EFFECT OF THE USE OF HALF-BLOCKS IN MECHANICAL BLOCK PAVING

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(On behalf of C.R.O.W. Working Group
'Half-Blocks in the Pavement')

Summary

The C.R.O.W Working Group 'Half-Blocks in the Pavement' has constructed a concrete block test pavement on the heavily loaded Smirnoffroad in the Rotterdam port area. By means of mechanical paving 4 block patterns have been realized, i.e. herringbone and elbow bond, each of them with and without half-blocks in the mechanically laid block layers. On the 4 test sections/block patterns the following aspects have been investigated:

- structural aspects, i.e. the development of the damage types transversal unevenness, irregularities, straightness of the block pattern and rutting during a 4 year period
- ergonomical aspects, i.e. the productivity and physical loading of the paviors (crew)
- the construction costs (material and labour) of the concrete block toplayer
- esthetical aspects (visual impression).

After presentation and discussion of the various measurement and observation results the conclusions with respect to the applicability and other aspects of the 4 investigated block patterns are given.

1. Introduction

In normal Dutch mechanical paving practice, concrete block layers (each about 1 m², blocks in herringbone bond) are laid in herringbone bond in which the concrete paving blocks have an angle of 45° to the road axis. Eack block layer contains 8 small gaps that are filled up on the works site with full-blocks to create interlock between adjacent block layers and to avoid continuous joints. This paving method requires 2 paviors near the clamb of the paving machine. Elbow bond (in fact herringbone bond, but now the blocks are parallel or perpendicular to the road axis) is very often used for parking places but it is very rarely applied on trafficked roads.

The C.R.O.W Working Group 'Half-Blocks in the Pavement' was established in the middle of 1991 as a follow up of another C.R.O.W Working Group, namely 'Comparison of Paving Methods', that studied a number of current Dutch mechanical and manual paving methods. In the final report of the latter Working Group [1] one study concerned the mechanical paving of block layers in which the above-mentioned gaps are filled during manufacturing with 8 half-blocks. In this way rectangular concrete paving block layers are obtained that simply can be laid next to each other on the works site, which seemed attractive from some points of view.
The task of the Working Group 'Half-Blocks in the Pavement' was formulated as follows:
The Working Group shall determine to what extent savings on mechanical paving construction costs can be obtained by using concrete block layers with half-blocks. This shall be investigated in a heavily loaded test pavement, where the following aspects have to be taken into account:

- Structural aspects: what is the pavement life in the case that block layers with half-blocks, laid down in herringbone or elbow bond, are applied compared to the life of pavements that consist of layers without half-blocks. The usually applied herringbone bond, consisting of block layers without half-blocks, shall be taken as the reference pavement.
- Economical aspects: what savings on mechanical paving construction costs can be obtained in practice by applying concrete block layers with half-blocks.
- Esthetical aspects: What is the visual impression of the concrete block pavements for the road users and the road authorities.
- Ergonomical aspects: To what extent the application of layers with half-blocks and the elbow bond will result in a more pavior-friendly paving method (lighten the physical loading of the paviors).

2. Test Pavement

The Working Group's test pavement was realized on the Smirnoffroad in the Rotterdam port area. This test location was offered by Municipal Works of Rotterdam
The Smirnoffroad is a heavily loaded road where 4 test sections, each with a length of about 100 m and a width of 8 m, could be realized. Further advantages of this location were the type of surrounding area (industrial yard, small number of crossings/side-streets, few cables and piping within the pavement) and the fact that construction of the test pavement could start almost immediately.
However, the time of construction was not favourable. Section I was constructed in December '91 in a rather rainy period, which could have an effect on the realized compaction of the layers (especially the base) below the concrete block toplayer. The remaining 3 sections were constructed in February '92 under better climatic conditions.

On the existing sand sub-base a light-bound base of 300 mm crushed concrete/masonry with stabilisator was applied, and on top of the base a 50 mm bedding layer of crushed sand.
The top layer consists of rectangular concrete paving blocks with dimensions 211*105*80 mm.
The Smirnoffroad, the adjacent parking-places, the entry and exit ways and the parellel roads all have been paved by the same contractor, that used a crew of paviors with a Schaeff vacuum paving machine. All test sections have been paved by nearly the same crew, that was very experienced in mechanical paving without half-blocks. It was however the first time for them to mechanically pave concrete block layers with half-blocks.

