STRUCTURAL DESIGN OF CONCRETE BLOCK PAVEMENTS BASED ON TRANSVERSAL AND LONGITUDINAL UNEVENNESS

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Summary

At the Delft University of Technology a research program is performed to gain more knowledge about the development of permanent deformation (rutting) in Concrete Block Pavements (CBP), caused by traffic loadings. For this research a good insight into the stresses introduced in the substructure of a CBP is needed, as discussed elsewhere [1]. On the basis of the stresses that develop in the substructure of a CBP the development of permanent strain and the associated rutting is explained [2].
In this paper the results of numerous rutting calculations are discussed. In these calculations layer thicknesses, materials applied in the layers, wheel load magnitudes, wheel load lateral wander, wheel load contact pressures and subgrade stiffnesses are varied.
The effects of the axle load magnitude on the rut development combined with repeated vehicle simulation make it is possible to determine the development of longitudinal unevenness, i.e. a rut depth varying with the chainage. As shown in this paper a CBP can now be designed on the basis of both transversal and longitudinal unevenness.

1. Introduction

The goal of this research project is to get insight into the development of rutting in Concrete Block Pavements (CBPs). Hereto a method was developed that consists of three parts.
The first part of this method is the determination of the stresses that develop in the substructure as a result of a wheel load. As discussed in the paper "Resilient behaviour of Concrete Block Pavements and the Granular Materials used in the Substructure" [1] these substructure stresses are calculated by means of an axial-symmetric finite element model that takes into account the resilient behaviour of the applied granular materials as determined on the basis of triaxial test data.
The second part of this method concerns the permanent strain development in the substructure caused by the stresses in the substructure. As discussed in the paper "Rut Development in Concrete Block Pavements due to Permanent Strain in the Substructure" [2] the stress dependent permanent strain development in the applied granular materials is hereto taken into account. Again triaxial test data is needed, this time for the determination of the permanent strain development in the applied granular materials.

The third part of the method is discussed in this paper. The results of numerous calculations as discussed in [1] and [2] are used to describe the rutting behaviour of CBPs.
Given this rutting behaviour repeated vehicle simulation is applied to simulate the effects of dynamic axle loads on the development of both rutting and longitudinal unevenness (roughness).

2. Transversal unevenness (rutting)

2.1 *Introduction*

As discussed elsewhere [2] rut development in a CBP is a result of permanent strain development in the base, if any, the sub-bases and, in a properly designed CBP to a very small extent, the subgrade. This development of ruts in CBPs is described by an equation which equals the equation that was applied to describe the permanent strain development in granular materials [2]:

$$RD = A_c\left(\frac{N_{st}}{1000}\right)^{B_c} + C_c\left(\exp\left(D_c\frac{N_{st}}{1000}\right) - 1\right) \qquad (1)$$

Where:

RD:	rut depth [mm]
N_{st}:	number of wheel load repetitions [-]
A_c, C_c:	model parameter [mm]
B_c, D_c:	model parameter [-]

The method developed to determine rutting in CBPs results in the rut development as a function of N. By means of multiple regression the results of such calculations can

be used to determine the values of A_c, B_c, C_c and D_c. It is clear that these values amongst others depend on the substructure design, the applied granular materials, the amount of lateral wander, the wheel load, the contact area and the stiffness of the subgrade.
For this research numerous calculations are made. In these calculations the following input variations are considered:

Wheel load:	30 kN,	50 kN,	70 kN
Standard deviation of lateral wander:	100 mm,	200 mm,	300 mm
Substructure thickness:	500 mm,	1000 mm,	1500 mm
Thickness of the base course:	0 mm,	200 mm,	300 mm
Stiffness of the subgrade:	30 MPa,	60 MPa,	120 MPa

The wheel load was both varied on the basis of a constant contact area (radius 150 mm) and on the basis of a constant contact pressure of 0.707 MPa. A limited number of additional calculations was made considering very thick base layers of 450 mm and 750 mm.

Within these calculations three sub-base sands and two unbound base course materials are involved, resulting in six combinations. Similar to [1] and [2] in this paper only CBP designs in which the Zaanweg sand and the Pascalweg base material are applied are discussed. The same methodology is however also applied for the other five material combinations considered.

2.2 *Model parameter determination*

As mentioned before, the values of the rutting parameters A_c, B_c, C_c and D_c (equation 1) depend on the wheel load, the contact pressure, the standard deviation of lateral wander, the thickness of the base, the thickness of the sub-base and the stiffness of the subgrade.

In [2] the development of the rut depth as a result of permanent strains in the substructure was discussed. It is stated in that paper that the development of permanent strain throughout the CBP substructure is known. As a result the rut depth at any distance from the wheel track centre can be determined.
In the Netherlands the rut depth is mostly measured using a 1.2 m long straight edge. This relative rut depth as a result of the finite length of the edge can be smaller than the absolute rut depth, see figure 1.

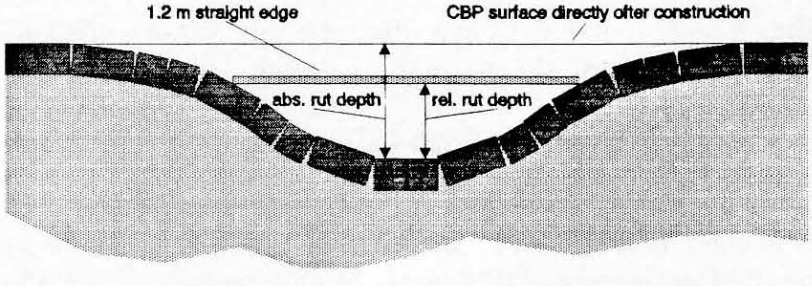

Fig. 1 Difference between the absolute rut depth and the relative rut depth.

