Twin-layer continuously reinforced concrete pavement on the N511 at Estaimpuis (Belgium): an investigation of the optimization of surface characteristics

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ABSTRACT

The general consensus is that durability, an absence of deformation, and low maintenance when the road structure has been correctly designed are among the most desirable features of concrete pavement.
By contrast, driving comfort and rolling noise are the characteristics most likely to give rise to discussion.
A great deal of significant progress has been made in these areas in recent decades and where in particular we may mention the improvements in surface treatments (such as the super smoother and aggregate exposure), the use of fine aggregates and fine porous concrete.
To obtain a better understanding of the problems posed, the options available for the construction of an experimental section of twin-layer continuously reinforced concrete pavement was defined.
The principal variable examined in this experimental section related to the size of the aggregate used in the upper layer.
Various tests carried out immediately after the completion of the site (roughness, evenness, acoustic measurements) were then supplemented by a new series of measurements (roughness, evenness, noise levels, surface texture).
The data taken as a whole made it possible to assess the appropriateness and effectiveness of the selected alternatives.

1. Introduction

The N511 between Dottignies (part of the Mouscron urban area) and Wattrelos (France) is a border-crossing road that links the Belgian and French motorway networks.
It serves developing economic areas and has to carry a significant volume of local and through traffic.
The construction of the roundabouts at the ends, which are paved with CRC, was completed in 2003.
The pavement of the road itself was only temporary and it became a matter of urgent necessity to install permanent pavement.

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The large volume of traffic that the N511 has to carry justifies the choice of continuous reinforced concrete for the permanent pavement.
The road runs through flat landscape in open countryside, which makes it ideal for testing the acoustic performance of a road pavement in good conditions.
The section of carriageway used for the experiment is relatively small as it is only 1250 metres long. At a time that the road world is so concerned with the measures to be adopted in the context of sustainable development policy, it was thought that it would be appropriate to test, under limited risk conditions, the twin layer pavement technique, using fresh concrete on fresh concrete.
This technique, although more expensive than traditional methods involving the laying of a single layer, ought to make it possible to produce a better surface finish than is the case for conventional techniques. The twin-layer concrete calls for the use of two slip-form pavers working in series instead of one. The second machine worked without interruption and laid a very thin layer of about 5 cm thick whose smoothness was particularly good. Indeed the machine progressed without difficulty, the 5 cm of concrete was vibrated using a vibrating beam and no particular effort was required to advance at a steady speed. Moreover the thin layer was made of fine grain aggregate of extremely good quality and durability.
The reinforcing used in the CRC was located in the lower layer laid by the first slip-form paver. It is located roughly in the centre, halfway between the top and bottom of the finished slab.
While complying with all strength and durability requirements, this technique makes it possible use lower quality aggregate or recycled products in the lower layer. In the latter case, the savings thus realized might make the technique competitive with the conventional method of laying concrete slab.

2. Project Information

The total length of the section is 1250 m. This was divided into 4 experimental zones.
The overall thickness of the CRC is 20 cm.
The pavement is 9.50 m wide, and was laid in two phases, 6.5 m on the right hand side and 4 m on the left hand side.
The essential characteristics of the 4 zones are summarized in table 1:

Table 1 – Characteristics of the 4 zones

Section no.	Length		Lower layer		Upper layer	
	RH side Width 6,5m	LH side Width 4m	Thickness	Aggregate (in mm)	Thickness	Aggregate (in mm)
1	348.85 m	380.85 m	15 cm	0/32	5 cm	0/7
2	321 m	322 m	14 cm	0/32	6 cm	0/10
3	303 m	270 m	12 cm	0/32	8 cm	0/14
4	291.65 m	291.65 m	12 cm	0/32	8 cm	0/20

In addition to complying with the requirements set out in standard specifications RW99, which are applicable in the Walloon Region, the following technical requirements were contractually imposed by the special specifications:

- The gutter was to be realized in concrete concurrently with the carriageway
- There is no anchoring abutment. This function is provided by the CRC rings of the roundabouts at both ends.
- The concrete had to be laid as 2 layers, fresh concrete on fresh concrete.
- Two slip-form pavers were to be used for construction purposes, where the distance during operation between the two machines was not to exceed 20 m. Only the second machine, which had to advance without interruption and continuously, was to be equipped with a super smoother.
- An air entraining agent was specified for the concrete of the second layer and the water to cement ratio was to be lower than 0.45.
- The surface treatment was to consist of exposed aggregate (chemical stripping). The quality and the quantity of the curing retardant to be matched to each of the selected aggregate size ranges of the surface concrete. A test section of at least 20 m^2 had to be built.
- The transverse profile of the carriageway was made of, from bottom to top :
  - a sub-base in stone of about 30 cm thick
  - a base in lean concrete 20 cm thick
  - two layers of bituminous concrete (an additional layer was added during the works after the planning of the upper part of the existing layer)
  - a covering of 20 cm of CRC, comprising two layers of concrete laid fresh on fresh with respective thicknesses of 15 cm and 5 cm.

3. Materials and the concrete mix

The specified cement was CEM III/A 42,5 N LA. CEM III/A is a blast furnace cement that may contain between 35 and 64% clinker and between 36 and 65% of blast furnace slag. The crushed materials of the lower and upper layers were porphyry. Porphyry is a volcanic intrusive rock that solidifies by the cooling of molten magma. It contains large crystals of quartz, feldspar, and chlorite, which are formed in the mass of the surrounding magma. In lithological terms, it should be referred to as “quartziferous diorite”. The concrete mixes were formulated in advance in the laboratory and were then passed onto the batching plant. They are summarized in table 2:

Table 2 – Concrete mix (all quantities in this table are in kg/m³, unless mentioned otherwise)

Concrete	Lower	Upper			
	0/32	0/20	0/14	0/10	0/7
Crushed porphyry 20/32 mm	450	-	-	-	-
Crushed porphyry 2/20 mm	720	-	-	-	-
Crushed porphyry 7/20 mm	-	750	-	-	-
Crushed porphyry 7/14 mm	-	-	730	-	-
Crushed porphyry 7/10 mm	-	-	-	730	-
Crushed porphyry 2/7 mm	-	375	355	345	1060
Coarse river sand 0/4 mm	385	485	485	485	485
Fine sand 0/1 mm	300	200	200	200	200
Cement	395	420	435	440	450
Plasticizer (en litres)	2,4	2,5	2,6	2,6	2,7
Air-entraining agent (as a % of the cement by weight)	0,15	0,15	0,2	0,2	0,2

The air-entraining agent and plasticizer were added in the batching plant. As can be seen the weight of cement per cubic metre of concrete is quite high. It is Belgian practice to make concretes with a high cement content in order to withstand the high traffic loads and the freeze/thaw cycles with the associated road salt. Current practice – as imposed by the specifications – calls for the use of a minimum of 375 kg of cement for each m³ of concrete made from 0/32 mm aggregate. With respect to this experimental section and taking account of the largest aggregate in the upper layer, which becomes smaller and smaller, the amount of cement per m³ in this layer increased as the aggregate became finer, so that it eventually reached 450 kg/m³ for the 0/7 mm concrete.
The water/cement factor generally used in Belgium is between 0.45 and 0.50. With a water content of this level, the incidence of slump at the edges of the pavement during installation using slip-form pavers is very low.
As for the aggregate grading of the various concretes, Belgian practice entails the use of continuously graded aggregate from 0 to 20 mm for a 0/20 mm concrete.

4. Execution

The site was specially timed to coincide with a visit to Belgium of a technical mission on the design and construction of roads, organized by the Quebec PIARC Committee and the Quebec Ministry of Transport.

