IS THE USE OF CONCRETE BLOCK PAVING FINITE

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Summary
Europe Combined Terminals (ECT) have successfully used concrete block paving in their container terminals for many years.
Dozens of hectares are surfaced with this type of material every year. Recently, however, ECT have been faced with rutting where Automated Guided Vehicles are used. The Rotterdam Municipal Port Management and ECT asked Heidemij Advies to conduct a study into the cause of the problems and to recommend ways to resolve them.
The study has been completed and a number of modifications to the surfacing have been proposed. These modifications related to:

- the shape of the concrete blocks;
- the thickness of the surface layer;
- the composition of the foundation.

The modifications have meanwhile been carried out and the redesigned surfacing structure is being used for ECT's new expansions in Rotterdam.
The paper describes the problem and looks in detail at the modifications to the concrete block paving.

Introduction
Europe Combined Terminals (ECT) have used concrete block paving as a surfacing material in their container terminals for some thirty years. Altogether some four million square metres have been surfaced in this way.
Concrete block paving has proved it can withstand the heavy point loads associated with containers, as well as the high wheel loads and large torsional forces exerted by the transporters. Concrete block paving also appears to be able to adjust to significant settlement, and it is easy to reuse when there is reconstruction. All in all concrete paving is an excellent surfacing material for heavily-loaded container terminals.
However it is not just the concrete paving which provides such good performance. Foundations are required underneath the paving in order to transmit heavy loads to the subsoil properly.
Recently, however, ECT have been faced with rutting in their terminal where Automated Guided Vehicles are used.
Heidemij Advies was asked to conduct a study into the cause of the problems and to recommend ways to resolve them.This paper reports on the use of concrete paving at ECT over the last thirty years, the onset of rutting, the investigation into this phenomenon and the proposed modifications to the surfacing.
Finally the future prospects for concrete block paving are discussed.

ECT and concrete block paving

ECT is a stevedoring company that deals primarily with containers.
They are one of the largest container handling companies in the world, and number one in Europe (table 1 and 2).

TOP 10 WORLD CONTAINER PORTS
1994

		TEU
1	Hong Kong	11,265,000
2	Singapore	10,600,000
3	Kaohsiung	4,899,000
4	Rotterdam	4,475,000
5	Pusan	3,750,000
6	Kobe	2,787,000
7	Hamburg	2,725,000
8	Long Beach	2,573,000
9	Los Angeles	2,518,000
10	Yokohama	2,320,000

Table 1

TOP 10 CONTAINER PORTS N-W EUROPE
1994

		TEU
1	Rotterdam	4,539,000
2	Hamburg	2,726,000
3	Antwerpen	2,208,000
4	Felixstowe	1,774,000
5	Bremen/Bremerhafen	1,502,000
6	Le Havre	873,000
7	Zeebrugge	609,000
8	Southampton	587,000
9	Gothenburg	401,000
10	Tilbury	382,000
	Total	15,601,000
	ECT total	3,390,000

Table 2

ECT is located in Rotterdam, Europe's most important mainport. An area was recently reclaimed from the sea at the entrance to the port of Rotterdam and turned into dry land.
Rotterdam Municipal Port Management and ECT are working together in this area to develop large-scale container terminals with deep-water access. Containers are brought to and from the terminal by enormous ocean-going container carriers.
Huge dock cranes are used to handle the containers, and onward transport is by feeder, barge, rail or road.
Special transporters such as Straddle Carriers, Multi Trailer Systems and Automated Guided Vehicles are used in the terminals.
There the total moves of containers is growing rapidly (fig. 1), concrete block paving is again being used for surfacing the newest terminals.