To take into account the way the rut depth is mostly determined in the Netherlands, the calculations performed for the further development of the design method discussed here consider both the

rut development in the centre of the wheel track and the rut development 0.6 m from this centre. The difference between these two rut depths gives the relative rut depth as measured using a 1.2 m straight edge.
For CBPs without a base course the values of C_c and D_c equal zero, A_c and B_c are not equal to zero and thus have to be explained by means of multiple regression.
To limit the size of this paper the equations fitted trough the calculation data are not discussed here, only the results are given, see figure 2 and 3.

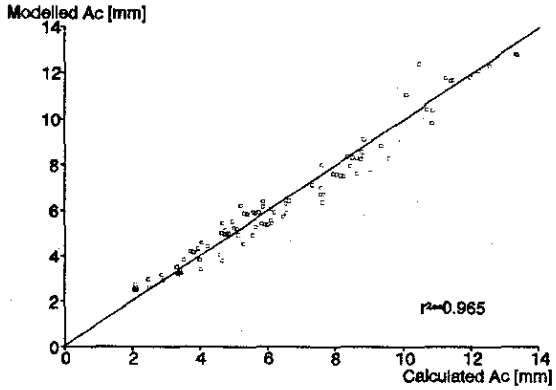

Fig. 2 Fit of the modelled A_c trough the calculated A_c for CBPs with a Zaanweg sand sub-base only.

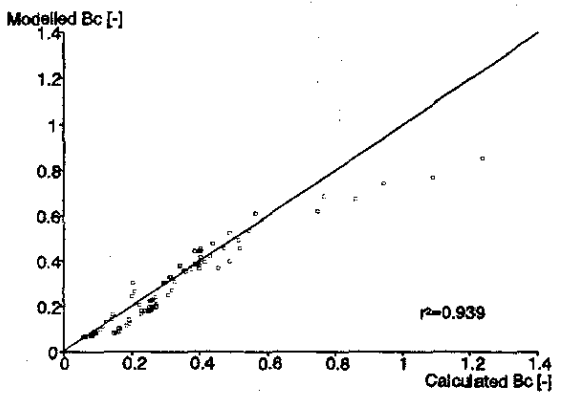

Fig. 3 Fit of the modelled B_c trough the calculated B_c for CBPs with a Zaanweg sand sub-base only.

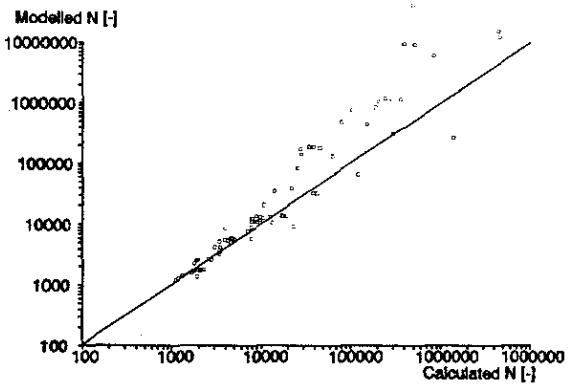

Fig. 4 Modelled design life plotted against the calculated design life for CBPs with a Zaanweg sand sub-base only.

In the figures 2 and 3 the modelled A_c and B_c values are plotted against the calculated A_c and B_c values. These calculated values are determined by regression on the calculated rut development of a single computation as discussed in [1] and [2].
Using the A_c and B_c values plotted in the figures 2 and 3, the development of the relative rut depth in CBP with only a Zaanstad sand sub-base is described. On the basis of these values of course the design life can be determined. In figure 4 this design life, based on a 15 mm relative rut depth at failure, as determined on the modelled A_c and B_c values is plotted against the design life determined on the basis of the calculated A_c and B_c values.
It is clear that the same analysis can also be performed for CBPs with a base course layer. Considering CBPs with a base course layer the rut development is again described by equation 1. Within the descriptions of the calculated rut developments D_c is related to C_c, $D_c=0.2 \times C_c$. For describing the behaviour of CBPs with a base course regression models explaining A_c, B_c and C_c are thus needed. Similar to the figures 2, 3 and 4 the results of this modelling are presented in the figures 5, 6, 7 and 8.

It is stated that the figures 5, 6 and 7 refer to CBPs with a base course of the Pascalweg base material over a sub-base of Zaanweg sand. All CBPs with a base course involved in this research have a 50 mm thick bedding layer of crusher sand.

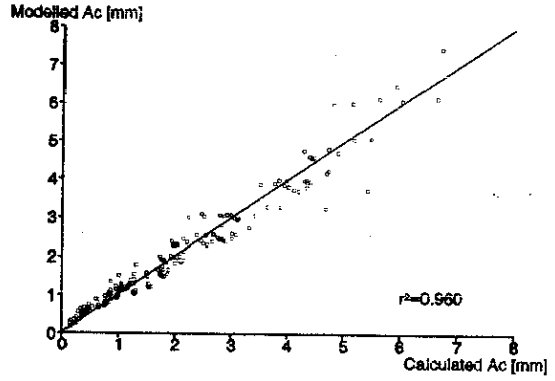

Fig. 5 Fit of the modelled A_c trough the calculated A_c for CBPs with a base of Pascalweg base material.

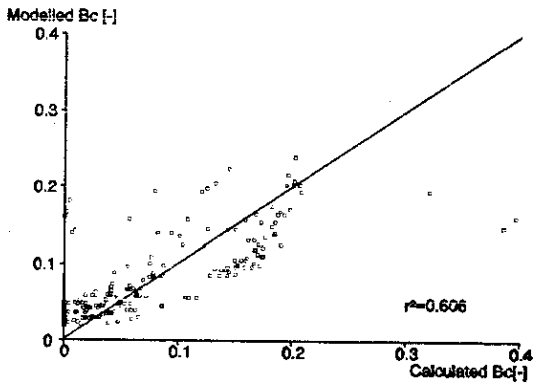

Fig. 6 Fit of the modelled B_c trough the calculated B_c for CBPs with a base of Pascalweg base material.

