Laboratory and fieldwork on block paving

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History of the NEN 7000 (1966)

CONCRETE paving blocks have been manufactured and used in the Netherlands since 1951 (see the paper of Mr van der Vlist presented to this conference).

In co-operation and dialogue with the first producers, a number of authorities such as the Rijkswaterstaat (Ministry of Transport), the City of Rotterdam and the City of Amsterdam drew up test specifications and test methods.

In the annual reports of, amongst others, the Rijkswaterstaat, the number of tests done and their results were mentioned.

The spectacular growth in the use of concrete paving blocks in the Netherlands after 1960 meant that it was impossible to keep a check on the level of quality of the total production. The consumption of the Rijkswaterstaat and both authorities mentioned above was a small part of the total use.

Tests were carried out by many recognised laboratories but they did not give any information about the test results except for the State Road Laboratory. Information about tests on deliveries was of course available from the individual producers, but co-ordinating this information without the producers being mutually committed was desired. FABES (the Association of Concrete Pavement Block Manufacturers) satisfied this desire.

In July 1962 this association of manufacturers was founded, with the following objectives:

(a) to promote and strengthen the dialogue between and the co-operation of the members;

(b) to improve the quality of concrete paving blocks and give information about their correct use;

(c) to consult or found and maintain a neutral authority charged with the regular testing of the quality of concrete paving blocks;

(d) to establish and maintain working groups and committees that, amongst other things, would give advice on technical matters.

Above all, it has been the active and collective aim to improve quality that has dominated the actions of this association.

After 1960 producers and users repeatedly questioned whether the test specifications agreed with what was needed in practice.

Concerning the Rijkswaterstaat, the test specifications dated from 1957, and the tolerances for, amongst other things, the length and width were obviously derived from burnt-clay bricks and the earliest concrete paving blocks (3% tolerance for length and width).

New and modern methods of producing gave room to the fact that on the one hand many wishes could be fulfilled, and on the other hand, the severity of the requirements had to be relaxed.

Concrete paving blocks should have properties that can cope in as broad a way as possible with demands and performance in practise. On the other hand, exaggerating these demands must be avoided in order to make economic production of concrete paving blocks possible.

This points out the great need for co-operation between users, scientists and producers in drafting the test specifications.

As already said, the founding of FABES made it possible to centralize the information available and to organize collective research.

The aim of this research was to get full insight into the quality of almost the total production. It is almost impossible for individual producers to bear the financial cost of such research, but as a group it became possible.

The examination of production quality was done in 1962, 1963, 1964 and 1965. A total of 25 samples were tested from each producer in 1962, 15 samples in 1963, 12 samples in 1964, and another 12 samples in 1965.

The producers had drawn up a concept for test specification which, on the one hand fitted in with the new production methods, and on the other hand with the existing test specifications (specifications of the Ministry of Transport, 1962, 1957). All the samples tested are compared to the specifications of Rijkswaterstaat (Ministry of Transport) 1962, and the specifications drafted by the producers.

In 1964 a standardization committee was established by the KOMO foundation and the NNI, in which users, laboratories and producers were represented. The object of the committee was to formulate a national standard for concrete paving blocks.

On the one hand the need for this resulted from the use of many standards which mostly differed from each other in small ways. On the other hand, the need was underlined by the severe winter of 1962/1963. In this winter it appeared that existing test specifications "dfd not give sufficient protection against damage to the top surface of concrete paving blocks, caused by frost and/or de-icing salts.

Many blocks which were being tested appeared to be unaffected, whereas others, were affected and became pock-marked or showed scaling. Concrete paving blocks that were provided with a top-layer suffered especially, losing this layer from the rest of the block.

From 1965 the above-mentioned committee proposed the so-called sand-blast test on the top-surface, which was brought within the scope of the FABES research. In the standard then existing for concrete paving slabs (N 501 and N 502), this sand-blast test had already been in force for years. After 1962, freeze-thaw tests were developed in different laboratories.

Suitable correlation between the existing freeze-thaw tests and the sand-blast tests were then sought, and with the publication of NEN 7000 this was said to have been accomplished.

The winters of 1963, 1964, 1965 and 1966 were mild and in no way could be compared with the winter of 1962/1963, so that comparison of freeze-thaw tests in the laboratory with circumstances in practice was not easily possible.

As argued earlier, a lot of data became available from the very extensive research undertaken by the producers during the years of 1962, 1963,1964 and 1965. These data were used by the standardization committee while formulating NEN 7000, complemented of course with data from practice and the laboratories.

NEN 7000 (1966) compared with the specifications of Rijkswaterstaat 1962.

The standardization committee

came up with test specifications for:
shape and appearance;
dimensions and dimensional tolerances;
top-layer;
skid resistance;
flexural strength;
loss of weight during the sand-blast test.

Further, it became possible, as a result of developments in production, to use statistics in a standard for concrete products. Many properties for which in the existing standards minimal values were required, were replaced by characteristic values.

Shape and appearance
The description of shape and appearance was greatly extended. Requirements were made for similarity and colour. The blocks were required to have no structural faults and be fairly straight, flat and rectangular. Even the bevelled edges were standardized.

Dimensions and dimensional tolerances
The first step to standardisation was the recommendation of the dimensions 213 mm x 105 mm. Furthermore, the maximum deviation from the producer's nominal dimension was specified—thus the number of elements per m^2 was fixed. The method of measuring with the "shapebox-meter" (shape measuring device) remained similar, but the tolerances for the length and the width differed significantly and became more severe.

As stated previously, at this point statistics were introduced with the use of standard deviations. Modern methods of production had contributed to this tightening up, which meant in practice that concrete block paving could be straighter. This soon resulted in the success of the method of "simple laying" instead of paving with the hammer. The height tolerance was also tightened up, with great benefit to the method of laying.

Facing-layer
The minimum thickness of the facing layer was prescribed, as was a reliable and durable connection between this layer and the rest of the block.

Skidding resistance
In the 1962 specification of the Rijkswaterstaat a minimum coefficient of friction of $f = 0.45$ for each block was demanded. This value was established on wet roads by means of a test vehicle and used the slipping wheel method (wheel slip 100%) with a standard speed of 20 km/hour.

This value was established as an average value for a certain length of road section (usually and preferably 100 m).

Because this test method can only be used on roads, the Leroux-value model 1956 was and still is used in the laboratory. With this apparatus it is possible to establish the skid resistance of a single block.

Correlation of research during the years 1956 to 1960 between the test vehicle and the Leroux apparatus made it evident that a Leroux value of 67 corresponds to $f = 0.45$. Consequently, 68 corresponds to $f = 0.46$, 70 corresponds to $f = 0.48$, and so on. Since the measurements of the test vehicle always give an average value for a certain road section and the results of the measurements with the Leroux apparatus are individual values for each block tested, the former requirement of 67 for each block was too severe, compared to the measurement with the test vehicle. The requirement in NEN 7000 (1966) therefore became a mean of 67 with a characteristic calculated minimum of 63.

The test method with the Leroux apparatus 1956 remained the same.

Flexural strength
In the "Eisen" Rijkswaterstaat 1962, an individual minimum for the flexural strength of 60 kgf/cm^2 was required, and the rate of loading was increasing to 50 kgf/sec. In the standard NEN 7000 (1966) the value of 60 kgf/cm^2 is maintained. The rate of loading, however, was brought up to the 1965 internationally accepted value of 0.5 ± 0.02 kgf/cm^2.

This meant a great improvement compared to the old method for which the rate of loading per second was much greater for thin blocks (i.e. 60 mm thickness) than for thicker blocks (i.e. 120 mm thickness). A consequence of the new rate of loading was that the quality of thin blocks had to be increased by approximately 8% to meet the original 60 kgf/cm^2 specification. However, previously each individual block had to meet the requirement of 60 kgf/cm^2, whereas, in the NEN 7000 (1966) because of the introduction of statistics, the characteristic value had to be 60 kgf/cm^2. Both changes forced the producers to improve the quality of blocks up to 100 mm thick. The equipment used for testing has not been changed.

