CONCRETE PAVEMENTS FOR PORT AREAS IN BELGIUM EXPERIENCE AND INNOVATIONS

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ABSTRACT

The growing transport by trucks and the increasing use of containers have created an important need for durable pavements with very low maintenance cost.

The Belgian port authorities and many operators prefer to use concrete pavements for port areas, as well monolithic concrete slabs (cast in situ) as concrete blocks.

Since 1980, in the port areas of Antwerp, Zeebrugge and Ghent more than 2.5 million m² container terminals have been paved with concrete.

The paper reviews briefly the Belgian experience and innovations with different types of concrete pavements for heavy-duty applications. Finally some design recommendations are presented.

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INTRODUCTION

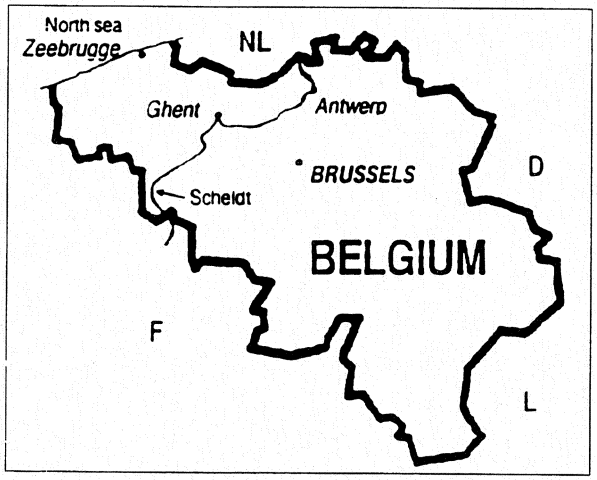
Due to a relative improvement of the economy, activities in industrial and port areas have experienced a marked picking up during the last years. Increased transport by lorries and growing use of containers required major constructions for work area improvement and created a need for durable pavements needing little maintenance.

Belgium's rich experience with concrete roads and the increasing interest for high quality surfaces induced private enterprises to follow the example of Public Authorities and to choose more and more concrete pavements, either monolithic pavements (cast in situ) or concrete block pavements (1).

Hence, more than 2.5 million m² concrete pavements have been laid since 1980, merely in port areas, used by wheel loads from 10 to 20 t, mostly in the port of Antwerp (fig. 1).

All types of concrete pavements constructed during the last 10 years, such as reinforced and unreinforced concrete as well as concrete pavement blocks, will hereafter be reviewed briefly. Some design recommendations for heavy duty pavements are given at the end.

