THIN CONCRETE OVERLAYS ON OLD ASPHALT ROADS

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ABSTRACT

"Thin Concrete on Asphalt" is a joint-venture project involving the Stockholm Regional Road Administration, Cementa AB (a Swedish cement producer) and the Swedish Cement and Concrete Research Institute (CBI). The project aims at building a test road in the Stockholm area in 1993. This presentation is a summary of a state-of-the-art report developed for the project.

INTRODUCTION

The cost of maintaining asphalt roads carrying large volumes of traffic with studded tyres in the Stockholm area of Sweden is very high. The repair of tracks formed by studded tyres every second or third year involves not only pure production costs but also high costs for road users. is The Stockholm Regional Road Administration consider the use of concrete in maintenance work to be an interesting alternative.

The resistance to wear by studded tyres can be enhanced and the maintenance cycle thereby extended from two or three years up to about 10 years. But it is not possible to simply lay a thin layer of concrete on old asphalt, because the difference in the modulus of elasticity is so large that there is a risk of a thin layer of concrete cracking under load. Other factors that must be taken into account are differential shrinkage, i.e., the difference in shrinkage between the concrete and the asphalt, thermal stresses and the risk of the concrete layer buckling out on hot summer days.

During 1993, a test road will presumably be built to study various design alternatives. This will form the basis for the future selection of materials and design methods.

LITERATURE STUDY

Concrete on asphalt is to be found in Europe in a number of cases as an alternative to the more common concrete construction on a cement bound roadbase. In Austria, for example, an asphalt layer is generally used as the roadbase under concrete. The thickness of the concrete is, as for a concrete on a cement bound roadbase, often thicker than 180 mm. This type of construction can therefore be characterized as a normal application. A division of the wearing course of concrete into thin overlays may be made for thicknesses between 100 and 180 mm. Literature contains examples of good experience of overlays of this thickness. A number of tests have been performed with very thin overlays, thinner than 100 mm, but with poor results. A description is provided below of experience gained from thin and very thin overlays.

There is experience of, above all, from Belgium (1), (2), (3), (4). Continuously reinforced and fibre reinforced concrete overlays have been tested in Belgium. Overlays have been placed both on asphalt and concrete. When overlays were placed on old concrete roads, a 60 mm thick layer of asphalt was used as a levelling layer before placing the overlay. An important issue concerning these overlays is whether or not there is bond between these two layers, i.e., between the asphalt and the concrete. Experience from

Belgium has shown high bond stresses between concrete and asphalt, even in drilled out cores that are several years old. Values from 0.5 to 2.0 MPa (measured by shear tests) were common. The old asphalt had been scarified before placing the overlay.

Something that is also emphasized in the articles from Belgium is that the buckling phenomenon should be studied in the case of thin overlays. The transfer of loads across joints is also a problem. Overlays on old concrete surfacing with a thin intermediate layer of asphalt often provide a good transfer of loads at joints. Overlays on asphalt surfacing require some form of mechanical load transfer. In Belgium, steel plates placed on the asphalt surfacing were used to improve the load transfer. In Belgium, the design axle load is 13 tonnes.

The thinnest continuously reinforced concrete overlays were 120 mm thick and reinforced with ϕ 12 mm BE 500 reinforcing bars. The percentage of reinforcement was between 0.65 and 0.70.

Fibre-reinforced concrete overlays were also tested. The conclusion was that joints must be made at from 5 to 15-meters. Experience from Belgium shows that it is preferable to use closely-spaced joints, down to almost 5 metres. Long distances between joints results in great joint movements. Fibres of type Dramix 60/80 were used at a rate of about 40 kg/m^3. The overlay thickness was between 100 and 120 mm. The enhanced fatigue strength of fibre-reinforced concrete permitted the use of thin overlays.

Tests have been made with very thin overlays, but with poor results. The very thin overlays were less than 100 mm thick. The tests performed were for surfacing thicknesses from 80 mm down to 30-40 mm. A test is reported from Denmark (5) on 30 to 40 mm thick wearing courses of plastic-fibre reinforced concrete on asphalt. The overlay was either placed with spaced joints at 4 meters to 16 meters or without joints. On the section without joints, cracks soon appeared at 10 meters centres. Longitudinal cracks appeared at the edge of the road. On the section with joints, it was found after two years that the maintenance costs were so high that the experiment was discontinued. To sum up, it may be said that the results of the Danish test were bad.

