CONTINUED APPLICATION OF MECHANICAL PAVING IN ROTTERDAM

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SUMMARY

Since about five years Rotterdam Public Works applies different types of paving machines for laying concrete blocks and other paving elements.
The use of these machines gives both a reduction of the paviour's hard labour and a financial saving. Since 1983 results have been achieved and progress has been made in Rotterdam.

A comparison is made between the different types of machines, with respect to the working methods and as the results (production, quality). Each type of machine has its specific field of application.

Using paving machines demands a totally different way of working, compared to the traditional hand methods. The management, the organization, logistics and the execution of mechanical paving are to be emphasized, as well as difficult obkects such as bendings, crossings etc. The training aspect for paviours-to-be is essential, too.

1. INTRODUCTION

Large areas of The Netherlands are below sea level. Dunes, dikes and stormsurge barriers afford the protection against inundation.
The subsoil consists largely of layers of peat and clay with very little bearing capacity. For this reason, the foundations of buildings are supported on about 20 m long piles reaching into the deep sand layers. A consequence of these soil conditions is that highways and streets are rubject to differential settlement.
In The Netherlands public utilities (water, electricity, gas and sewers) are led to buildings via an underground network. This cable and pipe network is often placed under the public road. See also ref. 111.
On account of these soil conditions and the established underground infrastructure it follows that roads and streets are paved with a flexible surface. In the last 50 years, motorways and main roads have been surfaced with asphalt. In towns and villages, partly for the accessibility to the underground services, road surfaces are mainly constructed as small element pavements.
This type of surfacing is also much used in industrial areas on roads and sites. Rotterdam, the largest port in the world, is in this respect, no exception. The intensive interest of the city of Rotterdam in all aspects of road surfacing is a natural consequence of its infrastructural situation. See tables 1 and 2.
In Rotterdam, the road work carried out annually covers an area of approximately 1.4 million m2. This is carried out partly by its municiple employees and partly by contractors.

Paving is a demanding occupation. This is evidenced by the fact that sick-leave among the paviours is twice that for the national average for all (manual) occupations. Add to this fact that the majority of the paviours is medically declared unfit to carry on this work after the age of 45.
For this problem refer to ref. [2] and [3].

Table 1 Function and pavement type of roads and streets in the city area of Rotterdam

function	area		pavement type	
			asphalt	small elements
	ha	%	ha	ha
main roads	321	17	160	161
access roads to quarters	203	11	74	129
industrial roads	207	11	11	196
shopping streets	53	3	17	40
residential streets	1,023	53	61	962
other roads and streets	93	5	36	57
total	1,900	100	355	1,545

1 ha - 10,000 m2

Table 2 Subdivision of the small element pavements

element, type	area in ha	area in %
setts and cobbles	45	3
burnt bricks	150	10
concrete paving blocks	550	35
concrete flags	800	52
total	1,545	100

1 ha - 10,000 m2

As a result of these facts, Rotterdam Public Works appointed a study group in 1982, giving it the task of improving the road paving technique, principally by the reduction of the heavy labour involved for the paviours and their helpers. Further objectives were the modernization of the craft, the raising of the technical standard of small element pavements and if possible to reduce the cost of these pavements.

One of the most effective means of reducing the heavy labour content is by the application of machines to place the concrete blocks. This is the main subject of this report. As early as 1984 at the second International Conference on Concrete Block Paving, in Delft, Rotterdam Public Works together with Europe Container Terminus presented a paper on the subject of the mechanisation of concrete block paving [4]. Since that time further developments have taken place. See also [5],

In parallel with this the study group explored a second avenue, namely the possible application of lighter materials. Briefly, the results are reported as follows:

- reduction of the thickness of the concrete blocks used in Rotterdam, from 90 mm to 80 mm. Further reductions are being investigated, see ref. [6];
-the use of synthetic materials to replace concrete in road drainage accessories. (Gullies, kerbs and manhole covers are considered as an integral part of the road surface and are indeed placed by the roadpaviours.);
- the use of multiple unit manhole covers, instead of the single monolithic cover.