The test pavement on the Smirnoffroad contains 4 test sections (Fig. 1):
- section I : herringbone bond without half-blocks (reference section)
- section II : elbow bond without half-blocks
- section III : elbow bond with half-blocks
- section IV : herringbone bond with half-blocks

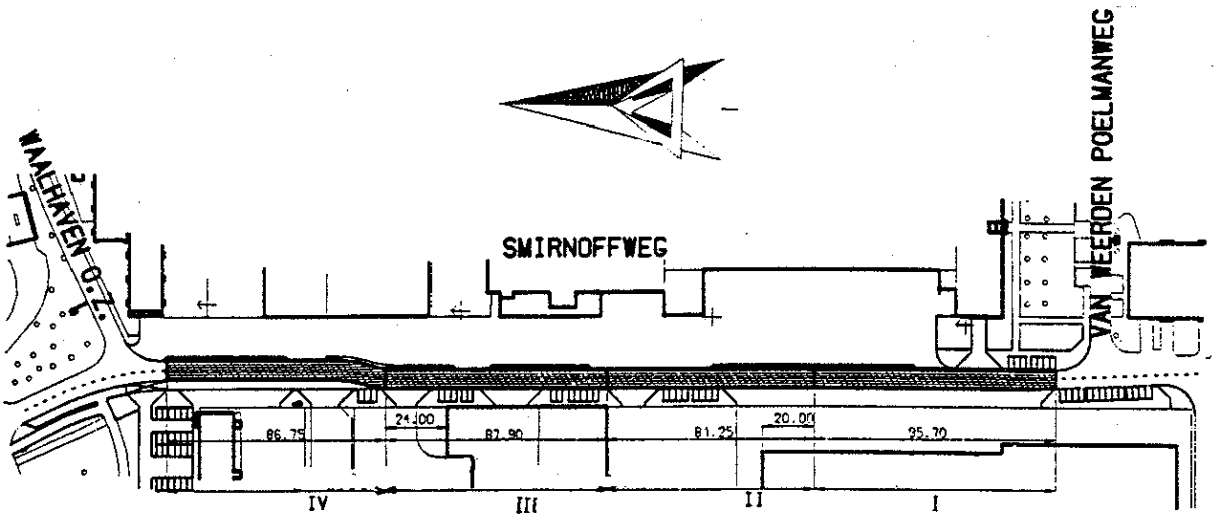

Fig. 1 Test pavement Smirnoffroad

After completion of the paving works in each test section 4 undeep saw cuttings were made in the transversal direction to serve as measuring lines. These saw cuttings, as well as some diagonal saw cuttings per section, are also used for visual observations.

3. Measurements

3.1 Introduction

Visual condition surveys have been done 5 times for determination of the general pavement condition of the test sections. Furthermore profile measurements on the transversal measuring lines were done immediately after construction and 3 times afterwards for determination of the relative displacements of the concrete paving blocks in the horizontal and vertical direction.
On two days traffic countings were performed to get an indication of the traffic loading.

3.2 Traffic Loading

Traffic countings on the test pavement Smirnoffroad have been done at November 3, 1992 and May 12, 1993. On the basis of these countings the traffic loading was estimated by assuming that the axle load measurements, carried out on the adjacent Albert Plesmanroad during some weeks in1984 and 1985 [2, 3], are still valid for the Smirnoffroad. In this way it was found that the traffic loading on the Smirnoffroad amounts about 3.10^6 equivalent 80 kN standard axle load repetitions during 10 years in the direction from the Albert Plesmanroad and about 4.10^6 equivalent 80 kN standard axle load repetitions in the direction to the Albert Plesmanroad. This traffic loading is similar to the one of a Dutch secondary road outside built-up areas, so the Smirnoffroad is a rather heavily loaded concrete block pavement.

3.3 Visual condition surveys

Visual condition surveys according to the C.R.O.W. system [4] were performed by Municipal Works Rotterdam about 4, 8, 20, 30 and 45 months after construction i.e. opening to traffic of the test pavement on the Smirnoffroad. It appeared from these surveys that only the damage types 'transversal unevenness' and 'irregularities' are present at the test pavement.
The observed amounts of light, moderate and severe damage have been transformed to the amount of equivalent moderate damage M_{eq} by means of the equation:

$$M_{eq} = 0.25L + M + 5S \qquad (1)$$

where: L = amount of light damage
M = amount of moderate damage
S = amount of severe damage

The development of the amount of equivalent moderate transversal unevenness is shown in Fig. 2.