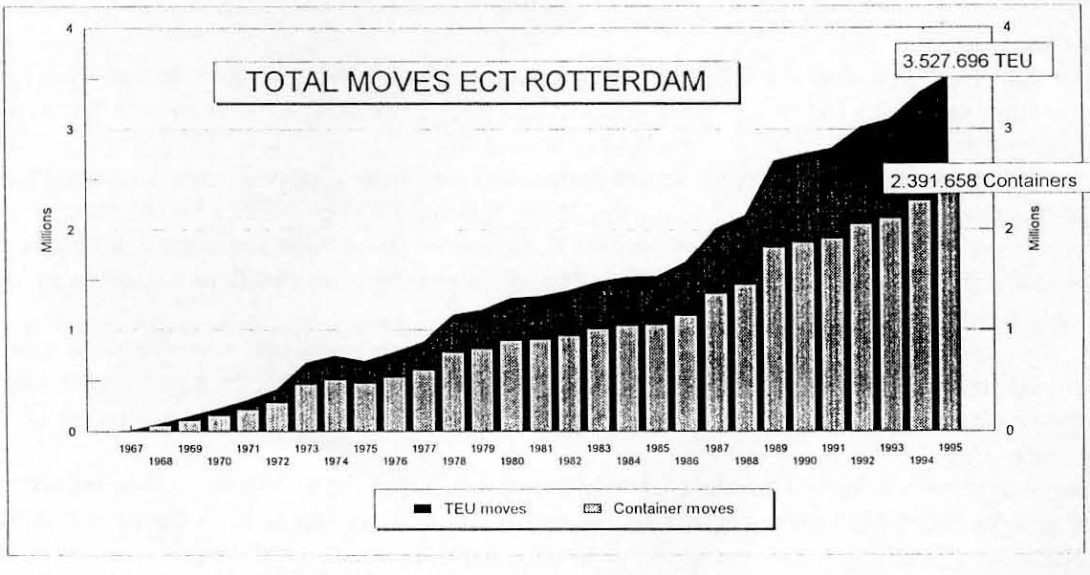

Figure 1

First-generation terminal

In 1967 the growth in container transport prompted ECT to start building their first-generation terminal, the Home Terminal, in Rotterdam (fig. 2).



Figure 2 *Home Terminal*

The site where activities started was covered with a layer of sand from the sea bed, below which was a layer of harbour silt with poor load-bearing capacity, and below that a peat/clay subsoil. The transport of containers in the terminal was done primarily using trailers with tractors and straddle carriers. The latter had wheel loads of between 125 kN and 170 kN. Heidemij designed a surface for this poor load-bearing subsoil comprising concrete block paving on a granular intermediate layer, with a foundation of sand cement stabilization.

The concrete block paving showed that it could withstand the high contact pressures of the containers (corner castings) and the large torsional forces caused by the rotation of the straddle carriers' wheels. A foundation was made underneath the concrete block paving comprising sand cement stabilization ('mix in place') about 330 mm thick. The surfacing was able to follow large degrees of settlement more than 1.5 metres in some cases, and it fully satisfied the requirements set.

This was reported in a contribution to the First International Conference on Concrete Block Paving in 1980 [1].

The concrete blocks were approximately 220 mm long, 110 mm wide and 120 mm thick (specifications by NEN 7000) and was laid by hand.

Second-generation terminal

In 1980 ECT decided to expand their activities by building on the Maasvlakte, an area at the mouth of the port of Rotterdam reclaimed from the sea.

The construction of the Delta Multi-Users Terminal (DMU) (fig. 3), covering an area of some 80 hectares, enabled the company to handle container carriers with a deep draught. The number of containers moves was still growing.



Figure 3 *Delta Multi-Users Terminal*

Generally speaking, the subsoil on the Maasvlakte is made up of sand with good load-bearing capacity. Containers are transported by Straddle Carriers, Multi-Trailer Systems and Frontlift trucks, and wheels loads vary between 100 kN and 200 kN.

Prior to the construction of the DMU Terminal, an extensive review was made of the surfacing that had been used up to that point.

Although no major settlement was expected on the Maasvlakte, concrete block paving on a foundation of sand cement stabilization was chosen once again. This was mainly because the surfacing had proved its worth in the Home Terminal(s), and also because compared with other surfacing, concrete block paving was cheaper. Furthermore it had been discovered that other types of surfacing (asphalt for instance) were soon damaged by the high contact pressures of the corner castings and were susceptible to damage from oil spills.

Despite a subsoil with a higher load-bearing capacity, the DMU Terminal required a thicker foundation than in the Home Terminal (about 450 mm) because of the increase in wheel loads and the higher frequency of container movements.

Those days the requirements set for the sand cement stabilization were:

- a compressive strength of at least 2 MPa after 28 days' setting;
- rejected if the compressive strength is < 1.5 MPa after 28 days' setting.