Loss of weight during the sand-blast test
This requirement, which was in use for concrete paving slabs (N 501 and N 502) was not included in the test requirements for concrete paving blocks. The NEN 7000 (1966), however, included this test for concrete paving blocks, with or without a facing-layer. The demand specifies that, after blasting 3500 grams of normal sand against the top surface of the block, the average loss of weight of the block shall be less than 35 grams. This test can be carried out with the Vogel and Schemmann sand-blast apparatus after it has been modified for the test.

As mentioned previously, this test served to establish the relationship between the quality of the top surface and the resistance of the block to frost and de-icing salts. According to NEN 7000 (1966), blocks without a top layer could be considered to be reasonably frost resistant if they met the values laid down for the flexural strength. The loss of weight during the sand-blast test gives supplementary information.

External control KOMO (Quality assurance and certification)
As previously stated, after I960 a spectacular increase took place in the consumption of concrete paving blocks. This lead not only to the demand for national standards, but also to an increase in the number of deliveries tested. Unlike the Rijkwaterstaat and the larger municipalities, the smaller authorities and municipalities had neither their own laboratories nor sufficient skilled labour at their disposal to carry out all the tests required. Most of the time, testing of deliveries was contracted out to commercial laboratories and was carried out to confirm the test specifications that had been chosen by the principal.

Very shortly after NEN 7000 (1966) was published, these specifications were adopted by other authorities so that testing became more uniform. This soon gave birth to the idea of certification for manufacturers who wished to qualify. Certification of companies in branches other than the concrete products industry was already established, and the idea of certification of concrete paving blocks was a big step forward. If, after thorough investigations, companies could obtain a certificate for concrete paving blocks, the consumers would not need to test the goods delivered. This would reduce the cost of testing remarkably and also increase the flexibility of manufacturers who wished to supply from more than one source.

By the end of 1966, 8 companies had agreed voluntarily to certificate their concrete paving blocks. The KOMO foundation was the authority that, supported by the government,

took the initiative to grant the certificate.

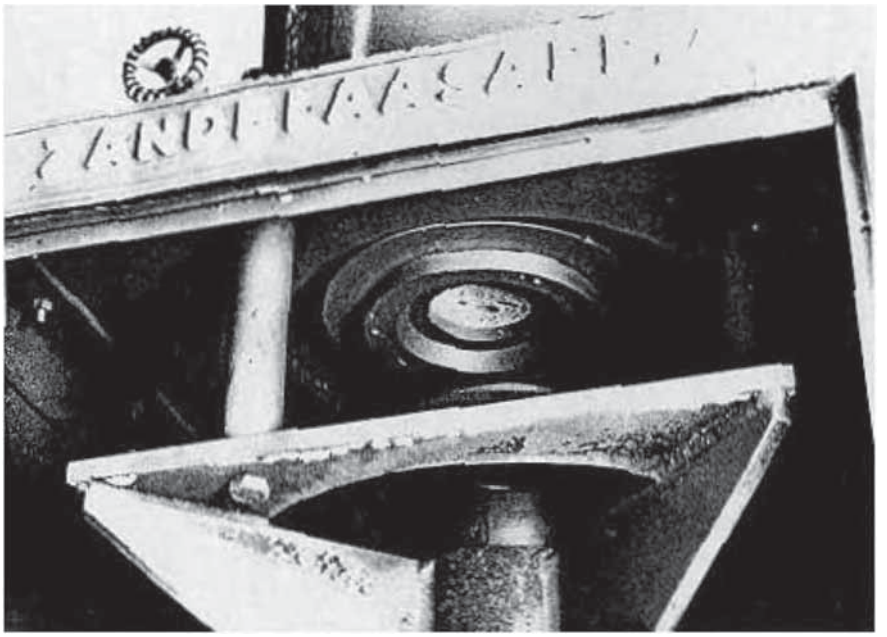
During a 6 to 12 month period, the companies' factories were thoroughly examined and the blocks were tested many times. Discussion was opened on:

(a) the attitude of the management and the leading personnel in matters of quality,
(b) the equipment of the laboratory and the skill of the personnel,
(c) the equipment in the factory,
(d) the quality control of the raw materials used and the arrangements fortheir storage,
(e) the daily production control,
(f) the intermediate control of the green product to reach an estimate *of* final quality at an earlier stage than NEN 7000 demands, and
(g) the final estimate of the quality of the completed blocks to conform to NEN 7000 (1966).

As shown previously, the ultimate aim of granting a certificate is simply that the delivered production should meet the specifications demanded by NEN 7000 (1966). However, great importance was attached to items (a) to (f).

A producer of concrete paving blocks, certificated or not, wants to know as early as possible whether his product will meet the standards laid down for the tests to be carried out 28 days later in accordance with NEN7000. Otherwise, under changed circumstances of production, it would be discovered too often and too late that production did not meet required specifications, with all the financial consequences.

In the years from 1967 till 1970, rules were established to meet the factors listed as (b) to (f). This was done by KOMO in discussion with the relevant producers whose numbers increased to 15 after a very short time.



Close-up view of the sand-blast apparatus.

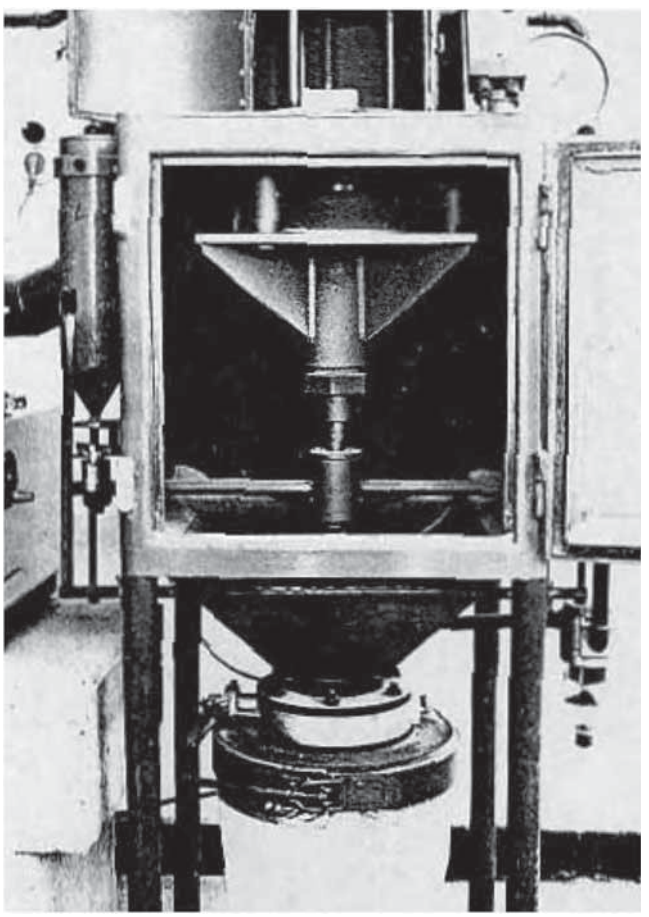
The rules and the corresponding control-activities were called the 1KB (Internal Quality Control System). These quality control activities were carried out daily by laboratory and key personnel, and recorded per production-unit in the daily reports. The daily reports were immediately available to the visiting inspectors who, on behalf of KOMO, surveyed and controlled Ute certificated companies.

The controls on the daily production were:

1. *control* by sieve analysis of the weighing of cement, sand and gravel on the basis of laboratory-established mix quantities,
2. control of the mixing time and vibrating time of mixers and production machines,
3. visual inspection of the freshly produced concrete paving blocks.
4. estimation of the height of freshly produced concrete paving blocks, and
5. estimation of the plasticity and shape of the concrete paving blocks immediately after production.

Intermediate controls for each day's production were:

1. estimation of the weight per unit volume of a sample from freshly produced blocks (this can often be done after four hours),
2. estimation of the length, width and height of 1-day old samples (if desired, the Leroux-value can also be estimated and the visupl inspection repeated),
3. testing of a sample of 7-day old blocks (each factory can correlate



The Vogel and Schemmann sand-blast apparatus

with this the strength after 28 days, depending on the type of cement used and the method of curing).

