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CONCRETE BLOCK PAVING IN THE NETHERLANDS DESIGN AND CONSTRUCTION

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In The Netherlands the application of concrete paving blocks for flexible pavements is common practice. Especially in the built-up areas, many streets have been paved in this way. Also, because of the presence of cables and pipes under the pavement sometimes repaving activities are necessary.
Formerly (concrete) paving blocks were mostly placed on a sand base only, approximately 1 m thick. In the last years, an unbound base of granular material combined with a sand sub-base has become more usual, particularly where there is heavy traffic.
Recently a design method has been developed that offers calculation of the lifetime of a road structure, based on the permissible rut-depth. In this method traffic loading and the properties of the layers beneath the top layer are the most important parameters. Also the phenomenon of "progressive stiffening" due to traffic loading is incorporated.
In the method of construction there are developments, too. The common hand-paving methods are harmful to the pavior's health. That is why the use of the new paving machines is being stimulated. Different types of paving machines are available and these not only improve labour conditions, but also increase production and decrease cost. Until now the application has been limited to new pavements; repaving has not yet been mechanised.
With the aim of Rational Pavement Management a system for element-pavement management and maintenance was developed. Based on visual inspection and on calculation, the residual life of a pavement can be estimated. This information is essential for an efficient planning of maintenance activities.

Introduction

As implied in the name, large parts of The Netherlands consist of lowlands with a ground level close to the mean sea-level or even several metres below it. Dunes and dykes give these areas protection against inundation.

The soil consists of clay and peat and has therefore little bearing capacity. Therefore the buildings are usually founded on piles that reach into the deep sand layers. In view of these soil conditions and of the developed infrastructure it is logical that roads and streets have been constructed as flexible pavements.

In this century most of the motorways and main roads have been constructed in asphalt. In the cities and villages the major part of the paving consists of small-element pavements. In former days usually burnt bricks or natural paving stones were used. After the Second World War the use of concrete paving blocks has increased constantly and nowadays it is the major paving element. See figures 1 and 2. During the last few years the production of concrete paving blocks has stabilized around the figure of 600 million blocks yearly, that is about one square metre per head of population.
Pedestrian precincts (footways and squares) and cycle-tracks are usually paved with concrete flags. The production of these is substantial too, about 0,8 m2 per head of population yearly.

Also on account of the little space available, the underground infrastructure in the built-up areas has especially been concentrated under the public road. Beneath almost every street there are cables and pipes (electricity, gas, water, sewerage, telephone, central-antenna, city-heating). From time to time the pavement has to be taken up for maintenance and replacement or for expansions.

The streets and roads constructed on the relatively weak subsoil are subject to settlement during a long period.

Figure 1. Production of concrete paving blocks.

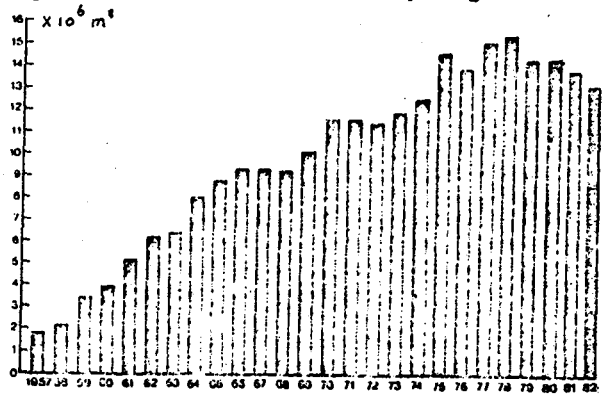
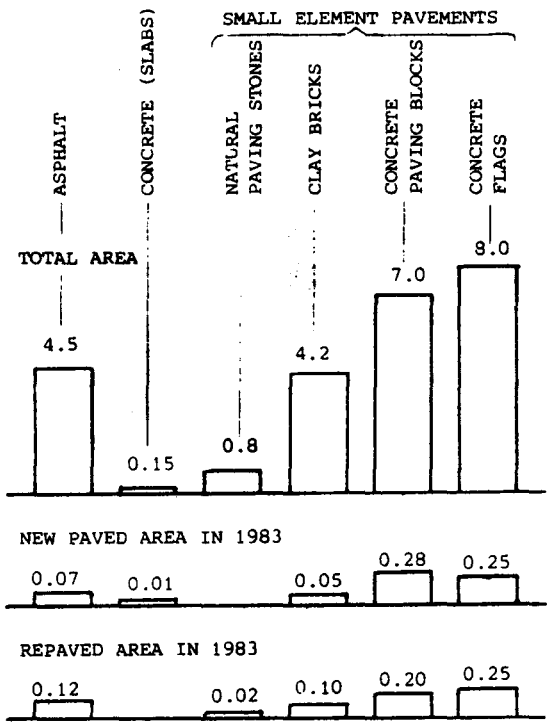


Figure 2. Paving of Rotterdam roads and streets.



Unit of areas: km2

After a certain time (for example 5 or 15 years) they will have to be heightened again.

Due to this settlement, and to the presence of cables and pipes, most Dutch streets are repaved several times before the paving elements themselves are worn out. On behalf of this repaving the elements must be cleaned (by scraping) and then relaid. For this, rectangulary shaped blocks ("Dutch stones") are more suitable than the non-rectangular ones which are frequently used in the rest of the world.

Qua utility, concrete paving blocks are quite applicable for element paving. The texture, the skid resistance and the light reflection are excellent and also a high level of flatness can be realized. The permanent flatness and particularly the limitation of rutting mainly depend on the subgrade and the applied base course.

Otherwise than for roads and streets, concrete paving blocks are also exceptionally suitable for the paving of industrial and harbour areas. The Rotterdam Port area contains several millions of m2 of this type of industrial pavement.

