A DOUBLE LAYERED CRCP : ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT

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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 in terms of safety and driving comfort, either to use lower quality and thus less expensive materials in the lower lift, or for both reasons at the same time.
In Europe this technique is commonly applied in Austria where recycled crushed concrete from former pavements is used in the bottom layer.

Driven by the growing environmental consciousness 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 highway N49 (E34) in Zwijndrecht near Antwerp. The construction took place in two phases: in the direction of Ghent in 2007 and in the direction of Antwerp in 2008. The double advantage of using reclaimed, less expensive aggregates and obtaining a quieter and smoother surface will undoubtedly promote this type of sustainable pavements.

The paper will conclude with an assessment of environmental, economic and social aspects for the double layered pavement in comparison with traditional construction techniques.

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 slip-form paver. With regards to construction, this method is simple and reliable.

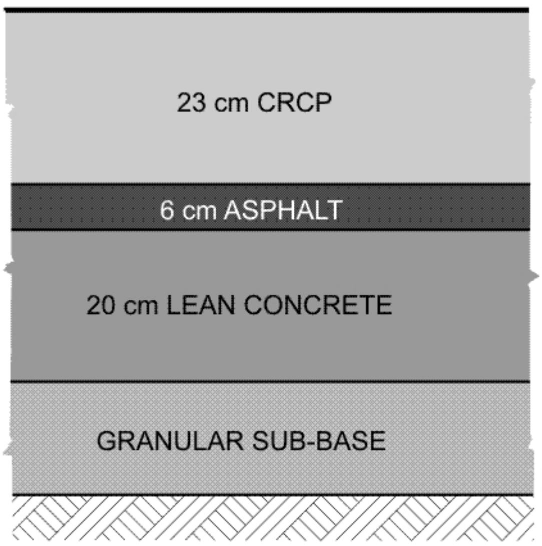

Figure 1 – Belgian standard structure in CRC for main roads

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 slip-form 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) [1].

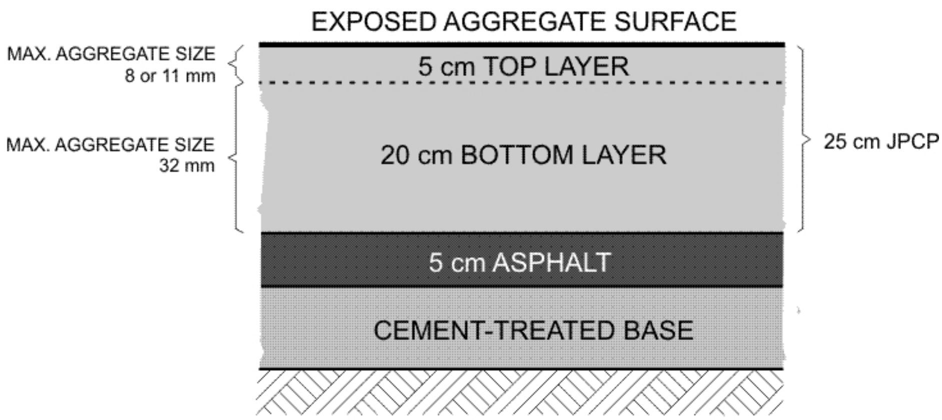

Figure 2 – typical structure of a motorway in Austria

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 slip-form paver, 2001) and the Place d'Armes in Dinant (two-lift slab concrete, white- and brown-coloured, laid manually, 2002) [7].

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 [3]. 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 [4]. 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

Section no.	Lower course		Upper course	
	Thickness	Aggregate (in mm)	Thickness	Aggregate (in mm)
1	15 cm	0/32	5 cm	0/7
2	14 cm	0/32	6 cm	0/10
3	12 cm	0/32	8 cm	0/14
4	12 cm	0/32	8 cm	0/20

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, are 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 [2].

Recycling broken concrete in pavement quality concrete was also the subject of a thesis at the Hogeschool De Nayer in Sint-Katelijne-Waver [5]. 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.

Figure 3 – faulting joints

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 between Km 2.8 and Km 5.8.

5. DESIGN ASPECTS

5.1 Demolition

It was planned to break up the existing lanes and hard shoulder. 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.