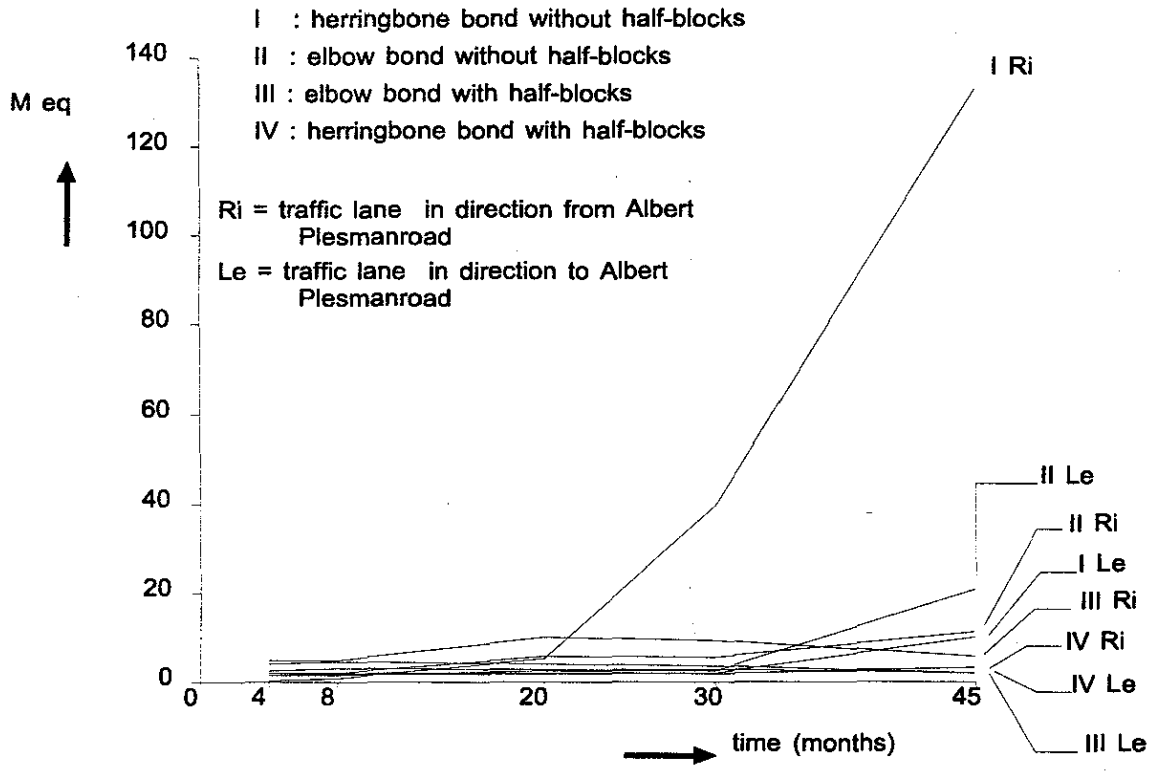

Fig. 2 Development of the equivalent moderate transversal unevenness M_{eq} (% of the total area) on the 4 sections of the test pavement Smirnoffroad.

It appears from Fig. 2 that quite some transversal unevenness develops after about 20 months in section I (especially the traffic lane Ri) and after about 30 months in parts of section II (especially the lane Le). The development of the transversal unevenness in lane Ri (direction from the Albert Plesmanroad) cannot solely be explained by a difference in concrete block pattern. Instability of the crushed concrete/masonry base and/or the sand sub-base is very likely to occur, resulting in a strong increase of the transversal unevenness after about 20 months.
In section I also some irregularities are present after about 30 months.
In the sections III and IV both the extent and the severity of transversal unevenness and irregularities remained very small.

3.4 Profile measurements

Immediately after completion of the test sections the x-, y- and z-coordinates of a number of points at the transversal measuring lines were measured (x-direction is parellel to the road axis, y-direction is perpendicular to the road axis, z-direction is vertical).
These measurements were repeated about 9, 30 and 45 months after opening to traffic. From these measurements the changes relative to the initial measurement were determined.

From the measured x-coordinates for each traffic lane both the mean absolute horizontal displacements parallel to the road axis and the standard deviation, relative to the initial measuement, were determined.