Figure 1 — Situation of Belgian ports



1. MONOLITHIC CONCRETE PAVEMENTS

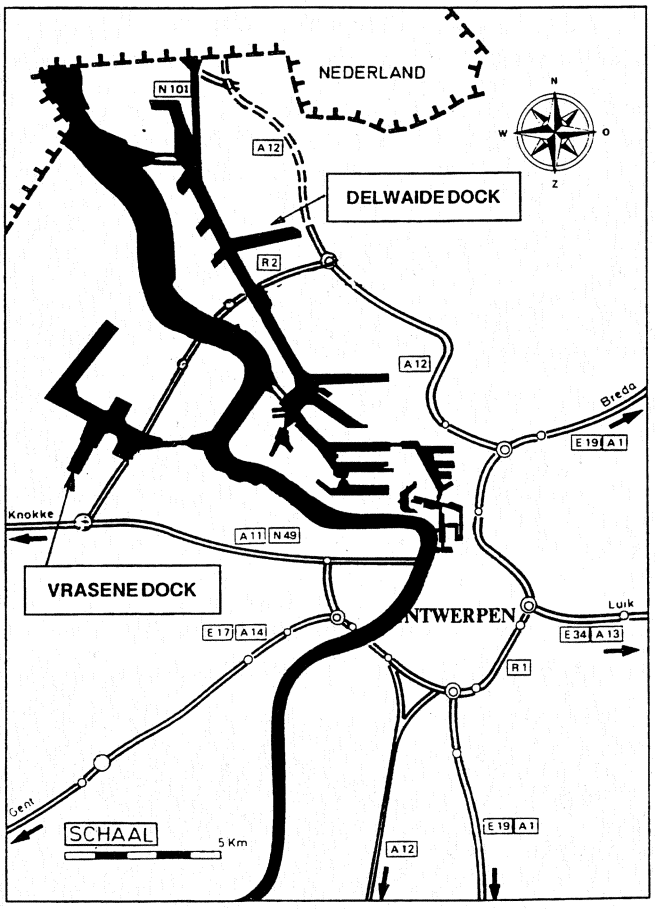
Antwerp - Delwaide Dock

Since the beginning of the eighties, great areas, mostly container terminals, have been paved in the Antwerp port area, especially on the right river bank of the Scheldt along the Delwaide dock which is 2220 m long and 300 m wide (fig. 2).

Due to great settlements, notably 15 cm and more, in the 3 to 5 m thick deposits of land fill, 20 to 25 cm thick reinforced concrete slabs (5 x 5 m), were practically always used, the reinforcement being mostly Ø 10 (150 x 150); the pavement rests directly on sand or on a layer of about 20 cm sand cement (mix-in-place).

In this way more than 800,000 m^2 have been paved along the Delwaide dock (2).

Figure 2 — Port of Antwerp



High strength concrete, as currently foreseen in Belgian road construction has been used: mean compressive strength on 90 days old cores of 100 cm^2 and 10 cm high, at least 60 N/mm^2. It is common practice to use at least 350 kg cement of strength class 40 per m^3 without addition of air entraining agents so as to obtain this strength. All those paved areas, mostly 5 to 10 years old, have required little repair and maintenance (fig. 3).

Figure 3 — Antwerp Delwaide dock, terminal Noord Natie



Locally observed failures, mainly near manholes and expansion joints, are rather due to lack of care in workmanship than to insufficient thickness. However it should be noted that in the long term, cracks are practically unavoidable in such relative thin slabs (20-25 cm) without special base and subjected to wheel loads ranging from 10 to 20 ton and more (fig. 4).

Figure 4 — Front-lift truck of 25 ton carrying capacity



According to the suggested design procedure of the Portland Cement Association (3) the thickness of plain pavements for container terminals should be 30 to 40 cm and even more.

Taking account of the Belgian high strength concrete (flexural strength fs 6.5 N/mm^2) the thickness could be reduced to 25-30 cm. In spite of the thicknesses thinner than theoretically necessary, applied along the Delwaide dock, the repair and maintenance costs seam today relatively low. Indeed, after 10 years of heavy container traffic the pavements are performing well, and the maintenance costs are very limited, namely maximum 0.5 % of the first investment costs.

As local repair and reconstruction costs are about 3 times higher than normal new construction costs, it seems that after 5 to 10 years max. 0.25 % of the 500,000 m^2 container terminals with reinforced concrete pavements, belonging to the Noord Natie needs repair works.

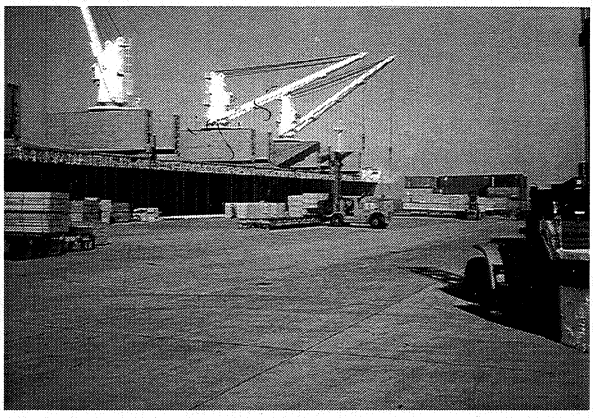
Such performance is excellent because for economical and operational requirements local reconstruction of well designed heavy industrial concrete pavements should normally be limited to max. 1 % of the surface after 10 years.

The good condition of the relatively thin concrete pavements along the Delwaide dock is probably due for a large part to the horizontal drainage system. This leads the water of the hydraulic landfill and also rain water penetrated in the permeable subbases by collector pipes to the dock.

Antwerp - Vrasene Dock

For the further expansion of the port of Antwerp, considerable pavement work have been undertaken since 1985 on the left bank of the Scheldt, namely along the Vrasene dock where, good results were obtained with unreinforced concrete slabs (5 x 5 m), notwithstanding great (differential) settlements of the soil. The contraction joints have been constructed with dowels and the longitudinal joints with tie-bars (Fig. 5).

