The development of concrete paving blocks in The Netherlands

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Brief history

IN THE NETHERLANDS the production of concrete paving blocks started in the very early fifties[1].

In 1951 the concrete products company Holland at Westervoort (near Arnhem) introduced the BKK concrete paving block, which was rectangular in shape. The dimensions on plan (200 mm × 105 mm) were very similar to those of the white-coloured concrete blocks (with a white top-layer) which had been introduced some years before for road markings. These marking blocks were brick-sized since they were mainly used in conjunction with burnt clay paving bricks.

Figure 1: An historical photograph showing the start of production of concrete paving blocks in The Netherlands during the early fifties. (BKK Betonklinderdei)

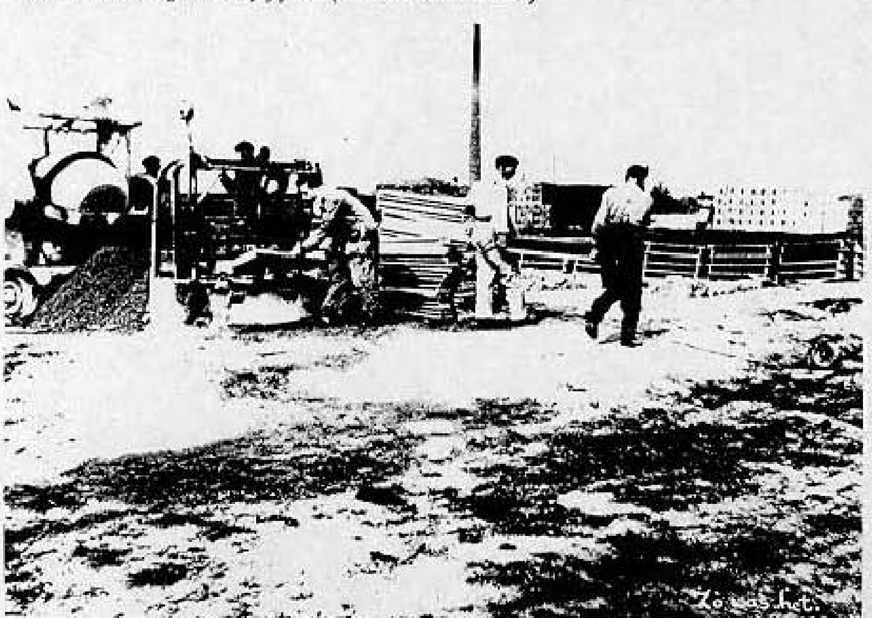

Figure 2: One of the first blockmaking machines of the early fifties, operating in the open-air. (Rheden Beton)

In the early years the production method used for the BKK paving blocks was similar to the rather simple process of making marking blocks, namely on small vibrating tables (Figure 1). Afterwards this production technique was abandoned in favour of well-known blockmaking machines of the pallet type. Nevertheless, the rectangular (brick-sized) shape, once having been introduced, has become the standard shape all over the country.

In 1952 the concrete products company Schokbeton at Kampen (near Zwolle) introduced the Ipro concrete paving block, which was I-shaped in plan. This block, of the interlocking type, has a length of 250 mm, with a width of 150 mm at each end and 100 mm in the middle.

In the early years the Ipro blocks were produced on a simple blockmaking machine such as was used for the manufacture of lightweight concrete building blocks. Afterwards this production method was developed into the now familiar mechanized automatic blockmaking process. However, in the Netherlands the share of the market taken by I-shape blocks and all other interlocking types has never exceeded 10% in total. Rectangular concrete paving blocks have become the 'natural successors' to the 'classic' burnt clay paving bricks.

In the fifties many paving block manufacturers became established throughout the country (Figure 2). New plants were set up not only by concrete products companies but also by burnt clay brick producers and even by others from outside the building industry. It is estimated that by 1956 production exceeded 1·5 million m^2 (approximately 25 plants), but in the very early sixties the total production of approximately 40 plants had already increased to about 5 million m^2 (Figure 3). In the same period the annual production of burnt clay paving bricks ranged from 6 to 7 million m^2.

There are some compelling reasons for the very rapid increase in the use of concrete paving blocks in the fifties and the early sixties (Figure 3). There was already a long-standing tradition of brick

TABLE 1: Carriageway surfacings of State roads, 1 January 1960

Road type	Length (km)	Proportion of bricks
Main	2615	363 km (13.9%)
Others	2249	777 km (34.6%)
Total	4864	1140 km* (20.9%)

* Surface area of about 6½ million square metres.

N.B. In the official Ministry of Transport survey, concrete paving blocks are not specified separately but are included under "concrete pavement."

paving which may have been due to both the absence of natural stone setts (rocks) and the abundance of natural clay sources (river-clay). However, in 1945 and since, there has been a shortage of traditional paving bricks. After the war, burnt clay materials were used for re-building and later for new building.

As Kellersmann is explaining in his paper[7], concrete paving block has never been regarded as a new phenomenon. Concrete blocks were in fact a substitute for burnt clay paving bricks. Moreover, they offered a cheaper alternative to conventional bricks, and this alternative proved to have a better structural performance. As a matter of course, road engineers, designers, road builders and layers, as well as the public at large, very soon became familiar with concrete paving blocks.

From about 1960 onwards, the paving block industry in the Netherlands began to develop into a highly mechanized and automated industry (Figure 4). Mechanization and, later on, automation were introduced, not only into the production process, but also into the handling, packaging and stacking of the blocks.

In the late seventies the annual production of concrete paving blocks in the Netherlands ranged from 13·8 million m² in 1976 to 15·8 million m² in 1978 (Figure 3), which equals 1 m² per head of population. In 1979 the total production of burnt clay paving bricks did not exceed 1·5 million m². Last year interlocking blocks took a few per cent only, in spite of the fact that at least 11 different types were available. It needs to be repeated, for a better understanding, that rectangular concrete paving block in fact was an 'imitation' of rectangular burnt clay paving brick, and apart from some individual cases, there never was a good reason to switch to another shape.