The standard deviation indicates the loss of straightness of the block pattern in the transversal direction: the greater the standard deviation Sx, the more irregular the cross section. The development of Sx is shown in Fig. 3. The horizontal displacements mainly occur in the period immediately after opening of the test pavement to traffic. After this initial period there is hardly any further loss of straightness of the bond (until 45 months).

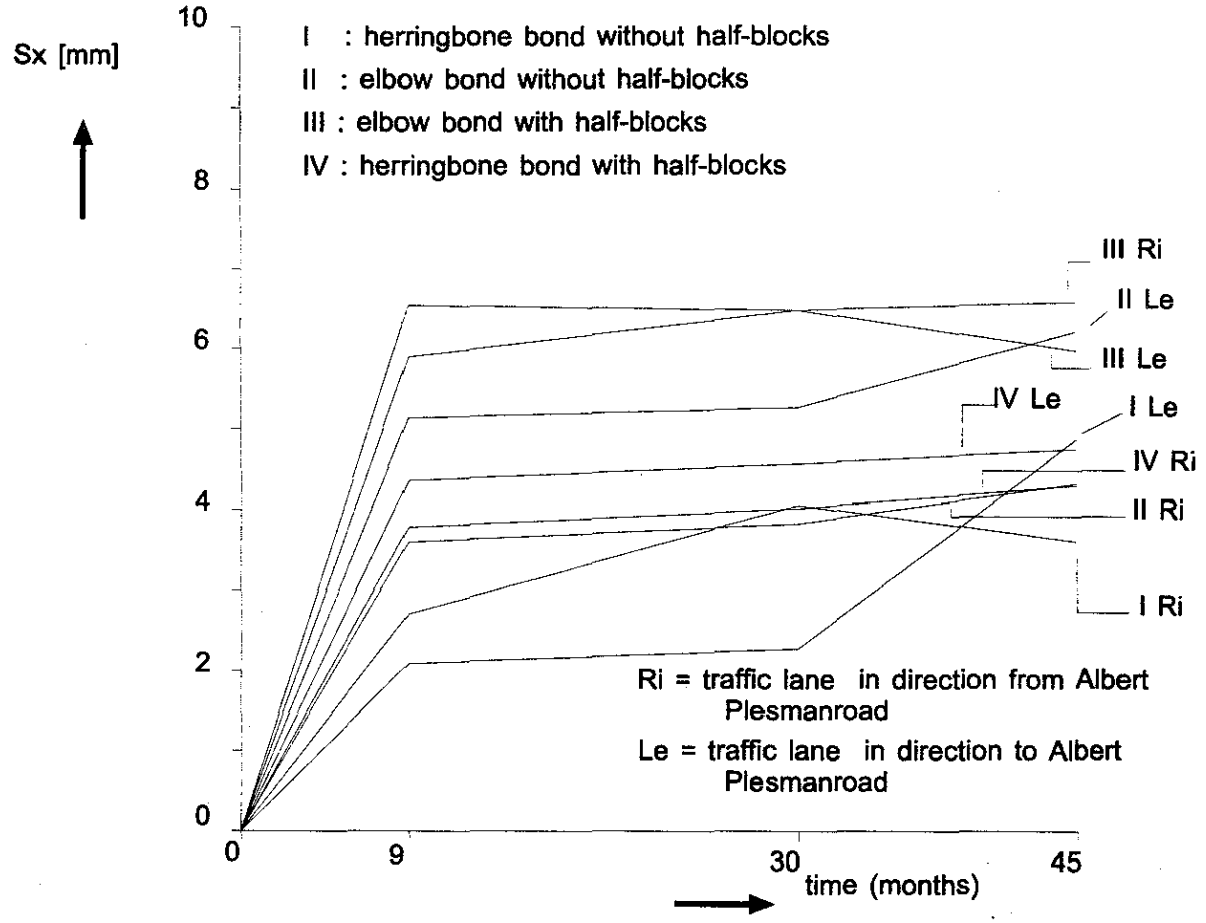

Fig. 3 Development of the standard deviation Sx (mm) of the horizontal displacements parallel to the road axis on the 4 sections of the test pavement Smirnoffroad.

From the measured z-coordinates for each traffic lane some figures with respect to rutting (below a 1.20 m long straightedge) were determined, i.e.:

- the mean rut depth RDm
- the standard deviation RDst of the rut depth
- the characteristic rut depth RDc with a probability of exceeding of 30%; RDc was adopted as the design criterion for concrete block pavements by the former C.R.O.W. Working Group 'Design of Small Element Pavements [2].

