THIN OVERLAYS OF STEEL FIBER REINFORCED CONCRETE AND CONTINUOUSLY REINFORCED CONCRETE STATE OF THE ART IN BELGIUM

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1. Introduction

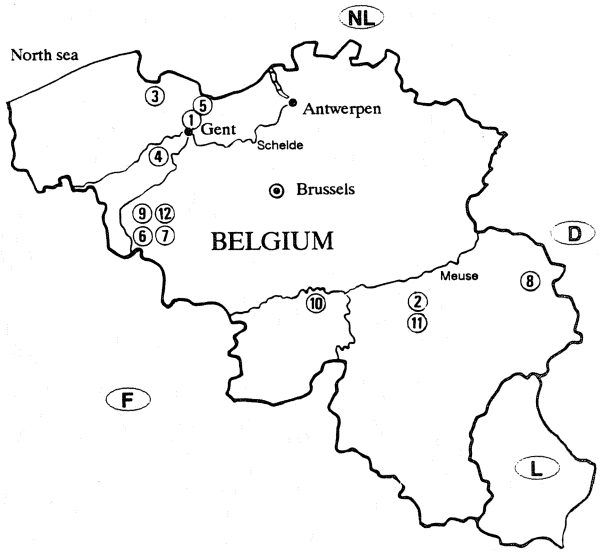
Resurfacing of existing roads with cement concrete is common use in Belgium since more than 10 years. About 500 km of roads (on an equivalent width of 7 m) have been overlayed during this period with "classical" continuously reinforced concrete pavement (CRCP - 20 cm thick - 0,67 % longitudinal steel). These overlays were constructed on old concrete roads (with partial bond) as well as on bituminous pavements presenting rutting problems.

With a renewed interest for the material steel fibrous reinforced concrete (SFRC) in the beginning of this decenium - interest which was essentially created by better incorporation possibilities and subsequent lower fiber contents - new uses in thin resurfacings (<15 cm) were considered.

Together with SFRC, alternatives were examined such as thin continuously reinforced concrete (TCRCP) with a thickness between 12 and 16 cm. Here the advantage of no joints has to be considered against the more difficult circumstances of construction due to the necessity of placing the reinforcement on roads where resurfacing has to be done under traffic.

Although they do not constitute an alternative for "thick" overlays, thin concrete resurfacings can be considered in cases where level constraints play an important role (bridges, adjoining constructions ...) and where the structural qualities of the existing pavement are yet not too badly distressed. In this way, the topic fits in the inevitable future rehabilitation (the story of the 4 R) of part of the Belgian road network. Especially in the Flanders, much ribbon development exists along a lot of roads. As a result of this, few - if any - overthickness can be tolerated. On the other hand bituminous pavements suffer from periodical traffic vicissitudes (rutting) on busy arterial roads because of the authorized 13 ton axle load.

Figure 1. Map of Belgium - Situation of test sections.



Since 1982 experimental sections of thin overlays have been constructed in Belgium for an amount of 171.000 m^2, or nearly 25 km equivalent 7 m width road.

Eight of these sections (127.000 m^2) are made of 10 to 12 cm thick steel fiber reinforced concrete (SFRC), six of them on a bituminous underlayer (insulation layer or scarified bituminous pavement) and two directly on the old concrete pavement.

Four other experimental sections (44.000m^2) should verify the possibilities presented by thin (12 and 14 cm) continuously reinforced concrete (TCRC).

Earlier the technology of SFRC - hooked steel fibers of Dramix type (N.V. Bekaert - Belgium) had been tested during several

years on experimental slabs of classic thickness.

In spite of the fact that most of the presented test sections are still relatively young, this report attempts to formulate some interim conclusions. They should lead to a clear-cut of thin resurfacing and to practical guidelines for their realization.

Furthermore, it is intended to set up some links between the existing empirical experience and thickness design computations with a four-layer computer program with and without bond at the interface.

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2. Thin resurfacings with steel fibrous reinforced concrete (SFRC)

2.1 Test sections

Tables 1 and 2 show the mean characteristics of the existing pavement, the surface preparation and the overlay itself for 8 test sections built between 1982 and 1987.

A distinction is made between the nature of the existing pavement (concrete or asphalt) and between the type of preparation work (bond, separation course, inlay ...) which is dependant on the condition of the old structure.

In the first experiments at Maldegem, different variables concerning the joint partern were built in (figure 2). At Gent (figure 3) and Vierset the variables were more related to the preparation of the old concrete surface.

As a result of rather varying experiences with direct resurfacing on concrete - and regarding the exceptional behaviour of Maldegem - a bituminous interlayer (separation layer or inlay) has been systematically foreseen in the subsequent test sections. Indeed, many old concrete roads (age 40 to 50 years) are often rather badly distressed and thus compel for preparatory repair work before a bonded overlay can be applied. On the other hand, inlays could possibly generate an ample and interesting market in the future.

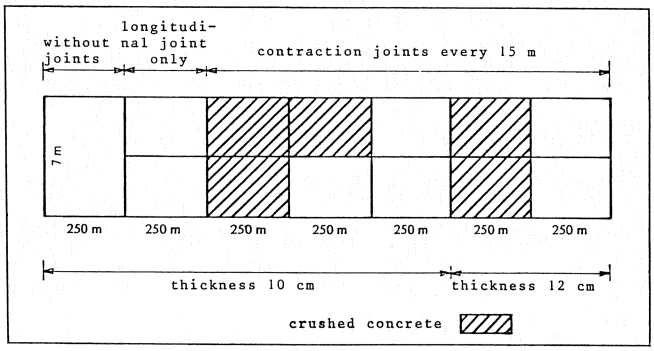
Table 1. Characteristics of experimental thin overlays in steel fiber reinforced concrete on old concrete pavements.

Experimental site	with direct bond		with asphalt separation course		
	(1) GENT	(2) VIERSET	(3) MALDEGEM	(4) ASTENE	(5) ZELZATE
date of construction	june 1983	july 1983	oct. 1982	sept. 1987	sept. 1987
area (m^2)	27.500	30.000	13.300	11.300	8.000
old pavement condition	heavily scaled but good structural condition	scaled but fairly good structural condition	badly deteriorated pumping and stepping	very bad many cracks, pumping and fragmentation	scaled but good structural condition transverse cracks
old joints	contraction dowels	expansion	expansion	expansion	contraction dowels
base course	crushed stone	none	none	crushed stone	crushed stone
traffic	very heavy (industrial)	light	rather heavy	heavy (>10.000 veh./d)	heavy
preliminary work	- simple cleaning - cleaning+grout - milling - milling+grout	- milling - milling+grout	- local slab-breaking - 6 cm open graded bituminous separation course	- general slab-breaking - 6 cm asphalt separation course	- 5 cm asphalt separation course - steel map above existing cracks
overlay thickness	10 cm	10 cm	10 cm and 12 cm	12 cm	10 cm and 8 cm
"Dramix" kg/m^3	40	40	50	30	30
steel fibers type	50/50	50/50	50/50	50/50	50/50
slab length	10 m = old joint pattern	10 m = old joint pattern	15 m (500 m without joints)	5 m	9-10-11 m = old joint pattern

Table 2. Characteristics of experimental thin overlays in steel fiber reinforced concrete on deteriorated asphalt pavements.