In the report which follows, the current application of mechanised paving is discussed. After describing in chapter 2 the paving techniques, including the manual methods, chapter 3 will describe the machines in use. In chapter 4 more specific execution aspects are discussed, followed in chapter 5 with an evaluation of the possibilities of Increasing the application of mechanical paving. Chapter6 pays attention to the training of the roadmen to operate the paving machines. Chapter 7 deals with new developments and finally, chapter 8 gives some conclusions and recommendations.

2. PAVING METHODS

In Rotterdam, three methods are in use for the placing of the road surface units, in this instance, concrete paving blocks.

- Manual block paving.
- Manual block laying.
- Mechanical block laying.

For a more detailed description see ref. [4]. Here, only the main characteristics are given as follows:

2.1 Manual Paving

The work of manual paving is carried out by two man teams. A team consists of a paviour and his helper.

The task of the helper consists of:

- applying the finishing touches to the previously formed sandbed and its rought profiled surface;
- to sort the piles of blocks on the sandbed surface and place these to hand for the paviour;
- clearing debris;
- brush sand into the joints of the completed pavement.

The paviour sets out the transverse and the longitudinal profile and hammer-taps the blocks placed to hand by his helper, into the sandbed. This work is done from a standing position on the sand. The paviour in Rotterdam works from a stooping posture in contrast to elsewhere where the paviour works from a kneeling or sitting position.

This method has the following advantages:

- because the work consists of a sequence of simple selfcontained activities, the necessity for close co-operation and tuning is but small. The supply of blocks there does not need to keep pace precisely with processing of same by the paviour;
- the bulk supply of the blocks can take place via the sand surface. In that way the newly laid pavement remains undisturbed and have a chance to settle. The joint brushing and vibrating to level does not have to be done immediately after the placing by the paviour;
- this method affords greater flexibility regarding block dimensions and shape, dimensional tolerances, paving bond patterns materials in use and the profile of the road;
- the size of the job is hardly of any consequence. Small jobs can be done equally economically.

The disadvantages of this method are:

- production is relatively low, about 80 m2 per day per team;
- all blocks are handled both by the helper and the paviour. Per day this means as much as 3,500 blocks with a total weight of about 14,000 kg;
- this method is relatively costly.

2.2 Manual laying

In contrast with manual paving, this method involves the placing of blocks without hammer tapping. They are placed by hand, on the sand bed already prepared exactly to profile. The team now consists of a block layer and his helper handing him the blocks. The block layer stands on the blocks already placed. The helper supplies the blocks in one of two ways:

a. By means of a roller conveyor
This is placed squarely to the road. The blocks are stored on the pavement and from there placed on the conveyor in pairs. The block layer walks along the conveyor placing the blocks in pairs on the sand;

d. Without conveyor
Here the helper has to place the blocks within reach of the block layer and behind him.

Advantages of manual laying are:

- higher production than with manual paving;
- the sand surface after exact profiling is not disturbed so the profile is maintained, even after the blocks are placed;
the cost is less than that of manual paving.

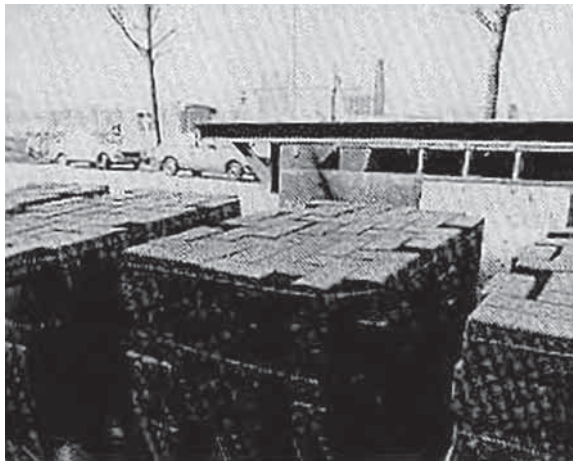
Disadvantages are:

- the sand surface, after the last finishing touch, must not be disturbed. This gives problems in towns from pedestrians and animals crossing over the prepared sand;
this method demands more space than with manual paving, because the blocks have to be stored off the road adjacent to the work in progress;
to achieve a flat road surface with tight joints, only blocks with but small dimensional deviations are suitable for this method of block laying;
all blocks zre handled by both the block layer and his helper. As the production is much greater, the workload is verv considerable. This was a reason for Rotterdam Public Works to push back the application of this method.

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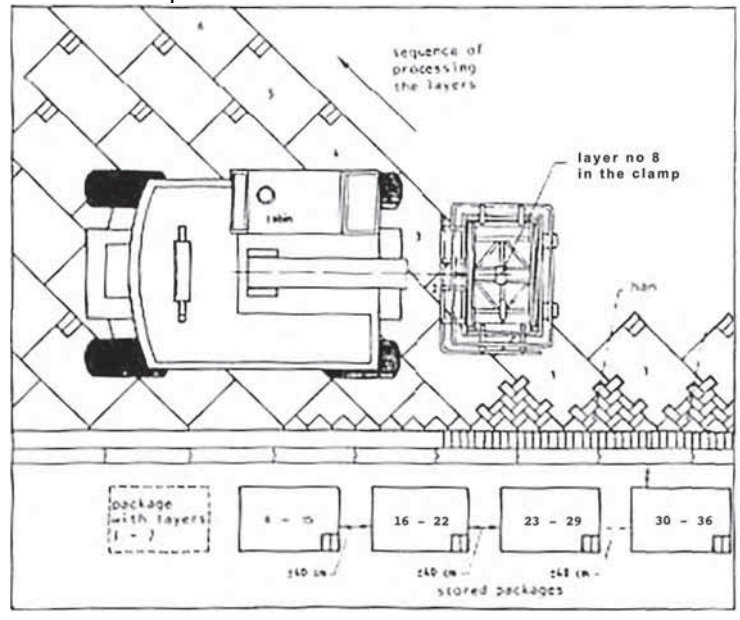
This method of paving by machine is the mechanised form of the manual block laying method.

Figure 1 Packages for mechanical paving



In Rotterdam, all machines in use employ a clamp or vacuum suction plate to place blocks onto the sand over an area of 1 m2. The sand is prepared to the right profile. The blocks are supplied by the factory in the desired order (elbow bond). See fig. 1.
Each machine is manned by a machine operator and two men attending the clamp or vacuum plate, as the case may be. The paviours direct the driver and manoeuvre the clamp/plate such that the layer of blocks drops exactly in place against the blocks already paved. Machine and personnel move about on the completed pavement. The block packages are standing, where possible, on the footways adjacent to the work in progress. If this is not the case, a forklift truck has to be employed to bring up the packages.
Mechanical paving still involves some manual work. Each drop by machine requires four blocks to be manually placed. The blocks, produced a supplied in an elbow bond, require en-bloc to be turned through 45 degrees to achieve a herringbone bond pattern along the length of the road. Mitre blocks have to be placed along the edges of the road. The triangles thus to completed (see fig. 2) have to be filled by manual placing, except when a vacuum plate is used.

Figure 2 Mechanical paving in herringbone pattern



Advantages of mechanical block laying are:

- by far the greatest bulk of the blocks is no longer hand placed, thus an enormous reduction in human labour is achieved;
- this method is relatively cheap;
- production is very high, thereby minimizing the inconvenience to residents and traffic;
- the quality of the pavement is excellent.