The development of the characteristic rut depth RDc is shown in Fig. 4. Also in this figure the excessive rutting on test section I due to instability of the crushed concrete/masonry base and/or the sand sub-base is clearly shown.

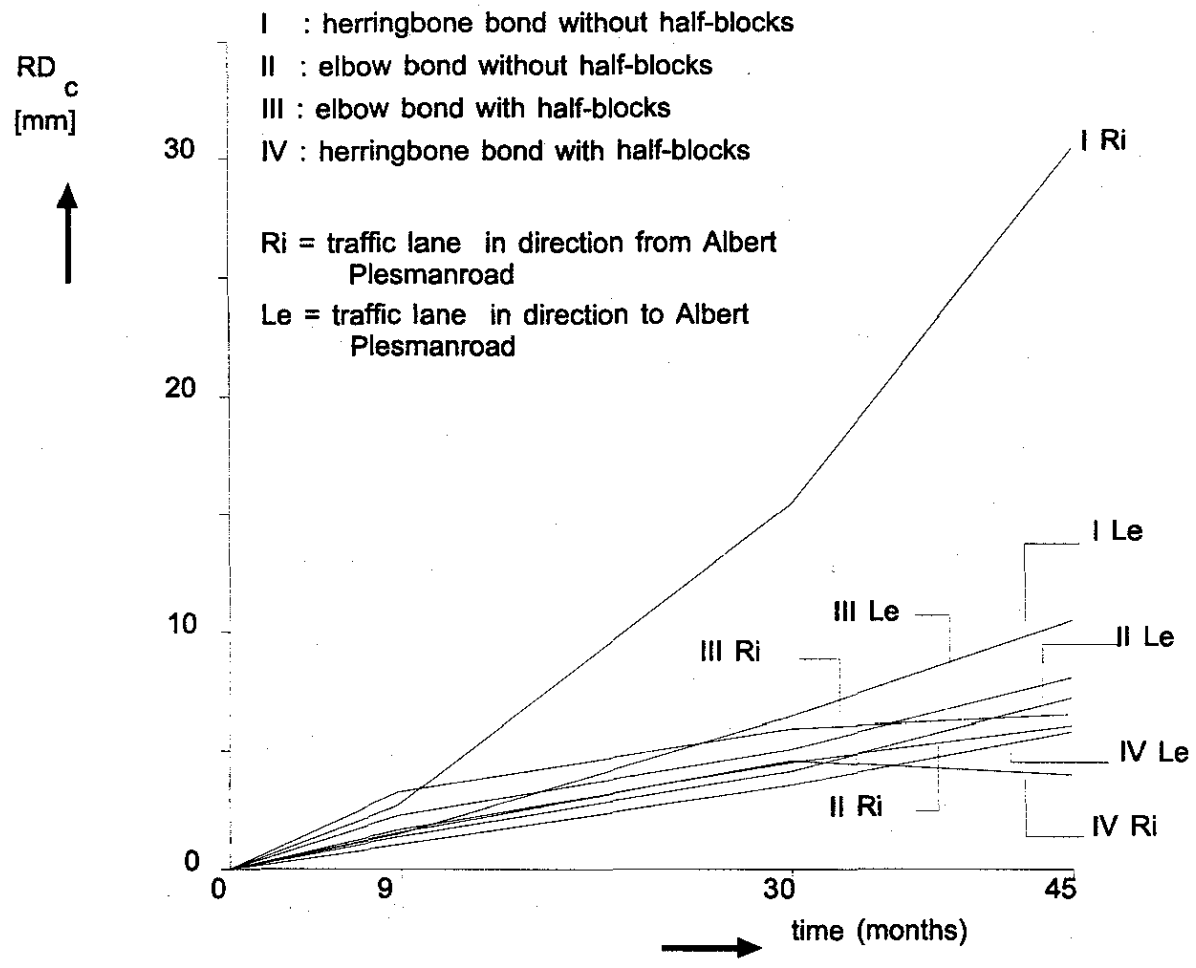

Fig. 4. Development of the characteristic rut depth RDc (mm) below a 1.20 m long straightedge on the 4 sections of the test pavement Smirnoffroad.

