THIN CONCRETE INLAYS ON OLD CONCRETE ROADS

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SYNOPSIS

The purpose of this paper is to evaluate thin concrete overlays as a repair method on out worn concrete roads. A test section has been carried out in south of Sweden. Fibre reinforced high strength concrete was used. Bond strength tests indicate a good bond between old and new concrete. Creep and shrinkage tests are discussed.

INTRODUCTION

In Sweden, the use of studded tyres is extensive. It leads to wear and rutting on Swedish highways with intensive traffic. A combination of studded tyres and de-icing salts enhances the problem, because the use of de-icing salts gives a wet surface. The wear increases on wet surfaces, see Bærland (1).

Asphalt concrete has been the predominant resurfacing material on both asphalt and concrete roads. Unfortunately, the wear resistance has been poor. On some roads, a new overlay has been placed every second or third year. The development of high strength or high performance concrete has, however, resulted in an interesting alternative for the resurfacing. A fibre reinforced high strength concrete has shown to be a promising material. A thin concrete overlay resists wear from studded tyres well and might postpone the need of a second resurfacing more than 10 years.

In the late 70s, some (normal strength) concrete roads were built in Skåne in the south of Sweden. The rutting depth is now between 13 and 15 mm. This depth cannot be accepted due to poor driving comfort. In a joint-venture between the Swedish Cement and Concrete Research Institute, the Swedish National Road Administration and the Swedish contractor NCC, a thin concrete overlay is tested on a part of the highway outside Helsingborg in the south of Sweden.

DESCRIPTION OF THE TEST SITE

In 1978, a 7 km long concrete road was built between Hyllinge and Väla close to Helsingborg in south of Sweden. The road is a part of the European highway No. E4. The road has two lanes in each direction. The plain jointed concrete pavement consists of a 200 mm thick concrete layer on top of a 150 mm thick cement bound roadbase. The distance between the transverse joints is 5 m. A longitudinal joint separates the high speed lane and the low speed joint.

The tests were carried out on a 470 m long test section, limited to the low speed lane in the eastbound direction.

REPAIR WORKS

In order to give room for a concrete overlay of decent thickness without enhancing the surface level, 35 mm concrete was removed. A planer was used. The removal was limited to a 3 m wide strip in the middle of the lane. One meter was saved closed to the shoulder. The intention was to save another 60 mm close to the longitudinal joint not to damage the joint. Consequently, the new concrete could be placed in a 470 m long, 3 m wide and 35 mm deep "box" (Figure 1).

