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MECHANICAL PAVING WITH CONCRETE BLOCKS

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SUMMARY
The use of paving machines in the application of element paving has proved to be a realistic alternative, both in large-scale projects (industrial estates) and in somewhat smaller scale projects (the broader city streets and squares).
The technique, in which concrete paving blocks are mechanically laid, results in increased productivity, lower costs and improved working conditions. The quality of the pavement is at least equal to that produced by other paving techniques.

In two projects, two types of paving machines have been tested. For the construction of a container terminal, Europe Container Terminus's Delta Terminal on the Maasvlakte at Rotterdam, the "Delta S" paving machine has been developed, in close co-operation among client, contractor and concrete block manufacturer. This machine is being utilized for laying so-called container blocks. There was an increase in productivity per worker of about 50% as compared with the manual laying technique which is usual for such areas. The area to be covered is about 80 hectares.

The second project was the partial reconstruction of two city streets in Rotterdam. In addition to the Delta S, use was made in this project of the Optimas paving machine.
To enable comparison with manual paving techniques: "manual paving" and "manual laying", these methods were used as well. There were five test areas, of about 1000 m2 each.
As compared with manual paving, mechanical laying resulted in an increase in productivity (80 to 180%) and a decrease in cost (5 to 30%). As compared with manual laying, however, this was not the case here.

1. INTRODUCTION

In this century, paving with small elements has become increasingly popular as a surfacing method for residential areas and industrial sites in the Netherlands. At first natural paving stones were used in a large proportion of roads and sites, especially in the Rotterdam urban and port area. The introduction of the concrete paving block has given small-element paving an extra stimulus.

The great interest of the Municipality of Rotterdam in all aspects of paving is a natural result of the infrastructural situation. See Tables 1 and 2. The amount of

Figure 1: Rotterdam area



Table 1 Land use in the city of Rotterdam

total area	27,000 ha
water area	7,400 ha
land area	19,600 ha
urban	6,000 ha
industrial and port	6,800 ha
agrarian	3,000 ha
miscellaneous	3,800 ha
(number of inhabitants	570,000)

1 hectare = 10,000 m2

Table 2 Paving of roads and streets

total area	2,465 ha	100%
asphalt paving	450 ha	18%
concrete (slabs)	15 ha	1%
small element paving	2,000 ha	81%
paving stones	80 ha	3%
clinkers	420 ha	17%
concrete paving blocks	700 ha	28%
concrete flags	800 ha	33%

Table 3 Pavings* ECT

Princess Margriet Harbour	110 ha
Delta Terminal, first phase	80 ha
Delta Terminal, maximum	400 ha

* concrete paving blocks

money spent annually by the Municipality for construction and maintenance of pavements amounts to about Dfl. 75 million. Element paving accounts for about Dfl. 60 million of this.
The paving of industrial and harbour areas is an internal matter affecting only the companies involved. The preference of the Rotterdam container stevedore ECT (Europe Container Terminus) for paving its sites (see Table 3) with concrete paving blocks, has formed the basis for a mutual interest in the problem of paving, which has led to this paper.

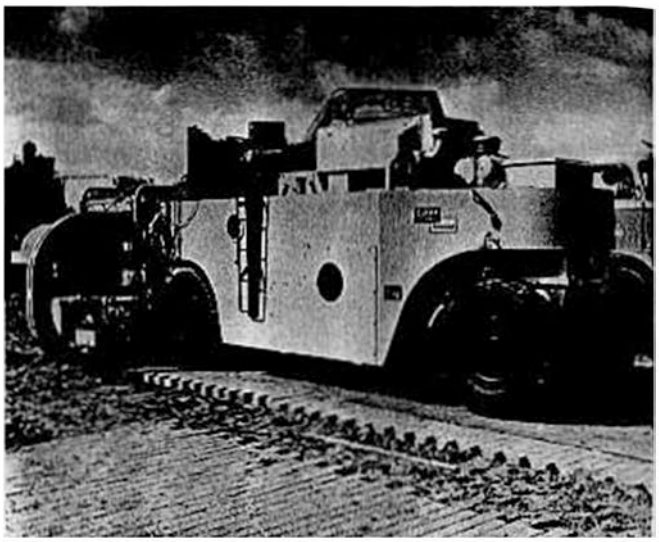
Since the fifties, attempts have been made to arrive at more modern methods of paving.
On the one hand, it was desired to humanise the labour involved - for paving is hard work - and on the other hand to increase productivity and reduce labour costs.

