HAVE THE LIMITS BEEN REACHED IN THE USE OF CONCRETE BLOCK PAVING?

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SUMMARY

Over the past four years, roughly half a million square metres of concrete block paving have been laid at Europe Combined Terminals (ECT), one of the world's largest container handling companies and number one in Europe. This concrete block paving, laid on a foundation of sand cement stabilisation, has been used at ECT for around 35 years and has demonstrated its excellent ability to withstand the high loads exerted by transport vehicles. However, damage to the paving is occurring as a result of the Automated Guided Vehicles (AGVs) riding on fixed routes. Research reveals that this damage is occurring primarily in the foundation. Several test sections have recently been laid, using various paving constructions, and ridden on by a fully loaded AGV for over a year.

It would appear that, in terms of construction and maintenance, the concrete block paving construction is still the cheapest form of paving. However, operational stagnation as a result of maintenance to the foundation restricts the application of concrete block paving in the AGV zone. This paper examines the results from the test sections and indicates where the limits in the use of concrete block paving are reached.

1. INTRODUCTION

Europe Combined Terminals (ECT) is a stevedoring company that deals primarily with containers. It is one of the largest container handling companies in the world and number one in Europe. It is located in Rotterdam, Europe's most important main port, on an area reclaimed from the sea at the entrance to the port of Rotterdam, which has been turned into dry land. ECT is working hard to maintain its position and is constantly busy expanding and improving its terminals. Approximately 200 hectares of new land are now operational on the Maasvlakte. Another 600,000 m^2 of terminal expansion is under construction.

Virtually everything at the new terminals is automated. On the sea side, the containers are transported using Automated Guided Vehicles (AGVs) and stored using Automated Stacking Cranes while, on the land side, Straddle Carriers are driven. As a result of the fact that they run on fixed routes, the AGVs in particular are causing problems for the paving.



Photo 1 Bird view of ECT Terminal(s)

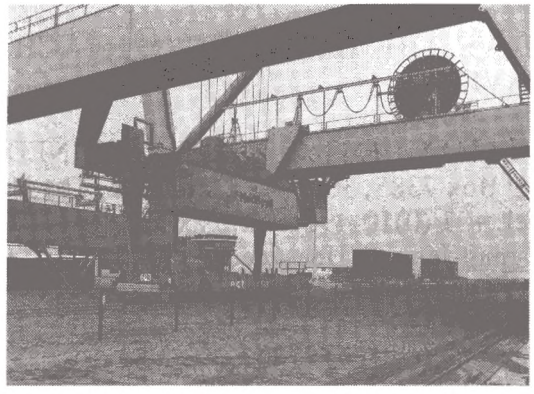

Photo 2 Automated Guided Verhicles

2. ECT AND CONCRETE BLOCK PAVING

With the advent of container transport around 35 years ago, ECT began to construct its first-generation Container Terminal in the city of Rotterdam. Container transport took place chiefly using tractors with chassis and Straddle Carriers. A special paving construction was developed for this type of transport, consisting of concrete block paving with a granular intermediate layer on a foundation of sand cement stabilisation [1].

In 1980 ECT decided to expand its activities to include deep water and to construct a Terminal at the entrance to the Port of Rotterdam. This is where it built its second-generation Container Terminal. At this terminal, containers were transported using Frontlift trucks, Multi Trailer Systems, Reach Stackers and Straddle Carriers. Given the high dynamic loads on the paving, the Straddle Carriers were fitted with additional wheels. Mechanical paving using concrete block pavers was developed [2].

In 1990 the decision was taken to construct the third-generation Container Terminal, the Delta Sea Land Terminal, where virtually everything is automated. Container transport is carried out using Automated Guided Vehicles (AGVs), Straddle Carriers and Frontlift trucks, while Automated Stacking Cranes are used in the Stack area.

Rutting soon became a problem for ECT in those areas of the Delta Sea Land Terminal where AGVs are used.

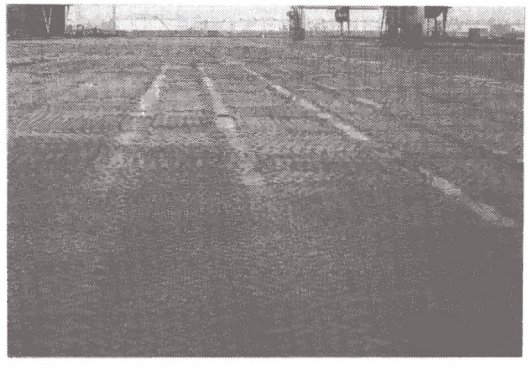

Photo 3 Rutting

In 1994 the Port of Rotterdam Authority, together with ECT, decided to undertake massive expansion of the Terminals through the Delta 2000-8 plan. Before this work can start, the problem of rutting has to be investigated [3].