From all these measurements, it is possible to guarantee the quality according to NEN 7000 at an early stage and with a high level of certainty.

Laboratory and held work on block paving

In the years after 1966 much data became available after certification. Much more than previously the properties of every batch of concrete following NEN 7000 were available, and without much effort it was possible to check the properties after testing of the relevant batch. This is very important because, in case of a complaint, the properties of a batch change with time, except for the dimensions (traffic for instance changes the skid resistance).

In course of time the flexural strength increases, whereas the loss of weight by a sand-blast test becomes less.

Complaints in 1968 and 1969 were concerned mainly with the deterioration of the road surface. Several batches became pock-marked, i.e. the mortar was lost from between the aggregate, and when this continued the aggregate eventually became loosened from the road surface.

On the one hand this was caused by the severe winter of 1967/1968 when more damage than usual was caused by the frost and the de-icing salts. On the other hand this fault showed up during the autumn of 1968 in batches that were delivered during the summer of 1968, and were without any frost influence.

By inspection it was found that blocks that, by mistake, had been laid upside down or were used on their side as a kerb, did not show similar deterioration. Obviously the problem was limited to the top surface of the block as produced. The early test results of the delivered batches were examined and these showed that all the batches had easily passed the NEN 7000 test. In a number of batches the flexural strength fell far above the minimum; in others, the loss of weight by the sand-blast test was between 30 and 35 grams, and in a few, between 25 and 30 grams.

Table 2: *Loss of weight (gm) due to the blasting of 500 and 1,000 grams of sand respectively and due to 'brushing' over length of 100 and 500 m respectively.*

Test		Sand-blast		Brushing	
Series No.		500 gram	1,000 gram	100 m	500 m
A	11	3.0	5.5	1.0	2.0
	12	3.6	6.5	0.7	1.8
	13	4.5	6.4	0.6	1.1
	18	5.7	8.7	0.7	2.1
	19	5.2	7.5	1.6	3.6
	20	4.7	7.7	1.1	2.5
B	11	3.8	6.7	0.8	0.8
	12	3.6	6.0	0.6	1.0
	13	3.4	6.6	0.4	0.9
	18	4.6	7.9	1.5	3.1
	19	4.5	7.1	1.4	3.0
	20	5.3	8.2	2.1	4.7
C	11	3.1	5.2	0.4	1.1
	12	4.8	7.3	0.1	0.8
	13	4.5	7.3	1.0	1.9
	18	5.3	5.7	0.8	1.9
	19	3.1	5.9	0.2	1.0
	20	5.8	8.9	2.0	5.1
D	11	7.9	11.9	3.5	6.8
	12	12.7	18.4	5.3	7.7
	13	7.6	12.1	1.9	4.3
	18	7.6	12.7	2.5	5.1
	19	6.9	10.6	0.9	4.9
	20	7.6	11.2	2.2	5.2
E	11	4.3	7.3	1.7	3.7
	12	4.2	7.5	1.5	2.9
	13	6.9	10.2	3.4	6.1
	18	4.4	7.1	0.8	1.8
	19	4.9	7.5	1.1	2.1
	20	4.4	7.1	1.6	—
F	11	8.7	12.9	4.2	9.1
	12	4.4	8.3	1.6	3.2
	13	7.9	11.7	3.8	8.1
	18	5.2	8.3	1.0	2.5
	19	5.8	9.8	1.3	2.9
	20	4.2	6.5	1.0	2.2
G	11	5.8	8.9	2.6	5.0
	12	6.1	9.0	1.1	2.5
	13	4.6	8.1	1.4	3.1
	18	3.9	6.6	1.0	2.1
	19	5.6	9.1	0.6	1.8
	20	5.1	8.2	0.8	1.5
H	11	5.5	10.0	1.1	2.3
	12	10.4	14.0	4.5	9.6
	13	9.5	14.0	5.5	9.3
	18	7.1	11.4	3.8	7.8
	19	7.5	11.3	4.7	9.3
	20	9.0	13.8	—	—
I	11	8.0	12.0	4.4	7.0
	12	7.1	10.2	1.3	3.3
	13	6.6	9.6	3.6	6.4
	18	6.3	10.3	3.2	7.7
	19	6.6	10.1	1.4	3.1
	20	7.0	10.0	1.9	4.3
K	11	3.5	7.8	0.2	1.1
	12	4.6	8.1	0.3	0.7
	13	4.1	8.1	0.6	0.7
	18	5.3	9.3	3.0	5.0
	19	4.3	7.5	0.4	1.0
	20	3.5	7.2	0.5	1.1
L	11	4.0	8.0	0.5	0.8
	12	4.3	8.9	0.2	0.5
	13	5.1	10.2	1.0	1.8
	18	4.3	8.3	0.7	1.6
	19	4.7	8.6	1.0	2.2
	20	3.0	7.1	1.2	1.7

Table 1

Sample	Average weight loss in sand-blast test (gm)	Average Flexural strength (kgf/cm^2)	Characteristic (kgf/cm^2)
A	24-6	77	62
B	24.6	76	66
C	23.8	79	71
D	29.0	71	54
E	24.2	76	66
F	24.2	73	65
G	25.4	74	66
H	33.6	77	65
I	32.0	86	76
K	28.4	62	57
L	33.8	61	56

The fault could not be explained by any failure to meet the requirements of NEN 7000.

The requirements of NEN 7000 were obviously not sufficient; certainly, one or more of the tests was not severe enough to predict the deterioration of the top surface.

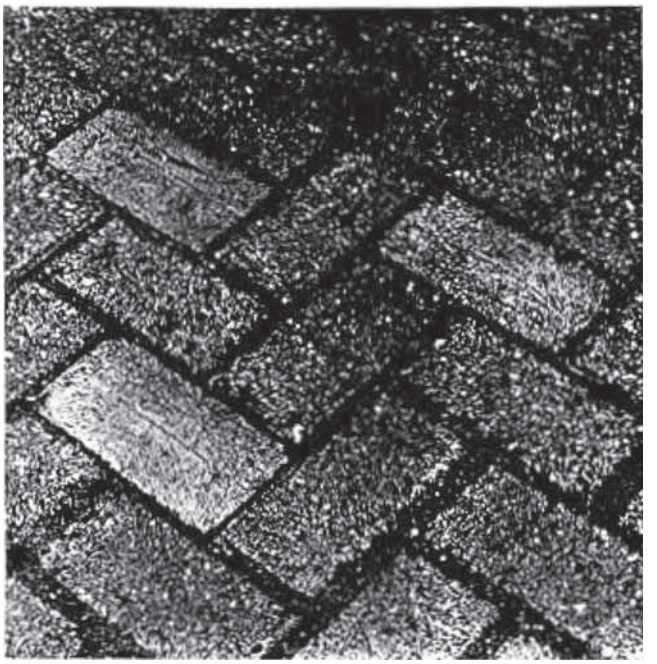
Initiated by the KOMO foundation and in co-operation with the State Road Laboratory, Institute TNO-IBBC and FABES, an *ad hoc* committee was established of which the author had the honour of being the Chairman.

This committee set out to examine the unexplained deterioration of the concrete paving blocks and to suggest ways in which NEN 7000 (1966) might be modified, if necessary.

The committee started its work in 1970, with the following aims:

1. To enlist the co-operation of Netherlands concrete block manufacturers employing different





Two views (above and right) showing the differences in the degrees of deterioration between blocks laid the right way up and those laid upside down (or on their side at a kerb).

production techniques including:
different kinds of cement,
different kinds of aggregates,
different ways of curing (natural and steam curing),
blocks with and without facing layers.

2. To ask these manufacturers to make available for test one daily batch out of their current production.

3. To get a large sample (of 150 blocks in this way) and have them stored under natural circumstances on the floor of the laboratory, and available for tests on them if it should become neccessary.