However there are also disadvantages, namely:

- the method can only be used with new blocks supplied by the factory in the desired order to the site;

- the design of the road must have few or no variations in materials;
- there must not be too many obstacles, manhole covers and such like;
- the road must not have too many bends because each bend requires a hand placed section to match;
- each machine has its own requirement for operating space in terms of width and job size to function cost effectively. Generally they are too big for narrow streets.

3. MACHINES USED IN ROTTERDAM

Rotterdam uses three types of paving machines which employ the block laying method. These are:

- the Optimas block laying machine (see fig.3);
- the Delta S block laying machine (see fig.4);
- the Schaeff block laying machine (see fig.5).

Table 3 Comparison of cost of the different paving methods, applied in the city area

paving method	relative cost
manual block paving	100%
manual block laying	70%
mechanical block laying	
- Optimas	90%
- Delta S	70%
- Schaeff	65%

Table 3 provides the cost of each in comparison to manual paving.
Table 4 gives the most important characteristics of each machine. Further information on the properties of each machine is as follows:

3.1 The Optimas

This is the first or oldest of the three machines. It is fairly small and of light construction. Because the jib is fixed to the chassis the blocks can only be placed where required by manoeuvring the whole machine. The machine, however, is very easy to manoeuvre. The blocks are placed on the sand bed and the clamp is released. It can be said that its most prominent asset is that its required operating width is small. This makes it very useful for small to middlesize jobs.
There are, however, also disadvantages:

- the mechanical clamp proves less reliable than the hydraulic clamp of the Delta S or the vacuum plate of the Schaeff;
- the machine can not move packages of blocks;
- the machine can only handle blocks of a thickness up to 100 mm:
- this machine, in contrast to the other two machines, is a single purpose machine.

Figure 3 Optimas machine



3.2 The Delta S

This machine is the largest of the three. Suspended from the mobile jib, the clamp with its layer of blocks in manoeuvred into the correct position. The moment a trip mechanism is actuated by contact with the sand bed. the blocks are released and drop through a height of about 30 mm on the sand. The undercarriage of the machine is equipped with wide pneumatic tyres, making it easy to move without leaving tracks in the newly laid, but not yet vibrated road surface. On a platform, behind the crane a number of filler blocks may be transported. The cabin rotates with the jib on the undercarriage giving the operator a good view of the work at hand.

Table Characteristics of the different types of paving machines

type	machine	mechanism	operating	connection jib chassis	max. reach	necessary working width	job minimum	average daily production in city streets
Optimas	special paving machine	2 sided clamp	mechanically	fixed	1.50 m	3 m	400 m2	200 m2
Delta S	standard hydraulic crane	4 sided clamp	hydraulicly	rotating	5.75 m	5 m	800 m2	U00 m2
Schaeff	standard hydraulic crane	vacuum plate	pneumaticly	rotating	4.80 m	l m	750 m2	375 m2

The advantages of this machine are:

- by affixing forks to the machine, packages may be collected or moved:
- the machine is very reliable;
- the machine is a standard hydraulic crane and can therefore be applied to other duties.

Disadvantage:

- this machine is less suitable for in-town operation. Its large size makes manoeuvring in a confined space time consuming, so that output falls back. Then the operating costs are relatively high.

Figure 4 Delta S machine



3.3 The Schaeff

This machine works on a totally different system. It is equipped with an air-pump. The blocks are lifted by a partial vacuum and moved, by a plate furnished with suckers, one for each block.
During the transport of a package of blocks it can happen that the blocks are displaced a little relative to each other. Before picking up a layer of blocks, the blocks are pressed together by four clamps on the edges of the plate. Only after that, the vacuum pump is activeted.
In contrast to the Delta S and the Optimas, the blocks are not released before they have been placed onto the sand.
Similar to the Delta S the jib and cabin rotate in unison on the chassis.
The Schaeff is smaller than the Delta S but larger than the Optimas.