Because of their minimal size deviations, concrete blocks are more suitable for "laying down" than bricks or paving stones, which are usually "paved in".
"Laying down" requires a very careful preparation of the laying course. Production is higher, but here too the human labour involved is very arduous.
Because the movements involved are simple, "laying down" lends itself to mechanisation. Developments in this direction date from the 1960s. More recently, there have been important steps forward in this area, so that there are now a small number of different mechanical paving machines operational. These machines pick up and lay the blocks in batches of about 40, which are called "layers". Manual labour is still required for the proper joining of the different layers and for finishing along the edges.
The composition of the packages of blocks, consisting of 7-10 layers each, imposes higher standards on the production process (in the concrete factory), depending upon the laying pattern to be used.

2. HISTORY

Methods of paving using stones and bricks have not changed essentially in the centuries since these paving methods were first used. On a foundation of compacted sand or some other granular material, the stones or bricks were placed one by one and pounded in with a hammer.
At first the industrial revolution did not lead to any changes in this branch.
Mechanisation began only in the twentieth century. The earliest mechanisation consisted of steam rollers for compacting the foundation; vibrating plates - for compacting as well, but also to vibrate the paving itself into place solidly and evenly - and stonecutting machines. Also, wheel-loaders, mobile cranes and other construction and road construction equipment was implemented.
Equipment was developed to shake and/or scrape clean the stones to be reused. The manufacture of the paving bricks and stones, too, was largely mechanised. But the actual "paving" process remained unchanged.
After the Second World War a new method was used occasionally: the "laying down" of bricks onto a smoothly finished bed. This method can be used only if there are only slight differences in the height of the bricks. There was a well-known experiment in The Hague in 1952, where the bricks were laid from a working bridge over the street. The motivation

Figure 2: Amsterdam paving machine



behind such experiments was that production could be increased and less craftmanship was required. But the experiment was not followed up.
The development of concrete paving blocks opened new possibilities for mechanisation. These blocks have an almost constant quality and only very slight size deviations.
Because it was predicted in the 1960s that there would be a great shortage of labour in the Netherlands, the Municipalities of Amsterdam and Rotterdam developed a machine which was able to lay rectangular blocks onto a prepared bed in stretcher bond pattern. See Figure 2. However, the results were not entirely satisfactory, and the cost was high.

Yet the urge to mechanise was kept very much alive by increasing labour costs, the striving to reduce the ergonomic unhealthiness of the pavior's work and the desire for greater productivity.
Eventually, it resulted in the present generation of concrete-block-laying machines.

3. MECHANICAL LAYING TECHNIQUE

Machine

The most important characteristic of the paving process using the block-laying machines now operational is the use of the clamp construction, by means of which a package of blocks is taken up one layer at a time and placed on the roadbed.
The clamp, which is operated mechanically or hydraulically, is attached to a motor vehicle with a lifting mechanism. This concept can be worked out in very different ways. See Figures

Figure 3: Delta S block-laying machine



Figure 4: Optimas block-laying machine



3 (Delta S block-laying machine) and 4 (Optimas block-laying machine). The machine is operated by a driver and a pavior. The latter gives directions and checks to make sure the clamp is in the correct position, so that the layer to be laid is properly fitted against the previously placed paving.