Arcadis, an international consultancy bureau, was requested to investigate the damage.

3. RESEARCH INTO RUTTING

Research has been carried out into the possible causes of the rutting and improvement of the existing paving construction. It was assumed that concrete block paving on a suitable foundation of modified sand cement stabilisation "mixed in plant" on a normal stabilisation would be more resistant to the loads exerted by the passage of the AGVs. However, an extensive practical test, involving exposing the new construction to the actual load exerted by the AGVs, was intended to prove this. Meanwhile, the price of the (modified) paving construction had risen considerably since 1989 (approximatly 25%). For this reason, it was also decided to look into the potential application of alternative paving constructions.

4. PRACTICAL TEST

Following a literature survey, desk studies, laboratory and practical research, a practical test was started at the end of 1996, involving the mutual comparison of several alternative paving constructions. Six alternative paving constructions were chosen for testing, i.e.:

Section A highly stable asphalt concrete
Section B unreinforced cement concrete
Section C combination (top) layer
Section D highly stable asphalt concrete (Superpave)
Section E concrete block paving
Section F concrete block paving (on asphalt)

The dimensions of the test sections were taken as approximately 50 m long and 4 m wide.

4.1 Foundation

The foundation had already been laid in the place where the practical test was run. This consists of 200 mm of modified sand cement stabilisation on 450 mm of normal sand cement stabilisation. The base consists of sand.

4.2 Grids

Before a start could be made on laying the test sections, navigation cables (for the AGV's) with cable protection pipes ("grids") were fitted in the top of the foundation.

4.3 Paving constructions

Construction of the test sections began in November 1996. Various examinations and inspections took place both during and after construction.

Test section A: Highly stable asphalt
The top layer consists of asphalt mixtures of the following layer thickness: 30 mm highly stable asphalt (SMA) 0/11 on two layers highly stable asphalt (STAB) 0/22 (thickness 120 mm). Modified bitumen was used as a binder in all the asphalt mixtures (Esso: Flexipave 106).

Test section B: Unreinforced concrete
The design of the concrete pavement assumes a composition which satisfies the B75 characteristic. The concrete pavement is unreinforced and is applied in plates measuring 4 x 4 m. The plates are attached to each other using dowels. The concrete pavement is dimensioned as a construction with a thickness of 200 mm. To this end, 50 mm of the foundation is milled off.

Note
Immediately after laying, cracks appeared in the concrete plates and these collapsed fairly quickly under the load from the AGV as a result of severe cracking. For this reason, section B was reconstructed at the end of October 1997. The most important changes are:
- *concrete thickness 220 mm instead of 200 mm;*
- *transverse joints in concrete paving at the site of grids in sand cement ballast;*
- *sturdier edges, 280 mm thick, at the site of transition to test sections A and C;*
- *prevention of water accumulation by perforations on adjacent sections.*

Test section C: Combination (top) layer
The combination (top) layer consists of a porous asphalt layer, in which the hollow spaces are filled with a cement-thickened mortar. In this way, the porous asphalt top layer should ensure that the combination top layer is flexible. The cement-thickened mortar should provide high stability. Conventional bitumen 80/100 is used for the porous asphalt mixture. DENSIT was chosen for the cement mortar. The combination (top) layer with a thickness of 40 mm lies on two layers of highly stable asphalt STAB 0/22 (110 mm thick). Modified bitumen is used in the STAB layers.

Test section D: Highly stable asphalt concrete (Superpave)
In this test section, the asphalt mixture used differs from the conventional Dutch road-building mixtures. In this case, the mixture design is related to a certain amount of compaction energy, which is translated into a number of volumetric design criteria. The Superpave mixtures are dimensioned as the two undermost layers (125 mm thick). The top layer is of highly stable asphalt SMA 0/8 25 mm thick with modified bitumen; this is because of the open nature of the Superpave.

Test section E: Concrete block paving (traditional ECT construction)
This test section consists of the construction so far used at ECT. The top layer consists of 120 mm concrete block paving with a brick bed underneath it of granular material, 30 mm thick.