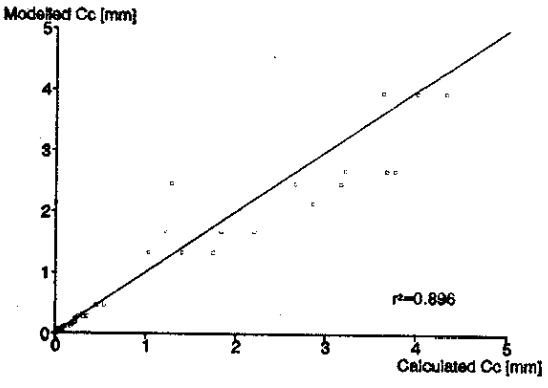

Fig. 7 Fit of the modelled C_c trough the calculated C_c for CBPs with a base of the Pascalweg base material.

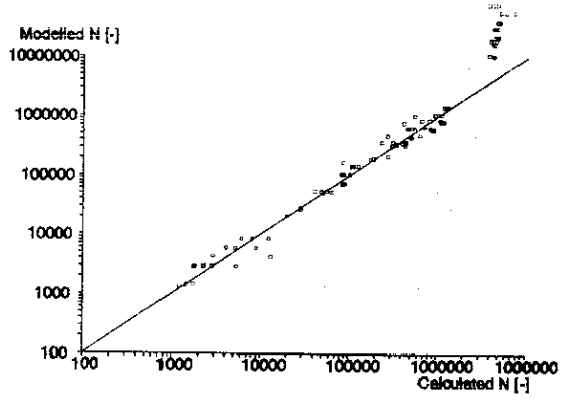

Fig. 8 Modelled design life against the calculated design life for CBPs with a base of Pascalweg base material.

2.3 *Model capabilities*

In the previous paragraph it is shown that the results of numerous calculations as discussed in [1] and [2] are described by equations fitted by means of multiple regression analysis. As a result we can now easily determine the values of A_c, B_c, C_c and D_c as a function of the wheel load, the standard deviation of lateral wander, the contact area or contact stress, the thickness of the base course, the thickness of the sand sub-base and the stiffness of the subgrade.
It is obvious that this information is the basis for CBP design. To show this four design charts are retrieved from the models discussed in the previous section. The

first two charts give the design life based on a 15 mm relative rut depth for CBPs with only a Zaanweg sand sub-base on a 60 MPa subgrade. The standard deviation of lateral wander, σlw, for these charts is 200 mm.
In the first chart, figure 9, the radius of the contact area of the various wheel loads is kept constant at 150 mm. In the second chart, figure 10, the radius of the contact area grows with the wheel load such that the contact pressure is constant at 0.707 MPa.

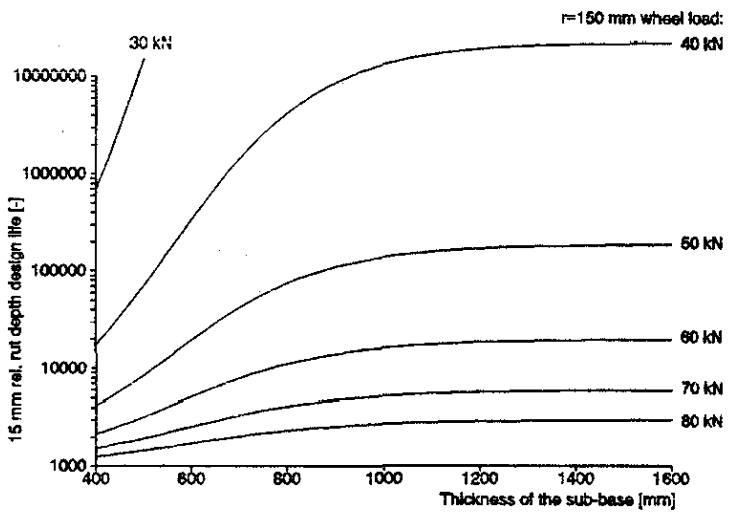

Fig. 9 Design life for CBPs with only a Zaanweg sand sub-base on a 60 MPa subgrade, σlw=200 mm.

For CBPs with a base course of the Pascalweg base material similar plots are made. For these plots the total height of the bedding layer, the base and the sub-base is kept constant at 1000 mm. Again the plots refer to a 60 MPa subgrade and a standard deviation of lateral wander, σlw, of 200 mm.
In figure 11 the 15 mm relative rut depth design life for various wheel loads, all having the same load contact area with a radius of 150 mm radius is given as a function of the base course thickness.
In figure 12 the design life for various wheel loads with a constant contact pressure of 0.707 MPa is given.

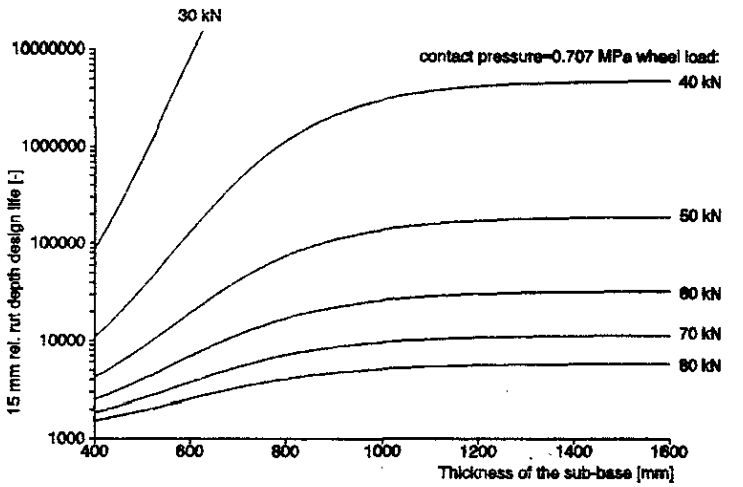

Fig. 10 Design life for CBPs with only a Zaanweg sand sub-base on a 60 MPa subgrade, σlw=200 mm.