Packages

The block-laying machine processes the blocks in rectangular layers of 40 to 50 blocks. The making of packages composed of complete layers in the desired order can be accomplished as part of the production process, but it is not a simple thing. To facilitate efficient processing at the site, the packages can be placed on pallets.
The number of blocks in a layer depends, among other things, on the dimensions of the blocks, in particular the height. For good processing, it is important that the blocks have only slight dimensional tolerances and are well squared.
If the paving is to be laid in block pattern, the layers are complete. In case of elbow bond pattern there are empty spaces left in the layers, or these are filled if necessary with half blocks. In stretcher bond pattern it is also possible to overlap the rows in a layer. The laying pattern is completed on site by putting the missing blocks (filler blocks) in place. This task is done by the pavior who guides the clamp.

Preparation of the bed

Just as in manual laying, the ground is prepared in such a way that the blocks need only to be laid down. After the bed, generally consisting of granular material, has been roughly shaped and compacted, the upper surface is carefully levelled to the correct height by means of a short screed or with a screeding beam.
In order not to disturb the prepared bed, the paving activities must be carried out from the area already paved.

Finisning the paving
The pavement is vibrated to level and sand is brushed into the joints in the traditional way. In order that the pavement is not disturbed, the vibrating and brushing should be carried out immediately after the blocks are laid, so that the supply and transport of blocks can take place over pavement that has been completely finished.

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

Limitation in its application
1. Mechanical paving in this form is adapted only to the use of new concrete blocks. The system has not yet been used for repaving using the paving elements already present. The problem that will have to be solved first is the packaging of the used blocks, after they have been selected by shape and size.

2. Because of the size of the paving machines, a minimum road width is required for proper manoeuvering. This varies with the system. The Delta S, for instance, is best suited for roads with a width of about 6 m or more. The Optimas needs a little more than 3 m.

3. This kind of mechanical paving is not very flexible in using a variety of block sizes and paving patterns within the same project. Decorative pavings in traffic-restricted residential areas, for instance, can better be realised in some other way.

4. Bends in the road disrupt the process more than in manual methods: a new point of ingress for the machine has to be made, and the transition between the two sections has to be "woven in".

4. COMPARISON WITH OTHER PAVING METHODS

4.1 Manual paving
This traditional method is characterised by the central and at the same time rather isolated position of the paving team consisting of a pavior and his helper. The task of the helper is to assist the pavior; that is to say, he prepares the already roughly shaped roadbed to the right height, carries the bricks or blocks, which have been dumped in the bed, sometimes quite a distance away, to the pavior, and does anything else that needs doing.
The pavior hammers every block into place, after correcting the height of the sand bed if necessary.
The work, then, is done in the bed itself.
The paving team is not so strongly dependent on a regular supply of blocks.
Because the completed pavement is not actually used, the vibrating down and brushing of the pavement can be done later.
Disturbance of the rough bed and of the piles of blocks are not of such great consequence.
An important advantage of this system is the large degree of flexibility as regards block sizes and shapes, size tolerances, paving patterns, the materials used, and the road profile. Also, there is no minimum for the size of a job. The disadvantage of this system is that all blocks pass through the hands of helper as well as pavior, so that the work can be characterised as arduous.

4.2 Manual laying
This method resembles mechanical laying in many ways. The preparation of the bed and the organisation of the work are basically the same.
The mutual dependency of the different activities is somewhat less, so that this process is somewhat less susceptible to disturbances.
Blocks are brought in across the completed pavement and the paving team, consisting of block-carriers and block-layers, or only block-layers, work from the completed pavement.
But in this system, too, all the blocks pass through the hands of the block-layers (and the block-carriers) so that the labour, especially because of its high tempo, is very arduous.
An advantage over mechanical laying is that size and shape tolerances can be little less stringent. This is particularly relevant to working with used paving elements.
Nor is a minimum working width required.