4. To lay the chosen blocks in a section of road carrying heavy traffic.

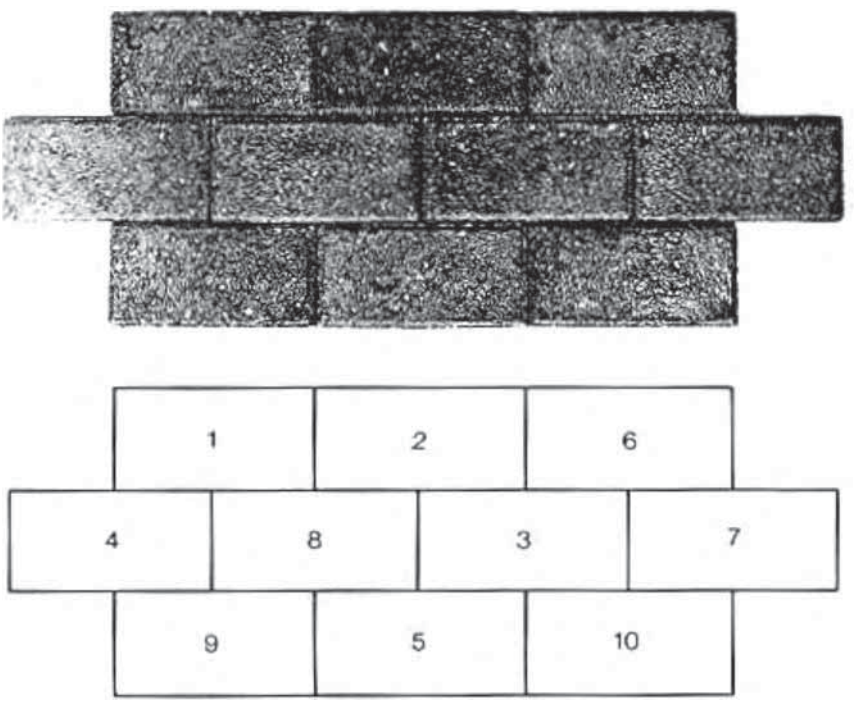
Action on Aim 2 above

In August 1971, nine producers were asked to make available blocks from the daily production of natural-coloured blocks during a certain week. Un-coloured blocks were chosen to remove any possible influence from the pigments, and to simplify thewisual inspection of the blocks.

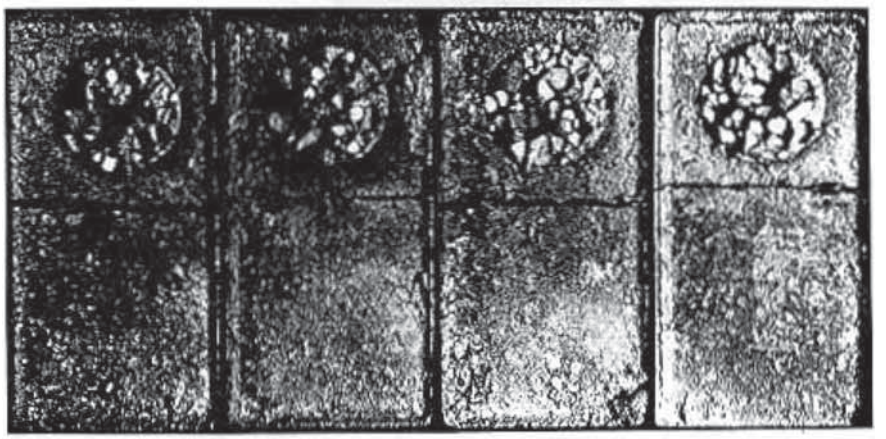
One producer was asked to make available samples with 10% extra cement. Another producer was asked to manufacture blocks with and without a chamfer.

The aim of the committee was to demonstrate that, if the top layer of the top surface of a block was of poorer quality than the sides or the bottom, this could have caused the deterioration by traffic and in winter by frost and de-icing salts. From tests according to NEN 7000 (1966) it appeared that all the delivered samples met the requirements of the iand-blast test but that three samples did not meet the flexural test. A survey is given in Table 1. Sample B is from the same producer as sample A, however, with 10% more cement. Sample K (without chamfer) is from the same producer as sample L (with chamfer).

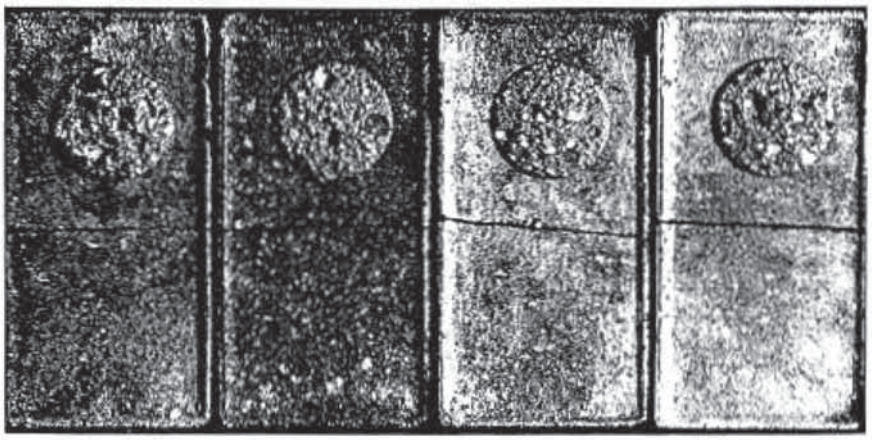
It is worth mentioning that the average sand-blast loss of sample F consists of about 30% of high losses and about 70% of low losses. Another point is that the low characteristic flexural strength of sample D is caused by the great variation in the sample (s = 10). The sand-blast values of D, H, I and L lead to the assumption that these samples were possibly more vulnerable to deterioration because experience in 1968 and 1969 had shown that excessive deterioration



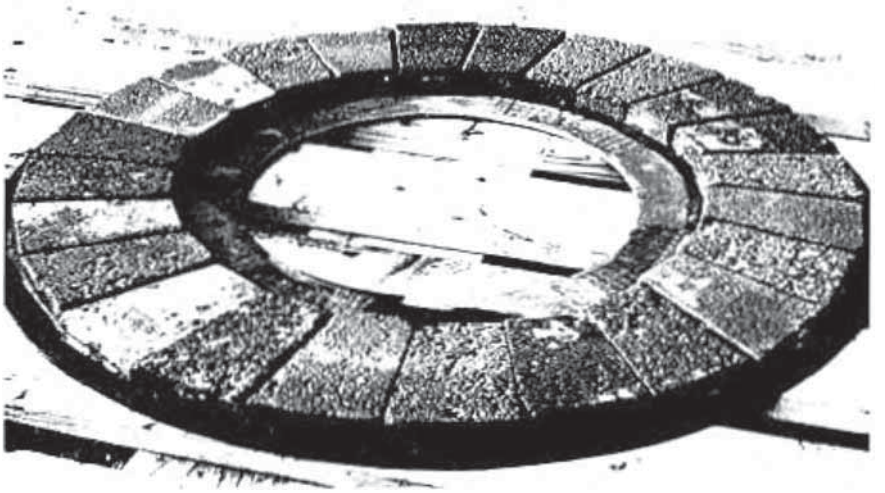
A representative sample of blocks rested under Aim 3.