Experimental site	"inlay"		strengthening course
	(6) GAURAIN	(7) VAULX	(8) JALHAY
date of construction	may 1984	sept. 1987	may 1985
area (m^2)	6.500	3.500	27.500
old pavement condition	heavily rutted	heavily rutted	badly deteriorated
foundation	lean concrete	lean concrete	crushed stone
traffic	very heavy	very heavy	light
preliminary work	cold scarification	cold scarification	structural strenghtening with 6 cm asphalt on lean concrete of variable thickness
overlay thickness	10 cm and 12 cm	12 cm	10 cm
"Dramix" kg/m^3	30	30	35 and 40
steel fibers type	50/50 and 60/80	60/80	60/80
slab length	10 m and 15 m	10 m	15 m

Figure 2. SFRC - Maldegem - Test sections.



2.2 Characteristics of steel fiber reinforced concrete

Fiber content reduced with time while fiber type choice remained rather uncertain. At Maldegem, 50 kg/m^3 short and thin fibers 50/50 (50 mm long and 0,5 mm thick) were used, while at Vaulx only 30 kg/m^3 longer and thicker fibers 60/80 (60 mm long and 0,8 mm thick) were mixed in. Finally, a come back to 30 kg/m^3 fibers 50/50 can be noted. All this has obviously to do with technological problems that initially have risen with "balling" of fibers as a result of improper mixing manipulations.

Table 3 gives an idea of the inert skeleton

Figure 3. Gent - Preparation old concrete surface.

A	B	C	D
580 m	1500 m	580 m	580 m
cleaning	cleaning + grout	milling	milling + grout

Table 3. SFRC - Mix design.

Fiber type	Test section / kg/m^3		Fibers	2/20	0/2	Cement	W/C
Dramix 50/50	(3)	Maldegem	50	1200	590	400	0,55
	(1)	Gent	40	1100	720	400	0,53
	(4)	Astene	30	1100	730	400	0,47
Dramix 60/80	(8)	Jalhay	40	1130	650	375	0,53
	(6)	Gaurain	30	1080	670	375	0,50
TCRCR (as a comparison)	(10)	Fosses	-	1200	600	400	0,47

Table 4.

Characteristics SFRC.

Section	Year of construction	Fibers (kg/m3) 50/50	Fibers (kg/m3) 60/80	Water (ℓ/m³) min. - max.	Strenght at 90 d (N/mm²) Compression □ 10 cm $\bar{x}$ (1)	Flexural 10x10x40 cm 1st crack $\bar{x}$ (1)	1st crack s (2)	max.after 1st crack $\bar{x}$ (1)	max.after 1st crack s (2)
Maldegem (3)	1982	50	-	208 - 226	72,7	8,3	0,7	7,7	1,0
Gent (1)	1983	40	-	196 - 226	56,6	6,6	0,5	5,5	0,6
Vierset (2)	1983	40	-	232 - 258	60,1	6,0	0,6	4,2	1,5
Gaurain (6)	1984	30	-	192 - 202	60,0	7,2	0,6	4,6	0,5
Gaurain (6)	1984	-	30	184 - 193	64,4	7,2	0,7	3,3	1,4
Jalhay (8)	1985	-	35-40	190 - 204	68,2	7,7	0,5	3,7	0,9
Vaulx (7)	1987	-	30	180	73,1	9,0	0,6	4,0	1,2
Zelzate (5)	1987	30	-	184 - 202	68,7	8,3	0,6	3,3	0,8
Astene (4)	1987	30	-	178 - 199	73,5	9,0	0,5	3,6	1,0

(1) $\bar{x}$: mean strenght (2) s : standard deviation

(set up with 2 fractions porphyritic rock 7/20 and 2/7 and sand 0/5). Mix design of TCRC (chapter 3) is also reported.

Table 4 shows the most important characteristics of the concrete itself, measured on in situ cast prismatic specimens. Strenght at 90 d is plotted against fiber type and fiber content as well as against the extremes in water content.

It is clear that a normal water content is achievable, even with thin fibers 50/50. This evolution, which has been obtained to a considerable extent thanks to more severe prescriptions concerning the sand, manifests itself in the compression strenght and the bending strenght at first crack.

A parallel series of laboratory tests - table 5 - showed once more that the measured strenghts are hardly influenced by the fibers (at the incorporated contents).

In contrast to the results of the "after crack" strenght at the different test sections, laboratory research done in referential conditions shows a difference in favour of fibers 50/50.

A global judgement about the values plead for fibers of type 50/50, certainly now that it is established that problems with the mix can be avoided with a minimum of craftmanship. Furthermore one should keep in mind that fatigue is the main criterion that eventually justifies the use of intrinsic more expensive steel fibers in particular applications of thin resurfacings.

Rilem-tests on durability against deicing salts, which were not always satisfactory for SFRC of the first generation, were clearly better in the here mentionned laboratory research, as shown in the last line of table 5. Low water content, coupled to a "honest" sand fraction and drastic cure of the fresh concrete, guarantees a winter resistant pavement.

Table 5. SFRC : laboratory tests.

Mean strenght after 90 d (N/mm²) \ Composition			Without fibers	Fibers 50/50 (40 kg/m3)	Fibers 60/80 (40 kg/m3)
Compression □ 10 cm			86,7	85,8	90,7
Flexural	1st crack		7,9	8,1	8,0
			6,5	6,8	7,1
	maximum after 1st crack		-	6,2	4,4
			-	5,3	4,1
Water content (ℓ/m³)			185	190	184
Loss in weight (g/dm²) under influence of deicing salts after 30 cycles (RILEM)			14,2	10,2	4,5

2.3 Behaviour (1988)

Maldegem (3) - Figure 4.

In the 500 m section without joints, cracks developed in an early stage at distances between 10 and 60 m, they present slowly evoluating distress.

The section with contraction joints every 15 m is not damaged at all. However approximately half of the neoprene profiles utilized to fill the joints are loosening under the influence of the great opening movement. 10 % of them, i.e. those joints that absorbed most of the initial shrinkage need hot pourred sealant.

