A DOUBLE-LAYERED CRCP: EXPERIENCES ON THE E34 NEAR ANTWERP (BELGIUM)

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ABSTRACT
The technique of double-layered concrete or two-lift paving is applied either to obtain a high-quality top layer, to use lower quality materials in the lower lift, or for both reasons at the same time. In Europe this technique is commonly applied in Austria where a typical motorway is built with a 25 cm-thick jointed plain concrete pavement consisting of a 20 cm lower layer and a 5 cm upper layer. For the coarse aggregates of the first layer, recycled crushed concrete from former pavements replace the natural stones while the top layer is made of small, polishing-resistant stones with a maximum aggregate size of 8 mm. Driven by growing environmental awareness and a desire for innovation, the Flemish Road Authorities followed the Austrian example and planned a trial worksite on a 3 km section of the E34 motorway in Zwijndrecht near Antwerp. Following Belgian tradition, the existing JPCP was replaced with a CRCP. The paper will describe the pavement design and construction details, the concrete mix design and the evaluation of the road surface characteristics of the finished road. By adopting the CRCP long-life pavement concept, the use of reclaimed aggregates and the result of a quieter and smoother surface, different aspects of sustainable construction are combined, to good effect, in this technique.

KEY WORDS
CRCP / DOUBLE LAYERED / TWO LIFT / RECYCLING

1. INTRODUCTION

A large number of Belgian motorways (approx. 40 %) and main roads is constructed in concrete. Since the mid-nineties, the standard construction method for this has been paving in continuously reinforced concrete with a thickness of 23 cm and a chemically exposed aggregate surface finish (see figure 1). The concrete road surface is laid in one lift with a single run of a slipform paver. As regards construction, this method is simple and reliable. A suitable macrostructure is required to obtain a low-noise road surface, i.e. the uniform spreading of fine stones – up to approx. 10 mm in grain size – on the concrete surface. This is taken into account, in the concrete composition, by imposing a maximum aggregate grain size of 20 mm and by keeping the content of fine stones (fraction 4/6.3) high, i.e. 20 % to 25 % of the sand/stone mixture.
Because of the skid resistance required, the stones on the surface must meet the requirements for polishing resistance, being PSV (Polishing Stone Value) ≥ 50. Stones with such a hardness and polishing resistance are only available to a limited extent. Mainly used for this in Belgium are porphyry, sandstone or crushed gravel, all three of which can be excavated in our country; or imported hard aggregates, such as basalt or Scottish granite. This strict but important requirement also makes recycled crushed concrete aggregates unsuitable in a concrete road surface.

The two-lift concrete technique affords a possible solution. It consists of dividing the concrete pavement into a bottom lift of approx. 80% of the total design thickness, and a top lift of approx. 20% of the total thickness. The thinner upper course makes it economically justifiable to use fine, hard but also more expensive stones. As a result, a high-quality upper course can be obtained with excellent safety and driving comfort properties. Because the lower course does not reach the surface the strict polishing resistance requirement no longer applies, and less noble and cheaper aggregates can be used. This permits the use of recycled aggregates, at least insofar as other requirements are also met (such as the workability of the fresh concrete and the strength and durability of the hardened concrete).

In order to obtain a unified concrete pavement, the fresh concrete of the upper course must be poured onto the fresh concrete of the lower course within a period of 1 to 2 hours. This is the more difficult aspect of this technique: two slipform paving machines are required, moving a few tens of metres apart, and the two concrete compositions must arrive practically at the same and right time on the site. This makes organisational and logistical matters more challenging than on a traditional concrete pavement construction site.

2. EUROPEAN AND BELGIAN EXPERIENCE IN TWO-LIFT PAVING

In Europe the two-lift concrete technique was chiefly developed in Austria in the early nineties, and has since been generally applied on their motorway network. A typical Austrian pavement structure is shown in figure 2. In the lower course, recycled broken concrete, originating from the broken-up concrete from the old concrete pavement, is used for the coarse aggregates (10 – 32 mm) (Beiglböck 2003).
In Belgium too, there was already experience of two-lift concrete and the use of recycled, broken concrete aggregates. Two-lift concrete was already regularly being used for ornamental concrete pavements in coloured, exposed aggregate concrete. This involves a lower course in grey concrete and an upper course of coloured-through concrete with coloured fine stones. The quite expensive colouring agents and coloured stones justify the use of this technique. Examples include the Sint-Jansplein in Antwerp (two-lift slab concrete, ochre- and black-coloured, laid with a slipformer, 2001) and the Place d’Armes in Dinant (two-lift slab concrete, white- and brown-coloured, laid manually, 2002) (Rens et al. 2004).