In the fifties concrete paving blocks were used on all types of roads, not only on municipal and provincial roads, but also on national roads. At that time a substantial proportion of the length of the whole network of roads, including state roads (also main roads and even parts of motorways), was paved with burnt clay bricks and later on also with concrete paving blocks. Regarding the national (state) roads, at the end of the fifties (as at 1 January, 1960) the situation was as shown in Table 1.

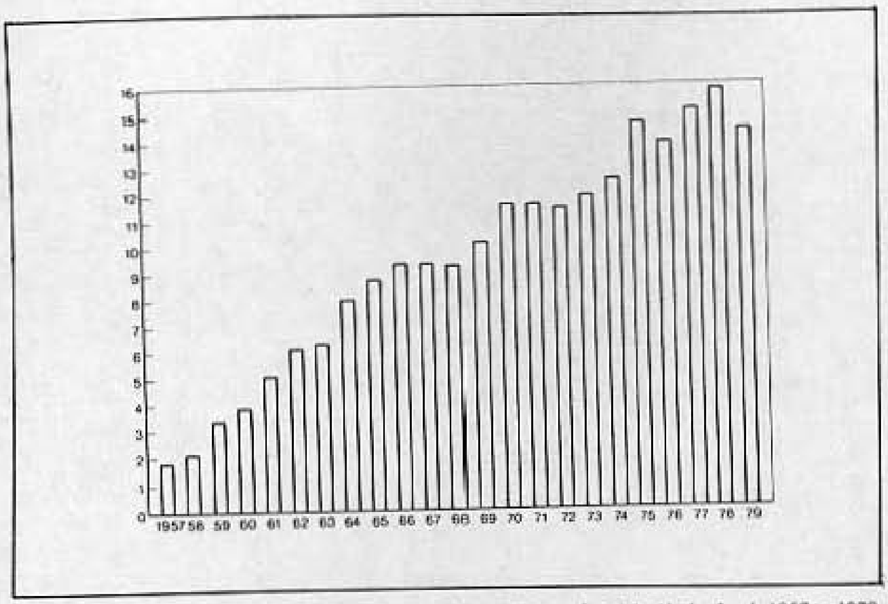

Figure 3: Annual production of concrete paving blocks (millions m²) in The Netherlands 1957 to 1979, according to CBS/The Hague.

Regarding the use on national roads, the State Road Laboratory took the initiative in preparing specifications for concrete paving blocks; these were published in 1955 and were in use until 1966 (see paragraph two of this paper).

In 1966 the first Netherlands Standard relating to concrete paving blocks (NEN 7000) was published, and in the same year concrete paving blocks were brought within the KOMO-scheme of Quality Assurance and Certification (see Mr Dreijer's paper[3]). For the sake of completeness, reference should be made to the activities of the SCW-Working Group D-2 from 1959 and to those of the Association FABES from 1962 (paragraphs 3 and 5 of this paper).

Owing to the revolution in traffic which started in the late fifties, concrete paving blocks as well as burnt clay paving bricks have been phased out of the primary roads network. However, because they have excellent town street characteristics, concrete paving blocks have become a highly accepted paving material for built-up areas, such as residential and shopping streets, pedestrian

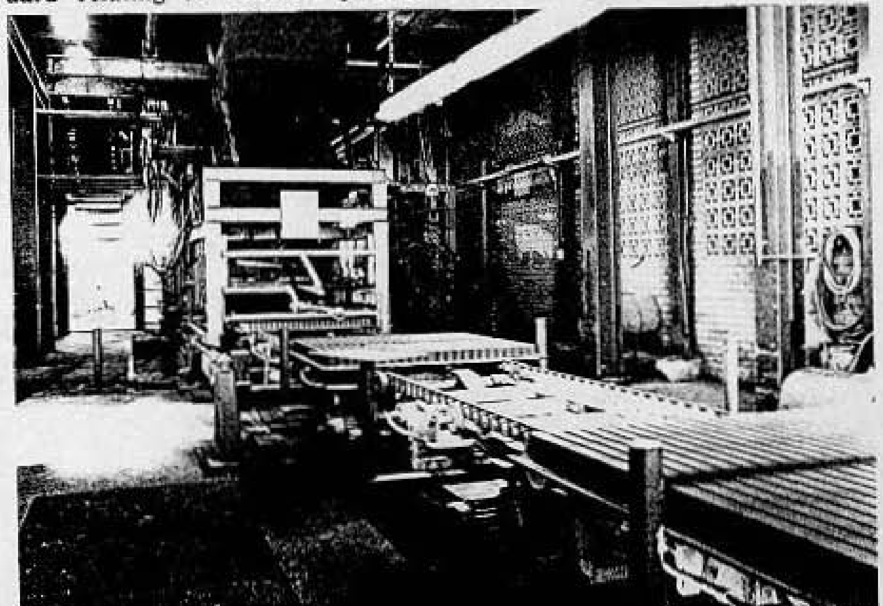

Figure 4: A fully mechanized and automated concrete paving block producing unit. (MBI Beton)

TABLE 2: Minimum flexural strength specified in 1950 and 1956.

Thickness	mean (kgf/cm²)*	individual (kgf/cm²)*
45 mm	64·2	57·8
50 mm	66·0	59·4
60 mm	65·3	58·8
70 mm	62·2	56·0
80 mm	58·6	52·7

*The conversion into SI units has been omitted because the original units are in kgf and cm.

areas, service stations, squares and yards, parking places, etc. As explained by Kellersmann[7] applications have been greatly stimulated by the introduction of smaller-sized concrete paving blocks and their so-called 'shaded colours'. The selection of concrete blocks for paving could be based on their low initial costs only. In the meantime, however, new arguments have proved to be equally important, if not more important, factors. In this respect attention should be drawn to arguments dealing with reinstatement, settlements, underground cables and ducts etc, re-use, visual aspects and environment.