Gent (1) - Figure 5.

The left lane presents relatively few damage, the intens heavy traffic (often overloaded), utilizing essentially the right lane. On the right lane, cracks develop always at the joint, indicating debonding at the interface. Obviously grouting had no positive effect, especially at the high temperatures during construction.

Considering the present condition of the resurfacing, about 7000 m^2 of the right lane will need to be replaced in a next future.

Vierset (2)

The great number of micro-cracks occuring along the slab edges and caused by exaggerated shrinkage in an early stage do not evolve very much under the influence of rather limited traffic. A dozen joints will have to be rapaired soon.

Gaurain (6)

In spite of relatively heavy traffic conditions, only one angle-crack (localized at an exit) has been reported. Bond with the bituminous underlayer is good, although the measured shear strenght is only ca 75 % of that at the Maldegem site (see § 4). Here too, the joint sealant tends to disrupt.

Jalhay (8)

Until now the behaviour is excellent; no cracking has been observed. However traffic conditions are very low.

Astene (4) - Zelzate (5) - Vaulx (7)

These sections were constructed on the occasion of PIARC World Road Congress in Brussels (1987). They still are too young for evaluation. Figures 6, 7, 8, 9.

Figure 4. Maldegem - Old concrete road (1935).



Figure 5. Gent - Scaled old concrete pavement.



Figure 6. Zelzate - Completed overlay (1987).



Figure 8. Astene - International visit during the 18th World Road Congress (Brussels 1987).

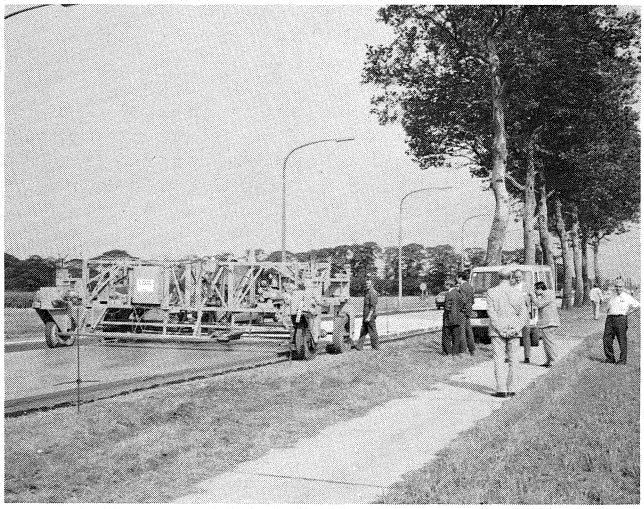
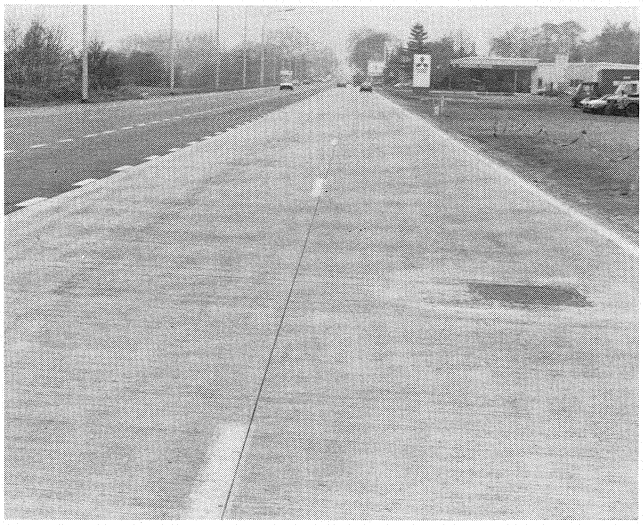


Figure 7. Zelzate - Welded wire fabric on top of bituminous interlayer at cracks in underlaying concrete pavement.



Figure 9. Vaulx - Inlay of SFRC.



3. Thin Continuously Reinforced Concrete Resurfacings (TCRC)

3.1 Test sections

Table 6 shows a survey of the most important parameters involved in the 4 test sections and in the reinforcement. At Gaurain and Fosses the reinforcing net was assembled and tied on the site (figure 10). In Gaurain the net was initially supported by individual plastic adapters (figure 11). These supports become unstable under the passage of the slipform paver, and most of them collapsed. Afterwards they were replaced by oblique continuous transverse supports which were also utilized in Fosses (figure 12). The impact on the crack pattern is clearly illustrated in figure 17.

At Modave and Vaulx (figure 13) an other type of continuous transverse support was tested. Here the net is welded; this may

Figure 10. Gaurain (h = 14 cm) - Inlay - On site tied bars on oblique transverse craddles.

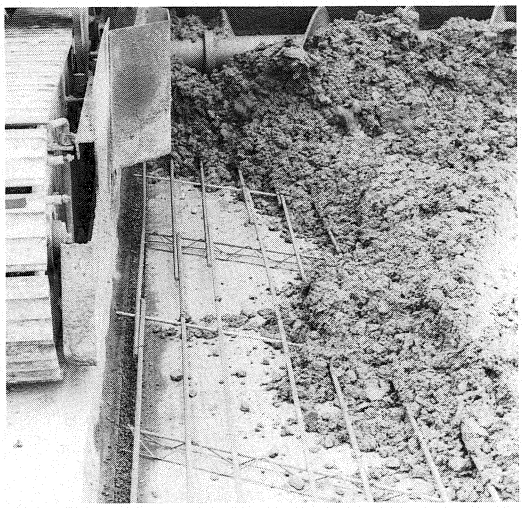


Figure 11. Gaurain - (h = 12 cm) - Individual supports.