An interesting alternative to thin concrete overlays has been developed during the latest years in the Scandinavian countries. A 30 to 40 mm thick overlay made of a new material that is a hybrid between concrete and asphalt is pored on top of the old asphalt layer. The aim is to find a material that combines the durability and wear resistance of concrete with the strain capacity of asphalt. The material consists of an open asphalt with aggregates between 8 and 12 mm and 25 to 30 percent void content. The voids are subsequently filled with a high strength mortar. Some tests with promising results have been carried out in Sweden, Norway and Denmark.

PILOT TEST SECTION OUTSIDE STOCKHOLM

In September 1989, a 375 m long test section was carried out on an old asphalt road about 50 km north of Stockholm. The asphalt pavement was scarified on the north bound traffic lane. The scarifying amount was intended to vary between roughening of the surface and a depth of 50 mm, but might have been more extensive. The surface was water cleaned after scarifying. A 70 to 90 mm thick unreinforced concrete overlay was placed on the north bound lane. With exception for working joints between different lifts, the overlay was placed without joints.

The pavement was inspected in October 1991. Transverse cracks had developed every 15 to 25 m. The overlay was mainly in a good shape, but some cracks had propagated to damages up to a width of 100 mm. Eight cores were drilled from the top surface of the overlay down through the asphalt layer. The bond strength was tested on two cores. The bond strength values were 0.2 and 0.3 MPa. The remaining six cores could not be tested because the asphalt part was too poor or too thin. That means a risk of rapid cracking of the pavement because the thin concrete overlay cannot carry the traffic load without composite action from a good asphalt layer of decent thickness. An inspection in July 1992 indicated that the test section might approach end of use without a second repair: a longitudinal crack had developed along most of it.

Following conclusions might be drawn from the test section: 1) The scarifying has to be done carefully. A decent thickness of asphalt must remain to support a thin concrete

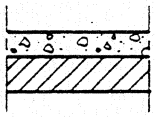
Boundary conditions of type 0



Boundary conditions of type 1



Section



Concrete
Asphalt

Start of shrinkage:	1 day
Temperature:	+20° C
Relative air humidity:	70%
Concrete tensile strength, ultimate value:	6 MPa
Concrete modulus of elasticity:	35 GPa
Poisson's ratio:	0
Asphalt modulus of elasticity:	2-3 GPa

Figure 1. Assumed static systems.

layer.

2) In order to prevent irregular cracking, the overlay ought to be jointed.

CALCULATION MODEL

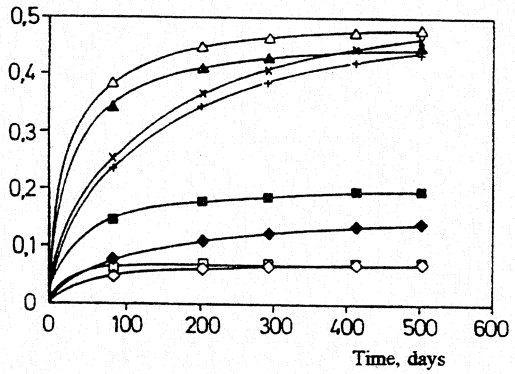
Shrinkage stresses

If a concrete overlay is placed on a surface of asphalt, internal stresses occur as a result of restrained shrinkage. The shrinkage of the concrete results in a decrease in the volume of the material. Stresses occur if the volume decrease is prevented by an internal or external restraint.

We elected to study the effects of overlay shrinkage by calculating a few simple examples. Here we assumed complete bond between concrete overlay and asphalt. Two different types of static system were calculated. One assumes a beam freely supported at two ends and the other a beam on fixed supports at both ends see Figure 1. The beams consisted of 50 to 100 mm of concrete on 200 mm of asphalt.

In addition, it was assumed that the free shrinkage was constant throughout the overlay. Proposals put forward in CEB(1984) (6) were used for the time-related shrinkage and creep functions and also for growth in strength. Both the shrinkage and creep in the rolled asphalt were assumed to be zero.

The calculations were made using a computer program developed by Silfwerbrand (7). The results are presented in Figure 2. As may be seen in the figure, in no case does the



Boundary conditions,	hc,	Ea
0	50	8 ■
0	50	2 □
0	100	8 ◆
0	100	2 ◇
1	50	8 ▲
1	50	2 △
1	100	8 x
1	100	2 +

Boundary conditions:
0 = roller bearing
1 = angular change bearing

Figure 2. The ratio between the maximum tensile stress in the overlay and the available tensile strength.

maximum tensile stress amount to half the available tensile strength. The greatest stress occurs whenever the change in length is obstructed, the overlay is thin (50 mm) and the modulus of elasticity of asphalt is low (2 GPa).

