BELGIAN APPLICATIONS OF CONCRETE INLAYS ON MOTORWAYS

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1. INTRODUCTION

All motorway managers are faced with the problem of rutting in dense asphalt road surfacings, which is due among other things to the steady increase in heavy goods vehicle traffic.

As a result, the residual service life of the slow (right-hand) lane decreases much faster than that of the overtaking (left-hand) lane, which is used mainly by light vehicles having a considerably milder action on road structures. It is, therefore, necessary to define specific and economically viable approaches to the structural strengthening of slow lanes.

Since 1993, the so-called "inlay" technique has been applied on four sites in the Walloon Region of Belgium. This technique consists of replacing the dense asphalt surfacing of the slow lane with a cement concrete pavement.

The first application took place near Mons in July 1993, over a 1,600 m stretch of the carriageway to Brussels of the Brussels-Paris motorway (E19).

A second site was opened on the same motorway in August 1995, this time in the direction of Paris and over a total length of 4,000 m.

In October 1995 and July 1996, respectively, two further jobs were carried out in the direction of Aachen on the Brussels-Aachen motorway (E40), each over a total length of 2,000 m.

2. FIRST APPLICATION : MOTORWAY E19

In 1995, the Brussels-Paris motorway (E19) carried in the vicinity of Mons an average daily traffic of about 29,000 vehicles in each direction, 20 % of which were heavy goods vehicles. The section Nimy-Jemappes-Mons was opened to traffic in 1970. Traffic volume increased by 50 % between 1986 and 1995. The structure of the pavement was composed of a 40 cm thick subbase in sand, an 18 cm thick lean concrete base, and several dense asphalt layers with a total thickness of 28 cm. The surface had been planed off several times and replaced with new layers. The latest repair dated from 1988. In 1991, a systematic survey of rutting in the slow lane of the section considered showed that the phenomenon had developed again to reach a depth of 20 mm.

Project design

In view of the situation it was decided to replace the surfacing in the slow lane with a cement concrete pavement, using the so-called "inlay" technique. This technique consists of planing off a dense asphalt surfacing to a certain depth

between saw cuts marking off the edges of the excavation, and then laying a cement concrete pavement in the cavity thus created. Several options were considered before making this choice. Besides conventional proposals to remove several layers by milling and replace them with new dense asphalt materials, it was recommended to plane off the right-hand lane to depths ranging from 14 to 20 cm and replace them with cement concrete - either fibre-reinforced or continuously reinforced or dowelled slab concrete.

The pavement structure was designed by the Belgian Road Research Centre's (BRRC) method (1), with several thicknesses for the concrete slab (14, 16, 18 and 20 cm).

Figure 1.a shows the streses at the bottom of the concrete, calculated for different slab thicknesses:
ext. corner = corner stress in the absence of load transfer at the joints,
free edge = edge stress in the presence of dowels transferring loads at the joints.

A stress of 3.63 MPa can be allowed in the concrete when the average compressive strength of 100-cm² cores taken from the pavement after 90 days reaches (60 + 1.645 S_R) N/mm² (S_R being the standard deviation). The service life in terms of equivalent 13-t axles is shown in figure 1b.

Given the average thickness (28,3 cm) of dense asphalt surfacing measured over the section considered, and because of the constraints involved in carrying out the work while keeping the overtaking lane open to traffic, it was decided to lay a cement concrete pavement in dowelled slabs 20 cm thick.

The initial design proposal for a 16 cm thick concrete slab reinforced with 30 kg of steel fibers per m^3 of concrete was rejected. Although the incorporation of steel fibres in concrete can be reasonably expected to yield a 5-% increase in flexural strength and retain some residual strength after failure of the concrete (2) steel fibers do not transfer loads across joints, so doweling remains necessary. Hence, a 16 cm thick slab reinforced with steel fibres will be approximately equivalent to an 18 cm thick slab without such fibres, but will be as strong as a 20 cm thick unreinforced slab. Also, the use of fibers normally does not reduce the curling phenomenon since the users of fibers requires a finer grading of the concrete, which in turn may require higher amounts of mixing water. Additional water in concrete will increase shrinkage and curling is related to shrinkage.

Standard cross section and composition

The following standard cross section was selected for the project (figure 2).