The mission, which was in Belgium from 9 to 13 June 2002, was led by Ms. Anne-Marie Leclerc, Assistant Deputy Minister and Director-General of Infrastructure and Technology of the Ministry of Transport.
The technical coordinator of the Mission was Mr Nelson Rioux, Head of the Roadways appraisal section and Chairman of the PIARC C7/8 Roads Committee.
Prior to the installation of the CRC, the road, which had been in operation for several years with a provisional bituminous pavement was examined and repaired where necessary.
Repairs were made to the lean concrete base and the existing pavement was profiled by milling.
Moreover the entire section was given a new 6 cm thick layer of bituminous mix (intermediate layer).
The works were carried out in generally favourable weather conditions for the construction of a cement concrete pavement, although the temperatures could hardly be described as warm for that time of summer.
The following pictures show some of the stages of the works on the site. As already indicated, the concrete was laid in two layers, fresh on fresh, by two separate slip-form pavers.

The percentage of longitudinal reinforcement is 0.76 % of steel with respect to the concrete section. The reinforcement was placed more or less halfway between the top and bottom of the slab. The average distance between cracks seen on the site was about 1 to 2 m.



Fig. 1: Laying the first layer



Fig. 2: View of the laying of the second layer, the paver is followed by the machine that sprays the curing retardant.



Fig. 3: Laying the second layer (detail)

The super smoother is a smooth beam installed on the rear of the slip-form paver. It is designed to improve the smoothness of the pavement by moving from side to side while at the same time performing a back and forth motion (see fig. 4).



Fig. 4: View of a super smoother mounted on the back of a slip-form paver



Fig. 5: Finishing of the rolling course and the spraying of the curing retardant followed by the protection of the concrete with plastic foil (behind the spraying machine)



Fig. 6: View of the surface texture of the exposed aggregate (exposed aggregate 0/10 mm)
Remark: the appearance of the other surfaces is very similar.

5. Tests on the concrete

Numerous tests were carried out, both on the materials and on the fresh and the cured concrete.
The tests carried out on the various concretes, as well the references of the methods used are listed below:

5.1. Tests on fresh concrete

These tests were carried out with the help of a mobile laboratory set up on the site of the works. The letters NBN refer to the Belgian standards for the various tests carried. These may be consulted on request.

- Slump-Affaissement NBN B15-232 (1st Edition March 1982)
- Vébé NBN B15-234 (1st Edition March 1982)
- Masse Volumique Humide [Wet Volume Mass] (MVH) NBN B15-213 (2nd Edition March 1982)
- Teneur en air Méthode à pression variable [Air content – variable pressure method] NBN B15-224 (1st Edition October 1970)
- Water content by the rapid burning (< 45 min) on a gas burner (T > 350 °C) of a sample of ± 12 kg of concrete

5.2. Production of samples for cured concrete tests and for conservation

- Cubes with a side of 15 cm (steel forms)
- Slabs of 40 x 30 x 15 cm^3 (wooden forms)
- In situ production on a vibrating table
- Samples left in situ in the covered form for 24 hours and then taken to the lab after being turned out of the form with T = 20 °C and RH ≥ 95 %

5.3. Tests on cured concrete

- Résistance à la compression [Compressive strength] NBN B15-220 (2nd Edition January 1990) on cubes (15cm x 15cm x 15cm) and cylindrical cores (S = 100 cm^2) taken from the slabs. The end faces of the cylinders were rectified using a diamond saw.

6. Results of the tests on the concrete

The averaged results for the fresh and cured concretes are summarized in tables 3 and 4.

