GRINDING OF A TRANSVERSELY GROOVED CEMENT CONCRETE PAVEMENT OF THE EUROPEAN MOTORWAY E 40 AT BIERBEEK

ir. C. CAESTECKER ir. L. HELEVEN

Belgium, a small highly populated country in Western Europe, has a long experience in the field of concrete pavements.
Since 1970, the Ministry of Public Works has resolutely opted for the technique of continuously reinforced concrete for the construction of motorways with a concrete surface. So a section of the European Motorway E 40 - Londen (GB) - Brussels (B) - Aachen (D) - Ankara (TR) - was built in 1972.

The pavement consists of a continuously reinforced cement concrete pavement (using porphyry stone) with 2 x 3 lanes of 3,75 m width or 2 x 11.25 m. It is a much used motorway section with over 63000 vehicles a day (20 % of which are lorries).

The surface texture, which was imposed in 1972, consisted of transverse grooves which were applied with a comb in the newly casted concrete immediately after the construction of the concrete pavement with a slip-form-paver. The intermediate distance between the teeth of the comb was 25 mm and the required depth of the grooves had to be at least 6 mm at the moment of opening to the traffic and at least 4 mm after 3 years.

On top of its easy application and its low costs, the main advantage of this technique is that it accelerates the surface drainage of the pavement and hence improves its skid resistance properties.

The Belgian Ministry of Public Works achieved not only a lasting (continuously reinforced concrete), but sufficiently skid resistant and thus a safe pavement at all weather conditions and speeds. In that period there was no legal speed limit in Belgium. Nowadays the limit is 120 km/h (75 miles/h).

The increasing concern about environmental pollution (noise pollution), both to the neighbouring inhabitants and the road users, involved that the deep transverse grooving was already substituted 10 years ago by the technique of chemical exposed aggregate of the concrete and recently by the additional adaptation of the grading and the compulsory supersmoother (longitudinal levelling beam). This allows to achieve road surfaces which, on one hand are sufficiently skid resistant (thus sufficiently safe), and on the other hand, sufficiently "quiet" (comparable to bituminous pavements).

The technique of chemically exposed aggregate and the adaptation of the grading provide a fine, skid resistant and noiseless surface texture, whereas the supersmoother contributes to avoid unevennesses with a wavelength of 50 to 500 mm, and most of all, the smallest ones, that is 50 to 150 mm, which are especially responsible for the rolling noise.

In the Technical Committee Report on Surface Characteristics to the PIARC World Road Congress in Brussels in 1987, the role of this type of irregularities was demonstrated and they were given the name of "megatexture". They range between macrotexture and roughness, which means that, by convention, they cover the range of wavelengths from 50 to 500 mm although the shortest among them, i.e. those from 50 tot 150 mm, cause the most trouble.

As far as newly constructed roads are concerned, rolling noise problems belong to the past. In case of existing concrete roads there are several possibilities to reduce the noise.
One solution is a porous asphalt overlay upon the concrete. This solution has a relative short life-time compared with the concrete road. So it is no real solution.

A better solution was being sought and found in the grinding technique. This grinding technique has been used for many years in the USA, mainly in order to restore the evenness of the concrete surface.

Before applying the technique two experiments were made:

1. On the A 12 - Brussels - Antwerp , a short section proved that the technique was also suitable for the Belgian concrete.
2. A second experiment was undertaken on a section of the A 2 Motorway between Louvain and Diest. This section was long enough to make the measurements of rolling noise as well as skid resistance and evenness.

The technique proved to be successful at all levels.
After those two test sections this technique was used to solve a noise problem at Bierbeek on the E 40, 29 km east of Brussels.

Grinding principle

The existing transverse grooves were completely grinded down on 5 of the 6 lanes and on 1/4 of the slow lane in the direction of Brussels with a high power TARGET PRM 3804, which is a very powerful grinding machine, originating from the USA, equipped with a series of diamond wheels closely placed one to another. Annexe 1 gives the most important characteristics of the TARGET PRM 3804. The aim is to achieve a reduction of the rolling noise as well as to maintain a sufficient skid resistance.

Grinding process

The grinding started on March 16, 1992 and was finished in 13 working days. In this way an average performance of 692 m^2/day was reached on a total surface of 2 x 11.25 x 400 m = 9.000 m^2. The effective cutting width of the machine amounts to 96 cm, which involves 4 passages per lane width of 3,75 m, taking into account small overlaps.