The width of the slabs is 4.50 m, to limit edge effects ; their length is 5 m. The asphalt was sawn to the full depth, i.e. 0.20 m. A vertical drain in porous concrete was constructed at the lower side, to prevent any stagnancy of water at the interface between the slab and the subbase. This drain also helped to keep the excavation dry during construction.

The maximum aggregate size was limited to 20 mm and the surface of the concrete was treated by chemical aggregate exposure in order to minimize rolling noise. The same concrete 0/20 mm had been successfully applied in September 1992 on a section of motorway E313 between the east and southern parts of the town of Hasselt.

Construction

The concrete mixture was composed as follows :
- 783 kg of porphyry 7/20 mm,
- 353 kg of porphyry 2/7 mm,
- 562 kg of Meuse sand 0/5 mm,
- 219 kg of Scheldt sand 0/1 mm,
- 385 kg of CEM III/A - 42.5 LA cement,
- 120 to 135 l/m^3 of mixing water.

The average W/C ratio measured during construction was 0.46.

The job was carried out in July 1993 - during the holiday period, to cause as little inconvenience to road users as possible.

The following operations were performed :

- planing off the existing asphalt surfacing to a depth of 20 cm ;
- sawing to make sharp edges to the excavation ;
- sweeping the bottom of the cut ;
- constructing a vertical drain at the lower side of the excavation and filling it with porous lean concrete ;
- installing dowel supports. The contractor preferred to use this installation technique rather than inserting the dowels into the newly laid concrete by vibration, since the hard shoulder at the job site was wide enough to allow side feeding of the concrete paver ;
- laying the concrete with a slip-form paver fitted with a longitudinal supersmoother-type finishing screed in order to achieve excellent surface evenness and - consequently - reduce rolling noise. The concrete was poured in hot weather, so that the contraction joints had to be sawn within a few hours after laying. The sawing was, therefore, performed with a light "soff-cut"-type machine, through the protective plastic membrane. There were no problems sawing through the plastic and this operation controlled the crack development at the joints adequately without any random cracks. After sawing, the joints were covered with plastic strips and sanded, to preserve the continuity of the protection ;
- exposing the surface aggregate by brushing the concrete the day after laying.

Deflection measurements

To verify the assumptions made in the design calculations, a series of falling weight deflectometer tests was carried out on the bottom of the excavation after planing. From the results it was possible to assess the bearing capacity of the various layers of the pavement and, hence, to calculate its residual life (3).

1. Characteristic deflection

The deflection values found were similar enough for the motorway section to be considered as homogeneous for bearing capacity.

The statistical distribution parameters were :

Distance(*) (in mm)	0	300	600	900	1200	1500	1800
Mean deflection (in μm)	223	167	117	80	53	37	28
Standard deviation (s, in μm)	43	40	28	19	13	7	5

(*) i.e.the spacing between the spot where deflection was measured (position of the geophone) and the point of impact of the falling weight.

Characteristic deflection was determined as the deflection value having only a 5-% chance of being exceeded :

$d_{car} = d_{mean} + 1.645\ s$

This resulted in the following values :

Distance (in mm)	0	300	600	900	1200	1500	1800
Characteristic deflection (in μm)	294	233	163	111	74	49	36

2. Residual moduli of the existing structure

Let us consider a pavement structure made of a first layer of 80 mm of type III dense asphalt, 182 mm of lean concrete, and 400 mm of drainage sand.

The moduli of the structure were backcalculated so as to fit exactly the deflection values measured.

The following values were found for the elastic moduli of the various layers :

$E_{dense\ asphalt}$ 9,200 MN/m²,
$E_{lean\ concrete}$ 4,900 MN/m²,
$E_{drainage\ sand}$ 30 MN/m²,
$E_{subgrade}$ 4,900 MN/m².

The value obtained for the modulus of the dense asphalt is well within the range of values usually observed under the temperature conditions of the test. The modulus of the lean concrete is slightly lower than usually (15,000 m²), probably owing to the use of shale as granular material. That of the drainage sand is extremely low and corresponds with a single-sized and, therefore, perfectly draining material. Finally, the modulus of the subgrade corresponds well with a material having a bearing capacity of 35 MN/m² measured by the plate-bearing test.

The usefulness of the condition survey, revealing low values for the moduli of the lean concrete and the drainage sand - which are usually not reckoned with -, should be duly noted here.