Figure 5 — Antwerp Vrasene dock, terminal Westerlund Unreinforced concrete slabs



The total area of these pavements, built in several phases, exceeds 200,000 m^2. To limit the damage, due to the expected settlements of this land fill area, 2 peculiar solutions were considered:

- *a "Sandwich"-method* for the pavement structure, namely:
  - 20 cm concrete slabs with dowelled contraction joints
  - 20 cm crushed stone
  - 20 cm sand cement (mix-in-place).
- *use of concrete pavement blocks* for bridging the settlements. Therefore, 12 cm thick rectangular concrete paving blocks have been laid in herringbone pattern 1.5 to 5 m wide immediately along the wall as well on the inner as on the outer side of the industrial buildings (fig. 6).

Even the concrete inside the halls has been placed by slip-form pavers in 5 m wide lanes.

Figure 6 — Antwerp Vrasene dock, terminal Fin West



After several years of heavy duty traffic and stacking of enormous rolls of paper, causing loads of usually 20 to 30 ton/m^2, it seems that, even with settlements of about 15 cm, especially inside the storage halls, relatively few cracks, mainly longitudinal, have appeared. Some settlements and corner cracks have been observed near manholes, sewer inlets and on the junction between plain concrete and concrete block paving. The application of reinforced concrete in these areas, as was done at the entrance of the buildings, and smaller slab sizes e.g. 4 x 4 m would probably have improved the performance. Thicker slabs, especially on the connection between plain concrete and paving blocks would also have been beneficial.

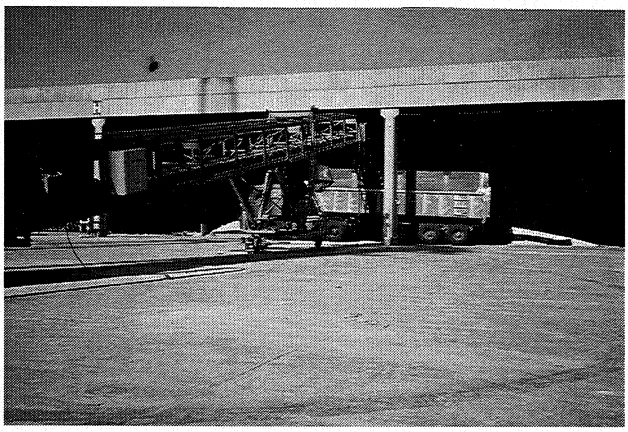
The concrete block pavement of this terminal, where plain concrete and paving blocks are combined showed some years after the construction great unevennesses; however, the latter could easily be eliminated by relaying.

Ghent - Terminals for coal and fertilizers

In the port of Ghent, where a big part of the nearly 24 million tons cargo consists of coal, 20,000 m^2 steel fibre reinforced concrete with 35 kg steel fibres (Bekaert) per m^3 has been placed in thicknesses of 20-23 cm in some terminals along the Middle dock in 1987-88.

A pavement of steel fibre reinforced concrete (Eurosteel fibres) has also been laid some years ago along the Middle dock for handling of fertilizers in bulk, (about 27,000 m^2) (Fig.7).

Figure 7 — Ghent Middle dock - Steel fibre reinforced concrete on fertilizer terminal



Considering the good bearing capacity of the sub-soil, a sub-base of crushed stone has been used, covered, partly in the coal terminal, by 15 cm lean concrete.

The addition of 30 to 35 kg/m^3 of steel fibres increases slightly the flexural strength and compared to unreinforced concrete it allows a reduction in thickness of 20 to 30 %. Therefore a thickness of 20 - 23 cm steelfibre concrete was chosen in the port of Ghent. Otherwise, steel fibre concrete is often used in special cases because of its postcracking behaviour and high fatigue-strength.

Although steel fibres have been used for terminals, the length of the slabs has still been limited to 6 m and their width to 4.5 or 5 m. Dowelled contraction joints have been used as for ordinary road construction. Those pavements were mostly laid by slip-form pavers in lanes of 4.5 or 5 m or in lanes of 9 m in which longitudinal joints were sawn. The contraction joints filled with an elastic compound seem to behave well despite the frequent scraping contact with coal.