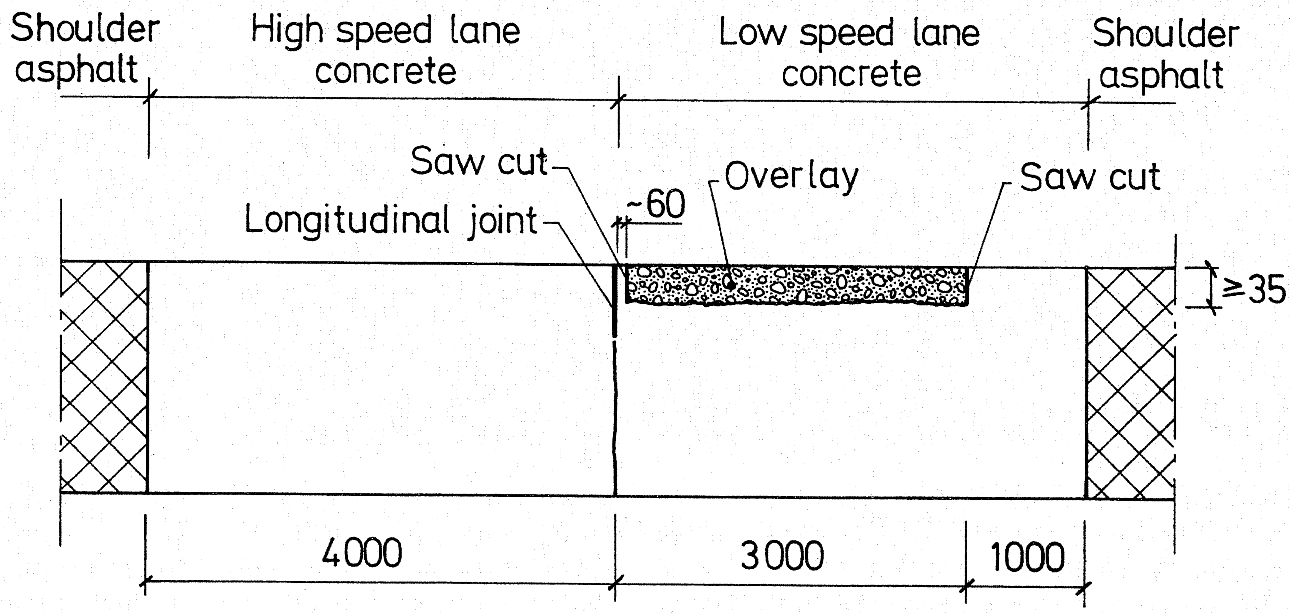

Figure 1. Repair of concrete road. (The scale in the thickness direction is exaggerated).

The scarified surface was cleaned by a high pressure water jet (water blasting). The pressure was between 800 and 900 bars. The water jet unit (Aquablaster) had four nozzles acting over a circular area with a radius of 500 mm. The surface was prewetted during 48 hours according to the Swedish National Road Administration (2). At time of overlay placement, the surface was superficially dry. No bonding agent was used.

The overlay was cast with an intended Swedish grade K55. The concrete mix proportion can be summarized in following items:

water-cement ratio	0.35 to 0.36
cement content	430 kg/m^3
aggregate 0 to 8 mm	800 kg/m^3
aggregate 8 to 11 mm	950 kg/m^3
fibre content (Dramix 30/50)	
air content	5 %
(plasticisers)	

An attempt was made to place the overlay with an asphalt paver. It did not succeed. The overlay was therefore placed with traditional casting technique. The overlay was vibrated with a vibrating screed. Initially, the overlay was membrane cured. Thereafter, it was moistened during a couple of days.

The original pavement had been provided with transverse joints every fifth meter. A soon as the overlay had started to harden, 3 mm wide and 30 mm thick saw cuts were made in the overlay above every joint. The saw cuts were widened to between 8 and 10 mm and were sealed with expanding joint bands.

The repair works were carried out in October 1991.

ROUGHNESS OF THE CONTACT SURFACE

The roughness of the contact surface has been considered to play an important role in a good bond between old and new concrete. Silfwerbrand (3), (4) has, however, shown that less importance ought to be taken to the roughness. Cleanliness and absence of micro cracks are more important. He compared sandblasted and water-jetted contact surfaces - both clean and without micro cracks - and found the average bond strength almost the same. The interface failures were, however, more frequent in the sandblasted surfaces. There might be a threshold value for the roughness.

The roughness of the contact surface was measured on several slabs with a simple equipment (Figure 2). Measurements were made between scarifying and water blasting as well as after water blasting. In (3), the measured surface profile is proposed to be transferred to a saw-tooth curve with two

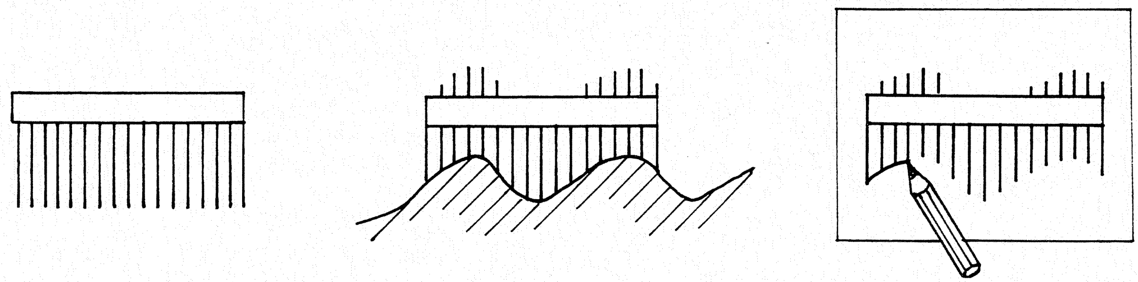

Figure 2. Measurement of surface roughness. From Silfwerbrand (3).