The Schaeff has the following advantages:

- the machine is reliable;
- by changing accessories the machine can also be used to place kerbs and paving slabs 0.5 x 0.5 m or 0.6 x 0.4 m:
- similarly to the Delta S the machine is also a standard hydraulic crane, and can therefore also be used for the placing of gullies and manhole covers;
- by cancelling out a number of suckers, smaller layers can be placed, thereby reducing the remaining manual labour content, compared with the two other machines.

One disadvantage applies:

- the machine can not handle packages of blocks.

Figure 5 Schaeff machine



3.4 Areas of application

It is evident from the foregoing description and mutual comparison, that each machine has its own area of application where it can be most effectively employed. The Delta S is the most suitable for large jobs with sufficient working space. The Optimas is preferred for relatively small jobs where little or no other work is in progress. The Schaeff has a wide area of application. Eminently suitable for small as well as medium size jobs. Certainly, where it is also used for the placing of kerbs and gullies, its cost effectiveness is very favourable.

4 EXECUTION ASPECTS

When working in city streets, we encounter two situations, namely: one, where the whole street is available for the work to be carried out, and the other, where, because of traffic flow or because of maintaining access to certain businesses and institutions (hospitals) the work can only be done in sections, one at a time. The latter situation is frequently the case, and presents high demands on work scheduling and the logistics of the materials when the mechanical paving method is being used.

In the first situation the normal procedure is applied as follows:

- the construction of the base course (0.3 m of crushed rubble 0-40 mm) and the compacting of same by rolling;
- the placing of the gullies;
- the placing and positioning of kerbs into lightly cemented concrete;
- the paving of the footways;
- the supply of the concrete paving blocks via the base course. The packages are placed on the footways;

- finishing to profile of the base course with fine grade hardcore 0-15 mm;
- the supply of bedding sand and machining to profile (layer thickness 0.05 m; coarse sand 0-2 mm or grit 0-6 mm);
- the placing of the gutters (manually);
- the placing of the mitres (manually);
- mechanical paving;
- brushing sand into the joints and the vibrating of the pavement.

When, however, the work has to be done in sections, the series of activities have each to be carried out in much shorter time periods. To ensure good results, planning has to be detailed and accurate. In addition, the supply of the paving blocks is more problematic; often the packages can not be placed on the footways and have to be brought up via the newly laid pavement. This has the following consequences:

- the newly laid pavement has to be vibrated earlier;
- a forklift truck is required to bring up the packages one at a time (increases costs);
- as there is not much space in the immediate vicinity to store a large amount of blocks, much thought has to go into the timely supply from the factory.

Another problem which arises when the work is to be done in sections, is to achieve smooth transfers between sections. Especially when the sections are not the full width of the road, it becomes difficult to achieve perfect locking up of the paving blocks crossways.
The overall quality of the finished work will therefore be less than maximal.

5. THE EXPANSION OF MECHANICAL PAVING

Recent years have seen a steady increase in machine paving, see table 5.

Table 5 Mechanically processed paving elements totals in Rotterdam

Year	concrete paving blocks (m2)	kerbs (running m)
1985	36,000	3,600
1986	72,000	30,000
1987	100,000	40,000

To further advance this expansion, other less directly related, possibilities have been explored.
Do the road design principles have to be modified?
What are the possibilities when resurfacing a road?

5.1 Design recommendations/conditions

An analysis, with an eye to mechanisation potential, of the standard design (lay-out) of roads and streets, shows that two principal factors determine mechanical paving:

- the degree of standardisation introduced at the design stage;
- the size of the job.