As shown by comparing figure 9 with figure 10 and figure 11 with figure 12 the effects of wheel load variations is larger when the radius of the contact area is constant. This is of course only logical since a larger wheel load now also leads to a larger contact pressure.
By comparing the figures 9 and 10 with the figures 11 and 12 a major difference between the rutting behaviour of CBPs with only a Zaanweg sand sub-base and CBPs with a base course of the Pascalweg base material and a Zaanweg sand sub-base is found.

The figures 9 and 10 show that CBPs with only a Zaanweg sand sub-base show a smoothly decreasing design life if the thickness of the sub-base is reduced. Even when the sub-base thickness is reduced to 400 mm the design life for 80 kN wheel loads is still about 1500 wheel load repetitions (depending on the contact pressure).

In case of CBPs with a Pascalweg base a much more abrupt decrease of the design life is found with a decrease of the thickness of the base layer. This more abrupt decrease is a result of base course failure.

As discussed in [2] a sand can be forced to stresses very close to failure without showing very rapid permanent strain development, as a result it is difficult to overload a sand.

A base material however shows a different behaviour. These materials can not be subjected to stresses close to failure without showing extensive permanent strain development. As a result a base material is easier overloaded, resulting in a rapid decrease of the design life with a decrease of the base layer thickness.

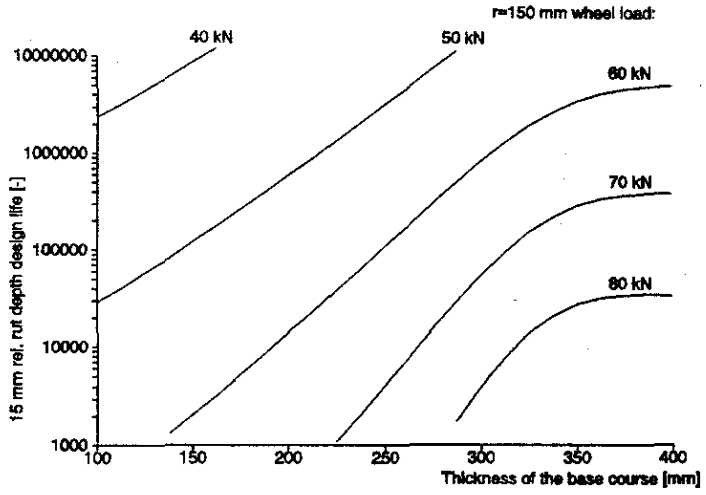

Fig. 11 Design life for CBPs with a Pascalweg base over a Zaanweg sand sub-base on a 60 MPa subgrade, σlw=200 mm.

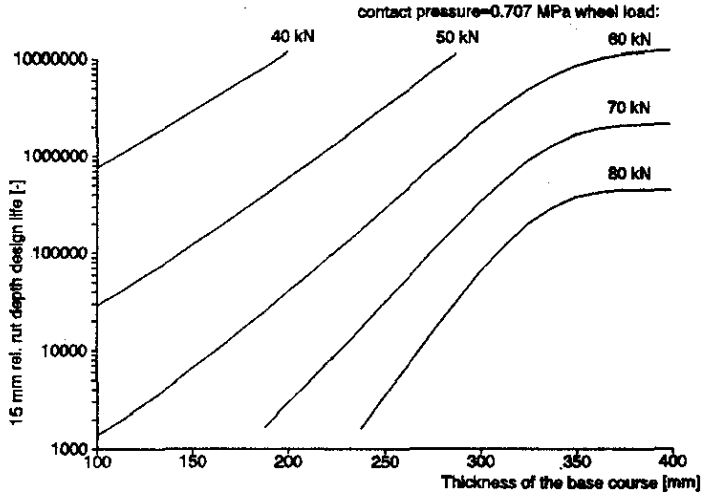

Fig. 12 Design life for CBPs with a Pascalweg base over a Zaanweg sand sub-base on a 60 MPa subgrade, σlw=200 mm.

Since the permanent strain development in an overloaded base material is more severe than the permanent strain development in a highly stressed sand CBPs with an underdesigned base layer have a shorter design life than the same CBPs without this overstressed base layer.

As shown by the figures 9, 10, 11 and 12 a Pascalweg base must be at least about 275 mm to 300 mm thick, depending on the contact pressure, to have a positive effect on the design life in case the CBP is loaded by 80 kN wheel loads. When the wheel load decreases the base layer thickness that leads to a positive effect on the design life of the CBP decreases too.

The figures 9 to 12 furthermore show the enormous positive effects of a well designed base course on the 15 mm relative rut depth design life. An increase of the design life by a factor 10 as a result of implementing a base is very well possible as shown by the following examples.
Without a base a CBP with a 1000 mm Zaanweg sand sub-base can only resist about 5000 80 kN, 0.707 MPa wheel loads, see figure 10. By implementing a 300 mm Pascalweg base course this design life is increased to about 60,000 wheel load repetitions.
In case of a 50 kN, 7.07 MPa wheel load the design life of the pavement with only a 1000 mm Zaanweg sand sub-base is about 120,000 wheel load repetitions. Applying only a 225 mm thick Pascalweg base increases this design life to about 1,200,000 wheel load repetitions.