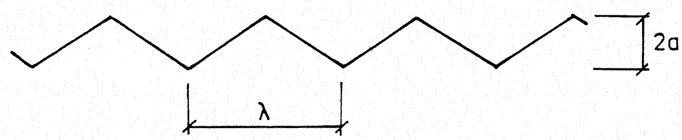

Figure 3. The concrete surface profile is transferred to a saw-tooth curve. From Silfwerbrand (3).

parameters: double amplitude 2a and wavelength λ (Figure 3). Measuring results are shown in Table 1.

Especially the amplitude value reflects differences in surface roughness. After scarifying, the surface was ribbed. The roughness along the ribs was small. After water blasting, the longitudinal roughness was the same as the roughness in the transverse direction. Comparisons with differently treated slabs in reference (3), show that the actual surface (scarifying and water blasting) had higher roughness than sandblasted surfaces but lower than hammered and water-jetted surfaces. If the removal process did not introduce micro cracks, it ought to promote a good bond.

BOND STRENGTH TESTS

In April 1992, four months after concrete placement, a total number of 27 cores with a diameter of 75 mm were drilled from the top surface, through the overlay and interface and down 20 to 30 mm into the old concrete. A steel plate was glued to the top surface of the core. A tensile force was applied to the steel plate. The force was increased to failure. Failure stress and failure mode were observed. The results are summarized in Table 2.

High failure stress values were obtained. The average exceeded 2 MPa. The single lowest value was 1.68 MPa (failure in adhesive). The lowest interface failure occurred

Table 1. Measured roughness values

Surface treatment	Double amplitude 2a (mm)	Wavelength λ (mm)
Scarifying (profile // longitudinal direction)	0.5	21
Scarifying (profile // transverse direction)	1.4	25
Scarifying + water blasting (// longitudinal dir.)	1.4	27
Scarifying + water blasting (// transverse dir.)	1.6	24
Water jet, reference (3)	7.7	44
Jack hammers, reference (3)	4.9	41
Sand blasting, reference (3)	0.4	32

Note. Distance between measuring points = 10 mm in all profile measurements

Table 2. Bond strength tests

Failure mode	Number of cores	Average failure stress (MPa)	Standard deviation
Adhesive	12	2.23	0.30
Overlay	5	2.67	0.35
Interface	8	2.28	0.35
Old concrete	1	2.59	-
?	1	2.36	-

at a stress of 1.79 MPa. According to the Swedish National Road Administration (2), average failure stress value m, required bond strength f_v and standard deviation shall meet following demand:

$$m \geq f_v + 1.4 \cdot s \qquad (1)$$

where, s=0.36 MPa is used if s<0,36 MPa (this case) and f_v=1.0 MPa. For the observed interface failures, this relation is fulfilled.

DIFFERENTIAL SHRINKAGE

Concrete structures cast in more than one lift are exposed to differential shrinkage. In this case, the shrinkage of the old concrete is negligible whereas the overlay will shrink. The old concrete is very thick compared to the overlay. Consequently, we have to consider a complete restraint. The restrained shrinkage will cause tensile stresses in the overlay. If they exceed the tensile strength, the overlay will crack. The shrinkage increases slowly with time. Due to simultaneous creep, there will be a beneficial stress relief. Simplified, we may state the non-cracking condition with following equation:

$$\frac{E_c \varepsilon_{sh}}{1 + \phi} < f_{ct} \qquad (2)$$

where, E_c is the modulus of elasticity, ε_{sh} is the shrinkage, ϕ is the creep coefficient and f_{ct} is available tensile strength. Hence, it is beneficial to use a concrete with low shrinkage and modulus of elasticity and high tensile strength and creep. It is almost impossible to design a concrete mixture with such properties, but it is still interesting to evaluate the different parameters in the equation (2).