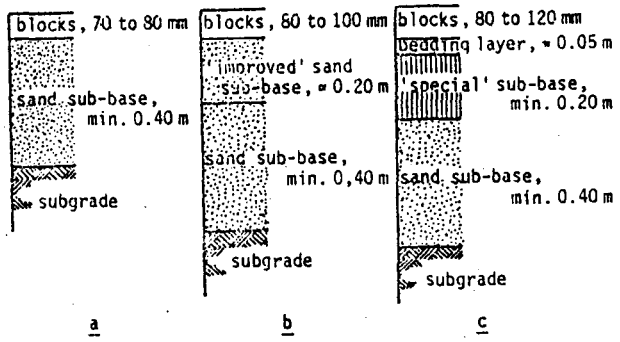
In the coming chapters the Delft design method, the mechanical method of construction and the element-pavement management system will be discussed.

The design of concrete block pavements for roads

In the Dutch road building practice, the "design" of a concrete block pavement still often means the choice of an appropriate standard pavement structure, considering the traffic loading (the type of road), the (cost of the) available construction materials, the subgrade (bearing capacity, permeability, ground water level) and the frost penetration depth (1). The behaviour of these standard pavement structures (figure 3) is considered to be "reasonable". However, often there is hardly any knowledge of the actual pavement performance under traffic loading.

Dutch roads normally have only a sand sub-base beneath the concrete paving blocks. Even on heavily trafficked roads there is usually no base.

Figure 3. Dutch standard concrete block pavements.



a concrete paving blocks on sand sub-base

b concrete paving blocks on 'improved' sand sub-base

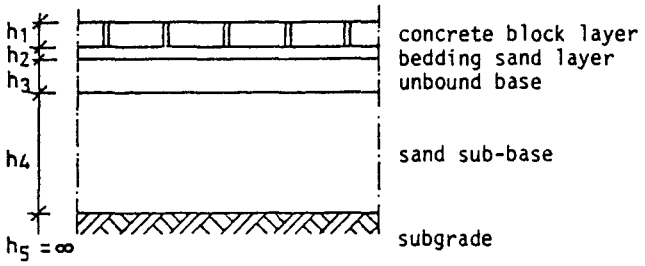
c concrete paving blocks on 'special' sub-base ('base'), covered by a bedding layer

The major part of the concrete block pavements is under the management of the municipalities. They have ever decreasing amounts of money available for the road maintenance, which in this case means the relaying of the concrete paving blocks by hand, which is very expensive. Therefore there has been an increasing need for a more rational design system for concrete block pavements, and for this reason, research was started in the early eighties.

Based on falling weight deflection measurements on in-service pavements and subsequent finite-element calculation, resilient deformation models were developed for concrete block pavements, consisting of 80 mm thick rectangular concrete paving blocks in herringbone bond, on a sand sub-base. After that a permanent deformation (rutting) model was developed, taking into consideration the measured "progressive stiffening" of the pavements. Next, similar rut depth calculatons were carried out for concrete block pavements with an unbound base and a sand sub-base (figure 4) in order to quantify the effect of an unbound base as a function of the traffic loading, the base thickness, the sub-base thickness and the bearing capacity of the subgrade. The design criterion for the pavement structure shown in figure 4 is rutting.

In this chapter the most important findings of this research and the resulting design charts for concrete block roads are presented.

Figure 4. Profile of the concrete block pavement structure with a base.



It should be noted that in fact the presented system is a design method for the substructure, especially the unbound base, of a concrete block

pavement. This is explained by the common Dutch practice, where normally only a sand sub-base is used for roads (figure 3a). Given this situation, the application of a base is considered to be the most important improvement with respect to the rutting behaviour of concrete block pavements. Compared with the effect of a base, the laying pattern, the concrete block thickness, the block shape, the joint width, the bedding layer thickness etc. are considered to be factors of secundary importance.

Research into the resilient deformation behaviour of concrete block pavements

In 1982 the Laboratory for Road and Railroad Research of the Delft University of Technology carried out research on 17 in service concrete block pavements, with a sand sub-base only, in the city of Delft (2). The concrete block layer consists of rectangular concrete blocks, dimensions l x w x h = 213 x 105 x 80 mm3, in herringbone bond. The thickness of the sand sub-base varies from 0.65 m to 1.5 m. The clay subgrade has a CBR-value ranging from 2% to 4%. The age of the pavements varied from 1 year to more than 20 years.
The Delft pavements are divided into 5 classes of sand sub-base thickness:

class A: sand sub-base thickness < 0.8 m (assumed 0.7 m)
class B: sand sub-base thickness 0.8 - 1.0 m (on average 0.9 m)
class C: sand sub-base thickness 1.0 - 1.2 m (on average 1.1 m)
class D: sand sub-base thickness 1.2 - 1.4 m (on average 1.3 m)
class E: sand sub-base thickness > 1.4 m (assumed 1.5 m)

Considering the traffic loading, in terms of the cumulative number of equivalent 80 kN standard axle load repetitions per lane (n), statistical relations were determined only for the classes C and E.

The analysis of the resilient deformation behaviour is based on falling weight deflection measurements. In such a deflection measurement a 50 kN dynamic load is applied on the pavement by means of a circular plate with diameter of 300 mm. The loading time is 0.02 s. The deflections (d) have been measured at distances of 0, 300, 500, 1000, 1500 and 2000 mm from the centre of the loading plate.