5.2 New pavement structure

The new pavement structure is shown in figure 4. For the reinforcement of the CRC, there was no difference to the single-lift concrete course.

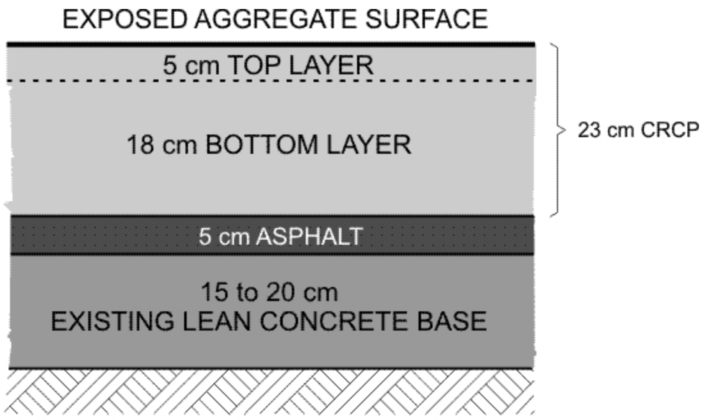

Figure 4 – new pavement structure on the E34 in Zwijndrecht

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 %.

Figure 5 – worksite in progress by two slipform pavers

6. ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT

6.1 Evaluation of the sustainability aspects

To which extent can a double layered concrete pavement be considered more sustainable than a traditional single layer pavement? Some of the factors that contribute to a more sustainable solution can easily be identified, such as the possibility of using less noble aggregates in the bottom layer. Other aspects, however, may have a negative effect on the assessment on the environmental, economic or social impact of this solution, e.g. the need for two batching plant and two paving machines.

For this particular worksite, no detailed study was done on environmental (life cycle assessment LCA) or economic impact (Life Cycle Cost Analysis LCCA). Therefore, we'll limit ourselves to general, mostly non-quantified considerations, to comparisons with other studies and researches and to some simple observations and findings that are directly related to this worksite.

6.2 Environmental assessment

Concrete motorways show in general excellent results in LCA's in comparison with asphalt structures [6]; [8]. The long lifetime, the favourable maintenance phase and the low embedded energy of concrete play an important role in these results. A reduction in the clinker content of the cement can reduce the environmental impact by up to 21% [6]. For the described worksites, the cement used was CEM III/A 42,5 N LA what stands for a blast furnace slag cement of which the CO_2-emission is limited to about 0,5 ton CO_2 per ton cement. This means a reduction of 45 % compared to a non blended Portland cement!

Which potential for a better environmental performance shows a double layered CRCP compared to the single layered construction? The answer lies clearly in the use of the recycled crushed aggregates, coming from the old pavement. For the extraction of one ton of virgin aggregates (limestone which is a suitable aggregate for the bottom layer) the following quantities of energy are consumed: 0.19 litres of gasoil and 2.78 kWh for electricity. This makes a total equivalent of around 1,63 kg CO_2 per ton aggregate. The estimated mass of recycled aggregates in the bottom layer - 60 % of the stones in a layer of 18 cm thickness – is 160 kg/m² , giving us an equivalent saving of 0.26 kg CO_2/m². Another saving is done in transport, taking into account the fuel savings related to the very limited transport on the worksite, compared to the long supply distances from quarry to the worksite. For an average distance of 75 kilometre between quarry and worksite and an estimated on-site travelled distance of 5 km, the difference is 70 km x 110 g CO2/km (truck 30 ton)/30 * 0,16 = 0,41 kg CO_2/m². Though relevant, these are still relatively small figures.

But considering the usage phase of the road, the potential environmental effect of the traffic load is up to 100 times more than construction and maintenance activities together. Even small reductions – only up to 2% - in fuel consumption, which can be obtained by improvements in surface texture, in evenness and also by the stiffness of the concrete surface, lead to a reduction in CO_2-emission (Global Warming Potential) that exceeds the impact of the motorway construction phase and maintenance phase together. In this field, the high quality top layer of a double layered CRCP offers the best possible combination in terms of texture, evenness and stiffness. This will further be discussed in § 6.4.

Another important aspect for the considered worksites is the fact that the existing base in lean concrete was still in good condition after thirty years of service so that it could be reused for the new road structure. This again meant a tremendous reduction in transport of old and new materials with al the linked advantages: less fuel consumption, less pollution, less deterioration of access roads, less traffic jams, etc.