There is no doubt that such arguments are decisive in the case of paved areas in villages, cities and town extensions. It should be noted, however, that the same arguments also govern in the case of agricultural pavements, rural roads, industrial areas, etc.

As Van Leeuwen explains, concrete blocks also provide an ideal surfacing for heavily-trafficked paved areas at container terminals (such as that of ECT in Rotterdam) and on similar port areas.

At the end of this brief history it should be noted that in the Netherlands even today, the amount of research undertaken on concrete paving blocks is limited. The major part of research has been directed towards the blocks themselves[5]. However, regarding future needs for reducing maintenance costs, it can be expected that more specific research on concrete block paving will be required. This may be initiated by a new working group to be established by the Study Centre for Road Construction (SCW). However that may be, use could be made of several papers presented to the First International Conference on Concrete Block Paving.

Specifications and Standards

The history of the Netherlands' Specifications and Standards on concrete paving blocks is interesting, since it explains the background to the Standard NEN 7000[4], fully described by Dreijer[5].

Early fifties (before 1955)

In the early fifties there were no special standards for concrete paving blocks. That is why some specifications were embodied in the tender documents or in the contract for particular jobs.

Then as much use as possible was made of the well-known specifications for burnt clay paving bricks, such as laid down in the then-operative Specifications for Road-Building Materials (the Eisen) issued by the Ministry of Transport, (first published in 1950 and later in 1953). These specifications dealt with:

tolerances in the dimensions (max. 4% if Class A-1),
water absorption,
resistance under a falling pear-shaped steel ball, and
loss of weight during the so-called 'rattler-test'.

However, use was also made of Standards N 501 and N 502 for concrete paving slabs (flags 300 mm × 300 mm), the edition of 1950 which was revised in 1956 with minor corrections only. These standards dealt with:

compressive strength (sawn cubes, edge length 100 mm),
Amsler abrasion test,
loss of weight in the so-called sand-blast test, and
flexural strength by central loading (mid-span loading).

The central loading test was specified over a span of 200 mm and with a rate of loading of 40 kgf/s. The standard did not specify minimum flexural strength, but minimum breaking loads, dependent on the thickness. By means of the so-called flexural equation M/W (in which M = flexural moment and W = modulus of resistance) the specified breaking loads can be converted to the minimum flexural strengths (if Class I) shown in Table 2:

The only noticeable minor correction introduced by the 1956 revision* is the addition that the concrete paving slabs shall be tested after being stored in water for 48 hours.

The testing of concrete paving blocks can be well illustrated by two examples:

a. In 1952 two samples each of ten blocks were tested by the State Road Laboratory (at that time established in The Hague). These samples were of blocks about to be used on State Road No 1 (a motorway provisionally provided with one carriageway). The tests related to the water absorption, the density and the resistance under a falling pear-shaped steel ball of 10 kilograms.

b. In the same year, a sample of ten blocks was tested by the Materials Laboratory of the City of The Hague. These tests dealt with compressive strength (sawn cubes), the sand-blast test (loss of weight), density, flexural strength (according to the standard for concrete paving slabs) and durability towards repeated freezing and thawing.

In both cases the tests were made according to what had been specified in the tender documents and in the contract respectively. (In the following years the Materials Laboratory of The Hague also used the so-called rattler-test (ASTM C-7, edition 1942) and the Amsler abrasion test).

First specification (1955)

In 1955 the State Road Laboratory (Ministry of Transport) published in draft form *Specifications for concrete paving blocks,* the first ones in the Netherlands and probably the first in the world. These specifications contained a few typewritten pages only. Only four requirements were included, of which only one dealt with the structural quality itself. In fact this specification was derived from those which had been published some years before for white coloured concrete marking blocks, to be used in conjunction with burnt clay paving bricks. Obviously, the requirements for dimensions were omitted since concrete paving blocks did not need to comply with burnt clay bricks, and the requirements for the 'reflection of light' and 'white top-layer' were also omitted as a matter of course. However, the requirements for dimensional tolerance, for planeness, for skid resistance and for flexural strength were retained. It hardly needs saying that these specifications related to rectangular blocks only.

The dimensional tolerance had been fixed at 3%. This requirement was stronger than that for burnt clay paving bricks (4% if Class A-1), which demonstrated the greater uniformity of concrete block dimensions. However, it dealt with all three dimensions in the same way, which is typical for burnt clay materials (linear shrinkage by drying), but it did neglect the reasons why a dimension of a concrete product could vary (variation in the filling or in the compaction, wear of mould, etc).

The skid resistance was specified as follows: Coefficient of friction $f > 0{\cdot}45$, since at lower values the greatest amount of skidding acci-

*A completely new Standard (NEN 7014) for concrete paving slabs was published in January 1972, which specifies a rate of loading per second of 0.05±0.02 N/mm² (about 0.5±0.2 kgf/cm²). The characteristic flexural strength (5%) shall not be less than 5.5 N/mm² (about 55 kgf/cm²), without any difference between Class I and a lower one.

dents had been observed. (The stated coefficient of friction was related to measurements at 100% slip and a speed of 20 km/h). The skid resistance should be measured by using the Leroux pendulum apparatus (Figure 6) and in this respect it had been assumed that a Leroux-value of 68 was equal to f=0·45. This measurement should be made in the two opposite directions until a constant value is obtained and the lowest value of the two measurements should be taken as the actual test result.