Two-lift, continuously reinforced concrete had already been used on two experimental sites on regional roads. The first concerned low-noise pavement test sections in Herne, laid in 1996. An 18 cm CRC lower course was given different top lifts of fine exposed aggregate concrete, porous concrete, split mastic asphalt and porous asphalt. These test sections were subjected to various measurements and assessments (Caestecker 1999). The general conclusion after 12 years of use is that a upper course in fine-grained, exposed aggregate concrete (0/7) performed best in the long term as regards noise production, while also being the most durable.

The second trial involved a series of five test sections in Estaimpuis built in 2001 (Debroux and Dumont 2005). The following lower course and upper course combinations were tested: see table 1. With these trial sections, there was the expected conclusion that the finer the upper course aggregates, the better the results for rolling noise. It was also concluded, however, that the quality of the road-laying, in particular the evenness of the driving surface, is an equally important factor.

Table 1 – Test sections in Estaimpuis, 2001

<table>
<thead>
<tr>
<th>Section no.</th>
<th>Lower course</th>
<th>Upper course</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thickness</td>
<td>Aggregate (in mm)</td>
</tr>
<tr>
<td>1</td>
<td>15 cm</td>
<td>0/32</td>
</tr>
<tr>
<td>2</td>
<td>14 cm</td>
<td>0/32</td>
</tr>
<tr>
<td>3</td>
<td>12 cm</td>
<td>0/32</td>
</tr>
<tr>
<td>4</td>
<td>12 cm</td>
<td>0/32</td>
</tr>
</tbody>
</table>

3. BELGIAN EXPERIENCE IN THE USE OF RECYCLED AGGREGATES IN PAVEMENT CONCRETE

Belgium also has a great deal of experience in recycled aggregates in road construction. Almost all applications, however, related to their use in sub-bases (unbound aggregates) and bases (unbound and cementbound aggregate mixtures, lean concrete and roller compacted concrete). Experience is more limited concerning recycled products in pavement quality concrete. In 1997 a concrete mix with 20 %, 35 % and 50 % crushed concrete was examined to replace the sandstone...
for the construction of a 400 m-long local industrial road in Ouffet. Ultimately, use was made of a concrete with 28 % recycled aggregates, size 5/20, originating from old concrete slabs. A thorough preliminary study and follow-up enabled the successful completion of this pilot project (Bolette et al. 2001).

Recycling broken concrete in pavement quality concrete was also the subject of a thesis at the Hogeschool De Nayer in Sint-Katelijne-Waver (Delgouffe 2002). The crushed concrete used for this originated from the break-up work during the renovation of the A12 dual carriageway in Meise. So the broken concrete in question was selected and of a high quality. Indeed, the same basic principle is also seen in Austria, where they only use crushed concrete which has been sourced from existing, broken-up pavements. In the thesis, concrete mixes were tested with levels of respectively 0; 25; 32.5; and 40 % broken concrete aggregate. The results of this study were very similar to those at the Ouffet site. The broken concrete, itself, usually did not meet the requirements of the Belgian specifications (as regards its static compression strength, crushing resistance, water absorption and frost resistance). As far as the properties of the concrete were concerned, the strength requirements were easily satisfied. Above a certain level of recycled material in the mix, a slight decrease in compression strength was observed. There is an increase in water absorption because broken concrete is more porous than natural crushed stone, and problems may arise with the workability of the concrete mixture.

4. SITUATION ON THE E34

The N49 is the popularly called “express-road” between Antwerp and Knokke, and in most places, is classified as a motorway forming part of the E34. On the territory of the Province of Antwerp the road pavement consists of concrete slabs with a thickness of 23 cm and a joint distance of 5 m, laid on a base of approx. 20 cm of lean concrete. Construction dates from around 1977. The road consists of two lanes and a hard shoulder in both driving directions; the hard shoulder is also in concrete slabs. Although the slabs were initially dowelled, serious step forming originated at the joints. The dowels may have been sawn through or broken but, in any case, they no longer did what they were designed to do and the road became very uncomfortable, particularly on the right-hand lane carrying heavy traffic. There was also clearly no more bond between the concrete road surface and the lean concrete base. At the joints the base was also seriously subjected to erosion. In recent years there were also increasing numbers of cracked slabs that had to be repaired, either with new concrete slabs or with asphalt. Even if the amount of cracked slabs remained within reason, general renovation became necessary because of poor driving comfort. The volume of traffic on the E34 in the Province of Antwerp in 2005 amounted to approximately 23,000 vehicles a day in the direction of Knokke, of which 25 % was truck traffic.
As part of an innovation programme, the Roads and Traffic Agency (AWV) of the Flemish Government had drawn up a list of potentially innovative applications for road-building. The use of recycled aggregates in road paving was one of them. This meant that for the renovation of a section of the E34, it was decided to apply two-lift concrete with recycled aggregates in the lower course.