3. Bending stress

The bending stress at the bottom of the concrete and in the middle of the slab was calculated by multilayer theory while assuming full slip at the interface between the concrete pavement and the underlying asphalt layer.

Then the bending stress at the edge of the slab, required for structural design, was calculated while assimilating the multilayer structure to a Westergaard two-layer structure (4).

The equivalent modulus of subgrade reaction, K, obtained by successive iterations was determined on the assumption that the bending stress in the middle of the slab was equal to that found by multilayer theory. The total slab edge stress obtained was 2.43 N/mm².

Finally, the stress induced by the thermal gradient was calculated. It turned out to be negligible.

4. Allowable number of standard loads

The allowable number of standard loads was found from the classical relation (while ignoring the thermal stress) :

$$\log N = a\,(1 - \sigma_{lim} / \sigma_m)$$

where a = 12 (average coefficient, varying with the reference consulted),
σ_{lim} = calculated stress,
σ_m = allowable stress (6.2 N/mm²).

The number of commercial vehicles, N_c, was given by : $N_c = N/0.25 = 7.92 \times 10^7$
(a value close to the value of 3.2×10^7 recommended by BRRC (R57/85) for dual two-lane motorways).

Results achieved

1. Bond between the cement concrete and the dense asphalt

The strength of this bond was evaluated by means of a shear apparatus (IOWA 406 test method) (5). A good bond in a way increases the thickness of the surfacing, thus reducing the stresses.

The mean value found on 11 samples was 0.75 MPa, with a standard deviation of 0.39 MPa. This is relatively low when considering the desirable average value > 1 MPa. This poor result can be ascribed to a lack of care in removing the dust from the asphalt after planing.

2. Compressive strength

An average compressive strength of 63.1 MPa, with a standard deviation of 3.2 MPa, was found on core samples after 90 days. It appears that, to attain the specified values with 0/20 mm aggregates, a mortar richer in cement must be used.

3. Physical characteristics of the concrete in surface and bottom slices

The water absorption values found in immersion tests on the top slices of specimens were all lower than 6 %, averaging 5.44 % of the dry mass. This can be considered a good result.

Similar measurements were performed on bottom slices ; the values were all lower than 5.5 % with a average of 5.1 %, which is excellent.

These values in principle indicate good compaction of the concrete and a satisfactory W/C ratio.

4. Resistance to de-icing salts

Resistance to the action of de-icing salts was tested on the top slices of three samples. Their respective losses in mass after 30 cycles of testing by the ISO/DIS 4846.2 method were 1.22, 31.0 and 12.1 g/dm². These are high values, suggesting that the cement content of the mortar has a predominant effect on the concrete's performance in freezing. A slightly higher cement content seems, therefore, highly desirable in the future for 0/20 mm concretes.

The use of an air-entraining agent can also be considered for such mixtures.

Conclusion

Traffic was allowed on the new pavement one week after laying. This application has demonstrated the feasibility of the technique, even under highly constraining traffic conditions.

Riding comfort is excellent and road users do not notice the difference in aspect between the overtaking lane and the slow lane. There are no problems with winter behaviour.

3. THE 1995 JOB ON MOTORWAY E19

With the lessons from the 1993 experiment in mind, a new application of the technique was made on the same motorway in the direction of Paris, over a stretch of 4 km.

The main differences with the first job were :

- a concrete composition with the same 0/20 mm grading but with 400 kg of cement per m^3 and an air-entraining agent for higher resistance to frost and de-icing salts ;
- dowel insertion by vibration into the newly laid concrete.

Excellent results were achieved, for the quality of the concrete as well as for the level of comfort and rolling noise.

4. THE JOBS ON MOTORWAY E40

On motorway E40 near Battice, the inlay technique was applied on two sections each about 2 km long in the direction of Aachen. The work was carried out in October 1995 and June 1996, respectively. The new pavements are in continuously reinforced concrete 23 cm thick, and the inlays are 4.5 m wide.

Project design

The existing pavement structure consisted of a crushed stone base and an asphalt concrete surfacing with a thickness varying between 20 and 28 cm. It had been constructed in the early sixties and was subject to many defects and to generalized rutting in the slow lane.