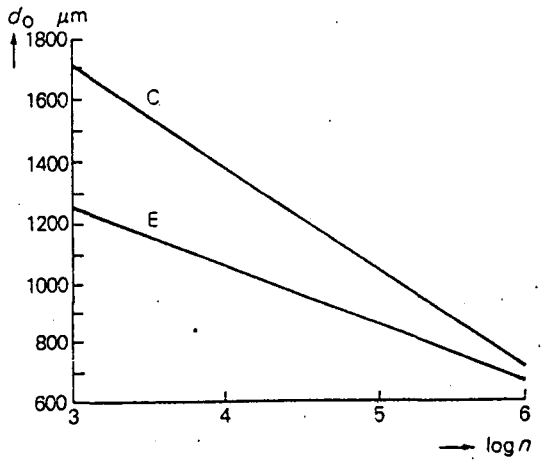
After the statistical processing of the deflection data it appeared that in both class C and class E all deflections decrease with increasing traffic loading n. For example, figure 5 shows the relationship between the maximum deflection d_o (in the loading centre) and n.
The elastic modulus E_o (N/mm2) of the substructure, which consists of the sand sub-base plus the subgrade, was calculated from the deflection (μm) measured at a distance of 2000 mm from the centre of the loading plate (d_{2000}) by means of the formula (3).

$$\log E_o = 3.869 - 1.009 \log d_{2000} \qquad (1)$$

First the measured deflections were analysed by means of the linear-elastic multilayer computer program CIRCLY (4), in which a load is carried by bending moments in the subsequent pavement layers. The Delft concrete block pavements, without a base, were schematized by a two-layer system, the concrete block layer being the top layer and the substructure being the second layer (2).

However, the deflection curves calculated in this way with the program CIRCLY did not agree with the measured deflection curves.

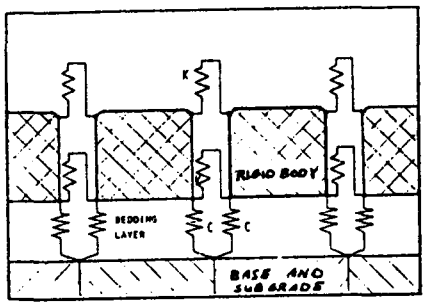
Figure 5. Relationship between the maximum deflection d_o and the traffic loading n for the Delft pavements.



Next the resilient deformation behaviour of the Delft pavements was analysed by means of the finite element program ICES STRUDL, since a special element type, called RIGID BODY, had become available that could be used for a proper schematization of the concrete blocks (5). In the calculations a plane strain condition was taken, which means that a vertical intersection is made through the total pavement structure including the subgrade (2).

The concrete block layer is schematized by a number of rigid bodies, which represent the concrete blocks, joined together by means of vertical linear springs, which represent the shear resistance of the joints (figure 6).

Figure 6. Model concept for the concrete block pavement in the ICES STRUDL calculations.



The spring stiffness k (N/mm) of the joints is:

$$k = \frac{G.h_1}{2v} \qquad (2)$$

where: G = shear modulus of the joints (N/mm2)
h_1 = concrete block thickness (mm)
v = joint width (mm)

The bedding sand layer is represented by vertical linear springs. The spring stiffness k' (N/mm) is:

$$k' = \frac{c.b}{2} \qquad (3)$$

where: c = bedding constant (N/mm3)

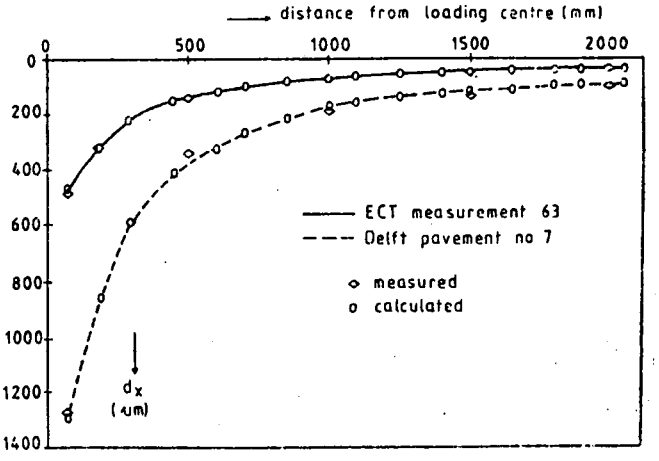
b = concrete block length or width (mm), assuming herringbone bond

The bedding sand layer is characterized by the bedding constant c, which is a constant for every deflection curve, in contrast with the spring stiffness k' which is dependent on the intersection length of the concrete blocks.

The layers beneath the bedding sand layer are supposed to be homogeneous, isotropic and linear-elastic continuous elements. They are characterized by their elastic modulus E (determined from the measured deflection curve) and Poisson's ratio ν.

By means of this finite element representation an excellent correspondence between the calculated and measured deflection curves was obtained. In figure 7 this is illustrated for one of the Delft pavements and for one deflection measurement on the ECT container terminal (concrete block pavement with 330 mm sand-cement base and a sand sub-base).

Figure 7. Two examples of measured and ICES STRUDL calculated deflection curves.



After all the calculations it appeared that on the Delft pavements the decrease of the deflections with increasing traffic loading n (figure 5) is due to an increasing load spreading capacity in both the concrete block layer (spring stiffness k, figure 8) and the bedding sand layer (bedding constant c, figure 9) and in the substructure (elastic modulus E_o, figure 10). This phenomenon, which is unique for small element pavements, is called "progressive stiffening".

Figure 8. Relationship between the joint stiffness k and the traffic loading n for the Delft pavements.

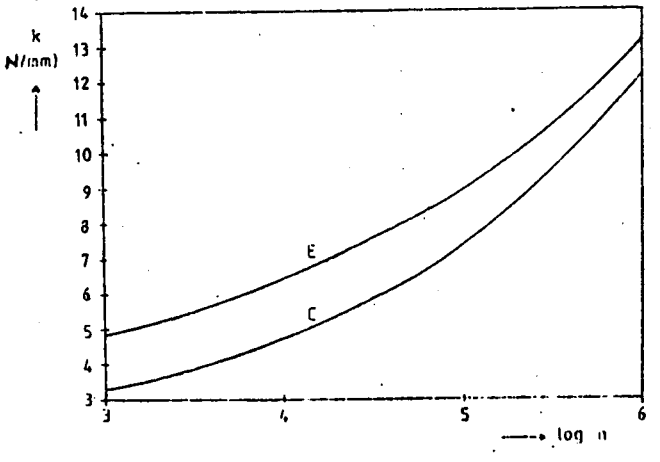


Figure 9. Relationship between the bedding constant c and the traffic loading n for the Delft pavements.