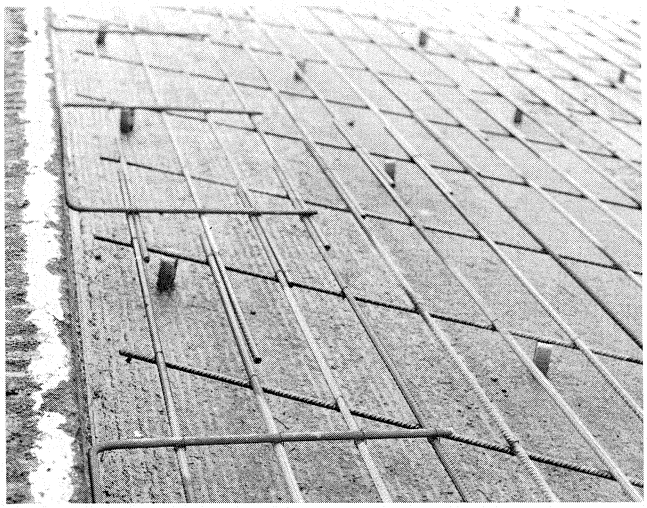


Table 6. Characteristics of thin overlays of continuously reinforced concrete (TCRCP)

Experimental site	(9) GAURAIN	(10) FOSSES	(11) MODAVE	(12) VAULX
	on site tied bars		welded deformed wire fabric	
date of construction	May 1984	May 1985	Dec. 1985	Oct. 1987
area (m^2)	13.000	20.000	3.400	8.000
old pavement	asfalt heavily rutted	asfalt rutted	deteriorated concrete	asfalt rutted
preliminary work	cold scarification over overlay thickness	roughning by cold scarification	+ 3 cm asphalt	scarification over overlay thickness
traffic	very heavy	heavy	rather light	very heavy
overlay thickness (cm)	12 / 14 / 16		14	12 / 14
REINFORCEMENT % longitudinal reinforcement (BE 500) (1)	0,62 0,74	0,59 0,69	0,61 0,68	0,65	0,75	0,65 0,76 0,88
Ø (mm) longitudinal bars	12	12	12 and 16	12	12	12 13 14

(1) BE 500 = Steel with a modulus of elasticity of 500 N/mm^2

be important for the flexibility of the system. The configuration of the right-angled net is so that eventual negative influences of overlap and right-angled transverse bars are reduced to a minimum (figure 14). The net with transverse bars Ø 8 mm every 100 cm has enough rigidity. With a weight of ca 150 kg the net is easy to handle.
A lug anchor with 3 transverse ribs is constructed (figure 15) at each contiguous existing bituminous pavement.

3.2 Characteristics of the reinforcement

For classical CRCP (20 cm), the mean distance between cracks fluctuates around 1,50 m for the most common Belgian circumstances. More than 80 % of these distances are situated in the "ideal class" B (80 cm - 300 cm). The synthesis diagram of figure 16 sketches the impact of the different parameters. So, 0,6 and 0,7 % were chosen for the longitudinal reinforcement (mostly with bars Ø 12 mm BE 500). Mean crack distances of 1 m to 1,25 m may be expected. In fact, the compromise between narrow crack openings (necessary for a certain degree of interlock in a thin concrete layer) and "not too small slabs" is rather narrow for TCRCP.
Certainly for TCRCR an uniform thickness of the concrete layer is essential. The following tolerances were imposed :

for h = 12 cm = ± 7 mm
for h = 14 cm = ± 8,5 mm
for h = 16 cm = ± 10 mm

Because of this, the real percentage of longitudinal steel is (for h = 14 cm) limited between min. 0,58 % and max. 0,71 % and the greatest possible steel stress will always be acceptable (see figure 16). Sometimes steel BE 600 is utilized for direct overlays on more variable underlayers.

Figure 12. Fosses (h = 14 cm) - Reinforcing steel and craddles.

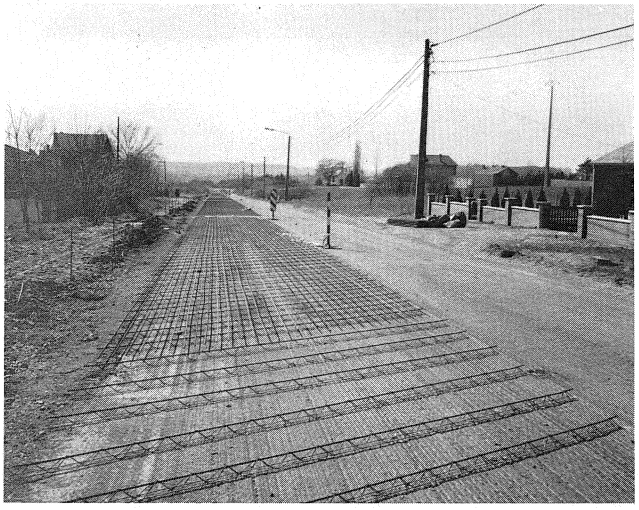


Figure 13. Vaulx (h = 12 cm) - In order to supply the concrete, the welded-wire reinforcement is placed immediately before the slipform paver.



Figure 14. TCRCR Modave - Design of welded-wire fabric.

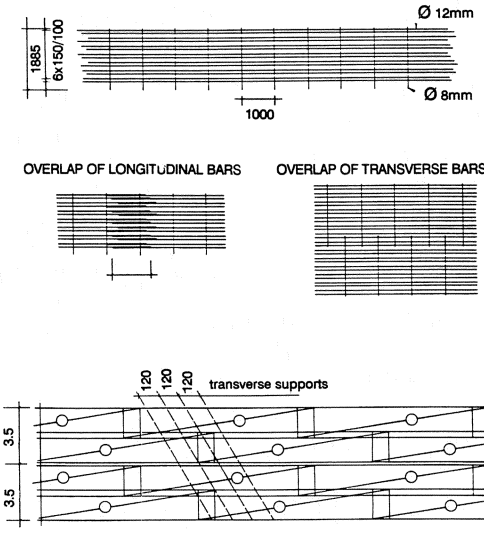
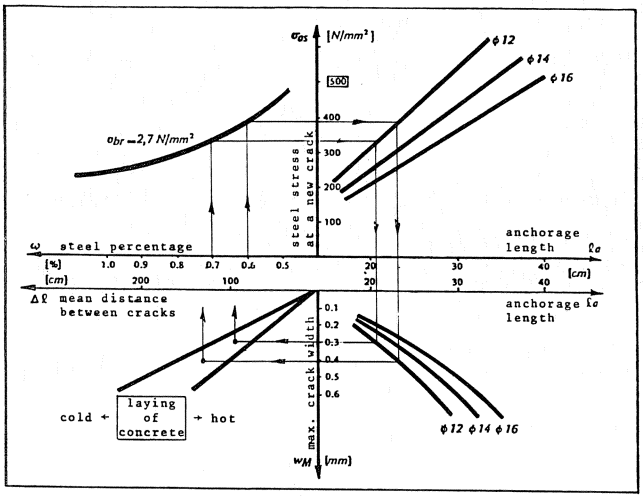


Figure 15. Lug anchors with three transverse ribs through the old asphalt pavement. Fosses.



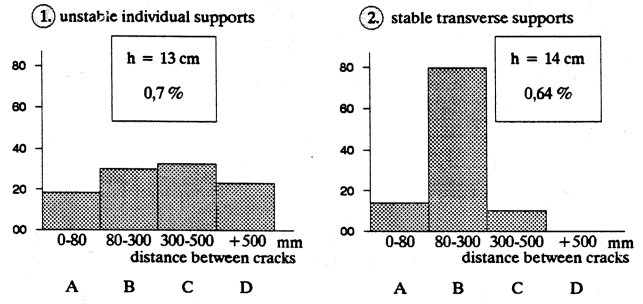
Figure 16. Thin CRCP - Design diagram.