Joints in the fertilizer terminal, carefully filled according to Belgian prescriptions for road construction, perform as well. The general state of these terminals after more than 5 years service is excellent.

Avelgem - Inland Navigation Terminal

For a container terminal in the inland harbour of Avelgem subject to axle loads of 100 t and wheel loads of 25 t, a 12,000 m^2 continuously reinforced concrete pavement has been designed, 25 cm thick (0.75% longitudinal reinforcement, Ø 20 every 15 cm) resting on a sub-base of 20 cm lean concrete and an underlayer of 30 cm crushed stone ; in addition geotextile has been placed under this layer. The first phase of this construction has been carried out in the spring of 1989 using slip-form pavers for 7 m wide lanes.

As the continuously reinforced concrete may expand or contract freely in Avelgem, abutment constructions were unnecessary making construction cost acceptable. This pavement is still too new for serious evaluation.

2. CONCRETE BLOCK PAVING

Port Areas

Increasing use has been made during the last 10 years of concrete blocks for the pavement of harbour areas and, as mentioned above, often in combination with monolithic pavements (4). The success of concrete blocks is due to their ability to meet with good results various situations and work conditions in port areas such as :

- heavy loads,
- differential settlements around quays, buildings and other structures with foundations...,
- settlement of land fill,
- near cranes and railway tracks,
- near utility ducts,
- irregular site dimensions.

The blocks were initially laid manually but yet mostly mechanically, the machines reaching outputs of more than 500 m^2 per day.

Antwerp - Extension Left Bank

Different companies, especially the Seaport-Katoennatie, have laid, mainly along the Delwaide dock, enormous quantities of concrete paving blocks (more than 600,000 m^2) because of sound technical and economic reasons.

The same company also started in 1990 a project entailing more than 1,000,000 m^2 concrete block pavements on the left bank in Antwerp along the Vrasene dock.

The structure which yet has become practically classic in Antwerp is the following :

- 12 cm rectangular concrete paving blocks (220 x 110 x 120 mm) laid in herringbone pattern,
- 5 cm bedding layer, mixture of about 50% crushed sand and 50% crushed stone 2/7, 35-40 cm sand cement(mix-in-place) or 25 to 30 cm crushed stone.

To attain a compressive strength of 5 N/mm^2 after 28 days according to ASTM D698, the land fill is mixed with about 180 kg/m^3 cement of strength class 30, which is achieved in a single layer by a deep mixer (fig. 8).

It has to be noted that before stabilization, a horizontal drainage system, mostly PVC-ribbed drains connected to collector pipes leading the collected water to the dock, is installed in the hydraulic land fill.

To avoid stagnation of water between the base and the paving blocks, Ø 50 mm holes are drilled in the lowest parts of the profile up to 10 m wide on both sides of the rows of inlets for surface water drainage, e.g. 1 per 2 m^2 and filled with crushed stone 2/7 so as to allow the water to percolate through the base and hence to reach the drainage pipes.

Figure 8 — Deep mixing the 35-40 cm sand-cement base with a single shaft mixer



Zeebrugge - New Ocean Port

Important construction works have been implemented since 1970, in the new and dynamic polyvalent ocean port of Zeebrugge, such as a large new sea lock and a new inner harbour (1300 ha). The paving of the port areas was mostly carried out in the eighties. More than 300,000 m^2 concrete paving blocks have been laid in the inner harbour since 1984. Here also, concrete paving blocks were preferred because the nearly 3 m thick deposit of land fill is liable to significant settlements. The following structures are used :

- 12 cm rectangular or interlocking concrete paving blocks
- 3-5 cm ternary sand (mix of crushed limestone, blast furnace slag and lime),
- 20 cm lean concrete or sand cement (mix-in-place)
- 15 cm sand cement (mix-in-place) or crushed stone.

The ternary sand consists of a homogeneous mix of crushed sand 0/2, crushed stone 2/4, granulated slag, lime (2%) and mixing water. This material which hardens slowly combines in fact the advantages of coarse paving sand and sand cement. The required compressive strength for ternary sand is normally 1 to 2 N/mm^2 measured after 28 days on Proctor test specimens.