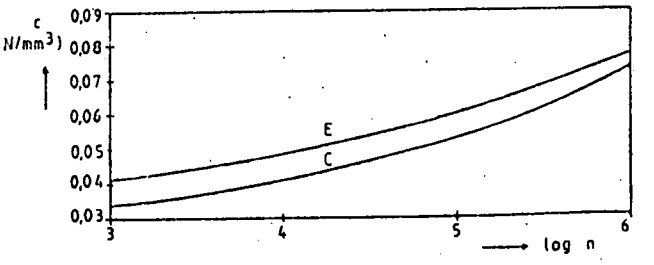
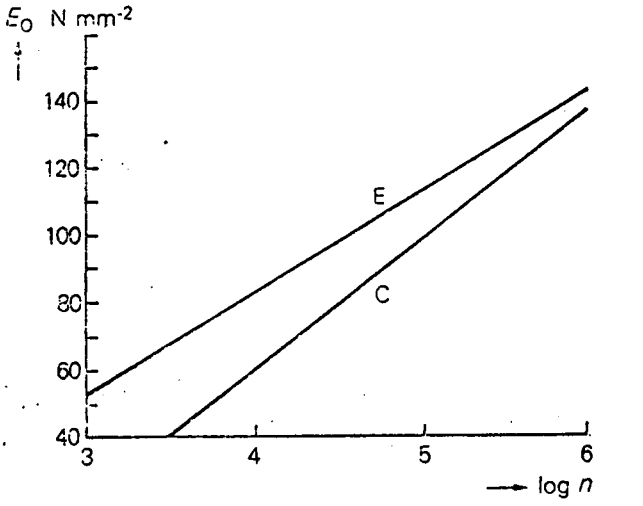


Figure 10. Relationship between the elastic modulus E_o of the substructure and the traffic loading n for the Delft pavements (initial (minimum) E_o-value fixed at 40 N/mm2).

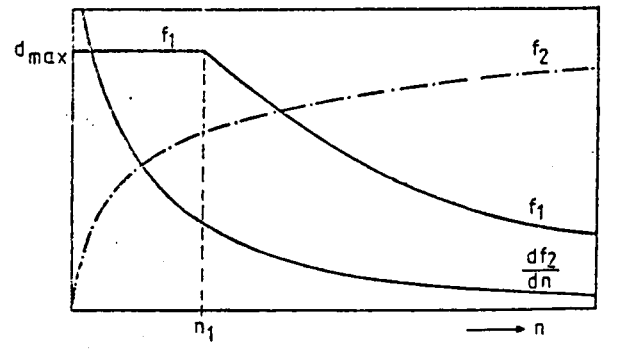


Calculation of rutting on concrete block pavements

In The Netherlands rutting is the design criterion for concrete block pavements with an unbound base, if any, and an unbound sub-base. Rutting can be defined as the sum of the permanent deformation, due to traffic, in the subsequent pavement layers including the subgrade.

The rut depth calculations were based on the permanent deformation models developed by the Belgian Road Research Laboratory for use in the design of flexible pavements (6,7). However, concrete block pavements show an increasing load spreading with increasing number of load repetitions n, and for this reason the permanent deformation models were modified (2) in the following sense (figure 11).

Figure 11. Schematical representation of permanent deformation functions.



$$\frac{d(\Delta h_p)}{dn} = f_1 \cdot \frac{df_2}{dn} \quad (4)$$

where: Δh_p = permanent deformation in a layer of unbound material
f_1 = elastic compression of the layer due to a standard axle load
f_2 = permanent deformation relation

The relation f_2 is (6,7):

granular material: $f_2 = a \cdot n^b$ (5a)

cohesive material: $f_2 = a + b \cdot \log n$ (5b)

For the Delft concrete block pavements (figure 10) a minimum E_o-value was found, which means maximum deflections d_{max}, in case of $n \leq n_1$, (figure 11) and an increasing E_o-value, or decreasing deflections in case of $n > n_1$. The function f_1, derived from the ICES STRUDL calculations, is:

$n \leq n_1 : f_1 = d_{max} = \text{constant}$ (6a)

$n > n_1 : f_1 = p + q \cdot e^{-\log n}$ (6b)

The permanent deformation in a layer of unbound material in a concrete block pavement is obtained by combining the equations 4, 5 and 6.

Granular material

$n \leq n_1 : \Delta h_p = d_{max} \cdot a \cdot n^b$ (7a)

$$n > n_1 : \Delta h_p = d_{max} \cdot a \cdot n_1^b + a \cdot p \cdot (n^b - n_1^b) + \frac{a \cdot b \cdot q}{b-0.4343} \cdot (n^{b-0.4343} - n_1^{b-0.4343}) \quad (7b)$$

Cohesive material

$n \leq n_1 : \Delta h_p = d_{max} \cdot (a + b \cdot \log n)$ (8a)

$$n > n_1 : \Delta h_p = d_{max} \cdot (a + b \cdot \log n_1) + b \cdot p \cdot \log\frac{n}{n_1} - b \cdot q \cdot (n^{-0.4343} - n_1^{-0.4343}) \quad (8b)$$

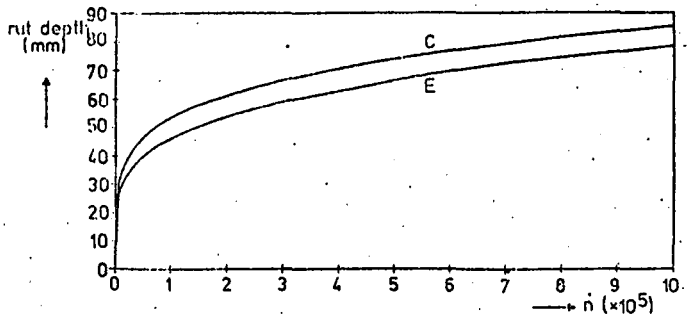
The equations 7b and 8b can be seen as the mathematical description of the phenomenon "progressive stiffening" on concrete block pavements.