Test section F: Concrete block paving (on asphalt)
This test section consists of the existing ECT construction of concrete block paving with a granular layer, but on an intermediate layer of highly stable asphalt SMA 0/11 (40 mm thick) which is applied to the foundation.

4.4 Load

An Automatic Guided Vehicle (AGV) rides continuously over the test sections, on the same track, at a speed of approximatly 3 m/s. The AGV rides fully loaded, with a container weight of approximatly 30 tons, total weight approximately 46 tons.

4.5 Frequency distribution

Various container weights are transported on the highways of the ECT terminals, with a loading degree of 50%, which corresponds to an even proportion of both full and empty trips by the AGV. The actual traffic load on the highways of the ECT terminals is converted into a traffic load with a certain equivalent standard load. For the equivalent standard load, an average load per axle of the AGV of 24 tons is assumed.

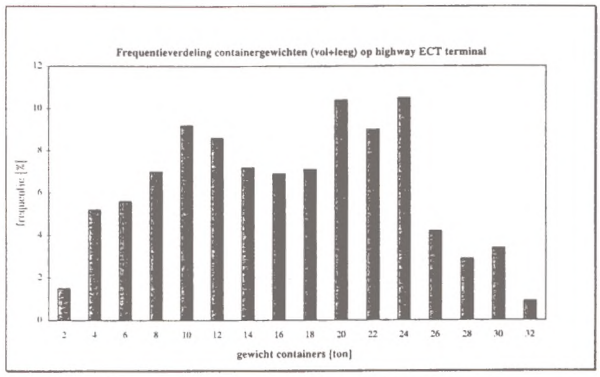

Figure 1 Frequency distribution

4.6 Axle load repetitions

The AGV made an eventual total of 62,183 circuits on the test sections, which correspond to 124,366 axle load repetitions for the AGV. The number of axle load repetitions is converted into an actual traffic load by the AGVs on the ECT terminals' highways. The actual traffic load cannot be determined in the same way for all paving constructions using the same method. The difference in the method used to determine the traffic load is caused by the occurrence of the critical stresses and strains at various positions in the constructions. The actual traffic loads for the various test sections are calculated as follows: asphalt/concrete block paving 3-7 years, concrete/combination top layer 7-8 years.

Note
The same method can be used for the test sections with asphalt and concrete block pavings. Specifically, the indicative strain occurs on the underside of the sand cement stabilisation in the asphalt and concrete block pavings. A different method must be used for the test sections with the concrete paving and the combination top layer. In the concrete and combination top layer pavings, the indicative stresses and strains occur in the paving itself and not in the sand cement stabilisation.

5. RESULTS

Rutting remained within the maximum 20 mm permissible for ECT on all test sections. However, some serious distortions did occur locally (at the site of the grids). These distortions have now been repaired.



Photo 4 Damage to asphalt



Photo 5 Damage to concrete block paving

- All the paving constructions tested (sections A to F) display damage and require maintenance to a greater or lesser extent;
- Good drainage is essential for concrete block types of paving (section E). Very importantly, great care must also be taken with the composition and finish of the foundation since this determines the behaviour of the overall construction over time;
- Asphalt under the concrete block paving (section F) displays a great deal of damage;
- The combination top layer (section C) and the (new) unreinforced concrete paving (section B) display little or no damage and also require less substantial maintenance. The concrete block paving (sections E and F) and the highly stable asphalt (sections A and D) display more damage and, as a result, also require major maintenance more frequently.

In determining the cause of the damage, a clear link can frequently be established with the grids (particularly in paving constructions involving concrete block paving (sections E and F)). The asphalt test sections and the combination top layer seem to suffer the least from the presence of grids and water, while, in the first instance, the concrete pavement (section B) and the pavings involving concrete blocks (sections E and F) suffer the most. The expectation is that the problem of "rutting" will be solved not only by adjusting the paving, but that adjustments will also have to be made to the AGVs. To summarise, the behaviour of the various test sections can be described as follows:

Section A: Highly stable asphalt concrete
The most frequently occurring types of damage on the test section are rippling and rutting. Final values of between 4 and 10 mm are achieved for the rutting. From approximatly 40,000 axle load repetitions, it would appear that a sharp increase in rutting can also be observed on this test section at higher temperatures. It is evident from organ drilling that the rutting is caused to the same extent through all the asphalt layers. No damage is observed at the site of the grids.