The new structure is composed of the following courses (figure 3) :

- a new road base formed by 6 cm of type III asphalt mix over 20 cm of lean concrete. The latter was mixed in plant, using the material from the old crushed stone base ;
- a pavement in continuously reinforced concrete, 23 cm thick. The longitudinal reinforcing bars are 20 mm in diameter and spaced 18 cm apart. The pavement is restrained at the end by a conventional anchor abutment ;
- a 4 cm thick overlay in SMA (stone mastic asphalt) covering not only the slow lane but also the overtaking lane and the hard shoulder.

This results in a composite pavement structure.

A vertical drain in draining materials with a 20/40 mm grading was constructed on either side of the excavation, down to the level of the existing subbase.

Construction

The concrete mixture was prepared with 0/32 mm sandstone aggregates and a cement content of 400 kg/m^3.

The following operations were performed :

- tearing up the existing pavement structure over a width of 4.5 m ;
- laying the base in lean concrete and type III asphalt ;
- installing vertical drains on either side of the cut ;
- placing the reinforcement ;
- constructing the anchor abutments ;
- concreting with a slip-form paver. The surface of the concrete was finished by longitudinal brushing ;
- spraying a bitumen emulsion to protect the concrete from drying.

5. CONCLUSIONS

The various applications of inlays have shown the feasibility of the technique, even under highly constraining traffic conditions. There are various alternatives for the design of inlays : dowelled slab or continuously reinforced concrete, low-noise concrete pavement or composite pavement.

In the present economic context, the inlay technique has many advantages. It can be used for structural strengthening restricted to the most heavily loaded traffic lane. The duration of traffic interruptions can be minimized if work is organized well.

In addition, considerable improvements can be achieved with this technique in the safety of road users, in surface evenness and in rolling noise levels.

Judging from the first experiments as described in this paper, the technique seems to have a promising future.

Figure 1 : E 19 Mons - Jemappes

Design of the pavement based on the method of BRRC

Figure 2 : E 19 Jemappes - Mons Standard cross section

Figure 3 : E 40 Battice - Eupen Standard cross section

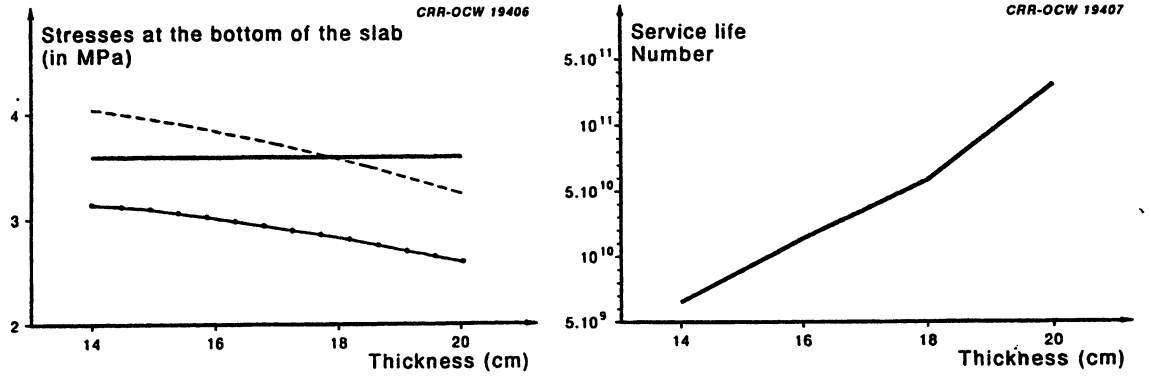
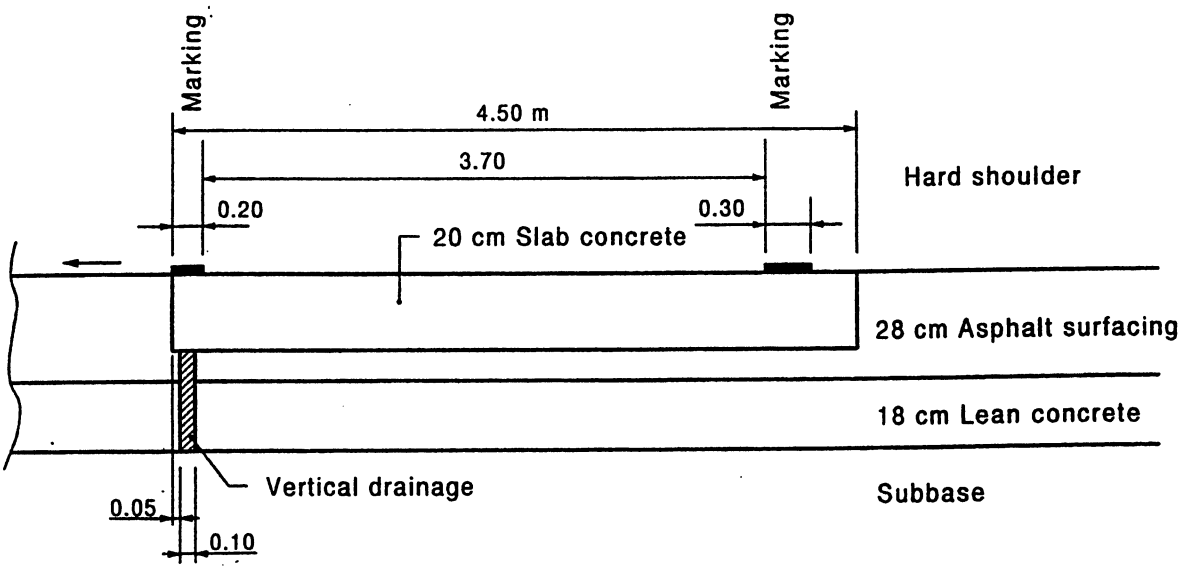