The machine can work on one lane. However, 2 lanes out of 3 were closed to the traffic for safety measures.

In order to avoid peak traffic, the works were carried out between 10 a.m. and 6 p.m. in the direction of Brussels, and between 7.30 a.m. and 4 p.m. in the direction of Liège. Traffic was allowed on all lanes out of these working periods.

The average progresses fluctuated between 1.3 to 2.5 m per minute; in bumpy zones performances fell back to less than 1 m per minute.

An average of 4 to 5 mm was grinded down on 5 out of 6 lanes, 2 to 3 mm being grinded down on the 6th lane (the slow lane in the direction of Brussels).

Achieved grinding result

groove depth : 2 to 4 mm
groove width : 3.2 mm (being the diamond wheel width)
intermediate distance of the grooves :
- the thickness of the steel blades on which the diamond is applied is 2.2 mm
- the thickness of the chosen spacers is 3 mm; this thickness was chosen out of 3 possible spacer thicknesses : 2.5 - 3 - 3.3 mm
  3.3 mm even results in a too coarse structure (danger for motorcycles !)
  2.5 mm results in a too fine structure (skid resistance !)

resulting in : intermediate distance of the grooves : 2.2 mm + 3 mm = 5.2 mm
numbre of diamond wheels is 184 (960mm : 5.2 mm)

To evaluate this project measurements were carried out before and after the grinding. These measurements are :
- noise measurements
- skid resistance
- evenness

A. NOISE MEASUREMENTS

A.1. Noise measurements BEFORE GRINDING

Two kinds of measurements were carried out to determine the noise characteristics of the transversely grooved cement concrete pavement before the grinding :

1° measurement of the total noise caused by the real traffic
The measurement microphone is set up at 7.5 m out of the axis of the slow lane; the height of the microphone position is 1.20 m.
The measurements were carried out on 2 spots, each time in both directions :

- direction Liège	:	at km 29.15
		at km 29.28
- direction Brussels	:	at km 29.26
		at km 29.16

The following noise characteristics were deduced from the measurement data :

L_{eq} : equivalent continuous sound
L_{10} : statistical level, used in several countries as an official recommended index
L_{NP} : Noise Pollution Level (used in G.B.)
$L_{NP} = L_{eq} + 2.56\ s$
where s is the standard deviation of the immediate levels around L_{50}

Are also being measured during the noise measurements per direction : the total number of vehicles, the % of lorries passing by and the wind velocity and direction.

2° measurement of rolling noise, by which all traffic is prohibited and only a test vehicle runs on the pavement.
The peak value is recorded when the test vehicle passes by with disengaged transmission.

The measurements were carried out when the test vehicle passed by on the
slow lane at a speed of 100 km/h
slow lane at a speed of 120 km/h
centre lane at a speed of 100 km/h
centre lane at a speed of 120 km/h

No measurements were carried out on the fast lane passages (aside the directional separator) due to the fact that there is a New-Jersey safety barrier which might reflect sound waves.

The test vehicle is a Fiat Regata, equipped with Uniroyal 165/65/R14 tyres in front and with GoodYear 165/65/R14 tyres at the rear.
The notches of the front tyres are 3 mm, the tyre pressure is 2.2 kg/cm^2.
The notches of the rear tyres are 3 mm, the tyre pressure is 2.5 kg/cm^2.
Wind velocity was zero during the measurements.

A.2. Noise measurements AFTER GRINDING

The same measurements were carried out as before the grinding.

1° Measurement of the total noise caused by the real traffic.
These measurements were carried out on May 14 and 15, 1992.

2° Measurement of rolling noise.
The wind velocity was zero during the measurements.

The results of the noise measurements are given in table 1 : Total Noise and table 2 : Rolling Noise.

The results show a significant reduction of both the **total noise** and the **rolling noise** ranging respectively from 5.4 to 7.0 dB(A) and from 2.6 to 6.1 dB(A).
The results are therefore very satisfactory.

B. SKID RESISTANCE

The skid resistance is measured with the new "ODOLIOGRAPHE". The skid resistance is the sideway force coefficient (SFC) measured at 50 km/h and brought to 20 °C.