The individual flexural strength of each concrete paving block should not be less than 60 kgf/cm². The specified central loading test was in fact the same as was specified in Standard N 502 for the testing of concrete paving slabs, mentioned before. However, the span (bearing distance) was reduced to 150 mm (see Figure 7) because of the length of the blocks (approx. 200 mm) and the rate of loading was increased to 50 kgf/s, for practical reasons. Having these modifications as well as the smaller width (approx. 100 mm instead of 300 mm) the flexural strengths being specified in Standard N 501 for 60 to 80 mm thick paving slabs had to be increased by 6 to 8%. That is why, for the concrete paving blocks, it was specified that the individual flexural strength should not be less than (rounded off upwards) 60 kgf/cm². According to the revised edition of Standard N 502, which was published in 1956 the blocks should be tested after being stored for 48 hours in water. Thus the flexural strength test was introduced for concrete paving blocks for the following reasons:

1. The test is already well-known from the testing of concrete paving slabs and the (re-calculated) minimum value of 60 kgf/cm² has proved to guarantee a sufficient practical quality (not so much the mechanical strength as the durability etc.)

2. The test is much simpler (less complicated) than any compression test (particularly that on sawn cubes) and consequently much cheaper.

3. Compared to compression strength, flexural strength could be regarded as a better criterion for wearing resistance, resistance against weathering, etc.

4. In a pavement, blocks are loaded in flexure more critically than in compression, where loading is the critical factor.

Though these specifications were drawn up by the State Road Laboratory dealing with the use of concrete paving blocks on state (national) roads, they were used by municipal and provincial authorities until the mid-sixties.

Towards a Standard (1955-1966)
The first Netherlands specifications for concrete paving blocks which was published in 1955 (see the foregoing) was only slightly modified until 1966, the year in which the first Standard on *Concrete Paving Blocks* (NEN 7000) appeared. In 1957 the original specifications were incorporated in the new edition of the *Specifications for Road-Building Materials* (the Eisen) issued by the Ministry of Transport. At that time, it was added that, for concrete blocks of the interlocking type, the dimensional tolerance should be 2% (cf. 3% for the rectangular blocks), in order to improve the interlocking effect. Having more results of comparative measurements on skid resistance, a Leroux-value of 67 (instead of 68) was assumed to be equal to f=0·45, which in fact was the only correction.

In 1962 another new edition of the *Specifications for Road-Building Materials* (the Eisen) was published. With regard to concrete paving blocks the only modifications were again one addition and one correction.

The addition dealt with the dimensional tolerence. For rectangular blocks this tolerance remained fixed at 3% but with the restriction 'for main roads only'. Since then, for other types of roads, the following differentiation had been introduced. As far as length and width are concerned, a tolerance of 3%. However, regarding the thickness, the tolerance was increased to 5% with a maximum of 4 mm. This differentation was in accordance, more or less, with a proposal made by SCW-Working Group D-2, which had observed some test sections in this respect.

The only correction dealt with the flexural strength test. For blocks of a width of 100 mm, minimum breaking loads of 60 kgf/cm² were specified (instead of a minimum flexural strength). The changeover from strength to loads was in agreement with the then operative Standards N 501 for concrete paving slabs (1956).

In 1967 another new edition of the *Specifications for Road-Building Materials* was published, about one year after the publication of the first Standard on *Concrete Paving Blocks*, NEN 7000[4].

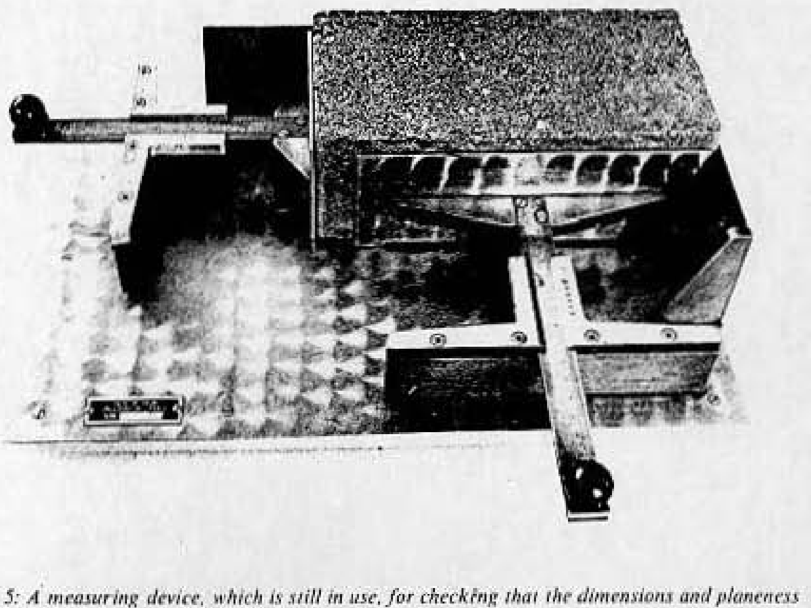

Figure 5: A measuring device, which is still in use, for checking that the dimensions and planeness conform to the Standard NRN 7000[4].

Working Group D-2 (SCW)

The start

The history of road construction in the Netherlands is marked by the establishment, in December 1957, of the Study Centre for Road Construction (SCW).

Working Group D-2, being one of the first SCW-Working Groups, was set up in 1959 and started with a very wide brief 'the manufacture and testing as well as the application of concrete paving blocks'. In the first years the Working Group restricted itself to a critical review of the existing Netherlands specifications (published in the 'Eisen' in 1957) and to the study of other possible requirements.