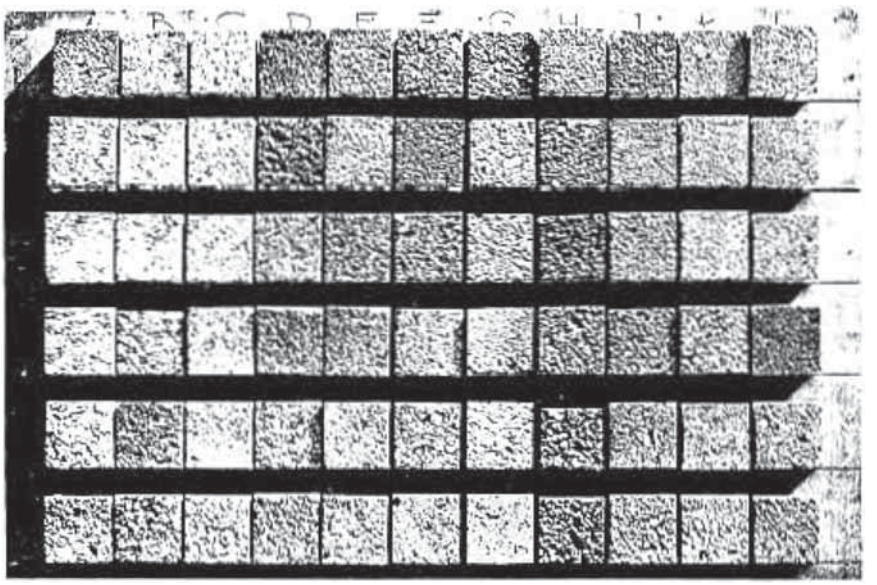
Four blocks after 1000 gram: of sand-blasting.



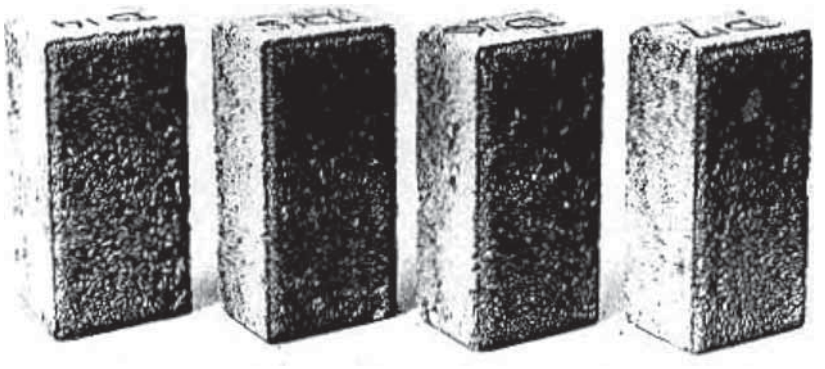
A further sample of block: after 1000 grams of sand blasting.



Block samples in position for the Amsler wearing (brush) test.



Results of the brushing tests on A to L.



Blocks D after the freezing test in sea water

took place when samples showed a weight loss greater than 30 grams.

Action on Aim 3

Per product a sample was composed from the eleven products, of which the blocks 1 till 4 had a closed surface, 5 till 7 a less closed surface and 8 till 10 a much more open surface. Furthermore, a second sample of 10 blocks was taken in which the blocks 1 till 15 corresponded with 1 till 4 of the first sample of 10 blocks, and 16 till 20 with 8 till 10 of the first sample. From the eleven samples, numbers 1 till 10 were tested on:

(a) water suction capacity.
(b) speed of drying,
(c) water absorption, and
(d) density.

These same tests were carried out on 'caps' of 15 mm thick concrete sawn from the tops of these 110 blocks.

Comparative examination of blocks and caps

Water suction capacity. There was no demonstrable difference between the average of the complete blocks and the caps.

Speed of drying. The average speed of drying of the caps of all samples was significantly slower (2 to 3 times) than that of the complete blocks. Sample L was as much as 5 times slower.

Water absorption in volume %. The average water absorption of the caps was 1.5 times higher than that of the complete blocks. For sample H the average water absorption for both was equal.

Density. There was no demonstrable difference in the densities of the complete blocks and their caps. In sample F it again appears that about 30% deviate strongly from the other 70%, a ratio that applied in all tests.

After these tests had been completed, the ten caps were glued on to a thin perspex plate so as to provide means of comparing the surfaces of unused blocks with the surfaces of blocks in the road.

On samples 11-20, the following tests were carried out:

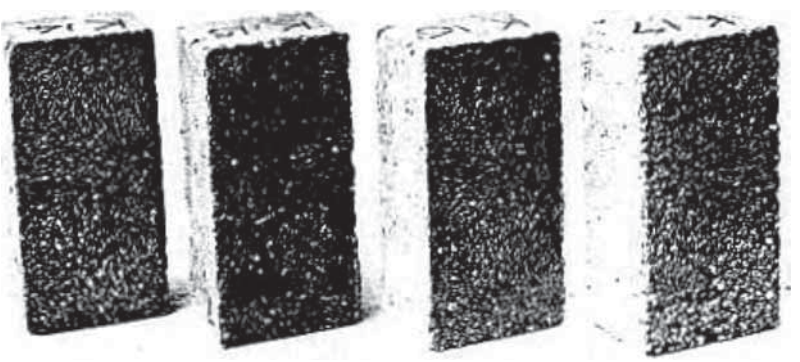
sand-blast test.
wearing (brushing) test,
freezing test (in seawater), and
combined freezing and brushing test.

Sand-blast test. The sand-blast test was carried out on half the top surface of each product for blocks 11-13 and 18-20. After 100, 200, 300, 400, 500 and 1,000 grams of sand-blasting, the loss of weight was measured.

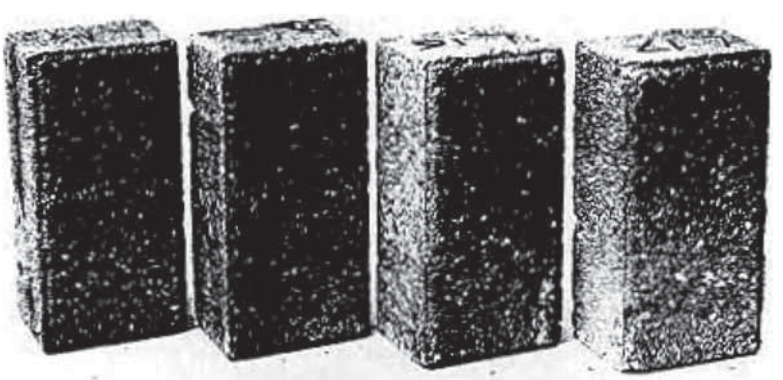
Wearing (brushing) test. For this lest an Amsler-apparatus was modified in such a way that a metal base plate was covered with 24 pieces of 6-row steel brushes placed in a circle around the middle point. From the other half of the 66 blocks used in the sand-blast test, specimens were sawn with dimensions 7x7x4 cm. (The dimension 7x7 is equal to the top surface of the block). These test specimens were weighed and placed in the holder of the Amsler-apparatus and exposed to wear by the brushes over a distance of 100 m. After this, the weight-loss was measured. After that another wearing trial of 400 m was carried out, and the weight-loss was measured again.

In Table 2 the loss of weight is given for all the eleven products and the 66 samples after blasting 500 and 1,000 grams of sand and after 100 m and 500 m of wearing trials. In general Table 2 shows that, if the weight-losses after sdnd-blasting by 1,000 grams are high, the weight-losses by a wearing trial of 500 m will also be high.