5. FIRST APPLICATIONS

5.1 Delta Terminal (Maasvlakte)
In 1982 construction began on E.C.T.'s second container terminal, the Delta Terminal. This terminal will cover an area of more than 80 hectares in the first instance, and can be expanded later to about 400 hectares. For the surfacing, ECT has chosen the same 120 mm thick rectangular concrete paving blocks that

were used on the home terminal.
The blocks are laid in herringbone pattern on a sand-cement stabilization surmounted by a laying course 50 mm thick.
The paving work began early in 1983 and should be completed within two years.
At an early stage, and in a rather unusual form of co-operation between client, contractor and concrete block supplier, possibilities were sought of applying the paving mechanically. This co-operation has led to the development of the Delta S block-laying machine.
Before proceeding to discuss the paving work itself, we must first describe the necessary adaptations in the production process, and the design of the paving machine.

Production of the concrete paving blocks
In the concrete plant, a mould the size of one packaged layer is used to produce the concrete paving blocks in elbow bond pattern. It is important to see to it that the mould is filled evenly with mortar. The empty spaces - there are no half-blocks - complicate the further packaging and transport. Laying of the concrete paving blocks on large areas demands stricter dimensional tolerances in length and breadth of the blocks than are stipulated in the Netherlands Standard NEN 7000. The Standard is based on the paving of roads and streets. Since in mechanical laying the blocks are not laid individually, but in large working units (one layer covers about 1.1 m2), the standards must be even more stringent, since deviations in the pavement caused by large deviations in the size of the blocks are more difficult to compensate for than in manual paving methods.
Compared to the Netherlands Standard NEN 7000 this means that the margins allowed there for the average and standard deviations must be about halved.
The consequence for the manufacturer is a shorter working-life of the mould.

Paving machine
The most important characteristics are listed point by point.
- The patented clamp construction clamps the layer on four sides. The clamp rotates freely on the jib. The layers, in elbow bond pattern, are placed on the bed at an angle of 45°, so that the resulting pavement is in herringbone pattern. The system is such that, after the clamp loosens, the blocks fall down a few centimetres, without tipping.
In this way, premature contact with the bed and consequent disturbance of it are prevented.

- For the sake of exchangeability, the crane and its jib are of a standard make.

- The undercarriage is provided with good-sized pneumatic tyres, which makes it easily moveable and prevents the formation of track grooves in the pavement not yet vibrated down.

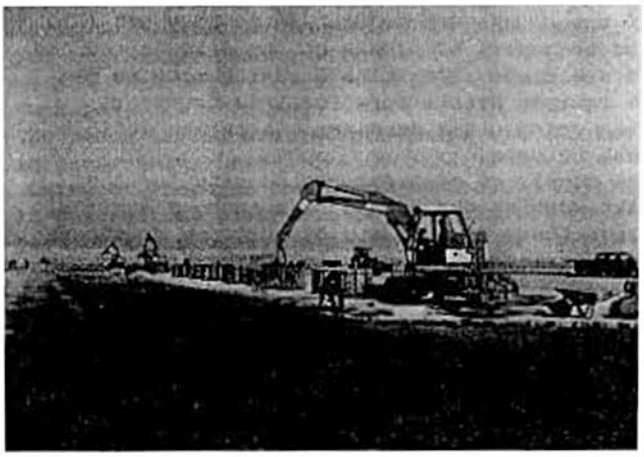
- On the shelf at the back of the crane, a supply of filler blocks is kept within reach.

- The cabin rotates with the jib, so that the driver has a good view of his work.

- The crane can also be equipped with a fork, to enable it to handle packages of blocks on pallets.

Procedure
In the paving process, the bed may be screeded to the precise height quite sometime before the machine lays the blocks.
The pavement is vibrated to level immediately after laying, however, so that, as far as possible, only completed work need be used for driving on.
On an extensive area such as this, where the paving is relatively seldom interrupted by drains, kerbs, etc., the concrete block paving is applied by a number of teams, each consisting of the paving machine with driver and one pavior.

Figure 5: Paving at the Delta Terminal



Results
The quality of the paving is excellent; the joints are narrow and the surface is very even.
The average production per team is about 500 m2 of paving in an 8-hour working day.
Table 4 provides a comparison with applying the paving by manual laying. In regard to both productivity and cost, mechanical laying is preferable to manual laying.