A granular intermediate layer was put on the stabilization and the concrete block paving was laid on this layer.

Mechanical pavement laying was developed in the nineteen-eighties, and concrete block paving was laid one square metre at a time (fig. 4) (Specification by NEN 7000, but a 10 mm sharper tolerance).

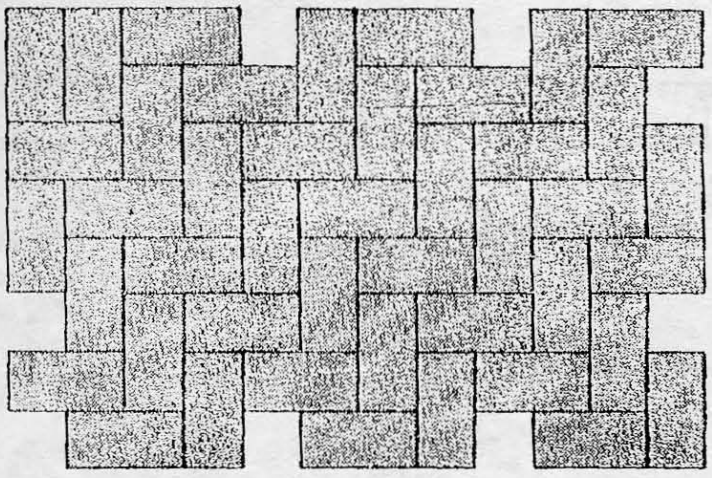

Figure 4 *One square metre at a time*

When being laid mechanically, the blocks were placed very close together and the upper edges of the concrete blocks could get damaged. The concrete blocks were given 'spacers' in order to ensure the joints were wide enough (fig. 5).

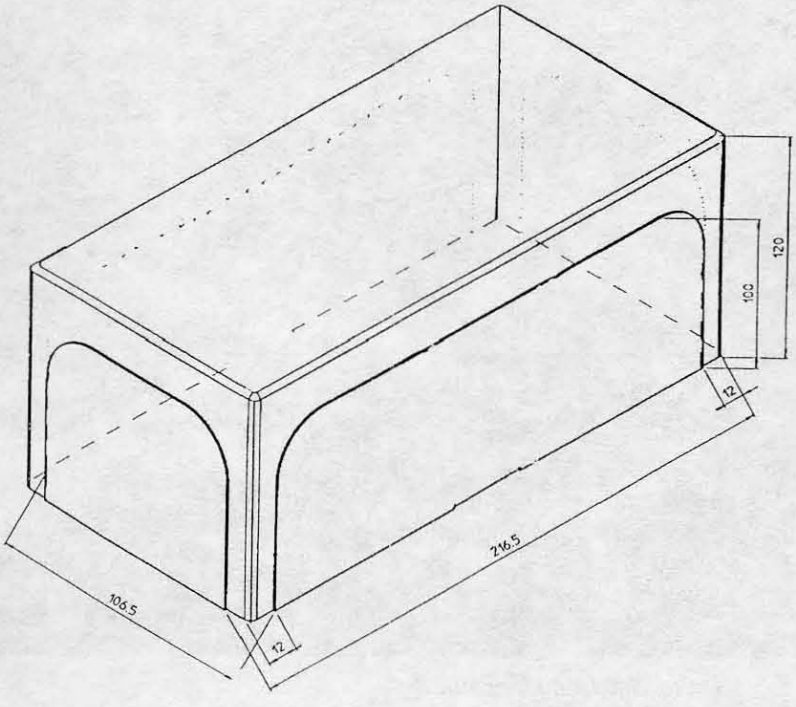

Figure 5 *Type of concrete block paving suitable for mechanical pavement laying*

The overall structure of the surfacing was as follows (fig. 6):

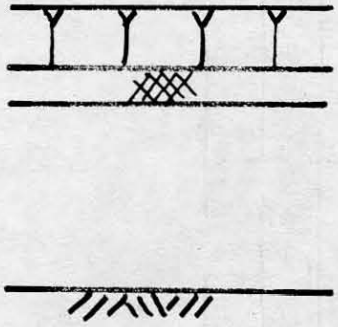

Figure 6

Third-generation terminal

ECT took a big step forwards in 1990 with the construction of the third-generation terminal, the Delta SeaLand Terminal (DSL) (fig. 7).