3.3 Behaviour and crack pattern

The recorded crack pattern is arbitrary estimated by a statistical histogram which subdivides the distances between cracks in 4 classes. In contrast with a simple mean distance value, this representation gives more information about possible risk zones (class A - figure 17). Consequently the ideal crack-class B contains a cumulated road length (or corresponding surface) in which all the cracks are at distances between 80 cm and 3 m.

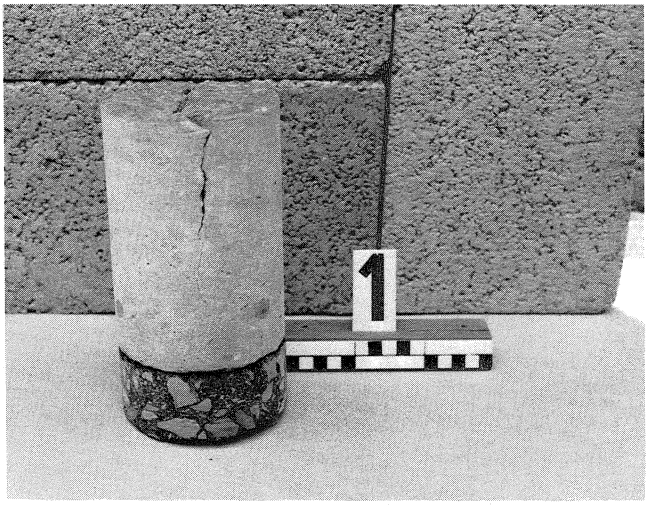
Figure 17. Gaurain - crack pattern.



Gaurain (9)

Figure 17 is an example of a crack pattern for a low steel net on unstable individual supports (fig. 17.1, h = 13 cm) and for stable continuous transverse craddles (fig. 17.2, h = 14 cm).
Histogram 1 can not be considered as ideal. It illustrates clearly the influence of the position of the net as it has also been demonstrated for classical thicknesses. However at this moment (1988) there is no damage at all. Figure 18 shows the lowly situated longitudinal bar and the relatively large crack opening at the surface. Tension in the steel closes the crack so that no corrosion occurs. The risk for fragmentation is low, partly due to the bond with the bituminous underlayer. On the other hand the histogram 2 can be called as exemplary.

Figure 18. Gaurain - Low steel net, large crack at the surface, fine crack in asphalt layer.



Fosses (10)

Initially, in the fall of 1986, the different patterns (figure 19) of the 6 sections could be called as ideal; indeed ca 80 % of the crack distances were situated in the class B. However the recorded evolution in the spring of 1988 needs careful consideration. For h = 12 cm the % in class A is very high : 35 % for 0,6 % longitudinal steel and 48 % for 0,7 % steel.
For h = 14 cm and h = 16 cm this trend is less important. The influence of the quantity of steel is evident, also for h = 16 cm. Indeed, the fact that class A is even slightly less occupied for 0,7 % (28,5 % against 30 %) is due to the bar diameter (Ø 16 mm). The lower bond between the steel and the concrete with Ø 16 mm diminishes the influence of a higher steel content.

Let it be noted that the cracks in all sections can be defined as fine to very fine (for 0,7 %) and that there is absolutely no question of any damage. The question arises then whether perhaps this abnormally close crack pattern for h = 12 cm could not be favourable. In fact in this case the pavement could really be considered as "semi flexible". Further evolution could eventually confirm this statement. In this context it is presumably advisable to accept at the moment for TCRCR a minimum thickness of 14 cm.

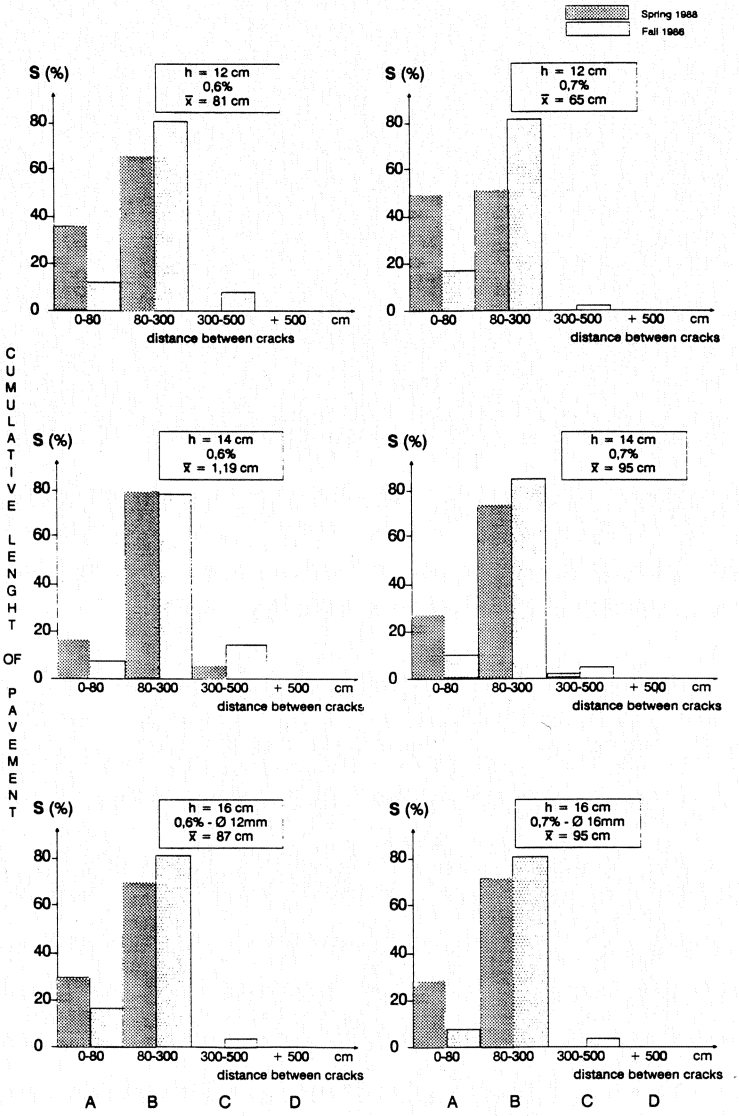


Figure 19. TCRCP - Fosses
Construction
May 1985
Crack pattern :
- spring 1988
- fall 1986

Modave and Vaulx (11) and (12) - welded nets

Modave has been constructed in winter conditions (5 °C), resulting in a mean distance between fine cracks of about 3 m. A comparison is diffucult to establish.
Vaulx is still too recent to enable any evaluation.