The type of concrete pavement chosen was CRC, thereby giving the best guarantees of a long and maintenance-free working life.

To reduce the potential risks, the allowed share of recycled crushed concrete was limited. Experience in Austria was also used to set the level. For the same reason, quality control was conducted by an independent body (COPRO), and the length of the site was limited to three km. When choosing the section to be renovated, account was also taken of roadworks planned for the coming years, in particular the construction of the Oosterweel link road for the Antwerp Master Plan.

5. DESIGN ASPECTS

5.1 Demolition

It was planned to break up the two lanes (approx. 7.5 m wide) plus a part of the hard shoulder (approx. 0.9 m). This meant a surplus width could be provided for the new pavement, and still with a narrowed hard shoulder in concrete slab.

The base in lean concrete, which was generally still in good condition, could be kept, but the upper 5 cm was cut away to create enough space in the new height profile for an intermediate course of asphalt.

The metal safety barriers were removed in the central reserve.

5.2 New pavement structure

The new pavement structure is shown in figure 4.

![Figure 4: New pavement structure on the E34 in Zwijndrecht](image)

For the reinforcement of the CRC, there was no difference to the single-lift concrete course (23 cm thick):

- longitudinal reinforcement: diam. 20 mm all 18 cm;
- transverse reinforcement: diam. 16 mm all 70 cm, and at an angle of 60°;
- concrete cover of the longitudinal reinforcement: 80 mm ± 10 mm; this meant the reinforcement bars were placed in the top of the lower concrete course.

At the end of the section in the Antwerp direction a traditional anchoring abutment with six lugs was built. There the road continues in old concrete slab. At the other end, in the Knokke direction, a
connection was made to an existing abutment of another CRC pavement. No anchoring was provided in the longitudinal joint between the new CRC pavement and the part of the slab hard shoulder that had been kept. This method had given no problems with similar work on the E34. No systematic influence of the joints on crack formation was observed in the CRC.

5.3 Concrete mix design

The following requirements were set for the upper course and lower course concrete mixes:

Upper course:
- Broken stone 4/6.3 with polishing resistance requirement PSV ≥ 50, no recycled material allowed;
- Sand for pavement concrete, no recycled material allowed;
- Blast furnace slag cement CEM III/A 42.5 N LA: minimum 425 kg/m³;
- Water-cement factor W/C ≤ 0.45;
- Air entrainer compulsory, air content of fresh concrete on the site ≥ 5 %.

Lower course:
- Broken stone 4/6.3 – 6.3/20 – 20/32 of which max. 60 % recycled materials originating from the broken-up concrete slab shared among the 6.3/20 and 20/32 fractions; and 40% natural crushed stone with no polishing resistance requirement;
- Sand for pavement concrete, no recycled material allowed;
- Blast furnace slag cement CEM III/A 42.5 N LA: minimum 375 kg/m³;
- Water-cement factor W/C ≤ 0.45;
- Air entrainer compulsory, air content of fresh concrete on the site ≥ 3 %.

5.4 Requirements of the hardened concrete

The following requirements were set for strength and durability:

Top lift:
- Compressive strength: characteristic value ≥ 50 MPa on cubes with 15 cm side, stored at 20 (± 2)°C under water or at 95% RH and at an age of 28 days;
- Water absorption by immersion: maximum average value of 6.3 % and maximum individual value of 6.8 %.

Bottom lift:
- Compressive strength: characteristic value ≥ 52.5 MPa on a drilling core taken from the pavement at an age of at least 90 days.

5.5 Safety barrier

A concrete safety barrier with functional requirements in accordance with EN1317-2 was manufactured on-site to replace the metal crash barriers:
- minimum containment level H2;
- maximum working width W6,
- a maximum acceleration severity index of 1.4 (class B).

The Step profile (H2 – W1 – B) meets these requirements.
6. WORKSITE ORGANIZATION AND CONSTRUCTION ASPECTS

The site was located on the E34 between Km 2.8 and Km 5.8 in the Knokke direction. The works were awarded to the company WEGEBO in Brussels. The contractual execution period amounted to 50 workdays. The contract amount was approx. 2 million euros (incl. VAT).