Note
One limitation when evaluating the resistance to rutting is that the test section was not loaded by the AGV during hotter periods (summer 1998).

Section B: Concrete pavement
Even after a small number of axle load repetitions by the AGV, the concrete pavement collapsed as a result of cracking, particularly at the site of the grids. Following repair (November 1997), the test section was loaded by approximatly 65,000 axle load repetitions of the AGV. The repaired concrete pavement displayed virtually no damage during this period.

Section C: Combination top layer
It would appear that slight hairline cracks and slight rutting are the most frequently occurring types of damage on this test section. Visual inspections reveal that the hairline cracks did not occur during one particular period, but that they increased over time and with an increase in the number of trips by the AGV. The hairline cracks also seem to increase during periods when the test section is not being ridden on by the AGV. The hairline cracks found on the test section only occur on the surface of the combination top layer, as was revealed by the inspection of drilling cores. The hairline cracks occur both in and in between the ruts and on sections which are not driven on. A large proportion of the hairline cracks occurs at the site of the grids. The occurrence of hairline cracks during periods of no load and on sections which are not driven on indicates that the shrinking behaviour of the rigid combination top layer can be seen as the most significant cause. The rutting which occurs on this test section consists of final values of 2-7 mm, indicating that this test section displays the least rutting.

Section D: Highly stable asphalt concrete (Superpave)
The most frequently occurring types of damage on the test section are rippling and rutting. Final values of between 6 and 14 mm are achieved for the rutting. From approximatly 40,000 axle load repetitions, it would appear that a sharp increase in rutting can also be observed on this test section at higher temperatures. It appears from drilling that the rutting is caused to the same extent through all the asphalt layers. No damage is observed at the site of the grids.

Note
One limitation when evaluating the resistance to rutting is that the test section was not loaded by the AGV during hotter periods (summer 1998).

Section E: Concrete block paving
The most frequently occurring types of damage on this test section are rutting and unevenness. The rutting and unevenness on this test section occur quite soon after the beginning of the test. The greatest damage occurs particularly at the site of the grids. On this test section, the rutting displays interim values of 4-13 mm. During interim repairs and while inspecting drilling cores, local cracking has been revealed on the upper surface of the modified sand cement stabilisation at the site of the grids. It is also evident, during repairs, that the damage to the modified sand cement stabilisation is located not only at the site of the grids, but that slight damage is also present in the sections between the grids. This reveals that the grids are a major cause of the damage occurring in this type of paving construction.

Section F: Concrete block paving on asphalt
The indicative damage on this section is represented by rutting and unevenness. Final values of between 3 and 12 mm are achieved for the rutting. Following repairs to the bends, local distortions of 29 mm are measured. The severe unevenness on this test section

occurs specifically at the site of the grids.Even after interim repairs have been carried out, severe distortions and rutting occur very quickly. Locally, some blocks are actually lifted and some blocks come loose. It is observed during repairs that the rutting occurs in the modified ballast at the site of the grids. It is also evident during repair that the damage is not confined to the site of the grids, but that damage to the modified sand cement stabilisation is also present to a severe extent in the sections between the grids. The asphalt layer displays virtually no damage and seems to have been distorted along with the modified ballast. It would appear that little or no bond is present between the asphalt layer and the modified sand cement stabilisation and both layers of sand cement stabilisation. It would appear from the repair observations that residual water under the asphalt and the weak spots at the site of the grids are the most significant causes of the damage. Moreover, it is clear that the absence of a bond between the various layers in the construction has led to imperfect load distribution.

6. CONSIDERATIONS AND CRITERIA

Asphalt mixtures are expected to remain sensitive to high temperatures and to demonstrate rutting after some time. Repairs to asphalt paving can be carried out relatively simply and quickly. Contractors have little to no experience in preparing and finishing Superpave asphalt. This implies additional risks in the use of this construction. Furthermore, asphalt constructions seem to be less resistant to torsional forces (rippling). The unreinforced asphalt paving shows no damage. Objections to this construction include the costs of laying, the completion time and the fact that repairs to concrete are more difficult to carry out than to the other alternatives. The presence of (steel) dowels in the concrete is regarded as an obstacle to steering the AGVs as a result of the possibility of breakdowns. Insufficient experience has yet been acquired of asphalt as an intermediate layer under the concrete block paving. Moreover, this construction requires additional drainage provisions.
In order to determine an "optimum" paving construction for the AGV zone, the various paving constructions have been tested against several user requirements and specific technical/functional and economic criteria. It is clear that the type of paving appropriate to the business of ECT is one which requires as little maintenance as possible. However, it would appear that none of the alternative paving constructions is 100% maintenance-free.
For this reason, an estimate has been made for each construction of the frequency and scope of the required maintenance. Optimisation calculations have been carried out for all the paving constructions. Calculations were then made, taking into account a new AGV (twinlift). The laying and maintenance costs of the optimised constructions have been calculated.