For both sections it appears that the orthogonal transverse bars do not negatively influence the crack pattern.

4. Bond at the interface
Bond with the underlayer - concrete or asphalt - is far the most important parameter in the design and construction (and in the final succes) of thin resurfacings.
Good bond with an existing concrete pavement increases the total layer thickness and thus decreases the stresses. Bond on a bituminous underlayer - scarified asphalt pavement or leveling course - also relieves stress. Bond acts as a regulating factor for cracks and joints. In the case of inlays, positive and durable bond can eventually reduce problems with water penetration.

On the one hand it appeared that actual bond cat not be obtained without risk, while on the other hand it has to be stated that resurfacing is practically mostly applied on concrete roads with more or less severe distress. Depending on this damage, either CRCP without separation course either TCRCR of SFRC with a separation course can be applied.

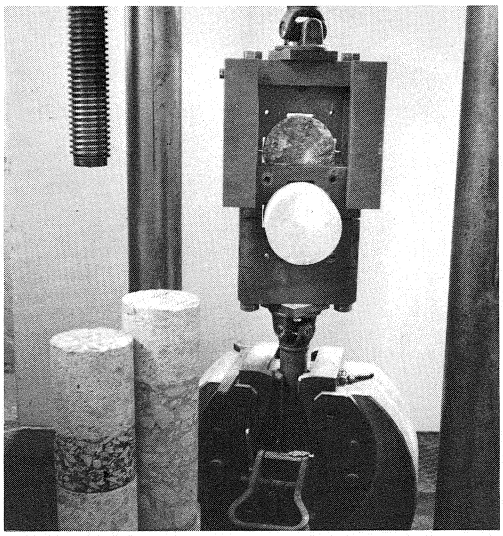
Furthermore it appears that good and uniform bond is possible on asphalt. This means that perspectives open up for inlays on bituminous pavements with rutting problems.

Table 7 reflects a series of tests (187) which were performed since 1985 with a shear device (figure 20) nearly identical to that of the IOWA-DOT.

Table 7. Bond results (shear Iowa device).

Site	Construction date	Bond test	Number of cores	Bond strenght (N/mm²) x̄	max.	min.
SFRC on bituminous separation course						
Maldegem (3)	10/82	1985	12	1,7	2,1	1,3
		1987	2	-	2,2	2,0
Jalhay (8)	5/85	1985	30	1,4	1,9	0,9
		1988	10	1,7	2,1	1,4
Astene (4)	9/87	10/1987	3	0,8	0,9	0,7
		1/1988	10	1,7	1,7	0,8
Zelzate (5)	9/87	10/1987	4	0,8	1,1	0,5
		1/1988	12	1,3	1,7	0,7
SFRC on scarified asphalt pavement (inlay)						
Gaurain (6)	5/84	5/1984	5	1,3	1,3	1,2
		4/1988	4	-	1,7	0
Vaulx (7)	9/87	4/1988	3	-	1,2	0,8
TCRCP on scarified asphalt pavement (inlay)						
Fosses (10)	5/85	9/1985	14	0,6	0,9	0,3
		5/1988	4	0,8	0,9	0,5
Vaulx (12)	9/87	5/1988	3	-	0,8	0
SFRC on prepared old concrete pavement						
Gent (1)	6/83	3/1985	24			
- cleaning				-	1,4	0
- " + grout				-	1,6	0
- milling				-	2,0	0
- " + grout				-	2,1	0
Vierset (2)	7/83	3/1985	15			
- milling				-	0,9	0
- " + grout				-	2,5	0
Laboratory tests (concrete on concrete)						
-dry surface			12	3,7	4,4	2,5
-wet surface	1985/86	1986	24	4,0	5,8	3,1
- " + grout			12	3,8	4,8	3,0

Figure 20. Shear device.



4.1 Direct bond (concrete/concrete)

Although the behaviour of the sections at Gent and Vierset can not be called very encouraging, they have to be situated in a clear context.

4.1.1 Gent - 1983 - (1) - Figure 3

- On the Gent-site the sections A and B (totalling 65 %) may not really be taken into consideration. Simple cleaning of the surface - even with the application of grout (section B) - is not enough to produce satisfactory bond. Furthermore, the expectations of the performances of SFRC were too high at the time. A re-surfacing thickness of 10 cm was combined with a high fiber content to overcome eventual imperfections of bond. A really bonded overlay may in fact be thinner (5 or 7,5 cm) and does not even need fibers.

- The sections C and D (35 %) do behave better. However section C (milling alone) is deteriorating more severely during last year. Only section D (milling with grout) can be stated as good although little difference was visible between the two sections during a long time. Now ca 80 % of the surface in the vicinity of the joints are in good shape.

  Against this the following facts have to be considered :

  . Section C, just as A and B, was badly distressed (figure 21) and sometimes asphalt leveling courses had been layed on the old concrete pavement. This was also the case for the areas near the joints, which means that bond

Figure 21. Deteriorated joints - Longitudinal joint with adjacent bike-way



would in any case be problematic.

. Section D lies on an old concrete pavement of better quality with few scalling problems and rather good joint areas.

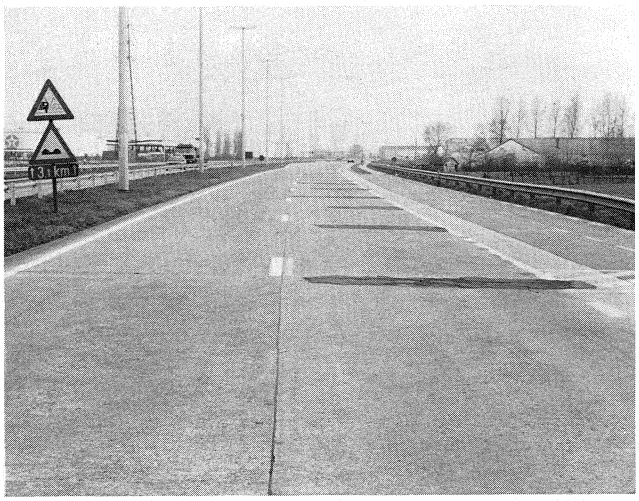
. Section C was constructed during hot weather, while for section D the temperature was rather normal (15 to 20 °C) which is favourable for grout applications. However this is not an argumentation for the necessity of grout because grout application is not a risk-free operation; it requires in fact experience and severe discipline (figure 22).