To avoid water stagnation between the base and the concrete block paving, in the inner harbour of Zeebrugge, large openings (Ø 30 cm, 1 per 15 m^2) were left in the base course and filled with draining material. This has proved to be entirely successful in allowing water to reach the drainage pipes.

It should further be noted that, as in Antwerp, a drainage system was installed in the land fill (drainage pipes of 80 mm and collector pipes of 200 mm).

Due to numerous railway tracks, some special arrangements were required in Zeebrugge to avoid problems with the pavements :

- instead of using crushed stone for the sub base, lean concrete was used between the tracks;
- special L-shaped concrete paving blocks were laid alongside the rail tracks (fig. 9).

Ghent - Railways

Interlocking concrete block pavements, mostly 8 or 10 cm thick, are frequently used in the port area of Ghent, mainly on railways. On the coal terminal, which has already been described and where mainly monolithic pavements or steel fibres reinforced concrete have been applied, the Ghent Port Authority ordered to lay a 5 m wide lane of interlocking concrete paving blocks on the site of the railways. Those blocks were laid on a bedding of 3 cm sand spread on a well compacted 20 cm thick base of sand cement.

High quality sand cement (180 kg cement per m^3) was chosen because this material is the most easy to compact between rail tracks and sleepers. For good fit between rails and pavement, the solution of the Belgian railways has been adopted which consists of 2 special concrete blocks, spacers and small filling blocks.

Figure 9 — L-shaped paving blocks along tracks

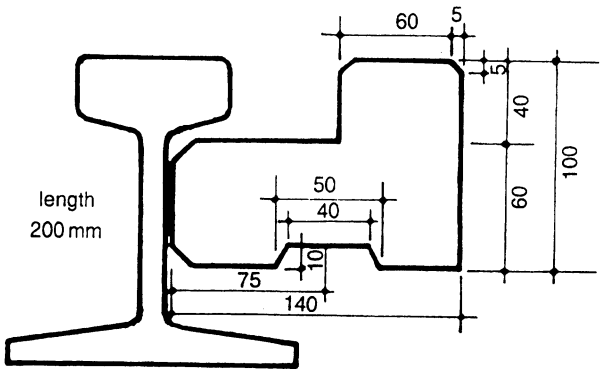
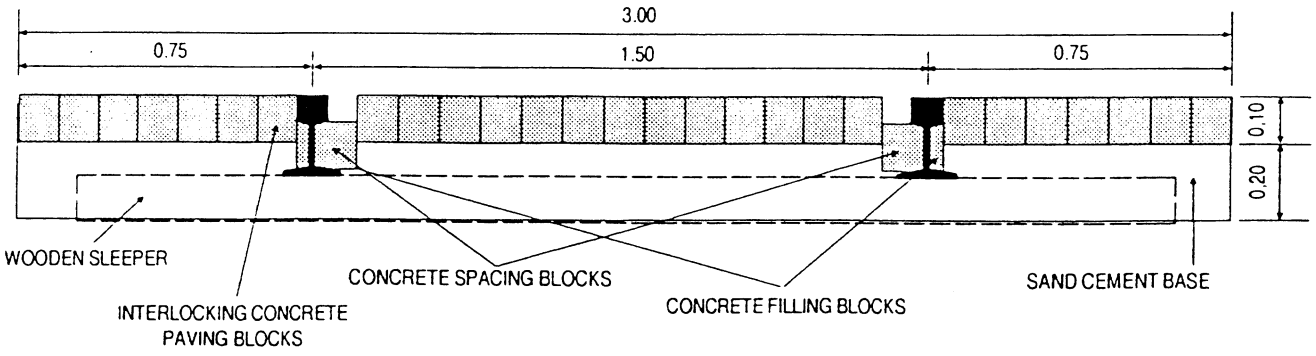