Figure 7 *Delta SeaLand Terminal*

Virtually everything is automated in this DSL Terminal. On the sea side, the containers are transported by Automated Guided Vehicles (AGVs) and stacked by Automated Stacking Cranes. Straddle Carriers and Frontlift trucks are used on the shore side.

During the preparatory phase of the DSL Terminal it was established that the increasing load and frequency of transport movements could cause problems in terms of the required foundation thickness. The thickness of the sand cement stabilization needed was becoming ever greater and recommendations were made to start an investigation into how to optimize the foundation. The foundation had grown in the meantime to a thickness of 550 mm, and it had reached the maximum thickness ('mix in place') which could be laid in one pass.

At the DSL Terminal, ECT were soon faced with rutting in the surfacing. This rutting occurred in areas where AGVs are used.
The AGVs move over the surfacing along fixed routes using a set pattern of guide points which have been installed in the surfacing.
The AGVs are not sprung and they have hydraulic drive and braking systems. The maximum wheel loads (aircraft wheels) are 130 kN (fig. 8).



Figure 8 Automated Guided Vehicle

First of all the pattern in which the blocks were laid was examined to see if it had any effect on the rutting [2].
However, no indication was found that the way the paving is laid has any influence on rutting, and the herringbone bond is still preferred.
It was decided to investigate the cause of the rutting and to draw up recommendations for improving the surfacing before the construction of a number of new terminals (the 2000-8 plan).
The investigation showed clearly that the rutting occurred primarily in the topmost part of the sand cement stabilization.
A number of causes of the damage were identified, such as:

- loose material in the topmost layer (sods/scrapings) that is created when re-profiling the sand cement stabilization,
- loose material that is created through over-compaction (sod formation/segregation),
- drying out of the upper surface,
- pulverization of the topmost layer,
- ingress of moisture (softening),
- possible ingress of frost.

A laboratory investigation was started into improving the resistance of the upper surface of the foundation to damage ('wear resistance'), with the solution being sought in the addition of a coarse fraction to the topmost centimetres of the sand cement stabilization.

Plan 2000-8

In 1994 the Rotterdam Municipal Port Management together with ECT, started work on the 2000-8 plan for the construction of a number of terminals for megacarriers in the third millennium.

Heidemij was involved once more in the construction of the infrastructure both above and below the surface, a job that will probably continue until 2003 and the first phase of which is under construction (fig. 9).



Figure 9 *Plan 2000-8 Phase 1*

The laboratory investigation into improving the sand cement stabilization showed that addition of a coarse fraction made mixtures less prone to pulverization and frost and gave them a significantly higher density and compressive strength than mixtures that did not have this fraction added to them.

In the end a mixture was proposed for the topmost layer of the foundation with a 50% coarse fraction, made up of concrete rubble and 50% sand, all mixed together with cement. A so called 'modified' sand cement stabilization. A layer of 0-20 mm concrete rubble was put directly on top of the sand cement stabilization and this layer was mixed with the top 100 mm of the fresh sand cement stabilization ('mix in place') to yield at the end of the process, after compaction, a 200 mm layer of 'modified' sand cement stabilization.

As well as the foundation modifications described above, it was also proposed to reduce the thickness of the granular intermediate layer between the concrete blocks and the foundation in order to reduce the chance of possible post-compaction in this layer.
Although the granular intermediate layer could possibly have some effect, it is not believed to be the actual cause of the rutting.
To be on the safe side, however, the thickness of the layer has been reduced from 50 mm to 30 mm, and the layer is put on mechanically using a spreading machine.

The chippings 0-8 mm for the granular layer must comply with the following specification:

screen	weight percent retained	
mesh size	min.	max.
C 8	0	10
C 5.6	20	40
2 mm	60	80
63 µm	90	100

Table 3

The thinner, intermediate layer meant that the tolerances of the concrete blocks had to be adjusted. These are now plus or minus 2 mm. The concrete block paving is vibrated and sharp sand is used to fill the joints.