Table 3 – Tests on Fresh Concrete

	Slump (mm)	VeBe (s)	MVH (kg/m^3)	Air (%vol.)	Water (l/m^3)
Lower concrete 0/32	15	5,5	2358	3,5	183
Upper concrete 0/D	31	4	2346	3,4	202

For a road classed as belonging to the primary road system (heavy traffic in excess of 2000 vehicles a day in each direction), the specifications imposed by contract (90 day compressive strength in MPa) are:

- Characteristic compressive strength R'bk : 50 Mpa (ou kg/cm^2)
- Min. mean comp. strength R'bm,min : R'bk + 1.645 Sr (Sr = standard deviation)
- Minimum individual comp. strength R'bi,min : 0.85 of R'bm,min

Table 4 – Tests on cured concrete

	Specified (min.)	Results
R'bm	56.54 kg/cm^2	68.62 kg/cm^2
R'bi	48.06 kg/cm^2	62.4 kg/cm^2

7. Tests on the pavement

The various sections of the pavement were subjected to the usual tests for roughness (sideway force coefficient measured with the odoliograph) and evenness (CE – coefficient of evenness measured with the longitudinal profile analyser (LPA)).
The required performance for roughness and evenness is:

- Roughness: SFC > = 0.50
- Evenness: Two evenness measurements were made: one for a wavelength of 2.5 m where CE 2.5 < = 35 and the other for a wavelengths of 10 m where CE 10 m < = 70.

The first results (obtained in 2002 after the completion of the works) are summarized in tables 5, 6 and 7.

Table 5 – Roughness Measurements

	Section 1 0/7	Section 2 0/10	Section 3 0/14	Section 4 0/20
mean SFC	0.66	0.70	0.69	0.62

Table 6 : Evenness measurements – CE 2.5 m per 10 m

	Section 1 0/7	Section 2 0/10	Section 3 0/14	Section 4 0/20
mean CE (2.5m)	15.15	16.2	14.7	17.05

Table 7 : Evenness measurements – CE 10 m per 20 m

	Section 1 0/7	Section 2 0/10	Section 3 0/14	Section 4 0/20
CP moyen (10m)	33.3	31.4	28.95	41.05

New roughness tests were carried out in December 2004 using a bi-trace SCRIM apparatus operating at 50 km per hour.

The results are shown in table 8.

Table 8 – Roughness tests with the SCRIM apparatus

Table summarizing mean SFC values by 10 m blocks in each section						
Aggregate size (section)	CARRIAGEWAY (France to Belgium) SFC			CARRIAGEWAY (Belgium to France) SFC		
	Left wheel	Right wheel	Mean for 2 wheels	Left wheel	Right wheel	Mean for 2 wheels
0/7 mm	0.66	0.65	0.655	0.66	0.64	0.65
0/10 mm	0.64	0.64	0.64	0.61	0.65	0.63
0/14 mm	0.69	0.69	0.69	0.69	0.66	0.675
0/20 mm	0.68	0.67	0.675	0.61	0.62	0.615
SFC = sideway force coefficient						

Overall the picture is one of excellent quality and the results are close to those obtained with the odoliograph in 2002.
Section 0/14 shows slightly higher results, which should be correlated with the results for surface texture shown below.

As for the evenness tests, the second series of measurements was carried out in October 2003 and the results are shown in table 9.

Table 9 – Evenness tests

Table summarizing mean CE 2.5 values by 10 m blocks in each section						
Aggregate size (section)	CARRIAGEWAY (France to Belgium) CE (2.5 m)			CARRIAGEWAY (Belgium to France) CE (2.5 m)		
	Left trailer	Right trailer	mean CE	Left trailer	Right trailer	mean CE
0/7 mm	15.1	13.0	14.05	15.8	11.7	13.75
0/10 mm	14.8	14.4	14.6	20.6	14.4	17.5
0/14 mm	14.2	13.1	13.65	17.1	11.8	14.45
0/20 mm	18.0	16.9	17.45	14.5	11.3	12.9
CE = coefficient of evenness						

The results confirm the values obtained in 2002, with evenness varying little from one section to another.
The CE values recorded by the left trailer are generally speaking higher than those from the right trailer.
The essential finding though is that the longitudinal evenness is very good.

8. Acoustic Tests

As indicated in the introduction, the N5111 is a border-crossing road between France and Belgium.
An initial reference situation could be recorded in June 2003, when the works on the border between the two country were still in progress, and as a result the traffic on the road was strictly local.