- The heavy traffic, especially on the right lane of the Gent-site, is often hold responsible for the lack of bond (figura 23).

Figure 22. Grout of good consistency. Problem of concrete supply.



Figure 23. Gent - Aspect of the overlay - Almost all deteriorations are situated in the right lane.



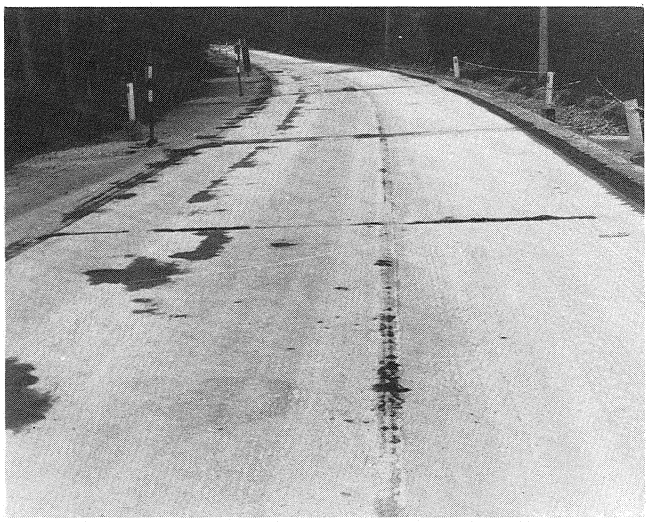
But, heavy traffic is only an accelerator for lack of bond manifestations, it is not in itself an inhibitor of debonding. In this respect the Gent-site has to be considered as a happy choise. Indeed, the leading parameters manifest themselves very quickly and eliminate possible wrong (and eventually too optimistic) interpretations.

4.1.2 Vierset - 1983 - (2)

- It is true that on the Vierset-site the whole surface has been milled; but this operation has been done only very superficially (figure 24). On the other hand it has to be said that milling is difficult and expensive. Shot blasting would perhaps be a good alternative.

- During construction weather conditions were warm and even hot, which of course is not favourable for the grout-operation. This (together with the resulting temperature fall during the following night) combined with the use of porous stone aggregate and a high water content has resulted in numerous fine shrinkage cracks at the slab edges.

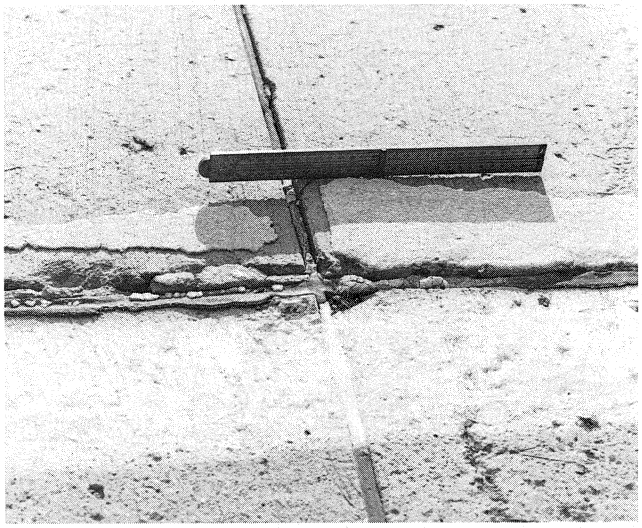
Figure 24. Vierset - Superficial milling of the old concrete surface.



A similar fact is noted in American literature (Donner Pass California 1981).

- Figure 25 gives an example of curling.

Figure 25. Curling of slab edge.



4.2 Bond with a bituminous underlayer

4.2.1 Maldegem - 1982 - (3)

- In this first test section a leveling course with ca 15 % voids has been layed on an old concrete pavement (1935). Due to the large irregularities of the surface and also to the fact that the original two-sided cross slope was changed in only one transverse slope, the thickness of this layer varies between 5 and 15 cm.

Figure 26. Maldegem
Core in joint - Bond at both sides of a strongly working contraction joint.

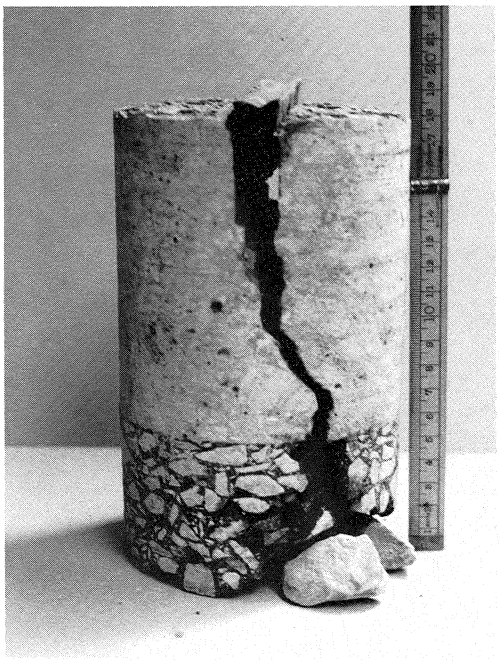


Figure 26 gives a remarkable view of the obtained bond which was strong enough to tear apart the asphalt layer.
Even after 5 years this bond has subsisted till near the joint edges and the asphalt layer seems to behave well.
As a matter of fact it will be indispensable to control the joint obturation regularly. Indeed preformed neoprene profiles between the long slabs (15 m) do absorb the movement with some difficulty. 10 % of them have to be replaced with hot pourred sealant.

On the other hand, the critical slab length (warping stresses) is smaller in the case of a bonded interface, which means that the length of slab to take into account when considering eventual buckling phenomenons (Euler) can be smaller, and this because of the greater weight of the slab.

- A random sample survey in 1987 showed that bond is improving with time (table 7).

- In comparison with other sites of table 7 the better characteristics of an "open" graded bituminous interface are evident. The more dense leveling course which was used on the following sections, shows in general a lower bond level, however the minimum values seem probably to be situated near an inferior limit.

4.2.2 Jalhay - 1985 - (8)

- Here a 6 cm thick uniform separation layer was layed on a subbase of lean concrete in such way that Jalhay cannot be considered as a real overlay since the existing asphalt pavement required important strenghtening.

- Table 8 gives bonding strenghts (30) a few months after construction (1985). Samples taken in june 1988 showed an increase of 10 to 30 %.

- The mean values for all the considered areas are very close. Exept for those obtained at 50 cm from the joints, all max. and min. values are similar.
It seems that at the joint there is some smoothening of the strenght, resulting in a lower standard deviation.