In the calculation of the progress of rutting on the Delft pavements (without a base) by means of the equations 7 and 8, three assumptions were made:

1. Permanent deformation coefficients in equation 5 (6,7):
sand sub-base: a = 2 b = 0.3
clay subgrade: a = 1 b = 0.7.
2. Channelized traffic.
3. The 80 kN standard axle loads have single wheels, load 40 kN (= 0.8 times the falling weight load) and diameter contact area 300 mm (= diameter falling weight loading plate); this assumption means that the measured or calculated deflections due to the 50 kN falling weight load have to be multiplied by 0.8.

The calculated progress of the rut depth on the Delft pavements, classes C and E, is shown in figure 12.

Figure 12. Calculated rut depth on the Delft pavements as a function of the number of equivalent 80 kN standard axle load repetitions (channelized traffic, single wheels).



The progress of rut depth, shown in figure 12, can also be described by equations:

$$RD = a_p \cdot n^{b_p} \quad (9)$$

where: RD = rut depth
n = cumulative number of equivalent 80 kN standard axle load repetitions per lane (channelized traffic, single wheels)
a_p, b_p = rutting coefficients

For the Delft pavements (figure 12) was found:

class C: $RD = 3.10 \cdot n^{0.246}$ (10a)
class E: $RD = 3.21 \cdot n^{0.233}$ (10b)

In the same way as described for the Delft pavements the progress of rutting was calculated for different subgrade conditions, so for different initial E_o-values. From these rut depth calculations design charts for concrete block pavements without a base were developed.

Next rut depth calculations were carried out for concrete block pavements with a high-quality unbound base, like well-graded concrete hardcore or crusher run. The permanent deformation coefficients (equation 5) of the base material were taken at:
a = 2, b = 0.2.
The calculations were carried out for a base thickness (h_3) of 0.1 , 0.2 and 0.3 m, while the total thickness ($h_3 + h_4$) of the base plus the sub-base was taken at 0.7 , 1.1 or 1.5 m. On basis of these rut depth calculations design charts for concrete block pavements with a high-quality unbound base and a sand sub-base were developed.

Design charts for concrete block pavements

Rutting is the design criterion for concrete block pavements with unbound materials only. Concrete block pavements are mainly applied on roads in built-up areas. Generally the vehicle speed does not exceed some 50 or 60 km/h and therefore, for the time being, the acceptable rut depth is fixed at 25 mm. By way of comparison: in The Netherlands on asphalt pavements on highways, with the risk of aquaplaning, a rut depth of some 18 or 20 mm is accepted.

From the calculated progress of rut depth (equation 9) it follows that the allowable number of load repetitions n is:

$$\bar{n} = \left(\frac{\overline{RD}}{a_p} \right)^{\frac{1}{b_p}} \qquad (11)$$

where $\bar{n}$ = allowable cumulative number of equivalent 80 kN standard axle load repetitions per lane (channelized traffic, single wheels)

$\overline{RD}$ = accepted rut depth (mm)

a_p, b_p = rutting coefficients

From the allowable number of load repetitions $\bar{n}$ the pavement life l can easily be calculated:

$$l = \frac{\bar{n}}{365 \cdot n_d} \qquad (12)$$

where: l = pavement life (years)

n_d = expected number of equivalent 80 kN standard axle load repetitions per lane per day (channelized traffic, single wheels)

Figure 13 shows the design chart of concrete block pavement with a sand sub-base only (acceptable rut depth 25 mm). The design curves for a sand sub-base thickness of 0.7 m are tentative.

Figure 13. Design chart for concrete block pavements, consisting of 80 mm thick rectangular concrete blocks in herringbone bond and a sand sub-base (channelized traffic, single wheels).

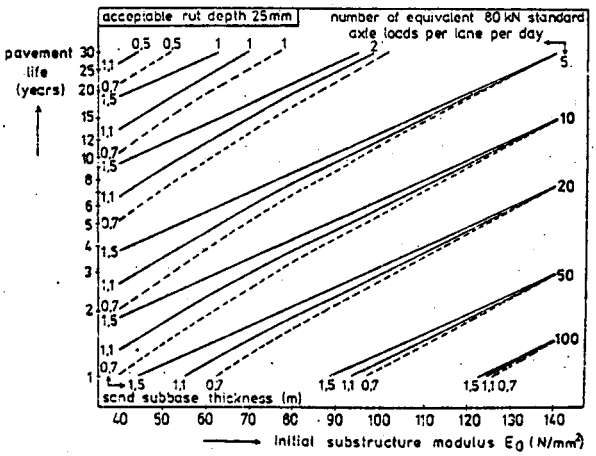
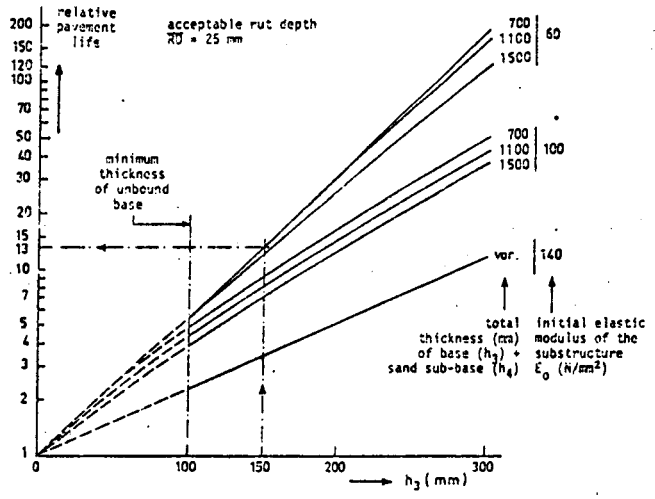


Figure 14 shows the great effect of a high-quality unbound base on the life of a concrete block pavement. With the design chart the life of the concrete block pavement with an unbound base and a sand sub-base relative to the life of the pavement with a sand sub-base only, but with an equal total thickness, can be determined (acceptable rut depth 25 mm). The relative effect of the unbound base is greater according as:

- the elastic modulus E_0 of the substructure (sand sub-base plus subgrade) is smaller;
- the thickness $h_3 + h_4$ of the unbound base plus the sand sub-base is smaller;
- the thickness h_3 of the unbound base is greater.