To achieve the optimum possible application of mechanical paving it is important that, at the design stage of the road, the following factors are taken into account:

a. Width of the road
To minimise the hand-work when applying mechanical paving, the road width must be in a favourable relation to the layer dimensions and the paving bond pattern.

b. Operating space available
Each machine to be used has its own minimum width requirement to operate efficiently (see table 4). Trees, electricity pylonsand other obstacles can hinder the operation.

c. Dimensions of the paving elements
Each format of paving unit requires a different approach and tool. Keeping the number of formats to a minimum is desired.

d. Material types and colours
Thorough standardisation and limiting the number of types is necessary.

e. Paving patterns
Acceptable bonds are, herringbone bond, elbow bond and stretcherbond. Unacceptable are so-called free or ornamental bonds and patterns.

f. Markings
Marking elements delay the work. A good alternative is painted or adhesive markings.

g. Shape and dimensions of sections
Rectangular sections containing a single type of paving pattern are most suitable for mechanical paving. Curving, projections, whether in- or outwards, demand much manual effort. Small sections with varying types of material are also unsuitable.

h. The magnitude of the job
To use the machines cost effectively, the task must afford a minimum period of two days work for each machine. See table 4.

5.2 The application of the elbow bond verses the herringbone bond

The machine packages are delivered in the elbow bond.
In Rotterdam the most often used bond is the herringbone bond. For this reason the layers of blocks have to be turned through 45 degrees with reference to the traffic flow direction. When placing rectangular block layers, empty triangles occur along the kerb edges. These have to be paved manually. This means that for a running meter of road one square meter (44 blocks) has to be laid by hand. This problem does not arise with the use of the elbow bond. Neither is it necessary to insert mitres in this case.
The herringbone bond dates back to the time

when burnt bricks were used. This type was dimensionally not very stable and had wide tolerances. In practise the herringbone pattern proved to be most able to cope with traffic conditions.
The question arose with the study group whether, in case of concrete paving blocks with its close tolerances, the elbow bond would not have the same quality work as the herring bone bond. Tests have been carried out in the port area of Rotterdam on one of the roads subjected cost to heavy and busy traffic. Alternate road sections were paved with the elbow and the herringbone bond. Measurements over a period of three years did not show up any significant differences. As a result the decision was taken to use the elbow bond more often.
In the meantime it proved possible, with the use of the vacuum machine, to avoid the previously mentioned manual effort, inherent in the herringbone bond. This is possible with the use of a wooden template. When this template is placed on a layer of blocks, the blocks under the template are not picked up by the vacuum plate.
The lifted layer then has a shape which exactly matches with the mitres.

5.3 Cost evaluation of repaving versus mechanical paving

The proces of repaving involves the restoration of the original profile of the road surface. The old paving is taken up and after levelling by either removal or addition the road bed is restored. Broken or worn-out blocks are substituted (loss). When the road requires to be raised much, the blocks can not be stored in situ, but have to be temporarily stored in a depot. This is also the case when the underground services are being worked upon simultaneously.
In a study, a comparison was made between repaving, using the existing blocks and mechanical repaving using new concrete caving blocks. In the latter case the old elements (burnt bricks, cobbles or setts or concrete blocks) are sold off.
The study showed that the last was no more expensive than the first and, moreover, that mechanical repaving with the new blocks is preferred for ergonomic reasons, certainly in the following circumstances:

- when a large quantity of the old blocks have to be substituted. In that case, the output with manual repaving is much lower than normal. In addition, there is the work of clearing and the removal of much debris;
- when the old blocks are to be temporarily stored in depot, the cost of transport, cleaning and sorting becomes very high;
- when average substitution (loss) coincides with but little raising of the bed.