6.3 Economic assessment

A comparative economic study between motorways built in asphalt and in CRCP, executed by the Walloon Ministry of Infrastructure and Transport in 2001 [10] concluded that either one is forced by existing financial constraints to choose for a solution that makes use of a bituminous pavement, which permits lower initial capital costs, or one opts for cement concrete, which allows substantial economies over a period of time. Depending on the assumptions that were made, the economies for concrete compared to asphalt started from the seventh to the fourteenth year after construction. Some of the parameters of this study certainly have changed over time. The thickness of the concrete pavement e.g. has been increased from 20 to 23 centimeters. Also the price of bitumen, which is directly linked to the price of petrol, has undergone very considerable fluctuations and is for the past years at a much higher level than it used to be at the moment of the study. The general conclusions of the study certainly will remain valid.

From the bidding documents of the construction projects on the N49, the prices for the double layered concrete pavement were less or more equivalent to those for a single layer pavement for a comparable size of worksite. This was not evident taking into account the extra difficulties of the two lift paving technique : the need for two batching plants and two slip-form pavers plus the additional labor, equipment setup, repair and fuel costs and the organization of a more complicated logistic and supply of concrete on the jobsite. The higher complexity is also linked to a higher risk for unforeseen problems such as equipment malfunctions or problems with one of the concrete mixes and also to a reduced speed of completion. In addition, the installation of a mobile screening and sieving plant was imposed in the tendering documents for the two worksites of respective sizes of about 25.000 m² (2007) and 33.000m² (2008), which in fact are too small sizes to fully compensate the transport- and installation costs. The fact that the overall price (initial cost) was not substantially higher than for a traditional singe lift construction was clearly due to the beneficial reuse of the recycled concrete aggregates in the bottom lift.

6.4 Social assessment

6.4.1 *Considered aspects*

General advantages of CRCP are the very long lifetime and the minimal required maintenance. Less reconstruction works and less frequent maintenance lead to a number of benefits : less traffic disruption and less hindrance to the road users (traffic jams, waste of time, road safety) compared to other types of pavements (all asphalt types and jointed plain concrete). Double layered CRCP doesn't seem to offer any extra advantages in that field.

For the road user, the pavement is experienced by its surface. That is why surface characteristics play an important role in the society's judgment on the roads, mainly through the aspects of safety and driving comfort. Safety is related to longitudinal and transverse evenness (absence of rutting – no risk for aquaplaning) and to the skid resistance or wet weather friction. Driving comfort is determined by longitudinal and transverse evenness as well and by the noise levels generated by the tire-surface contact. In addition, noise is even more crucial for the residents adjacent to the road. The characteristics evenness, skid resistance and rolling noise will be looked at for the described worksite.

6.4.2. *Evenness*

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 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 remaining hard shoulder. Also on other test-sections with two lift paving, the enhanced evenness quality was observed.

Figure 6 – the exposed aggregate concrete surface

6.4.3 *Skid resistance*

The skid resistance was checked with the SCRIM-apparatus. 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. It must be said that there are not yet experiences with long term performances of skid resistance of fine exposed aggregate concrete in Belgium, the oldest one (Herne [3]) being 15 years old.

6.4.4 *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 [9]. The program was co-ordinated 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 macrotexure 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 aggregrate 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 and that the fine exposed aggregate concrete can compete with any traditional type of dense asphalt layer.

Figure 7 – the finished pavement and barrier

7. CONCLUSIONS

The worksite on the N49 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 crushed 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 concept of enhanced sustainability in road construction.

Further optimisation of the concept is still possible through technology exchange between the countries that have experience with this way of construction as well as through a joint research. The type and amount of aggregates that can be recycled in the bottom layer is one of the interesting topics to be examined. In order to make the right decisions, a holistic and correct environmental analysis (LCA), over the complete lifetime including usage phase and for all of the relevant environmental indicators, has to be carried out.

The same is true for the economic aspect (LCCA). In spite of some difficulties that still exist today, the technique of the double layered concrete pavement – either jointed plain concrete or continuously reinforced concrete – is likely to become the standard solution in several European countries and states of the U.S.

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