From the above it may be seen that the internal stresses due to shrinkage alone hardly result in cracking of the overlay. Short distances between joints are the most favourable as the joints provide greater freedom of movement, while the dead load in combination with any loss of contact with the supporting surface in that case provides small increases in stress in the surfacing.

It should be added that it was assumed that the overlay consisted of high-strength concrete. If an inferior concrete is selected, the safety against cracking will diminish.

Stresses due to traffic

The stresses due to traffic are largely dependent on whether interaction can be achieved between the two layers. The bond between asphalt and concrete is therefore of decisive importance. According to experience gained in Belgium, one has often been very successful in achieving bond between concrete and asphalt.

A common construction for roads carrying large volumes of traffic is shown in Table 1.

It was assumed in the calculations that the roads were built for at least Traffic Class 6 or 7 (axle load 10 tonnes). The average number of vehicles per day is 15 000 - 30 000 for Traffic Class 6, and > 30 000 for Traffic Class 7. Figure 3 shows how the stresses in the lower edge of the concrete overlay vary with the thickness of the concrete and the value of the modulus of elasticity of the asphalt (axle load 10 tonnes). The figure also shows the significance of the interaction between the layers. The method of calculation used is described in (8) and (9).

The difference in the flexural stress between with and without bond in the event of a low asphalt modulus of elasticity is in the order of 4 to 5 MPa. With a high asphalt modulus of elasticity a thin overlay can in theory find itself in the compression zone of the construction. The stresses presented are for the free-edge load case. The maximum flexural stress at low asphalt modulus of elasticity is about

Table 1. Road construction for calculating stresses, basically for Traffic Classes 6 or 7 (see 'BYA', the Swedish National Road Administration's technical building directives and advice).

Layer	Thickness (mm)	Modulus of elasticity (MPa)
Asphalt layer	200	2000 - 8000
Roadbase gravel	600	150
Subgrade	-	50

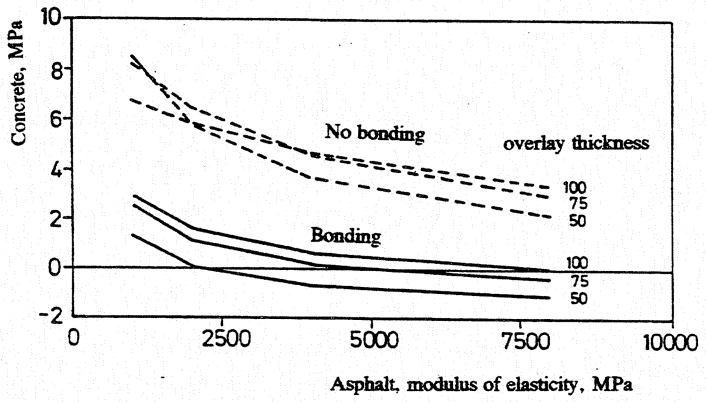


Figure 3. Flexural stress in the underside of a concrete overlay.

1-3 MPa if complete bond can be assumed.

To obtain sufficient bond, it is necessary to achieve a shear stress of about 0.13 to 0.46 MPa between the layers (1). A very important aspect is whether any form of load transfer is considered to exist at any joints, either by transfer through the aggregate or any mechanical arrangement. If the distance between joints is short, about 5 metres, the load transfer presumably can be achieved by interaction between the particles of aggregate, but if a long distance between joints is used, 10 to 15 metres, the concrete surfacing must be equipped with some form of mechanical load transfer.

Thermal stresses

As a result of heating from above, the concrete slab will tend to warp. This warping is counteracted by the dead load of the slab, which results in a bending moment that gives rise to tensile stresses in the underside of the slab. The calculations were made in the same way as for unreinforced concrete roads (see Eisenmann (8)).

Table 2 shows reduced warping stresses and that the critical length for a 100-mm thick slab is 3.3 m. The critical length is less than a reasonable distance between the joints in a concrete surfacing on an asphalt base. Furthermore, the table shows that the reduced warping stress for a 100-mm thick slab is about 2.0 MPa, and that the reduced warping stress is linearly proportional to the thickness of the slab.

Table 2. Warping stress and pavement thickness.

h (mm)	l_{crit} (mm)	σ'_w (MPa)
80	240	1.6
100	3300	2.0
120	3960	2.4

The temperature gradient used is a maximum value measured in southern Germany; a more realistic value for Sweden is 0.06 °C/mm. If this value is used, the stresses will be reduced to two-thirds of the values shown in Table 2.