The apparatus consists of a freely rotating fifth wheel with the smooth PIARC tyre and inclined at 20° to the direction of travel.

The ratio of the force, developed at the right angle to the plane of the test wheel, to the load of the wheel is the SFC.
The results are given in table 3 : Skid Resistance. The results show a very high skid resistance which is independent from the skid resistance before grinding, except for the 6th lane, where the grinding depth was less important than on the other lanes. Notice also the different skid resistance levels before grinding due to the different polishing actions by the traffic.

C. EVENNESS

The evenness is measured with the LPA (Longitudinal Profile Analyser built by the French Central Laboratory for Roads and Bridges). The measurement has been carried out with one measuring trailer (right hand side) at a constant speed of 72 km/h. The sampling rate was set at 25.06 cm.

The evenness coefficient is calculated for 3 basic wavelengths. These wavelengths are 2.5 m, 10 m and 40 m ($EC_{2.5}$ - EC_{10} - EC_{40}). The EC_i is the surface between the real profile and the mean profile for that wavelength. The calculation technique of the moving average is used. The units for EC_i are 10.000 mm^2/km.

The results are given in table 4 : Evenness. The classification of the EC-values are given in table 5 : Evenness Evaluation.

The results of the evenness measurements show a very good $EC_{2.5}$ after grinding. The other EC values EC_{10} and EC_{40} have a less important improvement. This is due to the grinding technique. The levelling is done by a sliding bar.

CONCLUSIONS

As a conclusion, it can be said that, based on the experiments carried out in Belgium as well as in some other European countries, grinding has proven to be an efficient technique for restoring the surface properties of old concrete roads and should therefore be considered in some cases as an economical and durable alternative to asphalt overlays in renovating concrete roads.

ANNEXE 1 : TARGET-PRM 3804 characteristics (Pavement Restoration Machine)

- Drive control : six wheel drive powered by a variable speed hydrostatic drive system which increases traction and mobility
- Power source : 402 hp Caterpillar diesel engine for the cutter head and machine hydraulics, with a smaller Perkins diesel to operate the vacuum system (slurry pick up)
- Cutting head : width : 96 cm
blade diameter : 35 cm
blade capacity : 184 blades

The 96 cm cutting head shaft was equipped for this operation with a gang of 35 cm diameter diamond impregnated saw blades, each 3.2 mm thick separated by 3 mm spacers to give the requisite "corduroy" texture which ensures good skid resistance.

- Weight : 20 t (42000 lbs) (includes grinding head)
- Dimensions : height : 2.9 m
length : 8 m
width : 1.8 m

Table 1 TOTAL NOISE caused by the real traffic

	BEFORE GRINDING Sept. 26, 1991					AFTER GRINDING May 14, 1992					YIELD
Location	time	L95	L10	Leq	LNP	time	L95	L10	Leq	LNP	Leq
Measurements direction Liège											
km 29.15	10:20	69	87	82.3	97	10:42	66	82	77.7	93	
km 29.15	10:40	71	87	83.0	98	10:54	64	81	76.8	92	
Mean value				82.6					77.2		5.4
km 29.28	9:45	72	90	85.8	102	11:09	69	83	79.0	92	
km 29.28	9:59	73	90	85.7	101	11:21	69	83	78.6	91	
Mean value				85.8					78.8		7.0
Measurements direction Brussels											
km 29.26	11:25	70	89	84.6	102	11:42	64	83	78.3	95	
km 29.26	11:37	72	89	84.6	100	11:55	64	83	78.3	95	
Mean value				84.6					78.3		6.3
km 29.16	11:53	68	89	84.2	102	12:09	66	83	78.8	94	
km 29.16	12:05	71	89	84.4	100	12:21	67	83	78.4	93	
Mean value				84.3					78.6		5.7
Traffic	1992 to 3024 veh/h % lorries : 19 to 22					1914 to 2496 veh/h % lorries : 15 to 23					

Table 2 ROLLING NOISE - Peak values in dB(A) produced by a test vehicle (average of 4 measurements).