A number of factors influenced the ultimate choice of the paving construction for the AGV zone, such as:

- ECT has switched to steering the AGVs using "transponders". This means that the grids become obsolete and can be removed (thus removing a major source of damage);
- the changeover has been made to "twinlifts", which means that two 20-foot containers can be handled simultaneously. This considerably increases the load exerted by the new AGVs on the paving (total weight approx. 80 tons rather than approx. 50 tons);
- the possibility of fitting the AGVs with double pneumatic tyres is being examined (this does not seem possible as a result of present software and the control problems with the AGV);
- the likelihood of AGVs becoming "derailed" is being examined. So far, little is known about this;
- the AGVs are being fitted with bigger tyres (Straddle Carrier tyres). Several have already been fitted with them.

ECT is eventually left with two paving constructions which are worth considering for the AGV zone, based on the results from the test sections and current understanding. These are:

Concrete block paving
Combination top layer

When choosing between these two alternatives, several aspects are important, such as:

- technical behaviour;
- completion aspects;
- finance;
- operational aspects.

Both alternatives have been examined more closely in the light of the above aspects, leading to the following:

Table 1 Comparison aspects

	Concrete block paving		Combination top layer
Technical behaviour	on the border between coping and having reached the limit of its capabilities		offers more possibilities for future operation (twinlifts)
Completion aspects	longer completion time due to hardening of modified stabilisation		quicker to apply
Finance	still the cheapest (in terms of laying and maintenance)		total laying and maintenance more expensive
Operational aspects	disruption more frequent and over a larger area, zone out of use for longer		less stagnation over a smaller area

"Given the technical limitations of the concrete block paving construction, the expected influence of twinlift loads, together with operational stagnation during repairs, the combination top layer is regarded as a sensible choice."

7. HAVE THE LIMITS BEEN REACHED IN THE USE OF CONCRETE BLOCK PAVING?

Severe rutting is now being observed in the AGV zone of the new Terminals; this damage is influencing operations and has to be repaired. Various (emergency) repairs have been carried out, although these would appear insufficient and a more "structural approach" to the damage is required. In this context, operational stagnation due to maintenance should be avoided whenever possible. A number of causes of the damage can be indicated:

- the fact that AGVs ride on fixed routes;
- the mixture for the modified stabilisation used as a foundation is not yet optimum;
- the grid (cable protection) breaks the continuity of the paving;
- water, which can percolate to the paving.

It has become clear that the grids fitted for the navigation, together with water, significantly influence the occurrence of the damage. It would appear that, in terms of construction and maintenance, the block paving construction is still the cheapest form of paving. However, operational stagnation as a result of maintenance to the foundation restricts the application of concrete block paving in the AGV zone. This has led to ECT's decision to provide the AGV zone with highly stable asphalt with a combination top layer and to provide the remaining areas of the terminals with the traditional concrete block paving.



Photo 6 Combination top layer for the AGV zone

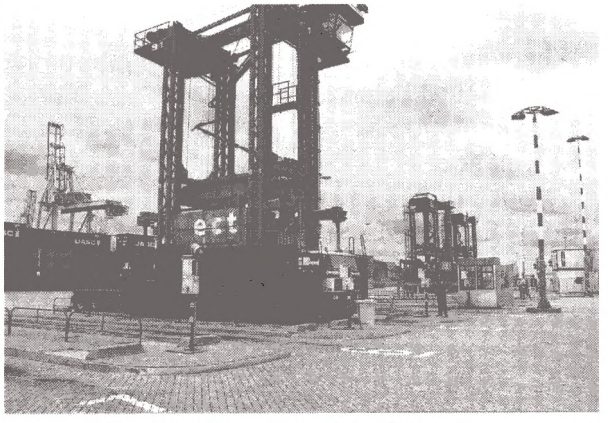

Photo 7 Concrete block paving for the remaining areas

LITERATURE SUMMARY

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