3. Longitudinal unevenness

3.1 *Introduction*

Pavements mostly show some initial longitudinal unevenness. As a result of this initial longitudinal unevenness vehicles passing the pavement will show axle loads that are not constant over the chainage.
In the previous section (figures 10 and 12) it is shown that the rut depth introduced by an wheel load heavily depends on the magnitude of the load. As a result an axle load varying with the chainage will introduce a rut depth varying with the chainage. Given the initial longitudinal unevenness the first vehicle travelling over a CBP will thus introduce a rut depth that varies with the chainage.
Since the rut depth effects the height of the longitudinal profile in the wheel tracks a rut depth varying with the chainage effects the longitudinal profile. The second vehicle travelling the pavement will travel over a somewhat different longitudinal profile than the first vehicle. The rut depth introduced by this second vehicle will again not be constant, as a result the longitudinal profile is slowly changed by traffic travelling the pavement.
By combining the rutting behaviour of a CBP with repeated vehicle simulation the development of traffic introduced longitudinal unevenness as a result of a varying rut depth can be simulated as discussed in the next paragraphs.

3.2 *Rutting behaviour*

For the simulation of the development of longitudinal unevenness the rutting behaviour of a CBP is needed as input. In this paper the CBP without a base as discussed in [1] and [2] will be used as an example. This pavement only has a 1000 mm thick Zaanweg sand sub-base which is placed over a 60 MPa subgrade.
On the basis of the rutting regression model discussed earlier the rutting characteristics given in table 1 are determined for this pavement.
The parameters A_c, B_c, C_c and D_c given in table 1 describe the development of the rut depth under a 1.2 m long straight edge according to equation 1. These parameters are determined for a 50 kN wheel load with a contact pressure of 0.707 MPa. The standard deviation of lateral wander is 200 mm.

Rutting pavement characteristics σlw=200 mm , L_{st}=50 kN					
A_c [mm]	5.56	B_c [-]	0.201	C_c [mm]	0.00
D_c [-]	0.00	M_c [-]	10.95	RD_c [-]	1.64

Table 1. Rutting behaviour of the CBP with only a 1000 mm sand sub-base.

The parameter RD_c gives the relation between the rut depth under a 1.2 m long straight edge and the absolute rut depth, for this pavement the absolute rut depth thus equals 1.64 times the rut depth under a 1.2 m edge. The determination of RD_c is possible since the development of the absolute rut depth, not discussed here, is also known.
The parameter M_c, load equivalency coefficient, is used to transform N repetitions of a certain wheel load, L, to an equivalent number N_{st} of 50 kN wheel loads introducing the same rut depth, see equation 2.

$$N_{st} = \left(\frac{L}{50}\right)^{m_c} \times N \tag{2}$$

3.3 *Vehicle simulation*

As explained earlier even a new CBP shows minor longitudinal unevenness. As a result the axle loads that are introduced by a vehicle are not constant with the chainage, and thus introduce a varying rut depth.
The effects of the dynamic axle loads on the development of a rut depth varying with the chainage, i.e. longitudinal unevenness can be simulated. Hereto a vehicle is simulated travelling over a longitudinal profile. This vehicle is really a half vehicle, it does not have left and right wheels but only a front wheel and a rear wheel [3]. In other words the left side of the vehicle reacts the same as the right side of the vehicle, both sides of the vehicle travel over exactly the same longitudinal profile.
As the simulated vehicle travels over the longitudinal profile dynamic axle loads are computed. During these simulations the absolute rut depth introduced by the front wheel is computed and subtracted from the longitudinal profile height. This subtraction is performed since ruts lower the height of the profile in the wheel tracks. The rear wheels of the simulated vehicle as a result travel over a longitudinal profile which is slightly different than the profile travelled by the front wheels of the vehicle. In other words the rut depth varying with the chainage as introduced by the front wheels is already present in the longitudinal profile travelled by the rear wheels.
A similar computation is applied during the simulation to determine the absolute rut depth introduced by the dynamic rear wheel load.

As a result of these computations the longitudinal profile after a vehicle passage is somewhat different from the longitudinal profile before the vehicle passage. By repeating these vehicle simulations the development of a rut depth varying with the chainage and thus the development of longitudinal unevenness is simulated.

3.4 *Simulation results*

In this paragraph the results of eight repeated vehicle simulations are discussed. In four of these simulations the initial longitudinal profile only shows limited longitudinal unevenness. This initial longitudinal profile, profile "a", is based on the profile measured on a new CBP in the city of Zaanstad. The other four simulations refer to a initial longitudinal profile in which the amplitudes of longitudinal unevenness are twice as large, profile "b".
These longitudinal profiles are travelled by four trucks. The properties of these trucks are based on a two axled DAF truck discussed elsewhere [3]. These trucks are loaded by pay loads which are equally spread over the load area of the truck. The pay loads are chosen such that the static rear axle loads become 125 kN and 160 kN respectively (wheel loads of 62.5 kN and 80 kN respectively). For both these trucks, vehicle 125 kN and vehicle 160 kN respectively, two options are considered, option "a" refers to a truck which has new shock absorbers, while option "b" considers a truck from which the shock absorbers lost half their shock absorbing power.