LOCATION		BEFORE GRINDING	AFTER GRINDING	YIELD
Measurements direction Liège : location km 29.15				
slow lane	100 km/h	85.1	80.3	5.1
	120 km/h	87.9	83.4	4.5
centre lane	100 km/h	87.7	83.7	4.0
	120 km/h	90.3	86.2	4.1
Measurements direction Liège : location km 29.28				
slow lane	100 km/h	88.3	84.1	4.2
	120 km/h	90.3	86.8	3.5
centre lane	100 km/h	88.2	84.6	3.6
	120 km/h	90.2	87.0	3.2
Measurements direction Brussels : location km 29.26				
slow lane	100 km/h	87.8	82.0	5.8
	120 km/h	90.1	84.1	6.1
centre lane	100 km/h	87.8	85.2	2.6
	120 km/h	91.3	87.5	3.8
Measurements direction Brussels : location km 29.16				
slow lane	100 km/h	86.6	80.5	6.1
	120 km/h	88.8	83.5	5.3
centre lane	100 km/h	88.1	85.0	3.1
	120 km/h	90.4	87.2	3.2

Table 3 SKID RESISTANCE

	BEFORE GRINDING Sept. 19, 1991	AFTER GRINDING May 7,1992
Measuring direction Liège from 29.0 to 29.4		
Slow lane	0.55-0.54-0.54-0.54 0.53-0.52-0.57-0.57	1.04-1.00-1.04-1.03 0.97-0.94-0.96-0.90
mean value	0.54	0.98
Centre lane	0.59-0.61-0.59-0.59 0.55-0.56-0.58-0.59	1.07-1.05-1.04-1.06 1.05-1.04-1.02-1.01
maen value	0.58	1.04
Fast lane	0.66-0.69-0.69-0.72 0.73-0.76-0.71-0.67	1.05-1.02-1.04-1.01 0.99-1.01-0.98-0.92
mean value	0.70	1.00
Measuring direction Brussels from 29.4 to 29.0		
Slow lane	0.54-0.55-0.56-0.54 0.56-0.55-0.56-0.53	0.91-0.85-0.84-0.83 0.82-0.76-0.83-0.89
mean value	0.54	0.84
Centre lane	0.63-0.62-0.64-0.69 0.67-0.65-0.63-0.64	1.02-1.03-1.03-1.04 1.02-1.01-1.01-0.95
mean value	0.64	1.01
Fast lane	0.70-0.70-0.71-0.74 0.72-0.73-0.71-0.74	1.08-1.04-1.06-1.04 1.03-1.03-1.03-1.01
mean value	0.72	1.04

Table 4 EVENNESS

		BEFORE GRINDING			AFTER GRINDING		
Measuring direction Liège							
	lane	Wavelength of smoothing basis in meters					
		2.5	10.0	40.0	2.5	10.0	40.0
km 29.0 - 29.1	Slow	27	40	45	24	28	39
	Centre	32	52	64	21	31	46
	Fast	45	69	86	23	36	63
km 29.1 - 29.2	Slow	30	45	90	21	27	77
	Centre	30	45	81	21	28	71
	Fast	39	67	105	23	36	73
km 29.2 - 29.3	Slow	38	85	169	23	55	163
	Centre	37	77	176	21	44	157
	Fast	48	85	196	24	54	177
km 29.3 - 29.4	Slow	28	37	73	20	26	62
	Centre	32	49	77	21	26	67
	Fast	31	47	84	21	28	70
Measuring direction Brussels							
	lane	Wavelength of smoothing basis in meters					
		2.5	10.0	40.0	2.5	10.0	40.0
km 29.4 - 29.3	Slow	26	39	69	20	32	65
	Centre	28	42	62	20	27	51
	Fast	30	41	62	20	22	45
km 29.3 - 29.2	Slow	31	56	83	22	43	84
	Centre	31	53	86	20	32	69
	Fast	34	69	96	20	36	72
km 29.2 - 29.1	Slow	26	51	111	29	45	109
	Centre	31	55	108	20	30	96
	Fast	37	53	113	22	35	104
km 29.1 - 29.0	Slow	28	55	70	22	43	61
	Centre	30	52	70	19	28	54
	Fast	33	48	65	20	26	45

Table 5 EVALUATION

	$EC_{2.5}$	EC_{10}	EC_{40}
very good	≤ 40	≤ 80	≤ 160
good	40 < ≤ 80	80 < ≤ 160	160 < ≤ 310
poor	80 <	160 <	310 <