Fig. 1a

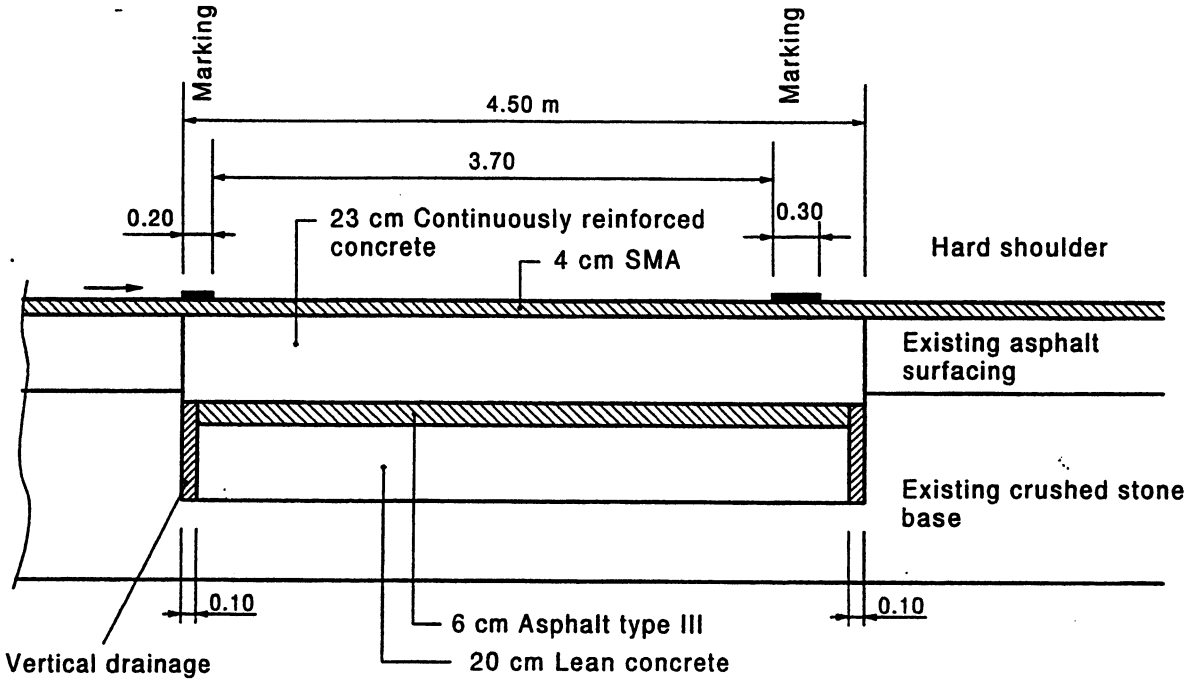
Fig. 1b

Fig. 1
E19 Mons - Jemappes
Design of the pavement based on the method of BRRC



CRR-OCW 19408

Fig. 2
E19 Jemappes - Mons Standard cross section



CRR-OCW 19409

Fig. 3
E40 Battice - Eupen Standard cross section

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