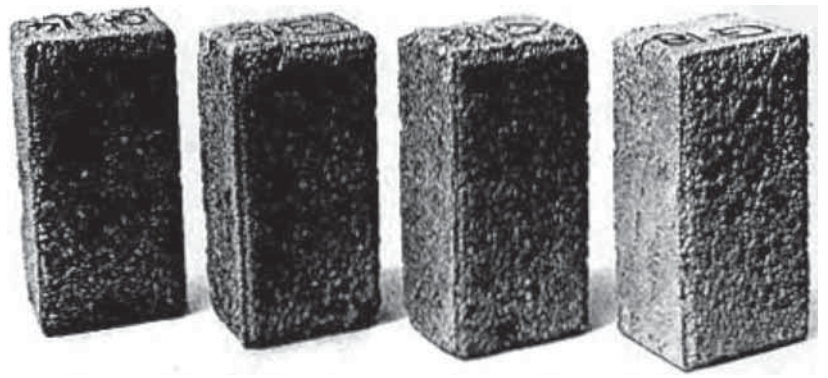
Freezing test in seawater. Block numbers 14 and 17 were frozen standing upright in 10 cm deep sand, saturated with seawater. Blocks 15 and 16 were frozen lying in the sand with a free top of 0- 5 cm above the sand. Per product blocks



Blocks K after the freezing test in sea water,



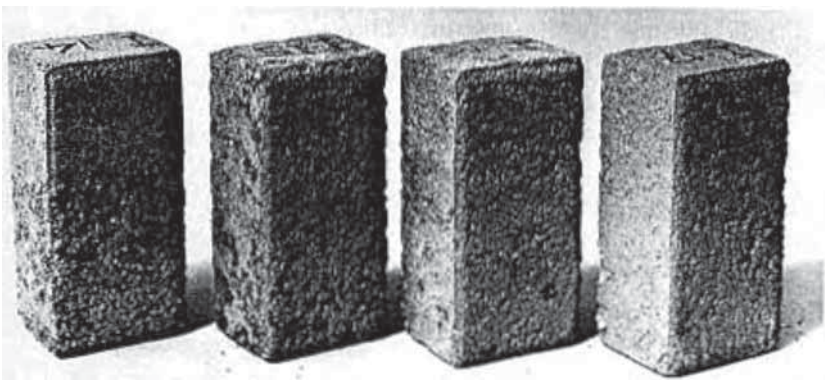
Blocks L after the freezing test in sea water.



Blocks G after the freeing test in seawater.



Blocks H after the freezing test in seawater.



Blocks I after the freezing test in seawater.

14—17 were frozen and thawed simultaneously, 25 limes. In the freezing tests, the top surfaces of sample D appeared to be partly sensitive to the test used; those of sample G were reasonably sensitive, but H and I were extremely sensitive; the latter became obvious after only 5 cycles. The samples of products K and L showed no sensitivity to the freezing test; neither on the top-surface, nor on the sides.

Combined freezing and brushing test. Products A, H and L were chosen for this lest, because the freezing tests in co-relation with the sand-blast test and the brushing test indicated great differences in results. For each product, two test specimens of about 7x7x4 cm were sawn from the top surface of the blocks having an average structure. A test specimen was also sawn from the long side.

After 0, 5. 10, 15, 20 and 25 cycles of freezing and thawing, brushing tests were carried out on these samples. As well as the loss of weight caused by frost damage during the freezing test, the loss of weight caused by the brushing test after that was estimated.

Product A showed hardly any damage on the top surface and the long sides after 25 cycles of freeze-thaw and 5 times the brushing test. Product H showed severe damage, especially on the top surface but also on the sides. Products A and H showed hardly any damage on the sawn surfaces. Product L showed no damage at all on the top and the sides. The sawn surfaces were, however, affected ("kernel concrete").

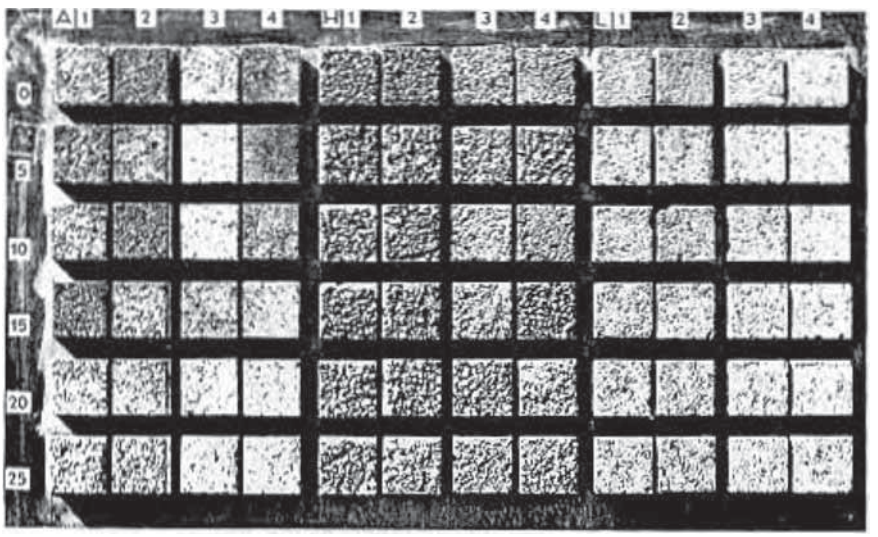
From Table 1 it can be seen that product L did not meet the requirements of the flexural strength (poorer concrete). The weight-losses during the brushing tests of the frozen block surfaces hardly deviated from the losses of weight of the corresponding wearing (brushing) test without freezing.

Actions on Aim 4

The test section was laid in a provincial road near Lekkerkerk. This was a new road with a length of 4 km, completely paved in concrete paving blocks. The intention was to give the road surface a new asphalt surface after a number of years when settlement had occurred.

The eleven test sections were fitted into about 300 m of road, covering the whole width of the carriageway, each test section being about 25 to 28 metres long.

The eleven products were clearly separated, i.e. for each product three rows of blocks were laid on



Series A, H and L after combined freezing and brushing.

their sides to denote the separation.

The test section was finished in the autumn of 1971. After an inspection of the lest section in December 1972, the following visual report was made:

Very good: scries C, 1, K and L
Good: scries A, B and G
Less good: series D, E, F and H

In this it turned out that the test section F performed well for about 70%, but that the rest was less good.

The road authorities provided data about the traffic density, the use of de-icing salts, snow or glazed frost, etc. The winters of 1972, 1973, 1974, 1975, 1976 and 1977 were mild and it was hardly necessary to take measures for skidding. During 1976 the authorities decided to cover the road with asphalt, so that the inspections listed in Table 3 had to be stopped. It was a pity that there was no chance of judging the effect of the severe winter of 1978/1979.

The inspection reports showed that the blocks that were paved on their sides had shown no changes in structure.

Looking at the laboratory results in relation to the weight-losses, after a sand-blast of 1,000 grams of sand, the poorer results with the products D, H and I co-relate well. For product F, the 30% bad elements must be kept in mind.

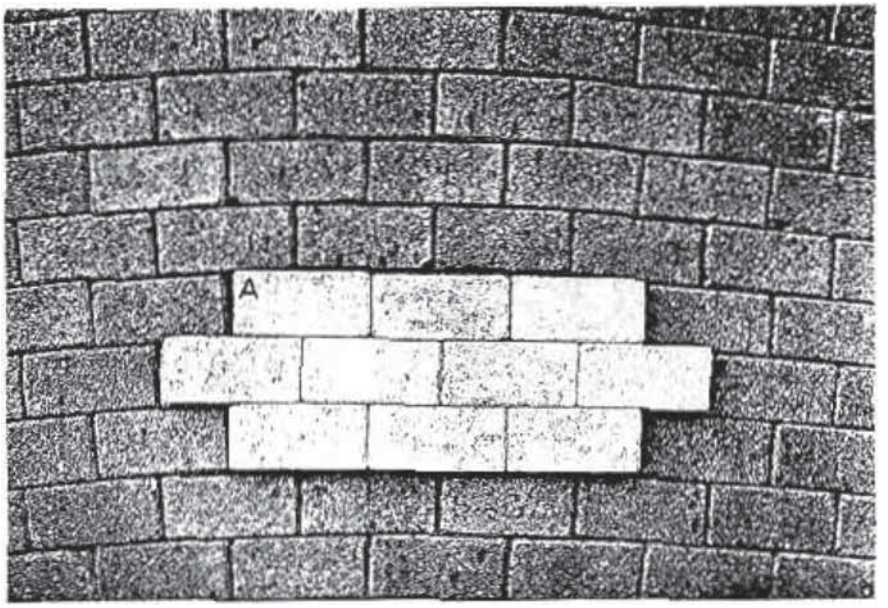
For product E, this explanation did not count, because E has a top-layer, at least with a different layer of heart concrete, placed by the second filling box. For product G, no clear conclusion could be drawn in relation to the sand-blast and wearing (brushing) tests although this product was shown to be reasonably sensitive to the freezing test in seawater.