For correct application of the broken concrete (ca. 14,000 tonnes in all), a mobile crushing and sieving unit was installed on site (a motorised crusher, type: Lokotrack 13.15 SR, and a sieve, type: Powerscreen Chieftain 2400). These units were subject to COPRO approval (viz. certificates of compliance). Sieving took place to 0/6.3 fractions; 6.3/20 and 20/32, of which the two last came into consideration for reuse in the lower course.

A mobile plant (Compactors Belgium, theoretical capacity 120 m³/h) was set up at the worksite to create the two types of concrete mixes. Its operation was subject to quality control by COPRO. Because only one supply route was available, namely along the retained part of the hard shoulder, the logistics for the supply of the concrete had to be meticulously coordinated, all the more so because only one load of fine-grained concrete was required for the upper course to every ca. three loads of concrete for the lower course.

The concrete pavement was laid using two slipform pavers (CMI – TEREX) in one single pass with a total width of 8.4 m (two 3.75 m lanes and a surplus width of 0.9 m on the hard shoulder side). An important advantage of concreting in two lifts is that the second machine only has to use a limited amount of concrete, so that a higher degree of evenness can be obtained.

The surface finishing consisted of exposing the broken stone skeleton in the upper course. A highly homogeneous exposed aggregate surface finish was obtained thanks to the fine granulometry of the composition of that upper course.

7. MEASUREMENTS AND EVALUATION

7.1 Requirements of the hardened concrete

The upper course did not always satisfy the (strict) requirement regarding cube compressive strength. The characteristic value after 28 days amounted to approx. 45 MPa instead of the required 50 MPa. This has two potential causes: on the one hand there may have been problems with the production and finishing of the test cubes at the mobile plant. The preparation of test samples, you see, has a big influence on the result of a compressive strength test. On the other hand, there is the high required air content of at least 5 %. Should the actual air content be a little higher, this would have a direct influence on the compressive strength. Each increase of 1% air, you see, gives a decrease in compressive strength of approx. 5 MPa. This problem was also observed already on the other sites with two-lift concrete. Nevertheless, it could be argued that this
result will not have adversely affected either the mechanical strength or fatigue resistance of the concrete pavement, nor the durability of the wearing course.

7.2 Evenness
The evenness was measured using a Longitudinal Profile Analyzer (LPA). The results were excellent with the exception of some sections where, in the right-hand lane, the profile had to match the level of the adjacent old hard shoulder.

![Figure 6 – the exposed aggregate concrete surface](image)

7.3 Skid resistance
The skid resistance was checked with the SCRIM. The transverse friction coefficient must be at least 0.48. The measurements gave results varying between 0.60 and 0.87 with 84% of the results above 0.70.

7.4 Texture and rolling noise
As a part of a Concrete Pavement Surface Characteristics Program, field measurements of noise and surface texture have been done in Belgium by the Transtec Group. The program was coordinated by the National Concrete Pavement Technology Center, the Federal Highway Administration, the American Concrete Pavement Association and a consortium of State Departments of Transport. The double-layered concrete pavement on the E34 was one of the three test sites in Belgium. The noise was measured by a near field (close proximity) technique via On-Board Sound Intensity (OBSI). The macrotexture was measured with the RoboTex (Robotic Texture) Measurement System.

The measured noise level (OBSI) was 101.7 dBA and the mean profile depth was 1.4 mm. This can be compared with similar measurements on a single-layer exposed aggregate concrete pavement with a maximum aggregate size of 20 mm, which is also situated on the E34: noise level of 105.3 dBA and MPD of 1.56 mm. This means that a reduction of more than 3 dBA was achieved with the two-lift paving technique!

8. CONCLUSIONS
Belgium is internationally known and recognised for the testing and development of innovative technologies for concrete roads. The above-mentioned sites in Herne and Estaimpuis are examples of this, as well the various completed projects of thin and traditional overlaying, the construction of roundabouts in continuously reinforced concrete, etc.
This also concerned a unique international first, albeit continuing on from existing experience, namely the simultaneous combination of two-lift concrete paving, continuously reinforced concrete and the reuse of broken concrete. This concept aimed for greater durability, both in the traditional sense in view of the long wear life a CRC pavement offers and, in the wider sense, namely the concern for the environment and finite natural resources. This project may certainly be regarded, therefore, as an optimised concept of sustainable road-building.

REFERENCES