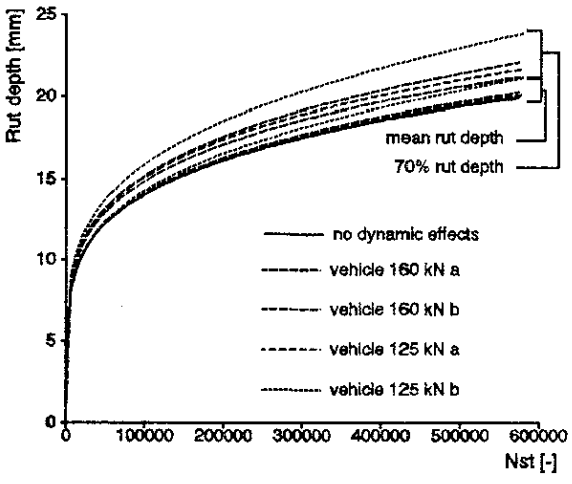

Fig. 13 Rut development for profile "a".

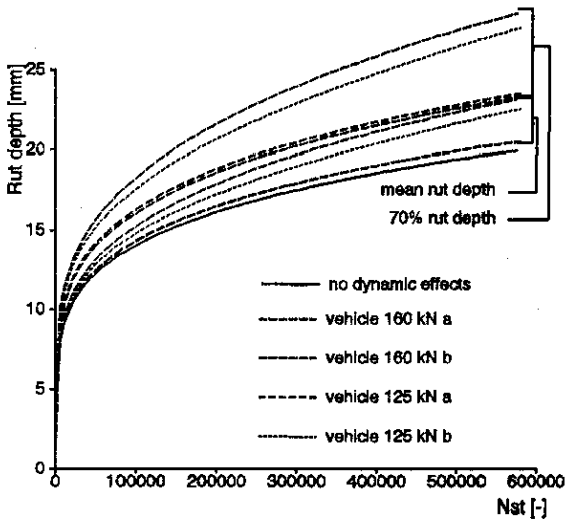

Fig. 14 Rut development for profile "b".

In the figures 13 and 14 the effects of dynamical axle loads on the relative rut depth development are shown. These figures clearly indicate that the rut development due to the repeated vehicle simulation is stronger than the rut development in case no dynamic effects are taken into consideration. It is clear that the design life, based on a 15 mm rut depth, is thus negatively effected by dynamic effects. In table 2 these effects on the 15 mm rut depth design life are presented.
Design life 1 in table 2 refers to the design life based on a 15 mm mean relative rut depth. As shown by this table this design life is reduced by 1% to 9% in case of initial profile "a", depending on the vehicle properties. In case of initial profile "b" this reduction is 11% to 34%, again depending on the vehicle properties.

In the Netherlands the characteristic rut depth with a 30% probability of exceeding, 70% rut depth, is mostly used as a design criterion. For this 70% rut depth the decrease of the design life as a result of dynamic effects is even stronger. In this case

initial profile "a" leads to a design life reduction of 26% to 46%. In case of initial profile "b" this reduction becomes 48% to 69%, again depending on the vehicle properties.

Longitudinal profile	Vehicle	Design life 1 x1000 [-]	Design life 1 % [-]	Design life 2 x1000 [-]	Design life 2 % [-]
a or b	none (static)	140	100	140	100
a	125 kN a	138	99	98	70
a	125 KN b	127	91	76	54
a	160 kN a	136	97	103	74
a	160 kN b	135	96	94	67
b	125 kN a	124	89	67	48
b	125 kN b	106	76	48	34
b	160 kN a	125	89	73	52
b	160 kN b	93	66	43	31

Table 2. Design life as influenced by tacking into account dynamic vehicle effects.

Table 3 is given to show the effects of the initial longitudinal profile on the 15 mm rut depth design life. In this table the 15 mm design life for profile "b" is given as a percentage of the same design life obtained on the basis of profile "a".

Vehicle	Design life 1 % [-]	Design life 2 % [-]
125 kN a	90	68
125 KN b	83	63
160 kN a	92	71
160 kN b	69	46

Table 3. Design life for profile "b" as a percentage of the design life for profile "a".

Repeated vehicle simulation also gives insight into the effects of vehicles on the development of the longitudinal profile of a CBP. These effects can amongst others be shown by means of the International Roughness Index IRI.
The IRI is calculated by simulating a standardized quarter vehicle travelling over a longitudinal profile at a speed of 80 km/h [3], [4] and [5]. During this simulation the

movements in the shock absorber of the IRI quarter vehicle are summed-up. Dividing these summed-up shock absorber movements by the travelled distance the IRI [mm/m] is obtained. The higher the IRI the rougher the longitudinal profile and thus the less the driving comfort.

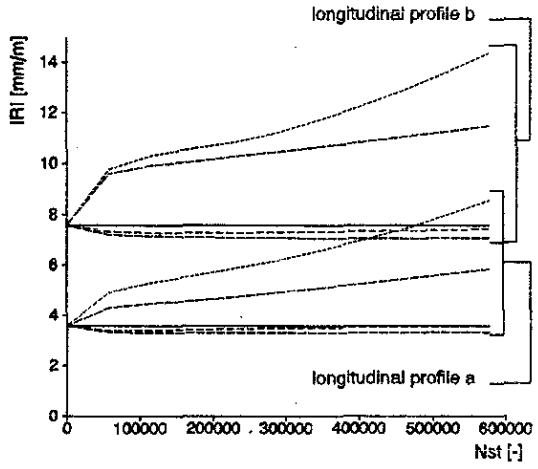

Fig. 15 The development of the IRI.

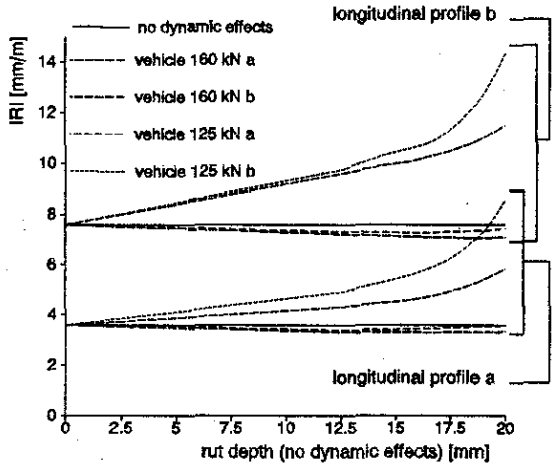

Fig. 16 The development of the IRI.