At high temperatures the concrete overlay tries to expand. If expansion is prevented, as in the case of a non-jointed construction or in a construction with joints where the joints have been filled with sand, gravel, etc., compressive stresses form in the overlay. If the overlay is thin and the stresses large, there is a risk of instability, the overlay will buckle out. For the sake of simplicity, only buckling out in a direction perpendicular to the longitudinal direction was studied. The slab was therefore considered as a beam. The buckling length for "Euler's second buckling case" can be written as shown below

$$l_{cr} = \sqrt{(\pi^2 E I / E \alpha \Delta_T A)}$$

Where E is the modulus of elasticity of the overlay, A its area, Δ_T the amount by which its temperature is increased, and α the coefficient of thermal expansion for concrete. It is assumed that the increase in temperature does not give rise to anything other than negligible stresses in the asphalt.

If the distance between the joints is less than l_{cr}, the compressive force caused by the temperature increase will be less than the buckling load and the surfacing will therefore remain flat.

An example is shown here to illustrate the problem. The following data were used:

Overlay thickness:	50 mm
Rolled asphalt thickness:	200 mm
Modulus of elasticity of the concrete:	35 GPa
Poisson's ratio:	0
Modulus of elasticity of the asphalt:	2 - 8 GPa
α =	10^{-5} (°C)$^{-1}$
Δ_T =	30 °C

Case 1 - The overlay lacks bond to the asphalt

The overlay buckles out without being prevented by the supporting surface. The cross section of the model beam is identical to that of the overlay. This implies that the area A = bh_c and the moment of inertia, I, is $bh_c^3/12$ in the equation. h_c is the thickness of the overlay and b its width. The critical length, l_{cr}, is provided by the expression:

$$l_{cr} = \pi h_c \sqrt{(1 / 12 \alpha \Delta_T)}$$

With the data shown above, the critical length is 2.6 m.

Case 2 - Complete bond between the overlay and asphalt. The moment of inertia of the cross section increases in comparison with that of Case 1. The critical length becomes 11.5 and 18.8 m respectively, depending on the whether the modulus of elasticity is taken to be 2 or 8 GPa.

The significance of the buckling problem increases with decreasing overlay thickness. Without bond between overlay and asphalt, a doubling of the overlay thickness implies a doubling of the critical length. Good bond between overlay and asphalt is important in minimizing the risk of the overlay buckling out. The calculated example indicates that the critical length increases by a factor of from 5 to 10.

Above it was assumed that the overlay can buckle out without resistance from the underlying subbase. If this is taken into account, using a suitable modulus of subgrade reaction, for example, the buckling load increases.

Combined stresses

Of the different stresses to which a thin overlay is subjected in accordance with the calculations it may be said that shrinkage should not constitute a problem. It is assumed that the construction contains joints at relatively close centres, 5 to 10 metres. At most a tensile stress of 1.5 MPa is obtained. If the construction contains no joints, a tensile stress of about 2.5 MPa will be obtained. The stress from traffic is greatest when the temperature of the asphalt is greatest. With a low modulus of elasticity of the asphalt, tensile stresses of the order of 1 to 3 MPa are obtained if there is complete bond. If the two, concrete and asphalt, layers do not interact, the stress will increase to 7 to 8 MPa. From this it may be seen that the bond between the layers must be achieved for the construction to work.

Warping due temperature gives rise to a stress of from 1 to 2 MPa and is linearly proportional to the thickness of the overlay. A thicker overlay results in a higher stress. The stress due to traffic (10 tonne axle load) was calculated for the edge load case. The warping stress is greatest at the middle. The combination of traffic and warping stresses should therefore be made for a traffic stress slightly lower than the edge stress.

In all, a durable overlay of steel-fibre reinforced K80 (80 MPa) concrete (with 40 - 50 kg/m^3 of fibres having an l/d ratio $\geq$ 75) should withstand the stresses that are relevant. This applies to thickness greater than 70 mm. It is important for the fatigue strength that the overlay is fibre reinforced. This effect was taken into account in the above assessment that stresses should not constitute a problem if there is bond and a short distance between joints is selected. The risk of buckling is considered to be low if the surfacing acts together with the asphalt and the thickness of the fibre-reinforced overlay is not less than 70 mm. Here it also assumed that the distance between joints is short. The transfer of loads in joints should be achieved by some means of mechanical device, such as that used in Belgium. The Belgian solution with a steel plate under the overlay joint ensures a good load transfer across joints.

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