Of products K and L it can be said that the heart concrete was of a less good quality, which meant that it did not meet the requirement for the flexural strength. The outer skin of these blocks obviously was good, which meant that the sand blast test and the wearing test gave good results and the performance in the road was outstanding.

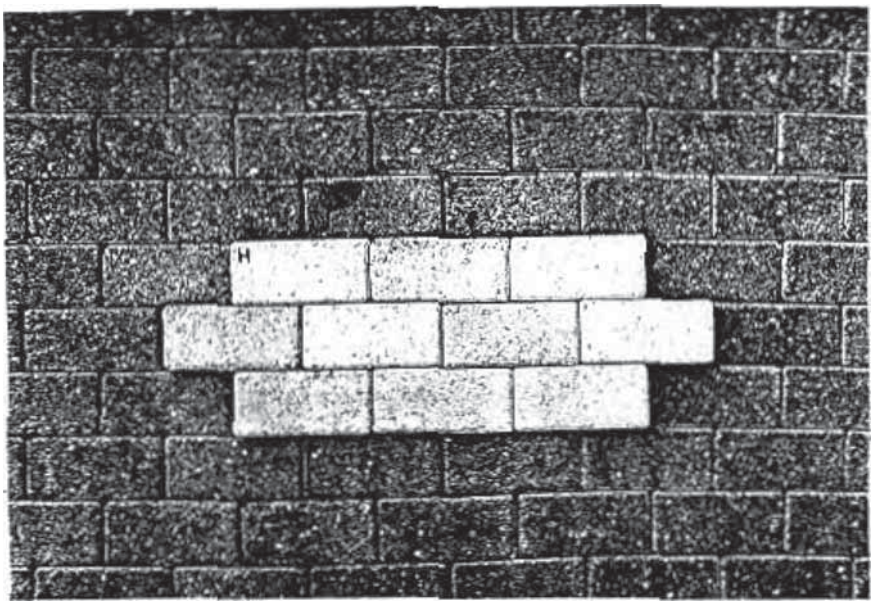
After this considerable research programme a number of recommendations were made to the manufacturers:

(a) Take care to achieve sufficient plasticity in the blocks to be produced (so as to close the surfaces, especially of the top).

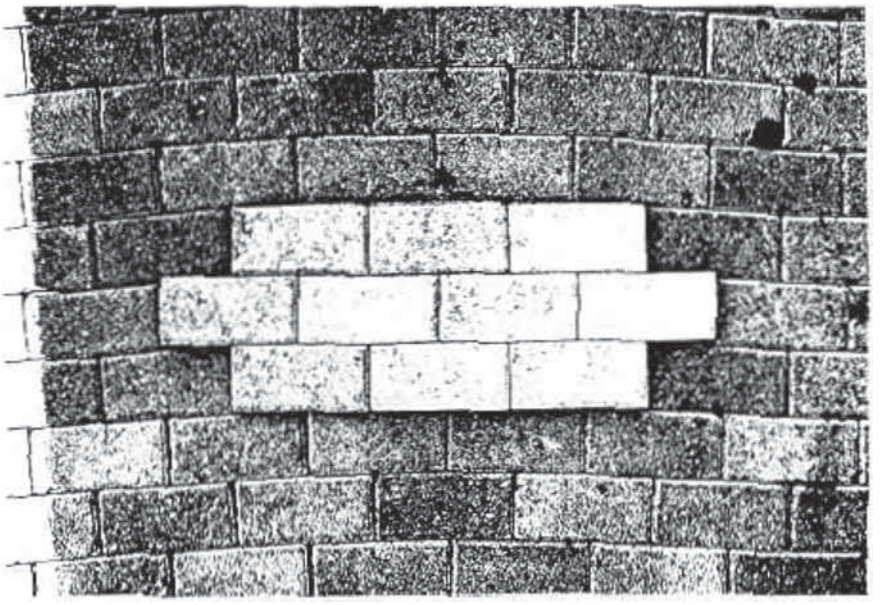
(b) Prevent drying out during the first 48 hours after production. This is even more important if blast-furnace slag cwncni is used. Blocks with this type of cement are more susceptible to drying out than



Good results were produced by series A in the test road.



Less good results were produced by series H.



Very good results were produced by series L.

blocks produced with ordinary Portland cement.
(c) Take care with steam curing, so as to prevent occasional "burning" during this process.
(d) Take extra care when providing the blocks with facing layers.

The manufacturers were also advised to try to achieve weight-losses of under 30 grams after blasting 3,500 grams of sand and—by intermediate checking—under 10 grams after blasting 1000 grams of sand.

These recommendations and advice have contributed to a better product with better top-surface resistance to the influences of traffic, frost and/or de-icing salts. The number of complaints relating to deterioration that were received after 1974 at KOMO decreased steadily, but more important was the proof supplied by the very severe winter of 1978/1979. This winter can be compared to the winter of 1962/63 which caused a lot of damage.
During 1979 the KOMO foundation and individual producers received hardly any complaints about failures of concrete block pavements.

Revision of NEN 7000 (1966)
In August 1974 the revision committee for the NEN 7000 was formed. As in 1964 this committee was responsible to both the KOMO foundation and the standardization organisation NNI. In the new committee, three members were included who had contributed to the original actual NEN 7000 (1966). The main reasons for the revision were the new information about quality of the top surface of concrete paving blocks, the skid resistance and the wish for standardization of the dimensions. The committee finished its job in 1979. The revised standard NEN 7000 was open for comment in the spring of 1980, so that the final version could be published before the end of 1980.

The revision had taken longer than the committee had expected. This was caused by the need for further research on the sand-blast test, the co-relation between the skid measuring test vehicle and the Leroux pendulum apparatus, and inquiries into the block dimensions used in the Netherlands and into the extent of their use.

The important point is that the modifications in the new NEN 7000 will become effective as a result of thorough research and discussions between users, laboratories and manufacturers.

Apart from editorial corrections and adjustments to the Si-units, fundamental changes have been introduced in:
- dimensions and dimensional tolerances,
- skid resistance,
- flexural strength, and
- loss of weight due to the sand-blast test.

Table 3: *Interpretation of block conditions in the test roads*.*

Block encoded	June 1972	Dec. 1972	May 1973	Oct. 1973	Nov. 1974	Nov. 1975	March 1976
A	a-I	a-II	a-II	a-II	a-II a-III	a-II a-III	a-II a-III
B	a-I	a-II	a-II	a-II	a-II	a-II a-III	a-II a-III
C	a-I	a-I	a-I	a-II	a-II	a-II	a-II
D	a-I	a-III	a-III	a-III b-I	a-III b-I	a-III b-I	b-I b-II
E	a-I	a-III	b-I b-II	b-I b-II	b-II b-III	b-III	b-III
F	a-I	a-II b-I	a-III b-I	a-III b-I	a-III b-II	a-III b-II	b-I b-III
G	a-I	a-II	a-III	a-III b-II	a-III b-II	b-I b-II	b-II b-III
H	a-I	a-III	a-III b-II	a-III b-II	b-I b-II	b-I b-III	b-I b-III
I	a-I	a-II	a-II	a-II	a-II a-III	a-III b-I	a-III b-II
K	a-I	a-I	a-I	a-II	a-III	a-III	a-III
L	a-I	a-I	a-II	a-II	a-II	a-II	a-II

*Criteria for interpretation of the results:
Stage a: Cement-mortar skin worn off, and consequently the course aggregates are just visible; otherwise, the top surface remains sound.
Stage b: Partial loosening of the cement-mortar between the coarse aggregates, which induced a rather affected top surface; consequently, the coarse aggregate (i.e. the gravel) has become visible.
The interpretation of the different manufacturers, based upon the above-mentioned criteria, would have led to a less differentiated interpretation, and that is the reason why a further subdivision was made into the following three classes: Class I, the beginning of the stage; Class II, half way through the stage; and Class III, the end of the stage.