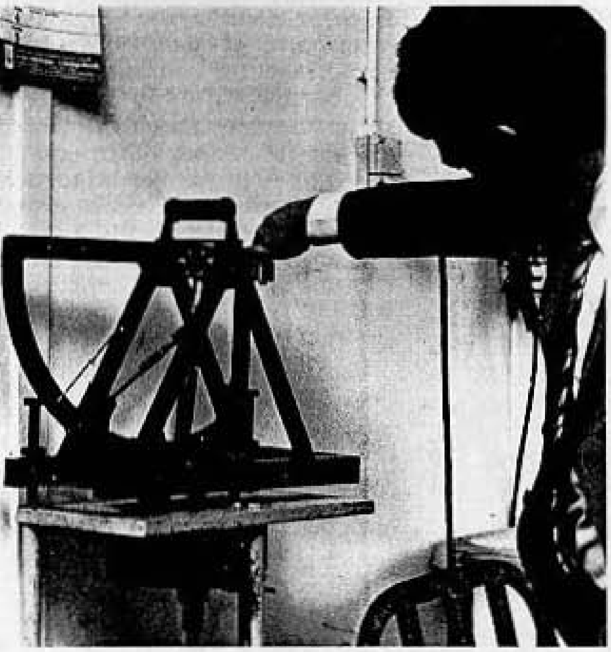

Figure 6: Leroux pendulum apparatus (model 1956) for testing that the skid resistance conforms to the Standard NEN 7000[4].

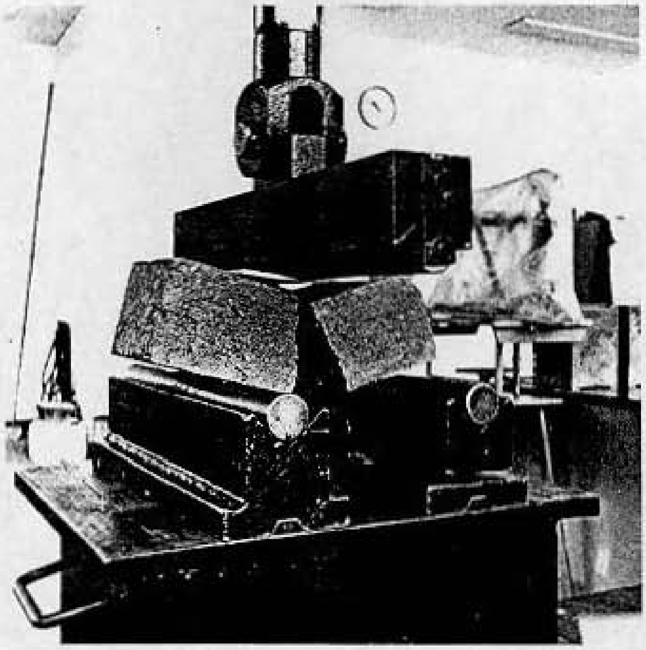

Figure 7: Flexural strength test (central loading), still in use, for checking conformity to the Standard NEN 7000[4].

In the 1957 'Eisen' an individual flexural strength of at least 60 kgf/cm² was specified. At the time the same test as well as comparable minimum values could be found in the specifications from neighbouring countries.

Belgium

Standard NBN 269, second edition of 1957.
Individual flexural strength – 60 kgf/cm²
Mean flexural strength – 72 kgf/cm²

German Federal Republic

Provisional directives* 1958.
Individual flexural strength – 55 kgf/cm²
Mean flexural strength – 65 kgf/cm²

Note—The specifications mentioned differed slightly in the span (bearing distance), rate of loading, etc.

SCW Report No 13[2]

The first report of the Working Group was published in 1963. It could be characterized by both the aim at 'standardization' and that at 'differentiation'. SCW Report No 13 advocates strongly the standardization of the dimensions in plan, viz. a length of 213 mm and a width of 105 mm. It also introduces a differentiation in the requirements according to the type of the pavement.

The dimensional tolerances were fixed as follows:

(a) Length not less than 212 mm (thus −1 mm as a maximum) and not more than 216 mm (thus +3 mm as a maximum). Compared to the then operative *Eisen* (1962), this tolerance had been reduced from 3% or approx. 6 mm to 4 mm, which could be done due to the specific properties of concrete in this respect.

(b) Width not less than 104 mm (thus −1 mm as a maximum) and not more than 107 mm (thus +2 mm as a maximum). Compared to the 1962 *Eisen* this tolerance did not change essentially.

(c) Thickness tolerence 3 mm for pavements on main roads, tolerance 5 mm on other roads.

The last mentioned differentiation had already been incorporated in the 1962 *Eisen* according to a proposal of the Working Group.

The tolerences introduced by SCW Report No 13 were in fact anticipating the Standard NEN 7000 of 1966[4].

SCW Report No 13 refers to:

Flexural strength test (central loading).
Compression test (sawn cubes or half blocks).
Resistance under falling pear-shaped steel ball.
Splitting tensile test.
So-called 'rattler-test' (ASTM C-7).

and furthermore:

Water absorption (porosity).
Volume weight (density).
Amsler abrasion test.
Loss of weight during the so-called 'sand-blast test'.

However, the Working Group concluded that there was no better test than the flexural strength test.

Winter 1962/1963

The exceptionally harsh and long winter of 1962/1963 caused a number of 'scalding cases' all of which were restricted to the top surface of the blocks. It was remarkable that one road section could present different degrees of damage. The Working Group tried to find a relationship, if any, between the degree of damage and the characteristic(s) of the blocks. A sample was taken from several road sections. Each sample consisted of three parts: no damage, light damage, and heavy damage.

The sampled blocks were subjected to different tests, after which conclusions could be drawn[5]. Some test blocks never complied with official requirements laid down in the *Eisen* of 1962, or of 1957. In some cases the flexural strength did comply with the specification, but then the damage observed could be explained only by assuming an insufficient quality of the top surface. It has been concluded by the Working Group that, in this respect, a judgement could be made by means of the sand-blast test only. Finally it was concluded that the freeze/thaw test, which was used at that time, did not show any relationship between the frost resistance and the flexural strength.