- Bond is also higher in the first construction lane (cores 1 - 15). Here $\bar{x}$ = 1,46, in comparison to $\bar{x}$ = 1,26 in the second lane. This (logically) means that pollution of the bituminous layer influences the achieved bond.

Table 8.
SFRC - Jalhay - 1985
Bond strenght (N/mm^2)

Mid slab			1 m from joint		0,5 m from joint		Edge	
Core nr	Distance from long.joint	τ	Core nr	τ	Core nr	τ	Core nr	τ
1	1,75	1,93	2	1,84	4	1,41	6	1,78
14	1,75	1,50	3	1,35	8	1,20	7	1,31
19	1	1,38	20	1,00	12	1,43	10	1,10
16	0,5	1,06	21	1,28	13	1,31	15	1,58
5	0,6	1,00	26	1,11	24	1,46	17	0,96
9	0,5	1,81	28	1,68	27	1,22	18	1,45
23	1	1,48	11	1,31			22	1,39
25	0,8	1,28					30	1,28
29	1	0,93						
	$\bar{x}_9 = 1,37$			$\bar{x}_7 = 1,37$		$\bar{x}_6 = 1,34$		$\bar{x}_8 = 1,36$
	$s = 0,35$			$s = 0,30$		$s = 0,11$		$s = 0,26$

$\bar{x}_{30} = 1,36 \quad s_{30} = 0,27$

4.2.3 Astene and Zelzate - 1987 (4) and (5)

- Bond has been determined already a few weeks after construction. In one of the few (3) strong working contraction joints (near a construction joint) the effect of the very effective bond could once again been observed. A ca 5 mm open contraction joint showed bond at both sides of the core. However the bonding strenght was rather low. New samples taken after 3 months showed an increase of the mean strenght from 0,8 to 1,2 N/mm^2.

4.2.4 Gaurain and Vaulx (inlay) - 1984 - 1987 - (6) and (7)

- Figure 27 illustrates a bond survey realized after 4 years. Cores were only taken in 10 m slabs. 15 m is no more considered as representative for the future.

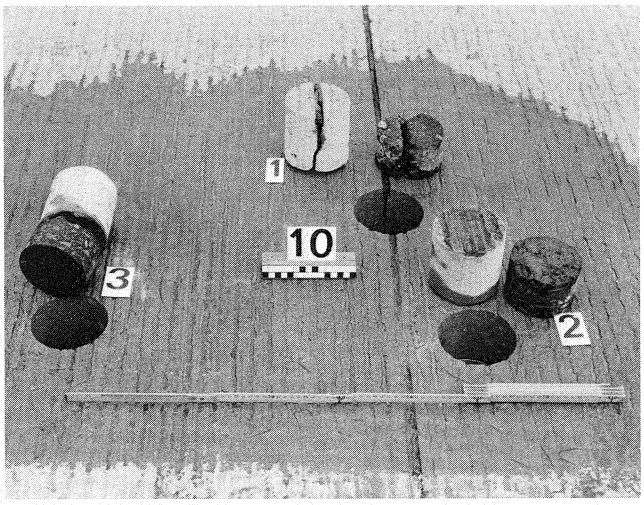
- Samples taken in the joint (as at Maldegem and Astene) do not cling any more to the bituminous underlayer although core nr 10 (figure 27) did initially cling; this is confirmed by the large crack in the asphalt core.
  Random sampling in 1988 reveals that bond does not always exist near the joints (until a max. of ± 50 cm). On the other hand, until now no distress has been reported (risk for longitudinal cracks).

- The less durable - or simply interrupted - bond is probably due to the fact that it concerns an inlay where the underlaying asphalt layer has been milled.

- Compared to the results of Astene and Zelzate (1987) the bond in Vaulx (1987) is rather low. This is undoubtly due to the fact that in this case we are dealing with an inlay.

- The behaviour near the joints of these partial or not bonded areas remains still an open question. One thing is certain : the preparation of the interface requires ample care.

Figure 27. Caurain - Inspection after 4 years.
10.1 In joint - initial crack in asphalt underlayer
10.2 Core at 12 cm - no bond
10.3 Core at 50 cm - partial bond



4.3 Bond TCRCR with bituminous underlayer

Bond samples have also been taken on inlays of TCRCP. Bond strenght is rather low, but, due to the small movement, bond seems to be durable (table 7 - Fosses 1985 - 1988).

5. Present main conclusions

5.1 Resurfacing with SFRC

- On a bituminous underlayer.
  The results can be labelled as very good. Till today, bond seems to be remarkable and durable. The best results were obtained with a new leveling course with an overall open structure (1,5 to 2 N/mm^2). For milled old asphalt layers bond strenght is 25 to 50 % lower. It is obvious that the behaviour of the asphalt layer will have to be closely observed in the future.

- On old concrete pavements.
  Bond seems to be a fundamental criterion for succes. Preparation work requires care and workmanship. Only adequate bond gives opportunities for overlays with a thickness of less than 15 cm. If bond is really achieved, steel fibers do not seem to offer economically justifiable advantages.

  . Intensive roughning of the old concrete surface by milling or shot blasting is necessary to guarantee durable bond. Grout does not seem to bring much (if any) improvement.

  . Direct resurfacing on concrete can only be considered when the condition of the old pavement is still relatively good. If not, local preparation work, by replacing badly distressed slabs, will be necessary. Direct resurfacing of old continuously reinforced concrete could become an interesting target.

  . As predominantly rehabilitation of an old concrete road is only considered when damage is already severe, a separation or leveling layer will generally be of vital importance.

  All in all, experience with bonded overlays "concrete on concrete" shows that the technique is still in an experimental stage, all the more because reflective cracking cannot really be avoided and controlled with steel fibers.

5.2 Resurfacing with TCRCR

- No problems at all were noticed with thicknesses of 14 cm; with 12 cm thicknesses caution is recommended untill the sections are at least 5 years old.

- Bars Ø 12 mm have a strong influence on the crack pattern.

- 0,6 % longitudinal steel seems to be amply sufficient. For h = 14 cm this means 6,5 kg/m^2 of steel (to be compared with 10,4 kg/m^2 for traditionnal CRCP of h = 20 cm). Compared to "thick" CRCP an economy of about 25 % can be realized.

  An old concrete pavement will however require a bituminous interlayer. On old asphalt pavement the economy is practically maintained (scarification is cheap).

- Utilization of welded-wire fabric can be interesting when resurfacing has to be done under traffic. Furthermore an economy of about 15 % can be obtained.

- Good support of the net with continuous transverse craddles is essential, as well as the limitation of the overthickness.

- In contrast to SFRC, treatment for roughness by chemically stripping if the aggregate (current use in Belgium) can evidently be applied without any difficulties.

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