Example: for a E_0-value of 60 N/mm2 the life of a concrete block pavement with 150 mm unbound base and 700 - 150 = 550 mm sand sub-base is 13 times greater than the life of a concrete block pavement with 700 mm sand sub-base only.

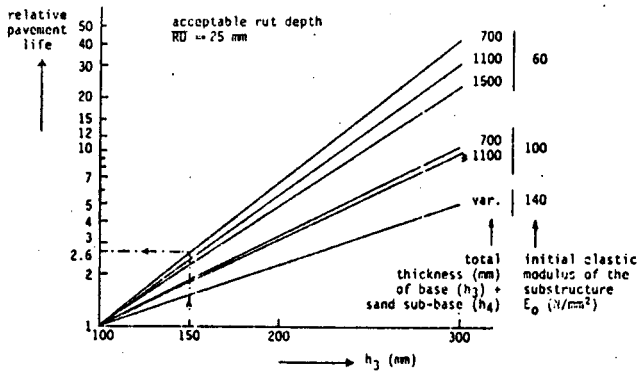
Figure 14. Life of a concrete block pavement with a high-quality unbound base and a sand sub-base relative to the life of a concrete block pavement with a sand sub-base only, both pavement structures having 80 mm thick rectangular concrete blocks in herringbone bond and a 50 mm bedding sand layer (channelized traffic, single wheels).



Finally, figure 15, which is derived from figure 14, gives the life of the concrete block pavement with an unbound base and a sand sub-base relative to the life of the pavement with 100 mm unbound base and a sand sub-base, both pavements having an equal total thickness.

Example: for a E_0-value of 60 N/mm2 the life of a concrete block pavement with 150 mm unbound base and 700 - 150 = 550 mm sand sub-base is 2,6 times greater than the life of the pavement with 100 mm unbound base and 700 - 100 = 600 mm sand sub-base.

Figure 15. Life of a concrete block pavement with a high-quality unbound base and a sand sub-base relative to the life of a concrete block pavement with 100 mm unbound base and a sand sub-base, both pavement structures having 80 mm thick rectangular concrete blocks in herringbone bond and 50 mm bedding sand layer (channelized traffic, single wheels).



Construction practice

Until a few years ago all paving of small elements was done by hand. Therefore in The Netherlands there are a large number of paviors; in 1980 about 16,000 of them.
In the sixties the need of mechanisation of the paving work arose. There were four reasons:

1. The increasing growth of the use of element paving.
2. The expected shortage of skilled labour.
3. The increasing labour cost.
4. The unhealthy labour conditions.

Especially this last item became more important. Research showed very clearly that the pavior's trade is a wearing one (8); very seldom does a pavior reach retiring age while still working.
Only in the late seventies were the first-generation paving machines developed. They are all block-laying machines that lay down the concrete blocks on the completely prepared bed.

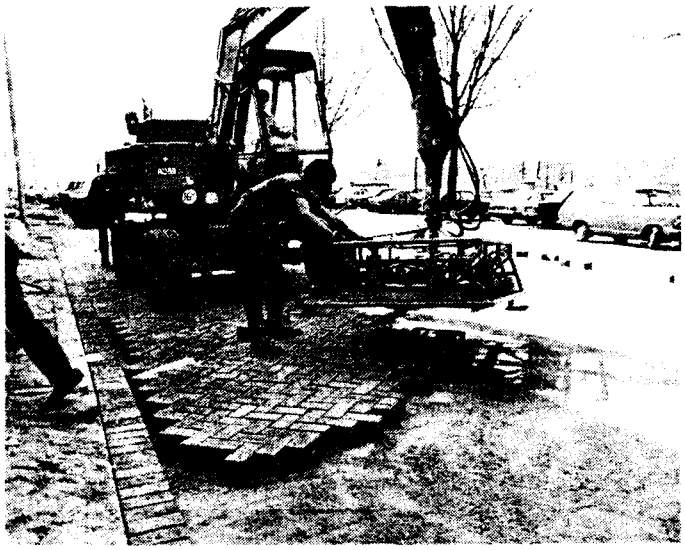


Figure 16. Delta S block-laying machine.



Figure 17. Optimas block-laying machine.

Machine

The most important characteristic of the paving process using the block-laying machines now operational is the use of the clamp construction, by means of which a package of blocks is taken up one layer at a time and placed on the roadbed.
The clamp, which is operated mechanically or hydraulically, is attached to a motor vehicle with a lifting mechanism. This concept can be worked out in very different ways. See figures 16 (Delta S block-laying machine) and 17 (Optimas block-laying machine). The machine is operated by a driver and a pavior. The latter gives directions and checks to make sure the clamp is in the correct position, so that the layer to be laid is properly fitted against the previously placed paving.

Packages

The block-laying machine processes the blocks in rectangular layers of 40 to 50 blocks. The making of packages composed of complete layers in the desired order can be accomplished as part of the production process, but it is not a simple thing. To facilitate efficient processing at the site, the packages can be placed on pallets.
The number of blocks in a layer depends, among other things, on the dimensions of the blocks, in particular the height. For good processing, it is important that the blocks have only slight dimensional tolerances and are well squared.
In case of elbow bond and herringbone bond there are empty spaces left in the layers. The laying pattern is completed on site by putting the missing blocks (filler blocks) in place. This task is done by the pavior who guides the clamp.
Fitting against the edges also requires some manual work. For this an extra pavior is employed.