SCW Report No 44 (1978)

In the years 1964-1966 Working Group D-2 was involved in the framing of Standard NEN 7000[4] which was published in 1966. After that their activities were concentrated on the composition of a final report which was finally published, after several delays, in February 1978. The SCW Report No 44 on *Concrete Paving Blocks*[3] certainly is the most complete publication of

*Vorläufige Richtlinien für die Herstellung und Verwendung von Betonflastersteinen im Strassenbau, Fassung 1958.

recent years. This explains why this report has attracted great interest, not only in the Netherlands but also abroad.

Pavement construction

Behaviour

In the Netherlands the mechanical behaviour of concrete block pavements was never the subject of any fundamental research. Apart from some tests in the thirties and the early forties, the same could be said with regard to the behaviour of burnt clay brick pavements. The brick tests started with the introduction of simple sub-bases in order to improve the performance. At the same time, improved sand sub-bases as well as lightly bound materials for joint-filling were tested with the same intention. As already stated, concrete paving blocks could be regarded as the natural successors to the classic burnt clay paving bricks, and that is the main reason why the blocks could be introduced instead of the paving bricks, without any special question on the design of block pavements. There was a very long tradition of burnt clay paving bricks, everybody was already familiar with small-element paving, and so nobody asked for a structural analysis of small-element paving when concrete paving blocks were introduced.

During the 30 years' history of concrete paving blocks in the Netherlands, only the so-called 'Rotterdam construction' has been based on both theory and experiment.

Van Leeuwen[4] says that the Rotterdam construction was designed in the mid-sixties for heavily-trafficked areas at container terminals and in similar port yards. A block thickness of 120 mm was accepted from the beginning, partly as a result of practical experience with smaller thicknesses but also 'by feeling'. Experiments with a specially-designed circular test track resulted in the acceptance of a laying course 50 mm thick, consisting of a mixture of crushed stone and chippings (0-8 mm) laid over a cement-stabilized sand (sand-cement) sub-base.

Assuming in the combined layer of blocks and laying course (total thickness 170 mm) a load distribution factor of 2·5, the required sand-cement thickness could be calculated by using the two-layer theory of Burmister. For the heaviest wheel loads, produced by straddle carriers, a thickness of 330 mm proved to be necessary.

Later on this design was approved by using the American Portland Cement Association's information *Thickness Design of Soil-Cement Pavements for Heavy Industrial Vehicles* (1975). However, the very best proof of the excellent performance of the Rotterdam construction is provided by the 1·5 millions m² of pavement which are now in use, mainly at the ECT container terminal in Rotterdam (Van Leeuwen[4] but also in other port yards in Rotterdam, Amsterdam and elsewhere.

As already stated, it could be recommended even to us in the Netherlands to focus our attention on a more rational design of concrete block pavements. This will ask for a better understanding of the general mechanical behaviour of small element pavings, in order to obtain a more realistic design method for block pavements under light and heavy traffic and to reduce the maintenance to an absolute minimum. Having no deep insight into the general behaviour of block pavements, designers have made an attempt to develop a reasonable explanation for the mentioned behaviour. This work was started by Meijer[3].

An attempt was made to demonstrate the effects and the advantages of some structural arrangements and details such as:

Small tolerence in the dimensions, i.e. dimensional accuracy.
Narrow joints, which should be properly filled.
Requirements for the layer(s) under the block paving (stability, thickness compaction, etc.)
Water control (drainage of surface and subsurface water, including groundwater).
Edge restraint, i.e. lateral support.

Static loads (load distribution)

Concrete paving blocks are generally smaller than the contact area of a motor tyre, and therefore, a block pavement will provide only a limited load distribution. Although a wheel of a vehicle will often bear simultaneously on two or three blocks, there will still be not much load-spreading effect.

Yet the load distribution must be greater than might be inferred from this, otherwise contact pressures of say, 0·6-0·8 N/mm² (600-800 kPa from wheels of commercial vehicles) would be transmitted undiminished to the sub-base. This would certainly be an excessive value, especially if there were a large number of load repetitions. The load distribution which must therefore be presumed to occur will obviously be better according to how well the blocks 'co-operate' with one another. The blocks will therefore have to lie close against one another, and the joints should not only be narrow, but also properly filled. (This is also important for limiting the penetration of water through the joints). If these conditions are satisfied, fairly high frictional resistance will be developed in the joints between blocks which seek to move relatively to one another under load (Figure 8). This friction prevents the blocks from undergoing excessive relative displacements and transmits part of the load to adjacent blocks.

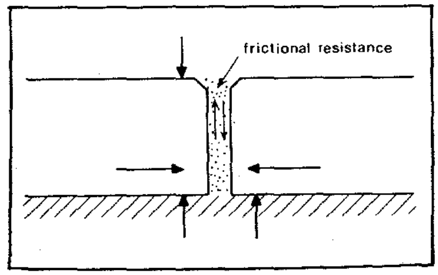

Figure 8: Frictional resistance between two blocks[3].

For the desired 'co-operation', i.e. for an effective load distribution, it is essential that all blocks have nearly the same shape and dimensions. Dimensional accuracy should therefore be good, which means small tolerances in the dimensions.

Moving loads

A block pavement, no less than a brick pavement, undergoes remarkable deformations under the wheel of a vehicle going over it. In front of a wheel a kind of 'bow wave' is formed, and behind it comes something resembling a 'wake'. These phenomena have been photographed with the aid of a high-speed camera when the creep of small paving elements was being studied[9].

Before, during and after the passage of the wheel, the blocks undergo some vertical movement. This almost certainly causes additional compaction of the sand under the blocks. In any case, it is a generally known fact that the sand sub-base, under small-element paving which has carried traffic loadings for long periods, often has a surprisingly high bearing capacity (expressed as CBR), and certainly much higher than at the time of construction of the pavement. This means that the shear strength of the sand sub-base, and consequently its resistance to deformation, has increased.