5.4. Mechanical paving with used blocks

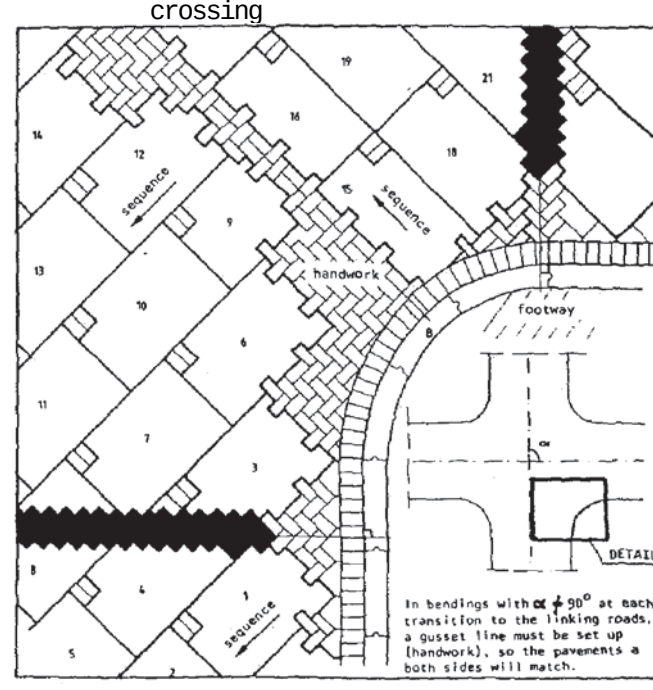
When it is desired to reuse the old paving blocks by the mechanical method, the blocks after cleaning and checking will have to be grouped in a bond-pattern to suit the mechanical method. Tests showed that with the vacuum method the old blocks are handled perfectly by the machine. If, however the cleaning, checking and grouping has to be done manually, then in the end there is a deterioration of working conditions and the costs rise very high. To the present day no mechanical means for these activities have been devised.

6. TRAINING

The mechanisation of road works has reached such a level in Rotterdam and has become so much part of every day life, that it has become necessary to adjust the training of would-be paviours to take account of this.

Rotterdam has itself a group of 55 apprentices. On-the-job training takes care of the practical side of the training, which takes 5 years. The theory is taught one day a week under the auspices of the Institute Craft Training Road and Water Works. Via this institute the State as well as trade and industry have a hand. Very soon after the introduction of the first machine(s) in Rotterdam, the apprentices of the city were assigned to work with the new machines and today it is an established part of their practical training, involving all the apprentices on a rota basis with every aspect of the craft.
There has been now for some time a manual on mechanisation [7]. This book is the result of the combined effort of the Institute, the contractors involved and the Rotterdam Public Works Department. The several techniques of paving are dealt with and the subject of the machines is also covered. Much attention is paid to the subject of mechanical paving of a.o. bends and road crossings, see fig. 6.

Figure 6 Paving pattern and sequence at a crossing



7. NEW DEVELOPMENTS

At this moment the possibility is being explored of applying the vacuum system to the paving of footways with a number of pavement flags 0.30 x 0.30 m in one single operation. A practise test is in preparation.

In addition, a system is under development where it is possible to regroup the factory supplied block packages into layers of 1.5 m2 in herringbone bond and then to be able to place theee layers via the vacuum system, see figure 7.
This system is in its infancy and will have to be further perfected. The introduction of this system means a saving on manufacturing and transport costs of the machine packages and also gives a reduction in the, at present, still necessary manual effort (4 blocks per m2).

Figure 7 Vacuum plate for rectangular herringbone bond layers



8. CONCLUSIONS AND RECOMMENDATIONS

Only the most important conclusions and recommendations are summarized here.

Conclusions:

- mechanisation is indispensable for the humanising of the paviour's craft;

- (new) concrete paving blocks, kerbs and flags and slabs can be processed mechanically;

- in the repaving activity, the mechanical regrouping of blocks-to-be-reused is the missing link for complete mechanisation;

the quality of machine laid pavement is at least equal to that of manually instated pavement;

- mechanical paving is cheaper than manual paving;

- mechanical paving makes high demands on work organisation and logistics;

- for very small scale work, the present generation of machines are either too big and/or too expensive.

Recommendations:

- the use of the manual block laying methods needs to be subject to stringent restraint for ergomomic reasons;

- in the training of paviours, the mechanical method of paving must be an integral part of the training program;

- to promote the use of mechanical paving, as early as the design stage, account has to be taken of the design criteria specific to mechanical paving;

- further technical development of mechanisation must be encouraged and supported. Special attention must be directed towards small and cheap machines for the very small scale work.

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