In the figures 15 and 16 the development of the IRI is presented. As shown by these figures the IRI will show a minor decrease if the CBP is travelled by the vehicles 125 kN a and 160 kN a. When the CBP discussed here is however travelled by the vehicles 125 kN b and 160 kN b a strong increase of the IRI is observed.
As shown by the figures 15 and 16 the increase of the IRI as determined for the vehicles 125 kN b and 160 kN b shows a progressive character. This is especially the case when the IRI is plotted against the rut depth calculated without taking into account dynamic effects, figure 16. This figure shows that the effects of vehicles on longitudinal unevenness become stronger when the rut depth becomes more serious. In case of an increase of the IRI due to dynamic vehicle effects a CBP will show a strong progressive increase in roughness implying chances of CBP failure as a result of roughness.

The IRI can also be calculated simulating the IRI quarter vehicle at other speeds than 80 km/h. Of course the results of such simulations can no longer be called IRI-values, for the sake of simplicity they will be referred to as IRI*. In the figures 17 and 18 the results of such IRI quarter vehicle simulations performed on the longitudinal profiles after 570,000 50 kN equivalent wheel load repetitions are presented, the value plotted at 80 km/h equals the regular IRI discussed earlier.

The figures 17 and 18 are very interesting. By varying the speed of the IRI quarter vehicle the wave length of unevenness for which the vehicle is sensitive is varied too. The higher the speed of the IRI quarter car the longer the wavelength for which the vehicle is sensitive. The plots given in the figures 17 and 18 as a result give a sort of fingerprint of pavement roughness.
Both the initial longitudinal profiles lead to an almost constant IRI*-value at speeds larger than about 20 km/h, see lines for no dynamic effects in the figures 17 and 18.

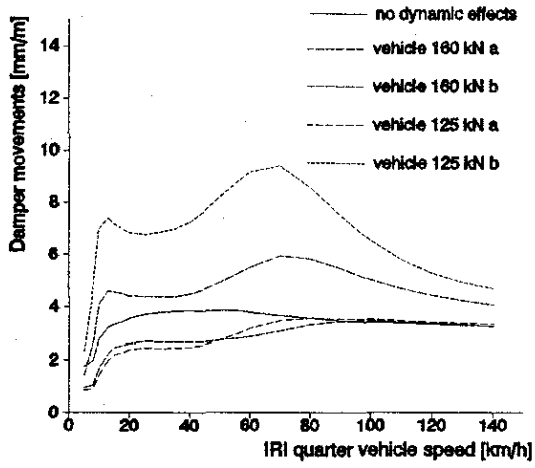

Fig. 17 Movements in the IRI vehicle shock absorber, longitudinal profile 'a'.

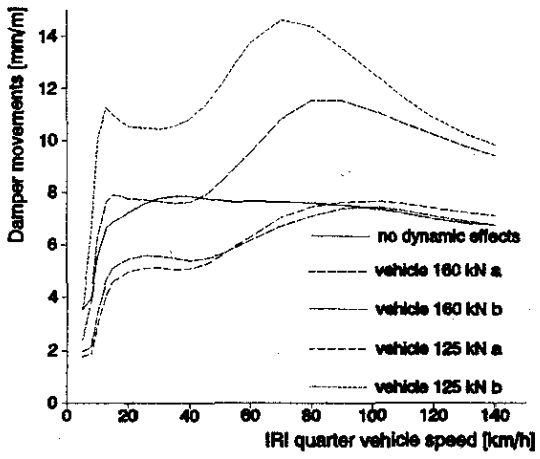

Fig. 18 Movements in the IRI vehicle shock absorber longitudinal profile 'b'.

The longitudinal profiles obtained after the repeated vehicle simulations discussed here lead to a IRI* that shows a strong dependency of the simulated speed. This indicates that the simulated vehicles have a wavelength dependable effect on longitudinal unevenness.

The lines found for the vehicles 125 kN b and 160 kN b in the figures 17 and 18 show a very strong resemblance with similar plots made on the basis of measured longitudinal profiles of CBP [3].

In the figures 19 and 20 the development of longitudinal unevenness in a 20 m long section of longitudinal profile "a" is presented. Figure 19 refers to the results obtained by simulating vehicle 125 kN a, in figure 20 the results of simulating vehicle 125 kN b are shown.
In the figures 21 and 22 the dynamic rear axle loads of respectively vehicle 125 kN a and 125 kN b are shown. These figures correspond with the figures 19 and 20 and show the development of the dynamic rear axle load with N.

The figures show that both vehicles have a smoothing effect on very short waved unevenness (wavelength < 1m). The effects of vehicle 125 kN a on unevenness with longer wavelength is only small, figure 19.
Considering figure 20 a total different picture is found. Vehicle 125 kN b again smoothens very short waved longitudinal unevenness. Unevenness with a wavelength of about 2.5 m is however enlarged by this vehicle as is clearly shown in the second half of the plotted profile section. Furthermore longitudinal unevenness with a wavelength of about 12.5 m is enlarged by this vehicle.