Use of Prandtl's theory

In SCW Report No 44 *Betonstraatstenen*[3] an attempt is made to clarify the behaviour of a block pavement with the aid of Prandtl's theory. This theory, originally published in 1921, was established for analysing the mode of failure under a uniform strip load such as that exerted by a strip footing or foundation. It presupposes the development of surfaces of sliding or shearing, which form wedges (Figure 9).

When a block pavement undergoes this type of deformation, 'hinging points' occur between adjacent blocks (Figure 9). The blocks are thrust against one another at those points, so that a kind of 'prestress' is produced in the pavement. (This phenomenon is elsewhere called 'progressive stiffening' or 'progressive interlocking'). As a result, the pavement, though consisting of separate blocks, behaves more or less like a rigid slab. Because of its relative stiffness and its weight, this 'slab' will counteract the formation of sliding or shearing surfaces in the underlying material. Such sliding (shear) surfaces will be less likely to develop if this material (e.g. a sand sub-base) possesses greater inherent stability. The loss of this stability has to be prevented by efficient water control, i.e. drainage of surface and subsurface water.

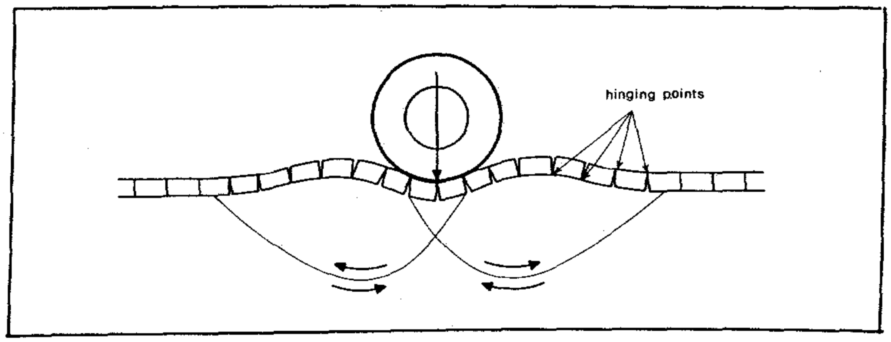

Figure 9: The behaviour of a concrete block pavement under load[3].

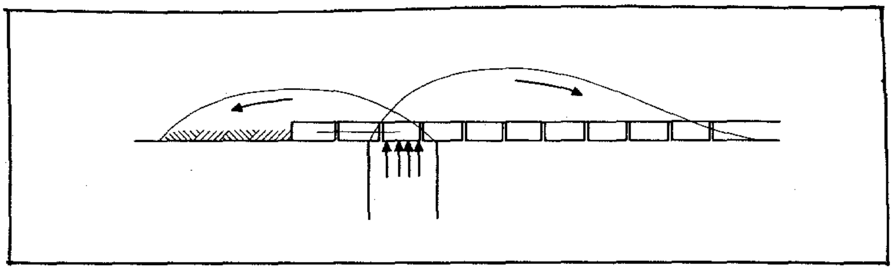

Figure 10: The behaviour of a concrete block pavement with inadequate edge restraint[3].

Conclusions

The pattern of forces in and under a concrete block pavement is evidently rather complex. The theory outlined in the preceding sections does, however, appear reasonably convincing. Some conclusions can be drawn, dealing with structural arrangements and details, and many years' experience in actual practice shows that these conclusions are correct.

An obvious conclusion is that the joints between the blocks should be narrow, they should remain narrow, and they should remain well filled to provide efficient load spreading ability for a long time. Therefore, high dimensional accuracy is required and this requires close tolerances in block dimensions in both the length and the width. (The thickness may present a relatively greater variation). The blocks have to lie close against one another to provide a tightly-laid block pavement, and therefore the blocks must be placed firmly against their neighbours when they are being laid, and this calls for good laying work by experienced skilled paviors. Filling the joints is accomplished by brushing in dry sand, but sometimes it appears that it is better to wash in a mixture of sand and water. In all cases vibratory compaction has a favourable effect.

The filling material could be a natural sand, which would have to comply with any minimum requirement concerning its grading. If only uniformly graded fine sand is available, a more angular-grained and better graded material (e.g. crushed-stone sand, i.e. crusher sand) should be preferred.

When rectangular blocks are used, which is normal practice in the Netherlands, a herringbone pattern provides a much better performance under load than simple stretcher bond (half-bond). It also offers better resistance to creep and to 'moving outwards' of the blocks. It is also less noisy under traffic than stretcher bond.

For the sake of completeness, the so-called 'interlocking blocks' have to be mentioned in this context since they have been developed for the purpose of offering greater resistance to forces tending to cause creep or lateral displacement of blocks. Nevertheless, of the total Netherlands paving block production, the share of interlocking types is only a few per cent. When rectangular blocks are used, sufficient lateral support is needed to prevent the blocks from migrating outwards. This lateral displacement of the blocks occurs under traffic loads when a transverse horizontal force component is developed, particularly because of the cross-fall (or additional cross-fall in bends). Even more serious is the fact that the material under the block pavement is also liable to be forced away sideways, which can also be explained with the aid of Prandtl's theory (Figure 10).

Therefore an effective edge restraint should be provided, which must not only prevent the lateral displacement of blocks, but also prevent the underlying material from being forced away sideways. The type of kerb construction for a given situation will depend on the traffic (intensity and weight), the properties of the material under the block pavement and in the road verges or shoulders, and on some other factors of less importance. The desired resistance to deformation of the block pavement under the load requires sufficient stability of the material under the pavement. This will govern the specification of the properties of the materials to be used. It will be decisive for the thickness of the layers, for the degree of compaction and for other requirements, which are the same as those required for other types of paving. Finally, it will lead to the choice of one of the three construction types which are described in the next section.