3.5 Conclusions

On the 4 sections of the test pavement Smirnoffroad the development of the damage types transversal unevenness, irregularities, straightness of the the block pattern and rutting has been measured. For each of these damage types a ranking of the test sections until 30 months after opening to traffic has been calculated, taking into account the deviating behaviour of section I (especially the traffic lane Ri). Assigning the same weighing factor to each damage type yields the following total ranking of the test sections from good to bad (after 30 months):

1. section I : herringbone bond without half-blocks
2. section II : elbow bond without half-blocks, and
   section IV : herringbone bond with half-blocks
4. section III : elbow bond with half-blocks

As already mentioned in 3.4, in the period between 30 and 45 months after opening of the test pavement excessive rutting occurred in section I due to instability of the crushed

concrete/masonry base and/or sand sub-base. As a consequence section I has to be excluded from the mutual comparison of the various block patterns. The total ranking (from good to bad) of the 3 remaining test sections after 45 months is:

1. section IV : herringbone bond with half-blocks
2. section II : elbow bond without half-blocks
3. section III : elbow bond with half-blocks

It should be noted that the concrete block pavement of the Smirnoffroad (as usual herringbone bond without half-blocks) next to the test pavement still was in a good condition at the end of 1995.

4. Ergonomical aspects

During construction of the concrete block pavement of the test sections on the Smirnoffroad ergonomical observations and time measurements were done. During the analysis of the measuring data the following differences were eliminated:

- the exchange of members of the paviors crew
- the exchange of the vacuum paving machine
- small differences in the paving methods
- differences with respect to the area to be paved
- measurement differences.

The measuring data have been transformed to an area of 1000 m^2.

Usually a crew of paviors, equiped with a vacuum paving machine, consists of 7 persons, i.e.:

- 1 driver of the paving machine
- 2 paviors for guidance of the clamp of the paving machine and for laying down the (whole) blocks, interlocking adjacent concrete block layers
- 1 person for preparation of the bedding layer
- 1 driver of a wheel-loader
- 2 paviors for paving the gutter, cutting of concrete blocks, compaction of the pavement and brushing in the jointing sand.

It appeared during construction that the paviors crew can be limited to 6 persons (1 pavior near the clamp of the paving machine instead of 2) in the case that half-blocks are applied. This single pavior is equally physically loaded as each of the two paviors in the case that no half-blocks are used.

On all the test sections not the paviors crew but the paving machine was determining the daily production that by consequence is nearly the same for every test pavement (Table 1).

Section	production (m^2)
I: herringbone bond without half-blocks	559
II: elbow bond without half-blocks	528
III: elbow bond with half-blocks	536
IV: herringbone bond with half-blocks	567

Table 1. Daily production (m^2) on the 4 sections of the test pavement Smirnoffroad.

In the case of application of half-blocks the number of manhours is 15% to 19% less because the paviors crew is smaller while the production rate is almost the same (Table 2).

Section	manhours
I: herringbone bond without half-blocks	100
II: elbow bond without half-blocks	96
III: elbow bond with half-blocks	77
IV: herringbone bond with half-blocks	85

Table 2. Number of manhours needed to construct 1000 m^2 concrete block pavement on the 4 sections of the test pavement Smirnoffroad.

5. Construction costs

The construction costs of the concrete block pavements have been calculated in a theoretical way. Deviating circumstances, that occur on every works site, were not taken into account.
The cost calculations are only valid for mechanical paving of layers (length 1.26 m, width 0.84 m) of rectangular concrete paving blocks (length 211 mm, width 105 mm, thickness 80 mm), either or not containing half-blocks and delivered on the works site by the manufacturer. Also the cost calculations were made for an area of 1000 m^2 (length 125 m, width 8 m). The cost data are valid for the Netherlands at the end of 1995.

First of all the material costs were calculated for each of the 4 test sections. The price of one concrete paving block in 1995 was Dfl. 0.3875 (layers with half-blocks) and Dfl. 0.40 (layers without half-blocks) respectively, while the price of one bisshop hat was Dfl. 1.05.
After the calculation of the total material costs per section, the savings per m^2 on the sections II, III and IV relative to the reference-section I (herringbone bond without half-blocks) could be determined (Table 3). In the case of elbow bond (sections II and III) the savings are caused by the lack of bisshop hats, while in the case of application of half-blocks (sections III and IV) the savings are explained by the lower price of the concrete blocks.