The test consisted of the installation of standing microphones on each side of the road, perpendicular to each of the four sections at a distance of 7.50 m from the axis of the lane and at a height of 1.20 m (ISO standard 11-819-1).
During the tests about 10 light vehicles made use of the road.
The recorded data are reproduced in table 10.

Table 10 – Acoustic Tests – reference situation June 2003

	Carriageway France to Belgium				Carriageway Belgium to France			
Section 0/D (in mm)	0/7	0/10	0/14	0/20	0/7	0/10	0/14	0/20
Noise level (dBA)	79.5	80.9	80.0	80.6	78.7	80.3	79.6	80.1

Additional tests were carried out in July 2003 in accordance with ISO standard ISO 11 819 -1 and using the SPB (Statistical Pass-By Method). Here about 100 light vehicles passed over each section.

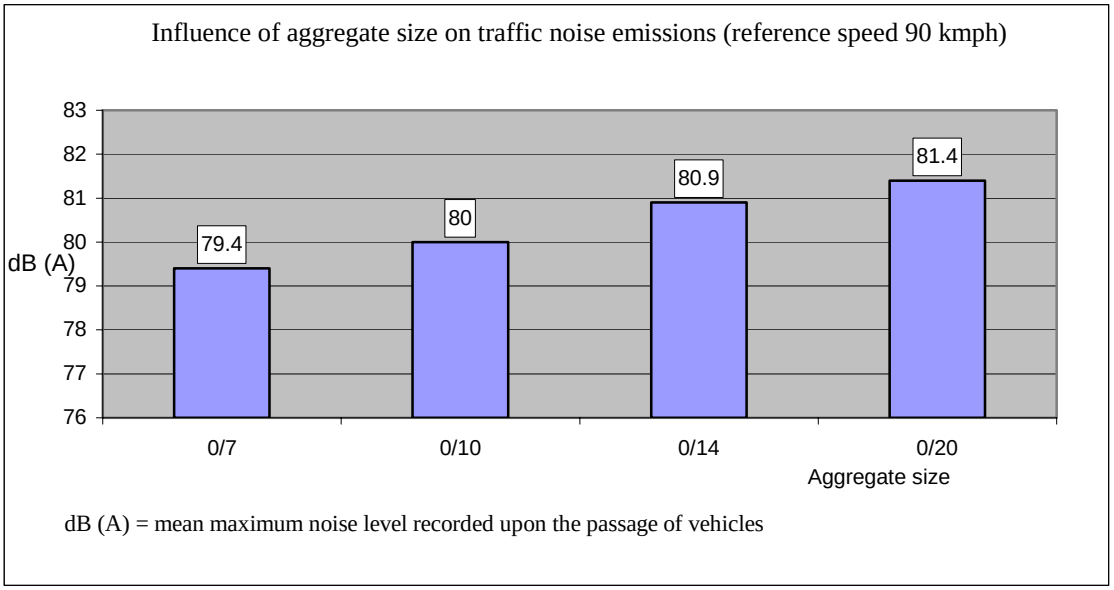
Table 11 gives a review of L_{veh} at 70 and 90 km/h calculated for each section. L_{veh} results from a regression analysis of maximum noise level against speed.

Table 11 – Acoustic Tests – July 2003

Reference speed (km/h)	$L_{véh}$ in dB(A)			
	Section 1 (4/7 mm)	Section 2 (7/10 mm)	Section 3 (10/14 mm)	Section 4 (14/20 mm)
70	75,9	76,6	77,2	77,8
90	79,4	80,0	80,9	81,4

The chart shown in table 12 shows only the noise levels at 90 kmph, the speed limit for the N511, in histogram form.

Table 12 – Noise levels at 90 km per hour



It will be noted that the noise level increases steadily in step with the increase in aggregate size.
It may be recalled that in France "low noise" pavements are those where $L_{veh\ (\ 90\ km/h\ )}$ is lower than or equal to 76 d(A).