Screeding of the bed

For the accurate screeding of the bed to the right level a screeding beam is used. In any case the bed consists of a granular material. In order not to disturb the prepared bed, the paving activities must be carried out from the area already paved. Therefore the vibrating of the pavement and the brushing of sand into the joints should be carried out immediately after the actual paving. Then the supply and transport of blocks can take place over pavement that has been completely finished.

Organization of the work

In the mechanical process the various activities, such as the screeding of the bed, the mechanical laying of the blocks, their supply and transport, the finishing by hand along edges and obstacles, vibrating the pavement down and brushing it, are all highly interdependent. Partly because the production tempo is high, it is of great importance that the activities are well co-ordinated.
It is advisable to screed the bed only very shortly before the blocks are laid. This affords the smallest chance of disturbance to the screeded bed. This applies especially to unenclosed sites such as streets and squares, where passers-by (including pets) are the chief cause of disturbance.
If the blocks are brought in as they are laid, the transport of blocks at the site is reduced to a minimum. The Delta S paving machine can be equipped with a fork for this transport; when using other machines a separate vehicle must be used.
The supply of packages at the site for the next working day should be kept to a minimum, since their disturbance by children or others will seriously disrupt the paving process.

Large-scale applications

In 1982 construction began on the second terminal of the container stevedor ECT (Europe Container Terminus). This Delta Terminal is situated in the western part of the Port of Rotterdam and covers an area of more than 800,000 m2 in the first instance, and can be expanded later to about 4 million m2. For the surfacing, ECT has chosen the same 120 mm thick rectangular concrete paving blocks that were used on the home terminal (9).
The blocks are laid in herringbone pattern on a 400 mm sand-cement stabilization surmounted by a bedding sand layer 50 mm thick.
The paving work began early in 1983 and was completed before 1985. At an early stage, and in a rather unusual form of co-operation between client, contractor and concrete block manufacturer, possibilities were sought of applying the paving mechanically. This co-operation has led to the development of the Delta S block-laying machine. Before proceeding to discuss the paving work itself, we must first describe the necessary adaptations in the production process, and the design of the paving machine.

Production of the concrete paving blocks. In the concrete plant, a mould the size of one packaged layer is used to produce the concrete paving blocks in elbow bond pattern. It is important to see to it that the mould is filled evenly with mortar. The empty spaces complicate the further packaging and transport. Laying of the concrete paving blocks on large areas demands strict dimensional tolerances in length and breadth of the blocks.

Block-laying machine Delta S. The most important characteristics are listed point by point.

1. The patented clamp construction clamps the layer on four sides. The clamp rotates freely on the jib. The layers, in elbow bond, are placed at an angle of 45° regarding to the direction of traffic, so that the resulting pavement is in herringbone pattern. The system is such that, after the clamp loosens, the blocks fall down about 30 mm, without tipping. In this way, premature contact with the bed and consequent disturbance of it are prevented.
2. For the sake of exchangeability, the crane and its jib are of a standard make.
3. The undercarriage is provided with good-sized pneumatic tyres, which makes it easily moveable and prevents the formation of track grooves in the pavement not yet vibrated down.
4. On the shelf at the back of the crane, a supply of filler blocks is kept within reach.
5. The cabin rotates with the jib, so that the driver has a good view of his work.
6. The crane can also be equipped with a fork, to enable it to handle packages of blocks on pallets.

Procedure. In the paving process, the bed may be screeded to the precise height quite some time before the machine lays the blocks. The pavement is vibrated to level immediately after laying, however, so that, as far as possible, only completed work need be used for driving on.
On this extensive area where the paving is relatively seldom interrupted by drains, kerbs, etc., 3 to 4 machines were used. The quality of the pavement is excellent: the joints are narrow and the surface is very even.
At first the average production was about 500 m2

per machine per day (8 hours), using a shift of one driver and one pavior. Later on an extra pavior was employed per shift and the production was increased to 750 m2. Table 1 provides a comparison with applying the paving by manual laying. This method was used formerly in The Netherlands and is still used elsewhere in the world. In regard to both production and cost mechanical laying is preferable.

Table 1. Results at ECT's terminals.

	mechanical laying Delta S	manual laying
production per machine per 8-hour working day	750 m2	-
production per man-day	250 m2	165 m2
comparable cost	95%	100%

Application in city streets (9)

For the relatively large-scale city work, the Delta S block-laying machine is quite suitable. For the really small-scale areas (small streets) in Rotterdam a smaller type machine is used, the Optimas block-laying machine. It has the following characteristics:

1. This machine has a mechanical clamp which clamps in just one direction.
2. The undercarriage is of a small and light design.
3. The cabin and the jib are connected immovably to the undercarriage. Manoeuvering is accomplished by moving the whole machine, which is quite mobile.
4. This machine cannot be used for transporting pallets of blocks on site.

The effectiveness of this system is clearly lower than the Delta S system. See table 2.

The activities concerned in mechanical paving in the city are much more interdependent. There is less space available. Where to put down the packages? It is also risky to have packages left at the end of a working day. The next day and certainly after the weekend some (or all) of the packages will have been disturbed. That is why the blocks must be delivered and paved the same day. The screeding of the bed, too, must be done just before the blocks are laid, in order to minimize the disturbance of the finished bed. Because of the high daily production, sufficient working length is needed, considerably more than for the hand methods. Also the accessibility of shops and the occurance of weddings or funerals, can become a threat to the paving process. These factors require:

1. A good working plan, only possible with a good co-operation among client, contractor and concrete block manufacturer.
2. An open eye to signalize bottlenecks at an early hour.
3. Improvisation talent, to cope with the problems effectively.