Table 4 Results at Delta Terminal

	mechanical laying Delta S	manual laying *
production per machine per 8-hour working day	500 m2	-
production per man-day	250 m2	165 m2
comparable costs for application of the paving	95%	100%

* Based on the construction of the terminal at the Princess Margriet Harbour.

5.2 City of Rotterdam

On the Noordereiland in Rotterdam, the Maaskade and the Prins Hendrikkade were partially reconstructed.
Catch pit gullies, drains and kerbstones were replaced and the footway was repaved.
The carriageway was narrowed to a width of 8 m and the paving stones replaced by concrete block paving in herringbone pattern. Along the footway a cross course was placed and along the stone paving to be retained, three stretcher courses were placed. Connection with the herringbone pattern was achieved through bishop's mitres and, wherever necessary, by making use of filler blocks or by cutting. The lids of the sewage drains in the road surface were adjusted to the right height. This paving job was made into an experiment, to test mechanical paving and compare it with manual paving and manual laying under similar conditions. To this purpose, the area to be paved was divided into 5 areas of about 1000 m2. In areas 1 and 2, on the Maaskade, the Delta S paving machine was used. Areas 3, 4 and 5 on the Prins Hendrikkade. Area 3 was paved by the Optimas paving machine. Area 4 was manually paved and area 5 was manually laid.

The activities concerned can be distinguished as follows:
- rough levelling and compacting of the sandbed;
- placing of the stretcher courses (by hand);
- screeding of the bed to correct height (not in manual paving);
- placing of the cross course (by hand);
- placing of the paving blocks (by hand or machine);
- vibrating the pavement to level;
- applying sand and brushing it into the joints of the pavement.

The rough levelling and compacting of the sandbed is the same for all areas. This goes for the stretcher courses as well.
In a comparison of the different methods, these activities can be disregarded.
The other activities are closely interdependent in each system, so that they are to be compared. In the comparison, the extra costs involved in the supply of blocks in pattern for mechanical laying will have to be included.
Areas 1, 2 and 4 include one or two slight curves, so that weaving in was necessary. In addition, area 4 includes a bus stop, with different paving and foundation. In the comparison, these elements, as well as work stoppages due to rain, are compensated for.
The carrying of blocks to the laying face (transport on site) is implicitly included in the paving.
Table 5 gives the results for each area.

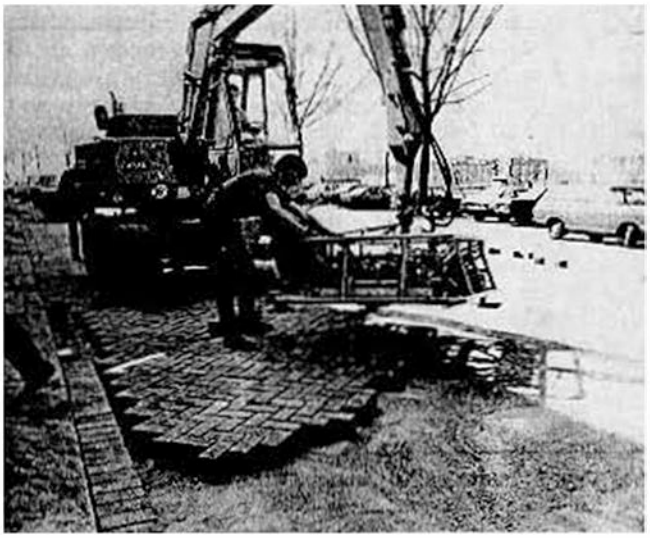
Figure 6: Mechanical paving and screeding of the bed