Figure 10 — Railway in the port of Ghent



3. CONCLUSIONS AND RECOMMENDATIONS

Monolithic Concrete Pavements

- Monolithic pavements of unreinforced or possibly reinforced concrete are a good solution for heavy duty industrial areas. The concrete quality has not only to be strong enough but must be resistant to deicing salts. This is obtained by using high quality concrete with high cement content, as is mostly done in Belgium, or with concrete containing an air entraining agent.
- Continuously reinforced concrete or reinforced concrete slabs are justified when considerable settlements are expected. Dowelled concrete slabs of limited size combined with the "Sandwich" method offer also interesting technical and economical perspectives for areas subjected to settlements.
- The various theories lead to great differences in the design of the required thickness. Anyway, recent Belgian experience shows that a concrete pavement about 25 cm thick and laid on a good base with cement bounded materials is able to support without problems wheel loads of 15 t to 20 t which are current on port areas.
- Good drainage combined with an effective evacuation of rain water extends considerably the life of concrete pavements. Water stagnation under concrete pavements should be avoided in any case, water stagnation between pavement and base is very dangerous and liable to cause considerable damage.

Concrete Block Pavements

When considerable settlements are to be expected, and also when monolithic (cast in situ) pavements are difficult to build (e.g. irregular shaped areas), areas subjected to heavy loads can best be made with paving blocks preferably laid in herringbone pattern.

Considering practical and esthetic imperatives, the best solution may often be found in concrete paving blocks, sometimes in combination with monolithic concrete.

To maintain the evenness of a paved area, subject to heavy loads, it is necessary beyond dispute to use cement bound bases, under concrete block pavements such as lean concrete, cement bound crushed stone or sand cement.

Cement bound bases and stabilized fill are absolutely necessary to avoid unevennesses in the pavement surface especially near manholes, sewage inlets a.o.

TABLE 1 — Recommended structures of monolithic pavements subject to heavy loads (6)

Maximum wheel load	**100 kN** (10 t)		**175 kN** (17,5 t)		**250 kN** (25 t)	
Concrete pavement	22-24 cm unreinforced concrete	20-23 cm reinforced concrete or CRC	25-26 cm unreinforced concrete	23-25 cm reinforced concrete or CRC	26-30 cm unreinforced concrete	25-28 cm reinforced concrete or CRC
Sub-base	20 - 23 cm lean concrete or 20 - 25 cm cement bound crushed stone or sand cement		20 - 23 cm lean concrete or 20 - 25 cm cement bound crushed stone or sand cement		lean concrete or *20 - 30 cm cement bound crushed stone or sand cement	
Underlayer	15 - 25 cm granular materials		18 - 25 cm granular materials		20 - 25 cm granular materials	
Subgrade	Es > 20 MPa CBR > 2					

Note : * If - Es ≤ 20 MPa structural improvement of the bearing capacity of the subgrade is necessary by stabilisation or by removing and substitute with sand.
* A - small reduction of thickness in comparison to unreinforced slabs is ontly allowed for heavily reinforced concrete slabs with load transfer in the joints or continuously reinforced concrete (CRC).

Table II — Recommended structures of concrete block pavements on industrial handling yards (6)

Types of loads	I	II	III
	Mainly trucks	Normal industrial areas	Heavy duty industrial and port areas
STRUCTURAL PARTS			
1. Crushed base			
paving blocks	10 - 12 cm	—	—
bedding material	3 - 5 cm	—	—
crushed stone base	25 - 30 cm	—	—
granular material	20 - 30 cm	—	—
subgrade min. Es	70 MPa	—	—
2. Cement bound base			
paving blocks	10 - 12 cm	10 - 12 cm	10 - 12 cm
bedding material	3 - 5 cm	3 - 5 cm	3 - 5 cm
cement bound crushed stone or sand cement	20 - 25 cm	20 - 30 cm	15 - 25 cm stab. crushed stone { 35 - 45 cm sand cement or soil cement 20 - 25 cm sand cement or soil cement
granular material	20 - 30 cm	20 - 40 cm	0 - 20 cm
subgrade min. Es	70 MPa	70 MPa	70 MPa
3. Lean concrete base			
paving blocks	10 - 12 cm	10 - 12 cm	10 - 12 cm
bedding material	3 - 5 cm	3 - 5 cm	3 - 5 cm
lean concrete	18 - 20 cm	20 - 25 cm	20 - 25 cm + 15 - 20 cm sand cement or stabilized soil
granular material	20 - 25 cm	20 - 30 cm	0 - 20 cm
subgrade min. Es	70 MPa	70 MPa	70 MPa
Laying pattern	herringbone	herringbone	herringbone

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