Next the labour costs were calculated for each test section for various hourly wages, i.e. Dfl. 50, Dfl. 55 and Dfl. 60. The starting point was a daily production of 500 m^2 (see Fig. 5). This means that the paviors crew needs 2 days (16 hours) to pave the area of 1000 m^2. In the case of application of half-blocks (sections III and IV), when the crew consists of 6 instead of 7 persons, thus 16 manhours are saved. Then the savings on labour costs, again relative to the reference-section I, can be calculated very easily for the sections II, III and IV (Table 3).

section	material	labour			total		
		Dfl. 50*	Dfl. 55*	Dfl. 60*	Dfl. 50*	Dfl. 55*	Dfl. 60*
II	Dfl. 0.40	-	-	-	Dfl. 0.40	Dfl. 0.40	Dfl. 0.40
III	Dfl. 0.94	Dfl. 0.80	Dfl. 0.88	Dfl. 0.96	Dfl. 1.74	Dfl. 1.82	Dfl. 1.90
IV	Dfl. 0.53	Dfl. 0.80	Dfl. 0.88	Dfl. 0.96	Dfl. 1.33	Dfl. 1.41	Dfl. 1.49

section II: elbow bond without half-blocks
section III: elbow bond with half-blocks
section IV: herringbone bond with half-blocks
*hourly wages

Table 3. Savings (per m²) on the concrete block pavement construction costs of the sections relative to the reference-section I (herringbone bond without half-blocks)

Finally for each of the test sections the amount of manual paving was estimated and from that the reduction of manual labour relative to the reference-section I (Table 4). In the case of elbow bond (sections II and III) the difference is obtained because no bishop hats and closing triangles have to be paved manually. In the case of application of half-blocks no (whole) blocks have to be laid to interlock adjacent concrete block layers.

section		difference (kg)
II:	elbow bond without half-blocks	8,500
III:	elbow bond with half-blocks	25,200
IV:	herringbone bond with half-blocks	17,500

Table 4. Difference in manual paving of the sections (each 1000 m²) relative to the reference-section I (herringbone bond without half-blocks)

6. Esthetical aspects

Originally it was the Working Group's intention to judge the esthetical aspects (visual impression) of the 4 test sections by means of panelrating through a (independent) group of reviewers, which have to some extent expertise in this field. But later on the Working Group realized that this would be rather impossible, considering the difficulties and obscurities with respect to the criteria to be used, their descriptions and their standards, the composition of the panel and the qualification of the individual members of this panel.
Therefore at November 7, 1995 four members of the Working Group independently got an impression of solely the condition of the block pattern. There was agreement between them that in the case of application of half-blocks the created continuous joints certainly in herringbone bond (section IV) but also in elbow bond (section III) are not really annoying. Furthermore it was observed that on section III the rectangular concrete block layers had moved a little bit with respect to each other in the direction parallel to the road axis. Nothwithstanding, it was the unanimous opinion of the members of the Working Group that, certainly in an industrial environment such as the Rotterdam port area, all block patterns applied in the test pavement

(herringbone and elbow bond, both with and without half-blocks) are acceptable from an esthetical point of view, also after almost 4 years of heavy traffic.

7. Conclusions

When applying concrete block layers with half-block only 1 pavior (instead of 2) is needed near the clamp of the paving machine. The physical loading of the individual members of the paviors crew is nearly independent on the block pattern and on the application, whether or not, of half-blocks.

Both elbow bond and the application of half-blocks give lower concrete block pavement construction costs compared to the usually applied herringbone bond without half-blocks. In the case of elbow bond with half-blocks the saving on the construction costs amounts about Dfl. 2.- per m^2 .

The block pattern has only a small effect on the structural behaviour of concrete block pavements. Herringbone bond yields a somewhat better behaviour than elbow bond and block layers without half-blocks result in a somewhat better behaviour than layers with half-blocks, the differences are however such small that each of the 4 block patterns is acceptable from a structural point of view (and certainly in an industrial environment also from an esthetical point of view). To obtain well-performing concrete block pavements both a good structural design and an adequate construction are however definite conditions.

8. References

1. "Comparison of Paving Methods (in Dutch)". (Publication 78, C.R.O.W, Ede, The Netherlands, 1993).
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3. "Design of Concrete Block Pavements for Roads (in Dutch)". (Publication 42, C.R.O.W, Ede, The Netherlands, 1991).
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