In order to evaluate shrinkage and creep of the actual concrete mixture, four prisms (100×100×400 mm) and nine cylinders (150×300 mm) were cast. All specimens were stored indoors. The cylinders were stored in water until testing. The prisms were kept moistened for seven days after casting and then stored in a room with temperature varying between 17 and 23°C. The relative humidity varied between 35 and 60 %. The average values were 19°C and 44 %, respectively. Compressive strength was measured on all cylinders and on two cylinders, also the modulus of elasticity was tested (Table 3).

Due to financial reasons, the tensile strength f_{ctm} was not tested. It can, however, be calculated using, e.g., CEB-FIP

Table 3. Material tests

Specimen No.	Age (days)	Compressive strength (MPa)	Modulus of elasticity (GPa)
HBGC-1	7	62.0	-
HBGC-2	7	62.9	-
HBGC-5	28	75.8	-
HBGC-6	28	78.5	-
HBGC-7	28	78.5	-
HBGC-4	28	(58.8)*	(39)*
HBGC-9	35	73.6	42.5
HBGC-3	121	83.8	-
HBGC-8	121	85.1	-

Note. *The compressive strength was remarkably low. The value is omitted in the evaluation.

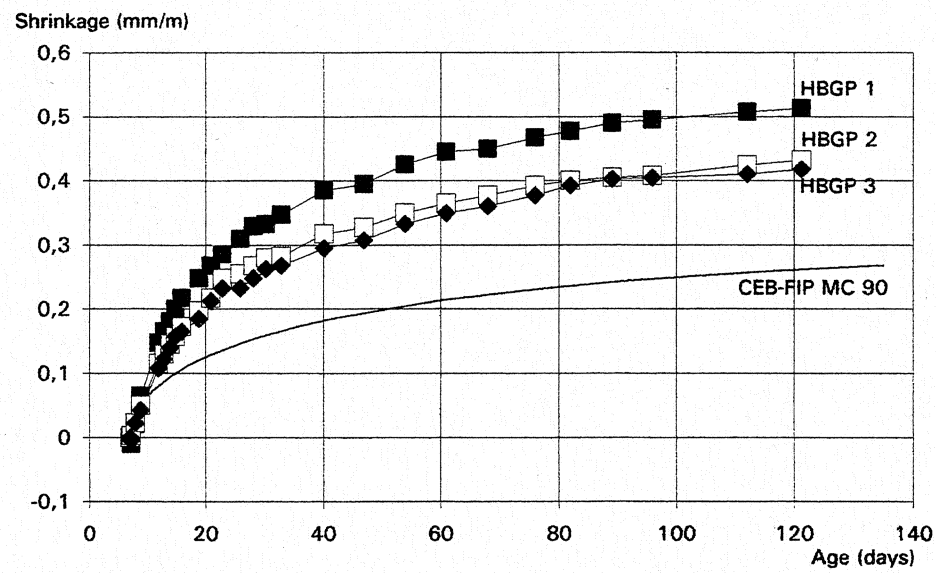

Figure 4. Measured shrinkage on prisms Nos. HBGP-1, HBGP-2 and HBGP-3 and calculated shrinkage according to CEB-FIP MC 90 (5).

MC-90 (5):

$$f_{ctm} = 0.30 \cdot (f_{cck})^{2/3} \qquad (3)$$

where, f_{cck} is the characteristic 28-day compressive strength. In lack of measurements, $f_{cck}=f_{ccm}$ - 8 MPa. f_{ccm} is the mean value of the 28-day compressive strength. Hence, f_{ctm}=5 MPa in this case. This value is approximately twice the tensile strength of normal strength concrete.

The shrinkage was measured on three prisms (Figure 4). After 120 days, the measured shrinkage was approximately 0.045 %. The measured shrinkage is compared with CEB-FIP MC 90 (5). The observed shrinkage is twice as large as the calculated one. At the test site, however, the shrinkage will be less because of higher relative humidity.

