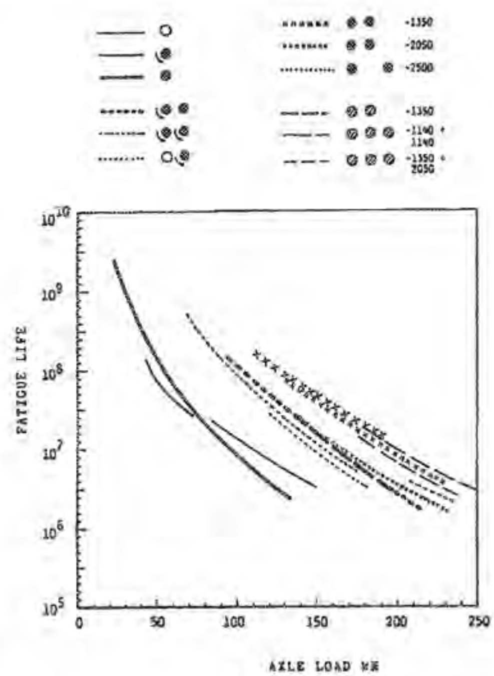
The comparisons of different axles based on the vertical stresses in the subbase

FIGURE 10

The effect of different axles for the base course is shown in Figure 9 (-200 mm from the surface), for the subbase in Figure 10 (-400 mm) and for the subgrade in Figure 11 (-700 mm). If the total thickness of a pavement is less than that of our test pavement, the values of the subbase (Figure 10) can ben taken as a subgrade.

Most curves in Figures 9 - 11 are similarly situated to each other as in Figure 8. The influence of driving axles is greater in the base and subbase course than in the asphalt surfacing. The detrimental influence of supersingle tires is less than in the asphalt surfacing, which is very logical, because in deeper layers the load pattern (single vs twin tires) and the tire pressure have less effect. Tandem axles are more advantageous compared to single axles in the subgrade. Mixed tandem axles are less advantageous compared to the other tandem axles. Unlike in the asphalt pavement, the spacing of tandem axles have some effect.

In order to have a quantitative result, the corresponding axle loads of different axle configurations were calculated (Table 1). The 100 kN



The comparisons of different axles based on the vertical stresses in the subgrade

FIGURE 11

Table 1 — Corresponding axle weights

	Bottom of asphalt layer	-200 mm	-400 mm	-700 mm
Trailer				
Single twin tire axle	100	100	100	100
Tandem axle, spacing 1.35 m	180	188	187	208
Tandem axle, spacing 2.05 m	180	188	187	195
Tandem axle, spacing 2.50 m	180	188	187	171
Tandem axle, supersingle tires, spacing 1.36 m	(122)	138	156	164
Tridem axle, supersingle tires, spacing 1.14 m + 1.14 m	(156)	181	201	202
Tridem axle, supersingle tires, spacing 1.36 m + 2.05 m	(148)	175	196	190
Tractor				
Front wheel	68	(78)	(86)	(100)
Tandem axle, one driving axle	146	147	145	166
Tandem axle, both driving	153&207	127&(160)	126&(160)	160&(175)
Tandem axle, single and twin tires	128	141	140	150
Single driving axle	83	110	108	113

Table 2 — The influence of different axles compared to legal limits

	Bottom of asphalt layer	-200 mm	-400 mm	-700 mm
Trailer				
Single twin tire axle	1.00	1.00	1.00	1.00
Tandem axle, spacing 1.35 m	0.62	0.45	0.45	0.24
Tandem axle, spacing 2.05 m	0.62	0.45	0.45	0.30
Tandem axle, spacing 2.50 m	1.48	1.32	1.32	2.34
Tandem axle, supersingle tires, spacing 1.36 m	2.50	1.82	1.07	0.85
Tridem axle, supersingle tires, spacing 1.14 m + 1.14 m	2.89	1.59	1.00	0.89
Tridem axle, supersingle tires, spacing 1.36 m + 2.05 m	6.41	2.64	1.70	2.14
Tractor				
Front axle	0.63	0.28	0.17	0.19
Tandem axle, one driving axle	1.45	1.38	1.48	0.81
Tandem axle, both driving	1.10	2.00	1.99	1.05
Tandem axle, single and twin tires	1.99	1.59	1.66	1.35
Single driving axle	1.66	0.69	0.76	0.65

carrying single axle was taken as a basis. Values in brackets have been extrapolated.

The legal limits of axle loads are in Finland: single axle 100 kN, tandem axles 160 kN (if the spacing is at least 2.5 meters, 200 kN), tridem axle 180 - 220 kN depending on the spacing. In Table 2 the influence of different axles are compared to those limits. If the value is more than 1.0 the axle is more detrimental from the point of view of the pavement and vice versa.

The standard tire pressure in this study was 800 kPa (115 psi). Some measurements were made using 700 kPa (100 psi) and 900 kPa (130 psi) Tire pressures. The strains and stresses were about 5 percent less in the former case and 5 percent more in the latter case. The results are only indicative because there were not enough points (with the present microcomputer measuring system that could have been seen during the measurements and more measurements could have been made).

We could not see any differences between the driving and carrying axles in the asphalt pavement, however, about 10 percent increase in the stresses in the unbound layers. The phenomenon is quite complicated, e.g. the distribution of the contact pressure between tire and pavement is quite different, if the wheel is driving or only carrying. The results here are based on a very small data.

Some measurements were made during the winter when the pavement structure is frozen. After the temperature correction due to the different asphalt stiffness was made, it was found that the strain in the asphaltic layer was 14 percent, stresses in base course and subgrade 30 and 15 percent of the unfrozen state. The water content of the pavement structure was not measured.

SUMMARY

If the values from Table 1 are combined, the results of the study can be summarized as follows:

A 100 kN carrying single axle with twin tires corresponds:

- a front axle of 75 kN,
- a driving axle of 90 kN,
- a driving mixed tandem axle of 140 kN,
- a driving tandem axle of 140 kN (both axles driving),
- a lift-up tandem axle of 150 kN (only first axle is driving),
- a carrying tandem axle of 180 kN (spacing 2.0 meters),
- a carrying tandem axle of 185 kN (spacing less than 2.06 meters),
- a tandem axle with super single tires of 130 kN,
- a tridem axle with super single tires of 165 kN (spacings 1.36 + 2.05 meters, load not evenly distributed),
- a tridem axle with super single tires of 170 kN (spacings 1.14 + 1.14 meters, load evenly distributed).

CONCLUDING REMARKS

The results of this study have not yet been compared to other studies.

All these measurements have been made on one pavement structure and at the temperatures close to 8°C (46°F), which is approximately the weighted mean temperature of the Finnish pavements. The temperature gradients were very small. In 1985 there were three different pavement structures but the results are not yet available. In 1985 some winter measurements were made and in 1986 measurements at higher pavement temperatures are foreseen, possibly including the measurements of permanent deformation (rutting). The measurements in 1986 will be more effective, because the microcomputer system works in real time and the measurements can be repeated until the transversal position/strain or stress curves are reliable.

The corresponding theoretical calculations using multilayer computer programs (Bisar, Chevron) have been begun.

The results which are only of interest for pavement design are not presented in this paper.

The studies concerning the effect of unevenness were begun in 1985 as a pilot study and will be continued in 1986.

From our initiative the Steering Committee of the Road Transport Research Programme of the OECD (Organisation for Economic Cooperation and Development) founded a scientific expert group I5 "Pavement Damage due to Heavy Freight Vehicles and Climate", which will make a state-of-the-art report of the theme. Its term is 1986-88 and in its first meeting in February the author was elected as a vice-chairman.

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