9. Surface Texture

Measurements were carried out in November 2003 using a laser profilometer.

The results are summarized in table 13.

Table 13 – Surface Texture Measurements

Influence of grain size on surface texture					
Section	MPD (mm)			ETD (mm)	ERNL (dBA)
	C'way (F-B)	C'way (B-F)	C'way (F-B)	C'way (B-F)	
0/7 mm	0.69	0.71	0.75	0.77	72.0
0/10 mm	0.84	0.89	0.87	0.91	72.3
0/14 mm	0.86	0.92	0.89	0.94	72.4
0/20 mm	0.88	0.67	0.90	0.74	72.6
MTD = Mean texture Depth measured in the track of the right wheel ETD = Estimated Texture Depth ERNL = Estimated Road Noisiness Level					

Examination of these continuous measurements, taken from the track of the right wheel, reveals an increase in texture depth as aggregate size increases, with the exception of section 0/20 of the Belgium to France carriageway.
The relationship between rolling noise and texture (ERNL) evolves in similar fashion.
From the rather tight correlation at about 80 mm and 5 mm, these two texture profile spectrum components are used to define an "Estimated Road Noisiness Level" namely by means of the following formula:

$$ERNL = 60 + 0.39 * LT_{80} - 0.13 * LT_5$$

where ERNL is in dB(A) and LT_{80} , LT_5 are octave band levels in dB re. 10^{-12} m², where the constant has an arbitrary value chosen for the ERNL value that should fall in the range of CPB values. ERNL is based on rolling noise measurements of a car fitted with ordinary tires, passing at 80 km/h, engine off. (DESCORNET in unpublished working documents of ISO/TC43/SC1/WG27)

10. Conclusions

10.1. Materials

The results for the installed materials may be considered extremely satisfactory.
These results undoubtedly reflect a high degree of vigilance and a constant concern for quality during the preparation and supervision of the works.

10.2. Surface characteristics

The results of the roughness and evenness tests show that the pavement offers an unusually high degree of safety and driving comfort for a cement concrete pavement. This observation is most certainly directly linked to the choice for the application of the concrete in two separate layers.
Because it only works with a limited thickness of material the paver equipped with the super smoother used for the upper layer, can concentrate its energy on perfecting the finish and evenness of the surface.

10.3. Acoustic Performance

As for the acoustic tests the results clearly show that the sound level increases in step with the aggregate size.
When it comes to priorities, the basic choice for working in two layers in order to achieve a high quality surface is clearly of vital importance.
There is no doubt that the noise levels experienced both inside vehicles and those measured at the side of the road are directly affected by the quality of the evenness of the pavement.
Next comes the choice of aggregate size for the upper layer. The measurements clearly show the benefits of fine aggregates: with a gain of 2dB(A) between sections 0/7 and 14/20.

10.4. Surface Texture

Both texture and noise level increase with aggregate size.
Apart from this aspect, experience on numerous other sites has taught us that a satisfactory control of the texture is also linked to the quality of the surface treatment, particularly those aspects that directly influence the values of the finished result and their uniformity, such as the quantity of retardant per unit of area, spreading smoothness, effective protection during curing, suitable delay before stripping, and brushing intensity.

10.5. Final Remarks

The intended objective, when designing this experimental section of the N511, was first of all to try construct a pavement that had optimal surface qualities in terms of comfort and safety, and secondly to test various aggregate sizes in order to assess their influence on those characteristics usually measured on a road pavement (roughness, evenness, surface texture, noise levels).

It seems safe to say that this objective has been achieved and the available data has made it possible draw specific conclusions.

Once again, it is worth repeating that the success of a concrete pavement is governed first of all by appropriate basic choices (type of materials, concrete mix), followed by a choice for the most suitable technical options (for the N511, the application of the concrete in two layer, aggregate exposure as surface treatment) and finally a sustained concern for quality during the performance of the works.