The sand used for brushing into the joints between the concrete blocks must comply with the following specification:

screen	weight percent retained	
mesh size	min.	max.
C 5.6	-	-
C 4	0	10
1 mm	10	45
63 µm	90	100

Table 4

Furthermore the drainage slopes on the site were modified and the surface drainage was improved. More holes were drilled in the foundation in order to allow water on the foundations to drain away to the subsoil/drainage more quickly.
All these changes have been implemented in the meantime and the total design is being evaluated.

In addition to improvements in the surfacing, the means of transport are also being evaluated. There is always an interaction between these two aspects. For example, a study is currently under way to see if the AGVs could be equipped with double pneumatic tyres and/or could be fitted with springs. A review is also being made to see if the AGVs could move over a wider area of the site, and therefore less along fixed paths.

Is the use of concrete block paving finite

The suitability of the present surfacing design is being evaluated prior to the construction of the new terminal (T2), which is part of the 2000-8 plan. Both technical and financial aspects are included (fig. 12).

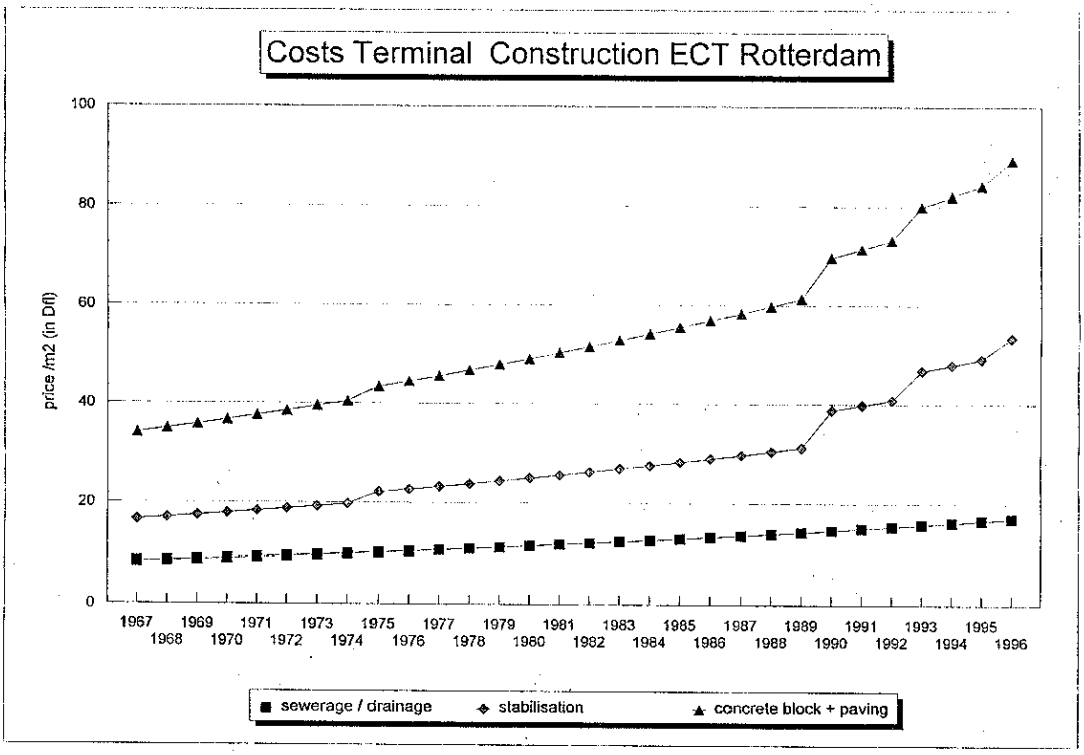

Figure 12

Although the concrete block paving performs well as such, it has been shown that the capabilities of the foundation could limit the further use of concrete block paving.
An investigation has started again into the possibilities offered by other surfacing materials, for example:

- high-stability asphalt concrete;
- roller-compacted concrete;
- reinforced concrete;
- etc.

Needless to say, improvement of the surfacing through the use of modified sand cement stabilization is being pursued as an answer to the problem of rutting. It will be clear, however, that changes to the foundation also have financial consequences.
The answer to the question, 'is the use of concrete block paving finite?' will ultimately be determined by the price of the overall surfacing design.

Literature

1. Van Leeuwen, H. "Use of block paving in European ports."

2. Bouman, S.R. e.a. "The influence of different types of block pavement on the (un)evenness of the surface of the world's largest container terminal."