The magnitude of creep was evaluated on the fourth prism. The prism was loaded in compression according to following scheme:

Age	Stress
7 days	5 MPa
14 days	10 MPa
28 days	15 MPa
61 days	20 MPa

The total strain was measured. It includes also shrinkage. The load-dependent strain can be estimated as the difference between total strain and the average shrinkage strain according to Figure 4. Total strain (elastic strain + creep + shrinkage), load-dependent strain (elastic strain + creep) and elastic strain (ratio between stress and modulus of elasticity) are shown in Figure 5. As a comparison, the load-dependent strain for the actual loading is calculated according to CEB 1984 (6). The observed load-dependent strain was lower than the calculated value. The actual creep coefficient ϕ might be only around unity instead of CEB's $\phi=2$. At the test site, the creep might be even less because of the higher relative humidity.

In conclusion, observed tensile strength, modulus of elasticity and shrinkage were higher than calculated values. The creep was lower. That means an obvious risk of cracking. On the other hand, the fibre content of 40 kg/m^3 might be sufficient for the occurrence of a beneficial crack pattern with narrow cracks.

CONCLUDING REMARKS

Intensive traffic and the use of studded tyres cause rutting on concrete roads. A fibre reinforced high strength concrete overlay is an interesting repair method. A test section has

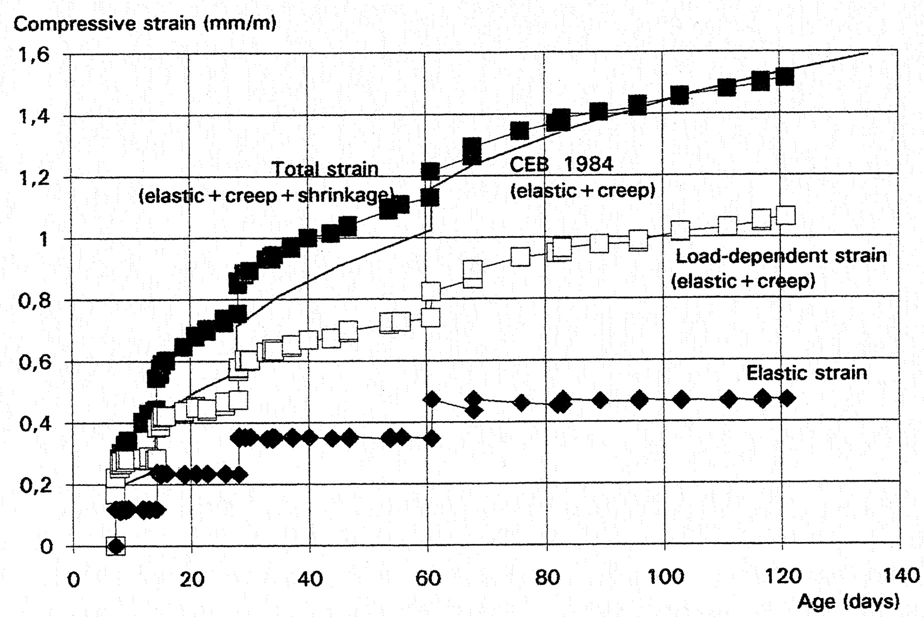

Figure 5. Measured strain values of creep prism and load-dependent strain according to CEB 1984 (6).

been carried out in the south of Sweden. Following conclusions can be drawn:

- Scarifying with a planer and subsequent water blasting give roughness values above values of sandblasted surfaces. That seems to be sufficient for promoting a good bond.

- A good bond (bond strength values above 2 MPa) between old and new concrete can be obtained. The surface must be clean, but no bonding agents are necessary.

- Fibre reinforced high strength concrete has high tensile strength, high modulus of elasticity, fairly high shrinkage and low creep. The combination leads to a risk of cracking, but the fibres are likely to control the cracking in such a way that only tiny cracks will occur.

References

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