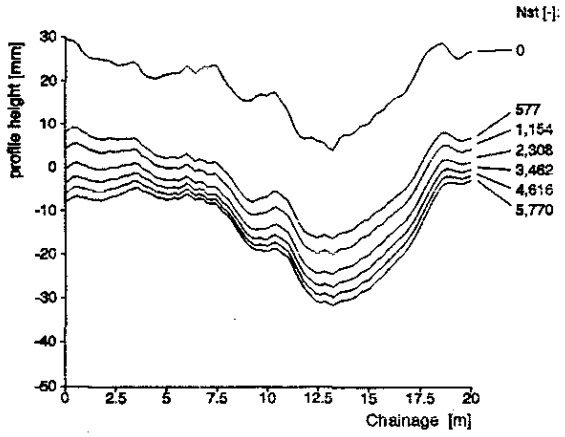

Fig. 19 Development of longitudinal profile "a" (vehicle 125 kN a).

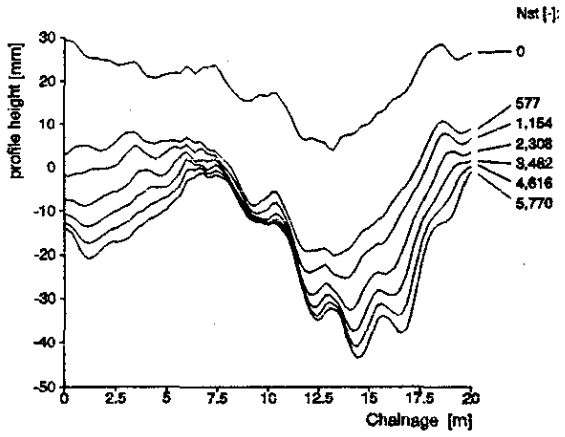

Fig. 20 Development of longitudinal profile "a" (vehicle 125 kN b).

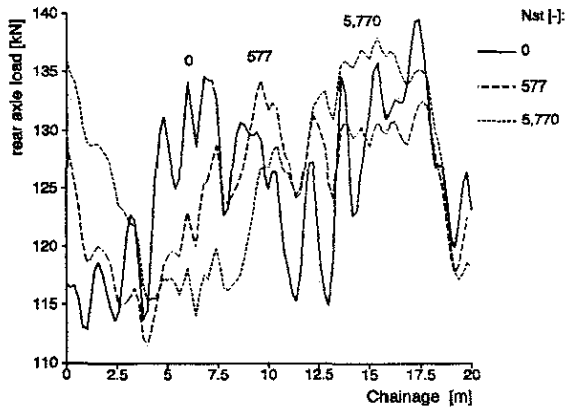

Fig. 21 Development of the dynamic rear axle load of vehicle 125 kN a (longitudinal profile "a").

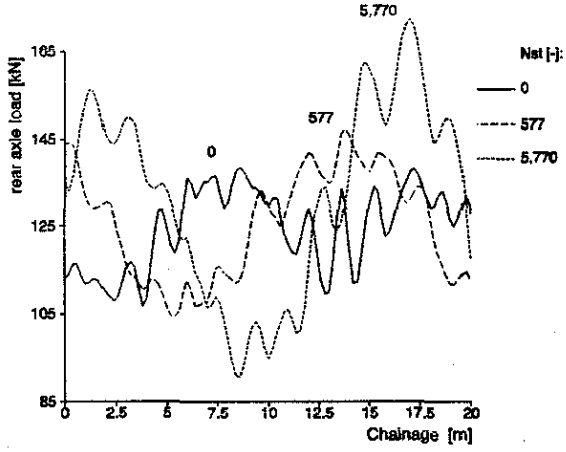

Fig. 22 Development of dynamic rear axle load of vehicle 125 kN b (longitudinal profile "a").

Both the figures 19 and 20 show that longitudinal moves a little bit forward due to the dynamic vehicle effects.

4. Conclusions

In this paper it is shown that CBPs can be designed on a theoretical basis taking into account the dynamic effects of traffic travelling over the pavement. For such a design first of all the rutting behaviour of the CBP is to be determined. As shown, all the necessary parameters can be obtained from the models discussed in the papers [1] and [2].

If these parameters are known repeated vehicle simulation can successfully be applied to simulate the effects of traffic on the development of transversal and longitudinal unevenness.

With respect to transversal unevenness (rutting), the design calculations discussed in this paper show that an enormous increase in the design life of a CBP can be obtained by applying a base course. If this base course is however not thick enough this positive effect is strongly reduced.
If the base course layer is underdesigned it will even have a negative effect on the design life of the CBP when compared to an equal CBP without a base. It is thus concluded that it is better to have a highly stressed sand sub-base than to have an over stressed base course layer.

The design calculations discussed in this paper show that dynamic effects have a negative effect on the rut development in a CBP. The smoother the initial longitudinal profile the longer the rut depth based design life of the pavement. The calculations discussed in this paper show that the 15 mm mean relative rut depth design life, design life 1, of the CBP is reduced to 92% to 69% when the pavement is poorly constructed, i.e. has a more rough initial longitudinal profile, see table 2.
Considering 15 mm rut depth with a 30% probability of exceeding, design life 2, these figures become even worse, 71% to 46%, depending on the properties of the traffic.
Given the large influence of the dynamic effects of traffic on the rut depth design life, it is concluded that these effects should be taken into account in the design of CBPs.

It is concluded that the properties of the traffic largely influence the effects of traffic on longitudinal unevenness. Traffic can either have a minor positive effects on roughness (expressed in the IRI) or have a strong negative effect. In the worst case roughness is strongly enlarged by traffic. This traffic introduced roughness shows a strong progressive character so that earlier failure of the CBP as a result of roughness can occur, depending on both the initial longitudinal profile and especially the properties of the vehicles travelling over the pavement.

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Centre ROW	Centre for Research and Contract Standardization in Civil and Traffic Engineering - The Netherlands,
Fabes	Dutch Association of Concrete Paving Block Manufacturers,
NVWB	Dutch Association of Road Contractors

and the Municipal Works Rotterdam.

6. References

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