Delta S

This is the first time that the Delta S machine was used for small-scale paving work.
The roadbed was levelled by two men using a short wooden screed and a shovel. Then the blocks were placed, by the paving machine and two paviors. One pavior guided the clamp and saw to the completion of the layers and the transitions between them. The other laid the cross course and the bishop's mitres. He also saw to the filling in of the triangular holes along the edges, which originated from the diagonal placing of the packages. Around the manhole covers too, manual work was needed.
Then a navvy vibrated the pavement to level and brushed sand into the joints. The blocks were brought to the machine partly by means of a wheel-loader, and partly by the paving machine itself, which was equipped with a fork for this purpose. In area 1 blocks with a thickness of 120 mm were used.
In area 2, the blocks were 100 mm thick.
The results for these two areas differ very

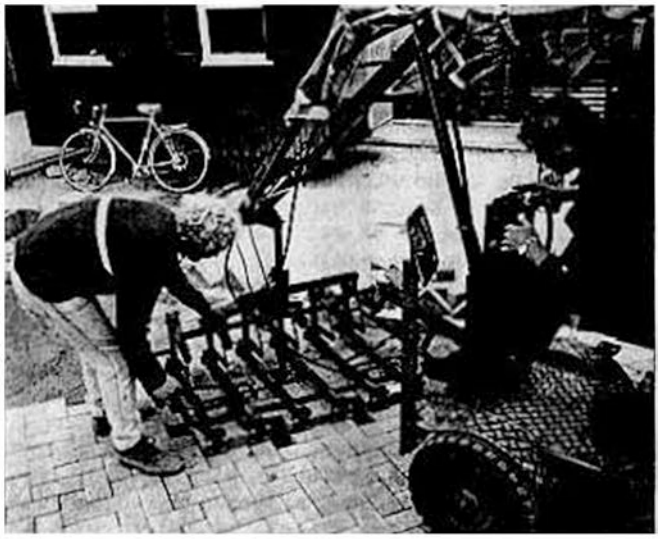
Figure 7: block-laying detail



little: the cost per m2 of pavement, for the activities to be compared, was 5-10% higher in area 1 than in area 2. The most important causes of this are the heavier work for the "second" pavior and the increased weight involved in the on-site transport.
The average production was 280 to 300 m2 per 8-hour working day.

Optimas
This paving machine is rather different from the Delta S. In the first place, it has a mechanical clamp, which clamps in just one direction. This clamp requires packaged layers that are completely filled in the direction of the clamp. The packages supplied at the time contained a total of eight half-blocks. Meanwhile, the mould has been adapted so that the number of half-blocks has been reduced to the necessary four.
After the layers are placed on the bed, the half-blocks lying beside one another are replaced by whole blocks. The half-blocks are carried off to storage.
Secondly, the undercarriage of the machine is of a much smaller and lighter design. This machine cannot be used for transporting pallets of blocks on site. It can be used, however, in a narrower working space.
Thirdly, the cabin and the jib are connected immovably to the undercarriage. Manoeuvering is accomplished by moving the whole machine, which is quite mobile.
The screeding of the bed, the block-laying and the vibrating and brushing are done in the same way as for the Delta S machine.
The same applies to the manual paving work along the edges.
The blocks used in this area were 90 mm thick.
The blocks were carried to the laying face by a wheel-loader.
The effectiveness of this system is clearly lower than for the Delta S. The average production per day was about 200 m2.
The comparable costs per m2 are 20-25% higher than for the Delta S in areas 1 and 2.
The total cost of using the half blocks in the Optimas system is estimated at about 10%.

Figure 8: Optimas machine (detail)



Manual paving
The paving in area 4 was applied in the traditional manner. An average of two teams, each consisting of a pavior and a helper, laid out and placed the stretcher courses and the cross course, prepared the bed and "paved in" the blocks. A navvy did the vibrating and brushing. Here, too, the blocks were 90 mm thick. The average daily production for the paving (not including stretcher and cross courses) was about 80 m2 per team.
The comparable costs, (excluding stretcher courses) per m2 for this area are only slightly higher than those for the use of the Optimas machine.