Recently a new type of paving machine has been developed (10). See figure 18. This one does not clamp but is equipped with an air-pump. The blocks are held up by a partial vacuum. The advantage of this principle is, that with this machine not only concrete blocks can be laid, but also other paving materials such as flags, slabs and kerbs. See figure 19. In theory all new paving elements can be laid with this machine. It can be equipped with a small excavator bucket too. So it is a real multi-purpose machine. Especially for small-scale work it can be used very effectively.

Repaving, which is reinstating the paving elements that are already present, has not yet been mechanized. The problems to be solved concern mainly scraping and testing the blocks and regrouping them into manageable units. Because repaving activities account for about half of all paving activities, it is very important from the point of humanization of labour to mechanize this work as well.

Table 2. Production of mechanical paving.

machine	large-scale	small-scale
Delta S	500 à 750	350 à 500
Optimas	-	200 à 250
Vacuum	-	300 à 400

m2 per machine per 8-hour working day

Mechanizing the paving activities is a real threat to (full) employment of paviors. The total amount of manual labour decreases substantially. See table 3. However, it must be kept in mind that the pavior's labour is heavy and unhealthy. Evidence of this is the large number of paviors who are declared unable to work from a medical point of view. When mechanical paving is done, the remaining manual labour is less heavy and ergonomically better. See table 4. Perhaps there is another bright spot: as block paving becomes cheaper due to mechanization and asphalt continues to get more expensive, more and more asphalt pavements in the built-up areas may be replaced by element pavements.

Table 3. Man-hours per m2 pavement.

	laying of the blocks	all paving activities together
manual laying	100%	100%
mechanical laying/large area	40%	45%
mechanical laying/small-scale	70%	75%

Table 4. Manual labour per man per day.

	m2	weight
manual layer	165	35 tons
mechanical pavior		
large-scale	75	16 tons
small-scale	70	15 tons

Figure 18. Vacuum paving machine.

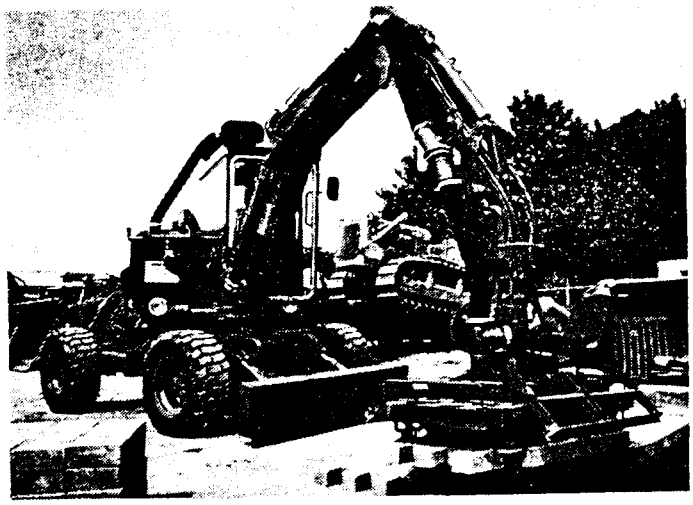
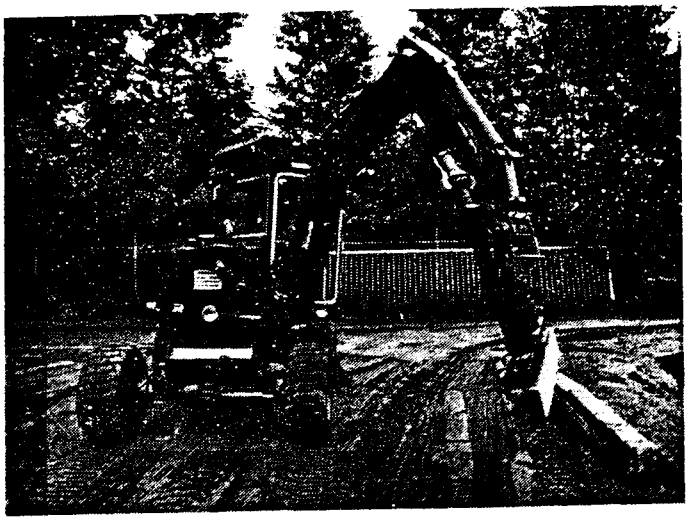


Figure 19. Vacuum paving machine with an accessory for placing kerbs.



It must be underlined that mechanical paving is still in its infancy.
In Rotterdam in 1983 about 1% of the total amount of new concrete blocks was paved mechanically. In 1984 this proportion rose to 15%. We expect that especially the mechanical laying of flags and kerbs will increase in 1985.

Pavement management

For continuous pavements (asphalt, concrete) maintenance planning systems were developed some years ago. Recently in The Netherlands a similar system has been developed for small-element pavements (11,12). It is based on inspections and measurements on the one hand and on calculations on the other

hand. With the data obtained one can estimate the residual life of the road. Then efficient planning and budgeting of maintenance work can be done. This system is not for concrete blocks only but also for other element pavers such as burnt bricks and concrete flags.
A detailed description of this system is given in the proceedings of the Second International Conference on Concrete Block Paving 1984 (11).

Concluding remarks

Based on falling-weight deflection measurements, carried out on in-service pavements, and on a rut depth model that includes the characteristic "progressive stiffening", a rational design method for concrete block pavements was developed in The Netherlands. This mainly theoretical design method is applicable to road pavements with rectangular concrete blocks laid directly over the sand sub-base or over an unbound base and a sand sub-base.

Mechanical paving is necessary to improve the pavior's working conditions. Stringent planning and execution are stipulated. Shortage of working space, continuation of traffic and accessibility can be bottlenecks.
Mechanical paving is less suitable for very small streets, for streets with many curves or where many different types of element are used within one work.
Mechanical paving of new materials is still evolving.
Repaving cannot (yet) be done mechanically.
If mechanical paving is well carried out, an increase in production and a decrease in cost can be achieved.

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