Table 4: *Road surface conditions from Very skid resistant to Dangerous.*

Qualification	Coefficient of friction f_v (test method used from 1959, 86% slip, "retarded wheels", 50 km/h)	Coefficient of friction f_g (test method used in the years 1946-1958,100% "locked wheels", 20 km/h)
Very skid resistant	0.70	0.60
Skid resistant	0.56-0.70	0.51-0.60
Moderately skid resistant	0.51-0.55	0.46-0.50
Rather slippery	0.46-0.50	0.41-0.45
Slippery	0.41-0.45	0.36-0.40
Very slippery	0.36-0.40	0.31-0.35
Dangerous	0.36	0.31

Dimensions and dimensional tolerances
The urgent wish of the users to standardize on a small number of shapes was met by intensive deliberation between the manufacturers associated together in FABES.

Deliberation between the users would not have lead to these results, because they are not capable of analysing the economic and technical problems that were to be faced by the producers.

The following standardized (nominal) dimensions were chosen:

Kei	shape:	211mm x l05mm
Dik	shape:	211 mm x 69 mm
Waal	shape:	200 mm x 50 mm

The height dimensions were also standardized as 60, 70, 80, 90, 100 and 120 mm.

With regard to the other interlocking blocks, the producer has to give the nominal dimensions.

The ad-hoc conlmittee on the sand-blast test recommended that the manufacturers should produce their blocks from concrete with the 'best possible' plasticity. Consequently the standard deviation for both the length and the width was modified from 1.1 to 1.2 mm.

On the other hand it was specified that the average of the length and the width should not be allowed to deviate more than 1.5 mm from the (standardized) nominal dimension. In the original NEN 7000 this was 2 mm.

In summary, the requirements for dimensional tolerances have been tightened up somewhat.

In 1966 the statistic extreme values were:

2 x 2mm + 1.65 x 1.1 = 5.8mm

but in 1980 they are

2 x 1.5mm + 1.65 x 1.2 = 5.0mm

The method of testing has not been changed.

Skidding resistance

By 1970 a change to NEN 7000 (1966) concerning skid resistance had made its appearance. The requirement for the average Leroux value of 67 and the characteristic value (5%) of at least 63 was changed to an average of 65 and a minimum of 60.

Since 1959 the State Road Laboratory has used the method of 86% slip at a speed of 50 km/h, in addition to the method of 100% slip at a speed of 20 km/h, both on an artificially wetted surface.

Many measurements using both these methods compared to measurements with the Leroux pendulum apparatus, were carried out at the same place where the measuring vehicle (a two-wheeled trailer) had been used, and these showed that the requirement of 67, minimum 63, was too strict a classification for skidding resistance in practice.

When the modification of the NEN 7000 came up for discussion, a revision committee on skidding resistance was formed. This committee was given the brief to examine the intermediate modification of 1970 again and to report on this to the main committee.

The revision committee had at its disposal the results of the many measurements done by the State Road Laboratory and the correlations developed between:

(A) "Locked wheels" (100% slip) measurements with a measuring vehicle on a wetted surface at a speed of 20 km/h, the measurements (skid resistance) being the average value over a road section greater than 10 m (mostly 100 m), and expressed as the coefficient of friction f_g.

(B) "Retarded wheel" (86% slip) measurements with a measuring vehicle on a wetted surface at a speed of 50km/h, the measurements (skid resistance) being the average value over a road section greater than 10 m (mostly 100 m) and expressed as the coefficient of friction f_v.

(C) Measurements with the Leroux pendulum apparatus Model 1956, of the skidding resistance of a wetted surface (expressed in the Leroux value L), the result of each fifth measurement being assumed to be the Leroux value.

Methods A and B can only be carried out on roads, whereas Method C allows measurements to be made on single blocks.

On the basis of the comparison of test results, independent of the method of curing way of hardening stated by the State Road Laboratory on one hand (Table 4), and the estimated correlations between the method A, B and C on the other hand, the committee reached the following conclusion:

The value L = 63 agrees with a reasonable rate of reliability with the values $f_v = 0.51$ and $f_g = 0.44$. Since the value $f_v = 0.51$ has been used by the Ministry of Transport since 1968 as a minimum for the acceptance of pavements on national main roads, the value L = 63 can be regarded as a minimum requirement on the types of roads where concrete paving blocks are used.

Analogous to the requirement for the characteristic minimum value in the correction dated 1970, the characteristic value (5%) was fixed at L = 58 with a standard deviation of 3.3.

The flexural strength

In fact, nothing has been changed. The value of 60 kgf/cm^2 became 5.9 N/mm^2, being the conversion into SI-units (60.0 x 0.981 = 58-86 kgf/cm^2 = 5.9 N/mm^2). The manufacturer opposed the value of 6.0 N/mm^2, because this would have increased the requirements by about 2%.

In 1966 the introduction of a characteristic flexural strength of 60 kgf/cm^2 in combination with a rate of loading of 0.5 ± 0.2 kgf/cm^2 was itself an increase compared to the earlier requirement ('Eisen' 1962) of an individual flexural strength of 60 kgf/cm^2 in combination with a rate of loading of 50 kg/sec, and producers did not wish to see a further increase.

Since the first use of concrete paving blocks it had been shown that the value of 60 kgf/cm^2 (according to the requirements of 1957 (1966)) fully met the needs of practise. So, how could tightening up the demand make sense?

Loss of weight due to the sand-blast test

The revision committee for NEN 7000 had at its disposal the full results of the research done by the ad-hoc committee on the sand-blast test.

The committee reported that the blasting of more than 1000 gram sand was a waste of time because thereafter the loss of weight was always linear with the amount of sand blown. Of course, this only counts for concrete paving blocks without any top or surfacing layer.

For concrete paving blocks with a 'decorating' or 'finishing' layer (second filling car), after blasting more than 1000 grams, the heart concrete is reached, and then for each manufacture a co-relation exists between the loss of weight by blasting and the flexural strength. This correlation depends on the maximum size and the quality of the aggregate.

The requirement for flexural strength deals with the quality of the heart concrete only, but the sand-blast test can only deal with the quality of the top surface of the block. Sand-blasting of 3500 grams means that not only the top layer, but also the heart concrete is blasted.

This caused errors of judgement when the quality of the top layer was being estimated according to NEN 7000 (1966). By lowering the specified maximum average loss of 35 grams to 30 grams the assessment would have been improved, but not far enough, because blocks with a bad top surface and a very good heart concrete could remain under an average of 30, whereas blocks with a very good top surface and a poorer heart concrete could exceed the average of 30 (See Table 2, product L).

The one and only way of getting the right idea about the top layer is by blasting less sand. This also has the advantage of lowering the costs of the test.

On the recommendation of the ad-hoc committee, the blasting of only 1000 grams was accepted. There was a need to repeat a number of tests and to follow the further performance of the test sections in co-operation with the ad-hoc committee. For that, a working group was derived from the revision committee. The visual inspections in Table 3 were made in co-operation with the ad-hoc committee.

In 1978 a final report contained the following statements:

(a) The way the texture of the top surface changes in practice is (more or less) mainly and directly due to (i) insufficient curing of the concrete during the first 48 hours, and (ii) the plasticity of the concrete during production.

(b) The way in which the texture of the top surface changes in practice, is related to the losses due to the blasting of 1000 grams sand. Greater losses will result in greater changes in the surface texture.

(c) If the kernel concrete has the quality that is required by NEN 7000 (1966), changes in texture will be restricted to the real surface layer only.

(d) Freezing tests, relating to the

frost and de-icing situation in practice, could produce additional information.

The note about frost resistance in the standard NEN 7000 has not been true in that loss of weight by sand-blasting gives additional information but its interpretation can lead to false conclusions. With the very extensive research between 1970 and 1978 co-related with field tests, it is possible to declare:

> "If concrete paving blocks meet the requirements for loss of weight due to the blasting of 1000 grams sand and for the flexural strength, it can be assumed with great certainty that these blocks are resistant to frost and de-icing salts.
> "The de-icing salts should be of the type normally used and should be applied according to well-accepted methods."