Manual laying
In area 5 the 90 mm-thick blocks were "laid down" by hand.
But this process was mechanised to the extent that use was made of a gravity-driven conveyer consisting of metal cylinders. See Figure 9.
Also, a wheel-loader was used for screeding the bed; this was finished by hand using a

Table 5 Results in the city of Rotterdam

area	1	2	3	4	5
method	mechanical laying			manual paving	manual laying
machine	Delta S		Optimas		
block thickness (mm)	120	100	90	90	90
production per 8-hour working day *	280 m2	300 m2	200 m2	145 m2	330 m2
comparable costs as compared to manual paving					
a. screeding; ** b. placing of blocks; d. vibrating to level and filling of joints;	26 %	25 %	25 %	24 %	25 %
c. laying of blocks;	41 %	39 %	57 %	76 %	40 %
e. extra cost of blocks; f. removal of half-blocks.	11 %	9 %	12 %	-	-
total	78 %	73 %	94 %	100 %	65 %

* the structure of the paving team is mentioned in section 5.2
** in area 4, levelling done by pavior's assistant

screed on a handle, so that the navvy could work without stooping.
Two block-carriers placed the blocks that had been put along the sandbed onto the conveyer and two block-layers placed them on the sandbed. They laid the cross course and the bishop's mitres as they went along. The vibrating and brushing was done in the same manner as in area 4.
The average daily production was about 330 m2. The comparable costs per m2 for this method are the lowest, namely about 65% those of the manual paving.

Figure 9: Conveyer-system



6. INTERPRETATION OF THE RESULTS

At the Delta Terminal, mechanical paving was done on such a large scale that the results can be considered very "hard". In the city, on the Noordereiland, on the other hand, the areas involved were relatively very small. The results, therefore, are much less "hard".
Another factor that makes it impossible to arrive at more than very general conclusions is the fact that three different block thickness were used: 90, 100 and 120 mm.

In order to achieve as realistic a comparison as possible, it should be remembered that previous experience has shown that manual laying of 120-mm blocks is about 15% more expensive than for 90-mm blocks.
No data is available on manual paving of such blocks, since paving elements thicker than 90 mm are very seldom used for paving in.

If mechanical paving is more generally applied, the extra cost for the special production and packaging of the concrete blocks will be reduced. Also, more experience with the system will allow its efficiency to be further increased. This holds true especially for its use in smaller projects.

7. CONCLUSIONS

1. Through the use of these types of paving machines, the manual placing of blocks is reduced to about 10% in the paving of large areas and to 20-30% in (not too narrow) city streets.
Ergonomically, this is a substantial improvement as compared to the manual placing of all blocks (manual paving and manual laying).

2. The quality of the surfacing applied with the machine is at least equal to that of the manually produced surfacing.

3. Rate of production with the Delta S block-laying machine is considerably higher than with the Optimas machine.
Comparison with manual methods is difficult because of the varying sizes of the teams.

4. In large-scale projects the use of the Delta S results in lower costs for paving than either manual laying or manual paving of concrete paving blocks.

5. Use of the Optimas paving machine results in lower costs than manual paving. Compared to manual laying, however, this method is more expensive - and will remain so.

6. During mechanical laying in the city, the change of disturbance of the levelled bed is much greater than on closed-off industrial areas. Therefore it is advisable to keep the time between the screeding of the bed and the laying of the blocks as short as possible.

A FINAL WORD

The use of block-laying machines for paving has just begun. As in every new development, some initial difficulties are encountered, which will be solved in due time.
For example, in the Optimas system, the number of half-blocks per layer has meanwhile been reduced to four.
There is also room for improvement in the method of screeding the bed in small projects.
In addition, ways are being sought to improve the work situation of the person who guides the clamp and places the filler blocks.
It is expected that these and other paving machines will find a wide application and that the quality of the technique and the humanisation of the labour involved will further improve.

This report was prepared in co-operation with "Luymes & Bal en Van der Straaten B.V." and "Rheden Beton B.V.".