Last but not least, effective water control is necessary to prevent loss of stability due to any harmful influence of water. This implies drainage of surface and subsurface water, including groundwater, which is equally applicable to other types of pavements.

Finally, it should be noted that the above-mentioned structural arrangements and details all have the intention of achieving interaction of the paving blocks (interlocking) and preventing deformation of the block pavement.

Construction types

Concrete block pavements often have to satisfy the following conditions:

1. The pavement should undergo the least possible deformation, even under repeated loads. For this reason its various layers (block paving, sand sub-base, special sub-base with a laying course) will have to possess adequate stability.
2. The layers under the block pavement (sand sub-base, special sub-base, with a laying course) must be

able to absorb the water seeping into them and must also be able to discharge it, without loss of stability.

3. In many cases a suitable kerb will have to be provided.

4. In SCW Report No 44 *Betonstraatstenen*[3] three types of construction are distiguished, viz. type A, type B and type C (Figure 11).

5. The heavier types (B and C) will usually be adopted for roads carrying heavier traffic loads, but this will not necessarily always be the deciding criterion.

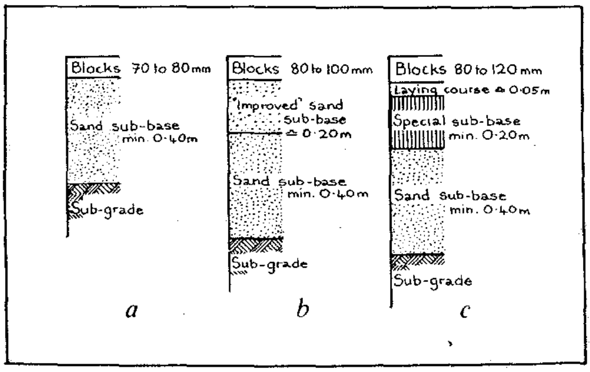

Figure 11: three construction types: (a) blocks on sand sub-base; (b) blocks on 'improved' sand sub-base; (c) blocks on a special sub-base ('base') covered by a laying course.

Types A, B and C are used in the following applications:

Type A
Pedestrian precincts and malls, footpaths, car parks for private vehicles, pavements for limited amounts of light traffic travelling at low speeds. e.g. contact pressures up to 0·2 N/mm² (200 kPa) and wheel loads up to 5 kN (0·5 tonne).

Type B
Residential roads, rural roads with little traffic, traffic lanes on car parks; in general, pavements with predominantly light traffic (private cars) and only a very limited number of heavier vehicles per day, e.g. 20, but only a few with axle loads of 80-100 kN (8-10 tonnes).

Type C
Roads, bus stops, industrial pavements and floors, storage yards; in general, pavements for heavy vehicles (lorries, fork lift trucks, etc.) exerting high contact pressures, e.g. 1-10 N/mm² (1-10 MPa).

A so-called 'improved sand sub-base' is used in construction type B, but it can also be used in types A and C, if the sand to be used would otherwise be unsuitable. There are various procedures for improving the stability of a sand sub-base: mixing with a better type of sand, mixing with granulated blastfurnace slag, mixing with cement (rather low percentages only, since the object is not to obtain a real sand-cement). Type C is characterized by a special sub-base covered by a laying course (which also acts as a levelling course).

The sub-base can be constructed from unbound material such as old road pavement material, hardcore, gravel, old stones, blastfurnace slag, scoria, crushed rock, etc. A sub-base of this kind must be laid and finished in the same way as a base or sub-base for a bituminous pavement

Lightly or fully bound materials are hydraulic blastfurnace slag, cement stabilized sand (sand-cement), etc. Such sub-bases are constructed in the same way as bituminous pavement. The laying course should be somewhat resilient, but also stable. For lightly trafficked pavements the material employed for the laying course is sand that fulfills these requirements. For pavements which have to carry heavy to very heavy traffic load, however, it proves to be recommendable to use another material, so-called crusher sand or a mixture of 'crushed stone and chipping' (0-8 mm) such as has now been successfully used for almost 15 years at container terminals and in similar port yards.

Fabes

In 1962 the Netherlands Association Fabes (Vereniging van Fabrikanten van Betonstraatstenen) was established by 21 concrete paving block manufacturers.

Fabes started with an exchange of technological knowledge in order to improve the quality of the concrete paving blocks and to obtain a more uniform quality of blocks. For four years the members regularly sent samples of blocks taken from their production to a control laboratory where several block properties were determined. Along these lines an insight into national production could be obtained. This proved to be a useful contribution to the work of the then newly-established Concrete Paving Blocks Committee of the Netherlands Foundation for Research, Approval and Certification (KOMO) and the Netherlands Standardization Organization (NNI). After a few years this committee presented the first Netherlands Standard for Concrete Paving Blocks: NEN 7000 *Betonstraatstenen-Keuringseisen*, dated June 1966[4,5].

In the seventies Fabes contributed to the work of the Betonstraatstenen (Concrete Paving Blocks) Working Group D-2 of the Netherlands Study Centre for Road Construction SCW (paragraph 3), which produced SCW Report No 44 on Concrete Paving Blocks[3].

In 1974/1975 the original rectangular block (the Kei-shape of approx. 213 mm × 105 mm, length to width ratio of approx. 2) was supplemented by a smaller block, the Dik (approx. 213 mm × 70 mm, length to width ratio of approx. 3). In 1977 a much smaller block was introduced and then Fabes decided to standardize the dimensions at 200 mm × 50 mm (the Waalshape, length to width ratio of about 4).

In relation to the already mentioned revision of NEN 7000, Fabes agreed to a further standardization of dimensions, viz. 211 mm × 105 mm (the Kei-shape) and 211 mm × 69 mm (the Dik-shape), which will be produced generally after a transitional period of only a few years.

It could be concluded that a national association of concrete paving block manufacturers such as Fabes is of great value in several respects.

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